Greening Textile Industry in Vietnam

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ABSTRACT

The textile and garment industry has made a remarkable contribution to the economic development of Vietnam and employs currently a large labor force of 2.5 million people. However, the textile industry is also seen as a most polluting and unsustainable industry due to the use of excessive amounts of materials and the release of large amounts of pollutants into the environment. In order to improve the environmental sustainability and effectiveness of the textile industry in Vietnam this study has looked into preventive measure, reuse/recycling options and improved end-of-pipe technologies, separately and in combination.

The end-of-pipe treatment is the last step in the greening production model. Textile wastewater is very difficult to treat, especially regarding the high color intensity. Removal of color from textile wastewater was studied by varying the pH, the application of a biological treatment step, the application of coagulation/flocculation and of Advanced Oxidation Processes (O_3, O_3/H_2O_2, Fenton's reagent). The coagulation process was very effective in color removal of insoluble dyestuffs (98%), but this process is not so suitable for wastewater containing only soluble dyestuffs (12-55%). Of the Advanced Oxidation Processes, the Fenton's reagent process was the most effective method for color removal (81-98%) for the four types of wastewater tested. The decolorization with the ozone process at low pH (pH 5) showed that direct oxidation by molecular ozone is much more selective in color removal than the oxidation by hydroxyl radicals. The presence of colloidal particles caused a 12-fold increase for ozone needed to obtain the same color removal efficiency as for a wastewater without colloidal particles. Each of the investigated processes could only remove one or a few types of pollutants from the wastewater, with the consequence that effluents could not meet all the discharge regulations. The combination of an activated sludge process, and a coagulation and ozone process yielded the best color (45 Pt-Co) and COD (30 mg O_2/L) removal at the lowest costs (0.3 €/m^3), compared with all other tested combinations.

Separate collection of wastewater streams in a factory can also strongly contribute to the efficiency and sustainability of wastewater treatment. In the wet processes of the textile industry 75% of the total water consumption is for rinsing purposes. Wastewater from most rinsing steps contains low amounts of pollutants and can be reused in other process stages or can be discharged without treatment.

An industrial ecology zone model, integrating preventive cleaner production approaches, a waste exchange network for reuse and recycling, and new end-of-pipe technologies, has been developed and assessed in two case studies: the Thanh Cong Company and the Nhon Trach 2 Industrial Zone. The greening production model developed for the Thanh Cong Company, a large-scale textile company in Hochiminh city, included the combination of cleaner production, external waste exchange and end-of-pipe technology. The dyestuffs, auxiliary chemicals, water and energy consumption can be reduced significantly when the proposed cleaner production, the external waste exchange options and the improved end-of-pipe technologies are implemented. Total benefits in savings per day can be more than 1,000 US$.

The industrial ecology zone model was designed in three steps. Firstly the greening production model developed for the Thanh Cong Company was applied to all textile enterprises in the industrial ecology zone that was considered. Secondly an outside waste exchange network was designed. The outside network includes reuse of waste plastics, waste paper and waste oil at recycling companies in the neighborhood. The last step is to treat solid waste and polluted air and to treat and reuse wastewater for irrigation (cotton cultivation), for use in sanitary systems and to water plants in the industrial zone.

The case studies of the greening production model and of the industrial ecology zone model demonstrated that a successful industrial ecology practice not only depends on the interaction between enterprises inside but also on the interaction with the actor networks outside the industrial system: the economic networks, the social networks and the policy networks. These networks can contribute in different ways to the implementation of the models. In the case study of a large textile company the economic network is very important in the implementation of the greening production model and in the case study of an industrial ecology zone the policy network play the most important role in the implementation of the industrial ecology model.

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ABBREVIATIONS

AOPs	Advanced Oxidation Processes
AOX	Aromatic Organic Halogen
APHA	American Public Health Association
BOD	Biochemical Oxyen Demand
COD	Chemical Oxyen Demand
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CENTEMA	Center for Environmental Technology and Management
Company D2D	Corporation for urban industrial development No.2
CP	Cleaner production
DIZA	Dong Nai Industrial Zone Authority
DO	Diesel oil
DO	Dissolved Oxygen
DONRE	Department of Natural Resource and Environment
DOST	Department of Science and Technology
ECC-HCMC	Energy Conservation Center of Hochiminh
EIA	Enviroment Impact Assessment
EPC	Environment Protection Commitment
EIP	Eco-Industrial Park
EPA	Environmental Protection Agency of the United Nation
EPD	Environmental Protection Division
FO	Fuel oil
HC	Hydrocarbon
FDI	Foreign Direct Investment
FAU	Formazin Attenuation Unit
Hepza	Hochiminh City Export Processing Zone and Industrial Zone Authority
HCMC	Ho Chi Minh City
INES	Industrial Ecosytem Project
IPMF	Industrial Pollution Minimization Fund in Ho Chi Minh City
IZ	Industrial Zone
IE	Industrial Ecology
IZA	Industrial Zones Authority
ISO	International Organization for Standard
LEP	Law on Environmental Protection
LOTECO	Long Binh Techno -Park
LCA	Life Cycle Assessment
MONRE	Ministry of Natural Resource and Environment
MoSTE	Ministry of Science, Technology and Environment
MOIT	Ministry of Industry and Trade
NGOs	Non Government Organizations
NO_x	Nitrous oxides
N_{total}	Total nitrogen
N-org	Nitrogen Organic
$N\text{-}NH^+_4$	Nitrogen ammonium
$N\text{-}NO^-_2$	Nitrogen nitrite

$N\text{-}NO_3^-$	Nitrogen nitrate
NSEP	National Strategy on Environmental Protection
OECD	Organization of Economic Cooperation and Development
P_{total}	Total Phosphate
$P\text{-}PO_4^{3-}$	Phosphate
PCs	People’s Committees
PVA	Polyvinyl Alcohol
PAC	Poly Aluminum Chloride
QCVN	National Technical Regulation of Vietnam
SO_x	Sulphur oxides
SS	Suspended Solid
SO_4^{2-}	Sulphate
TCM	Thanh Cong Company
TDS	Total Dissolved Solid
TSS	Total Suspended Solid
TCVN	Vietnamese Standard
UNEP	United Nation Environmental Program
UNIDO	United Nation Industrial Development Organization
UNDP	United Nation Industrial Development Program
US EPA	United State Asian Environmental Partnership
UASB	Upflow Anaerobic Sludge Blanket
VEPA	Vietnam Environment Protection Agency
VEA	Vietnam Environment Administration
VINATEX	Vietnam Textile and Garment Group
VNCPC	Vietnam Cleaner Production Center
VND	Vietnamese currency (Dong)
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

Chapter 1

General introduction on the Vietnamese textile and garment industry

1.1 Vietnam’s textile & garment industry’s development

Textile products are crucial for our life, especially in modern society. The textile and garment sector plays an important role in satisfying people’s basic needs as well as creating fashion and higher living standards. The demand for textile products has been increasing in the world, following both population increase and economic prosperity.

Over the last twenty years, Vietnam textile and garment industry has witnessed a strong development. In the year 1986, textile production did not supply enough to fulfill the domestic market demand and only few fabrics and clothing were exported. However from 2007 to 2009, Vietnam ranked among the top ten of textile and garment exporting countries and territories in the world. The Vietnam textile and garment industry has contributed remarkably to the economic development of Vietnam. In year 2009 this industry contributed 9% to Vietnam’s industrial value, 16.5% to the country’s export turnover and created nearly 2.5 millions jobs. This industry continues to lead other export industries in export turnover. Figure 1.1 indicates the textile and garment export market in 2009 and the growth in total textile and garment export value from 2000 to 2009. These data show that the export value has continuously grown almost 20% in the last seven years, with an especially large growth in 2007. In Vietnam, textile and garment export value ranks first, even before oil and gas (An 2008; 2009).

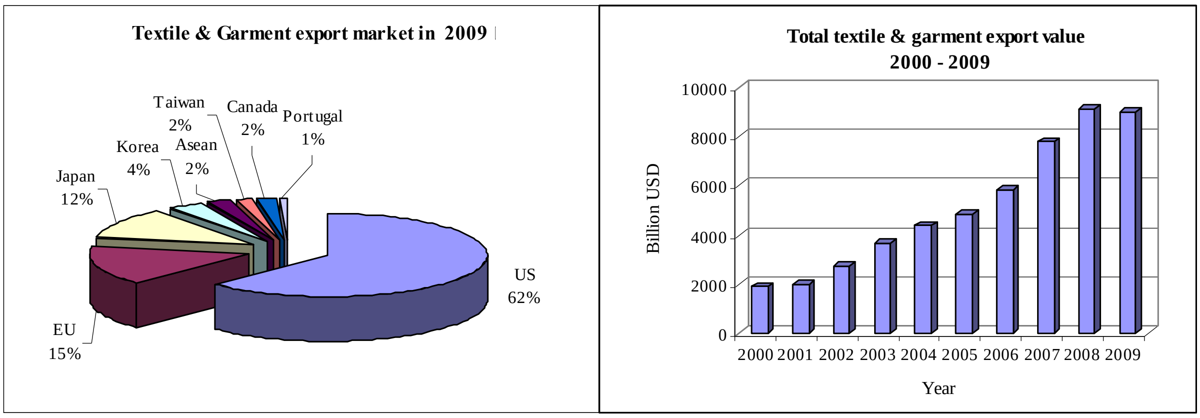


Figure 1.1: Textile & garment export market in 2009 and total textile and garment export value from 2000 to 2009

Especially after Vietnam changed fundamentally from a central planned economy to a market regulated one in 1986, textile and garment production changed dramatically. A selection in the textile and garment industry took place. The number of state-owned enterprises decreased due to lack of capital, old fashioned technologies and the end of subsidies, while the number of private companies, limited liability companies and joint stock companies increased over consecutive years. This marked a step forward, opening a new development stage for the textile and garment industry. In 2009 the industry comprised 2,500 companies of which 0,5% is state-owned, 1% is joint stock and limited companies (state-owned capital >50%) joint stock, 76% is limited companies (state-owned capital <50%) and private companies, 18.5% is FDI, and 4% is co-operations of national and foreign companies (An 2009).

In order to meet market demand and improve its competitiveness, the Vietnam textile and garment industry continuously invested and innovated equipment and technology. Production capacity of the industry showed an increase of 51,200 to 75,000 tons fabric over the period 1996-2000. In the 2005 the production capacity increased fivefold compared to the production capacity of 2000. Despite the adverse impact of the recent global economic crisis the production capacity in 2009 was the same as in 2008 with 187,000 tons of fibre, 480,000 tons of yarn, 1 million square meter of woven fabric, 200,000 tons of knitted fabric and 2.4 billion apparel products in 2009 (An 2007; 2008; 2009).

The prestige and quality of Vietnamese textile and apparel products are highly appreciated in the world market and the textile industry is seen as a very promising producer and exporter in the future, creating a large number of jobs and contributing to the elimination of hunger and the reduction of poverty. However, it is also seen as a most polluting industry, due to large chemical consumption, a huge water demand, high energy demand, as well as discharge of pollutants in great volumes of waste streams.

1.2 Environmental problems of the textile and garment industry

1.2.1 General manufacturing processes

The manufacturing process of textile and garment includes several steps and complex processes. In general, it consists of four main processes: yarn fabrication, fabric production, dyeing & finishing, and sewing. A large textile enterprise usually operates with four main processes: spinning, weaving, dyeing & finishing, and sewing, which usually are located in the same factory. A medium enterprise usually operates two processes: yarn fabrication or fabric production and dyeing & finishing. A small enterprise usually operates only dyeing & finishing processes according to requirements of the customer. The production processes and related waste generated are described in Figure 1.2 to better understand these processes. It is one the most important starting point to select suitable pollution abatement systems.

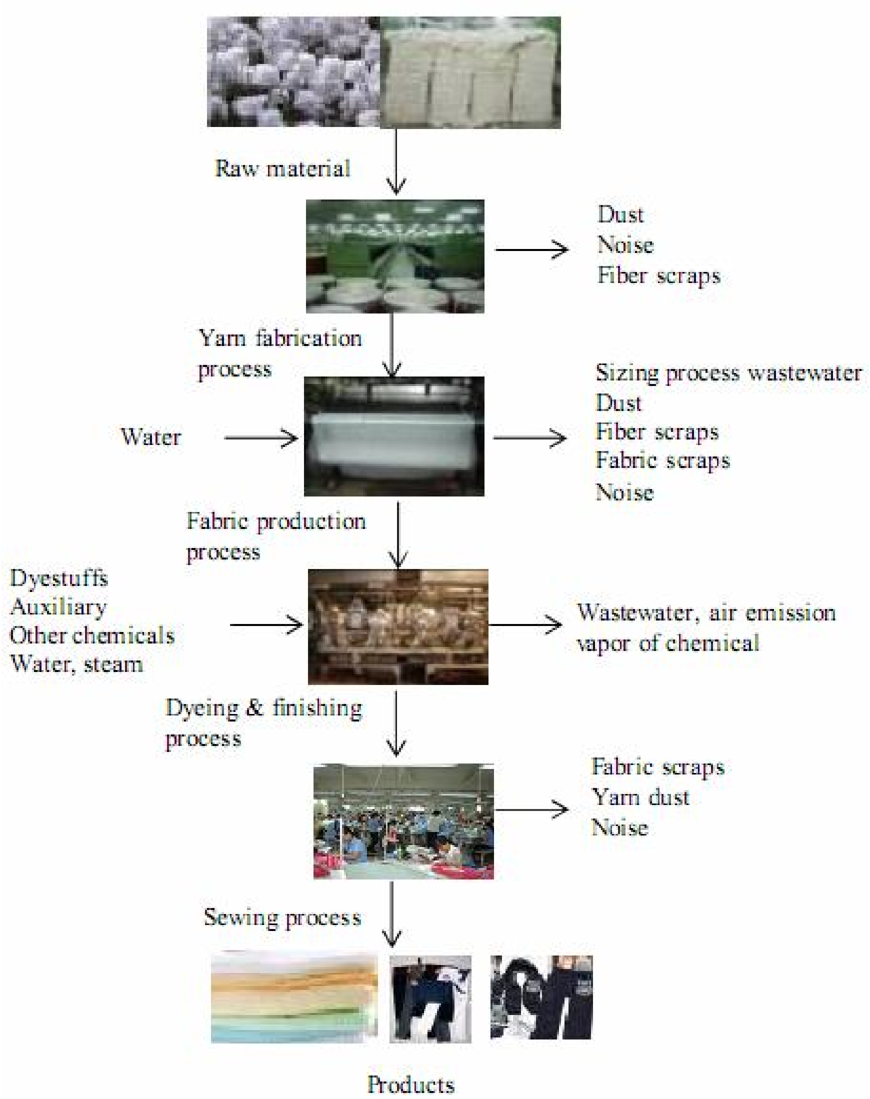


Figure 1.2: Main manufacturing processes and generated waste streams of a large textile and garment enterprise

Raw material

Raw materials used in textile industry are:

- Natural fibers such as cotton, wool, etc.
- Synthetic fibers such as nylon, polyester, viscose, etc.
- Blended natural and synthetic materials.

Yarn fabrication process

The yarn manufacturing process includes several steps such as opening/blending, cleaning, carding/combing, drawing, roving and the spinning process. The aim of this manufacturing process is to convert fibers into yarn or thread, which is used in the next fabric production process.

Fabric production process

The fabric production includes three production methods: weaving, knitting, tufting and non- woven. Weaving and knitting are most widely used in fabric manufacturing.

Weaving

Weaving is most commonly used for producing fabric. The process uses two set of threads, which interlace lengthwise (warp yarn) with widthwise ones (weft or filling yarn).

To prevent warp yarn from breaking during weaving, the warp threads are coated before weaving, to increase their strength and smoothness. Natural starches are the most commonly used coating material, although compounds such as polyvinyl alcohol (PVA), resins, alkali-soluble cellulosic derivatives and gelatin glue have been used. Other chemicals such as lubricants, agents, and fillers are often added to impart additional properties to a fabric. Remaining chemicals after sizing will become waste, which contribute to a high COD load in the wastewater.

Knitting

In the knitting process, fabric is formed through interlocking series of yarn loops. Rows of stitches are formed so that each row hangs on the row behind it, usually using sophisticated high speed machines.

Dyeing process

There are three main steps in the dyeing & finishing processes: preparing, dyeing, and finishing. In some cases, the dyeing step is replaced by a printing step. Each process is described more in detail below.

Preparing step

Preparation or pre-treatment implies preparation of suitable weaved materials for dyeing, printing, and finishing. In the preparation, impurities in raw materials have to be removed. To guarantee good quality of the fabric materials, suitable for the down-stream processes, several chemicals, auxiliaries and water are used in the pre-treatment step. The five stages of pre-treatment include:

Singeing(dyeing processing of woven cotton fabrics): removal of fibers protruding from yarn or fabric in order to create a smooth finish (EPA 1997). Pollutants associated with sizing include relatively small amounts of exhaust gases from the burners.

Desizing: complete and uniform removal of all sizing materials from the fabric. This is to optimize absorption in the subsequent dyeing and finishing steps. The sizing materials are removed with hot water or enzymes, depending on the sizing material that is used. The most commonly used sizing materials are starches or polyvinyl alcohol, resins, alkali-soluble cellulosic derivatives and gelatin glue, lubricants, agents, and fillers. So, remaining chemicals on fabrics will go into the wastewater. Desizing is one of the largest pollution sources for the dyeing and finishing process and can contribute up to 70% of the COD load in textile wastewater.

Scouring: removal of impurities from raw material. In general, alkali chemicals, together with surfactants, complexing, dispersing and reducing agents are used to remove fat, wax, protein, detergents, lubricants, inorganic substances and residual sizes. The alkali chemicals are used to saponify the fat on the fibers. The soap that is formed then serves to emulsify the remaining waxes and to wash away any dirt or other impurities. Waste that can be produced in the scouring process includes sodium hydroxide, waxes, greases, surfactants, chelating agents, sodium silicate, fibrous matter, processing oil, acid acetate and phosphate. These are thus also present in the composition of the wastewater.

Bleaching: whitening of fabric. Fabrics often require bleaching or whitening to prepare them for dyeing or printing or to produce a clear white fabric. Bleaching agents are chemical substances that oxidize colored compounds, thus removing color. Most generated pollutants from bleaching processes entering the wastewater are hypochlorite or chlorine, caustic soda, acids, hydrogen peroxide, and sodium silicate.

Mercerizing: enhancement of subsequent dye application, luster and appearance of the fabrics. In this process, the fabrics are immersed under tension in a highly concentrated solution of an alkali substance for short controlled period, then they are washed off and any excess alkali is neutralized. Caustic soda and sodium hydroxide are the main pollutants in this process, so wastewater from this stage has a high pH.

Dyeing step

The decoration of textiles can be achieved through varying the construction of fabric, by adding color through dyeing, or by applying color by printing patterns. The color may be added to fibers, yarns, constructed fabrics or finished products. The way of application of the dyes generally relates to the characteristics of fibers. The ability of fiber to accept each of the dyes, called substantiality or affinity, depends on several factors. One of the factors is availability of appropriate chemically reactive groups in both fibers and dyes; another factor is the chemical composition of the dye liquor. Various dyes, auxiliaries, and basis chemicals which are used end in the wastewater after the dyeing process.

The dyeing processes can be split into two main methods: batch and continuous method. The batch method is used to dye a large amount of yarn or fabric. The liquor and the textile are placed together in a vessel, and the required amount of dyestuff is added in accordance with the formulation/recipe. An intense interaction between the textile and the liquor then occurs. The dyeing rate and hence the dyeing time can be controlled within wide limits (about 1-2 hours). The (relative) dyeing rate increases with increase of dyeing temperature, fiber swelling, and carrier concentration. With increasing temperature, dye molecules can become more soluble (higher diffusion coefficient at higher temperatures) and then they can more easily bond to the fabric, resulting in decreased use of dyes, chemical concentration, and often a decreased fabric/water ratio. Generally, most textile companies in Vietnam use batch methods.

In the continuous dyeing method, the dyestuff is first dissolved or dispersed in the liquor. The dye liquor is locally applied in definite amounts to the textile, which continuously passes through this liquor. The diffusion transfer of the dye into to the textile is controlled by effective factors such as temperature and/or auxiliaries. The dye solution is continuously supplied to the bath to replace the quantity removed by the passing fabric. When the manufacturing process is changed from one color to another color, the remaining dye solution in the bath, the rinsing of the bath together with the associated pipes, produce a small volume of effluent with a high dye concentration.

Both the batch and the continuous dyeing method produce an effluent containing similar chemical constituents, namely the exhausted dye and other auxiliary chemicals. However, the concentration of exhausted dyes in the effluent streams from the two methods can vary considerably. For the batch dye process up to 90% of the dyes and auxiliary chemicals found in the final effluent stream comes from one-step of the process (Buckley 1992). Theoretical calculations by Glover and Hill (1993) propose a four-fold increase in dye concentration in the total effluent stream for a continuous process over the equivalent batch process. Besides, the volume of the wastewater generated from both methods also varies strongly. According to Glover and Hill (1993), 5 m^3 per ton of goods for a continuous process compared with 120 m^3 per ton for a batch process.

Not all these steps in dyeing processes are always necessary. The used steps can vary in dependence of the difference in end products, application and site-specific manufacturing practices, and type of fiber. Natural fibers typically require more processing steps than manmade fibers. Processing methods may also differ according to the final properties desired, such as tensile strength, flexibility, uniformity and luster (EPA 1997).

Printing process

Printing is the process in which a decorated surface with dye is pressed on the fabric. Pigments are used for 75 to 85% of all printing operations. They do not require a washing step and generate little wastewater. Generated pollutants from printing consist of dyes, pigments, thickeners, and auxiliary chemicals. These will go into the wastewater during the washing process, after the printing.

Finishing process

The purpose of the finishing process is increased quality of textile: abrasion resistance and tear strength of fabric. The process includes the use of chemicals and mechanical treatment. Application of chemicals is done in conjunction with mechanical finishing steps, which can involve brushing, ironing or other physical treatment used to increase the luster and feel of textile(Encyclopedia of chemical technology 1978; EPA 1997; Mattioli et al. 2002). There are hundreds of finishing chemicals, which include anion, cation, non-ion and blended silicon softeners. This process results in the generation of high concentrations of organic material in the wastewater, and small amounts of wastewater.

Sewing process

The finished clothes are fabricated into a variety of apparel and household industrial products.

1.2.2 Overview of environmental problems of the textile industry

From the general manufacturing process as described above, it can be concluded that textile processing generates many waste streams, including liquid wastes, gaseous wastes from the use of fuel, and solid wastes, some of which may be hazardous. The composition of the waste streams will depend on the type of textile facility, the processes and technologies being operated and the types of fibers and chemicals used. A general characterization of main three waste streams is listed below.

Wastewater

The textile industry is one of the most water polluting industries. Elements of concern of the textile sector are that it consumes a large volume of water, energy, dyestuff, auxiliary chemical agents and other chemicals. Wastewater arises at almost any step of the textile production process, from preparation of the fiber up to finishing of fabric process.

In order to have a basis for a general evaluation of the volume and the concentration of pollution of Vietnam's textile industry, the measuring of flow rate, sampling and analysis of wastewater, preparation of a questionnaire and data collection of different types of textile enterprises and products has been carried out.

The consumption of water per product unit of different textile enterprises (in scale and products) is indicated in Table 1.1. Water consumption varies widely between 10-415 L/kg product. In general, the consumption of water per product unit of knitting fabric is the lowest (10-40 L/kg product). However among knitting fabric companies, some have much higher water consumption levels (50-80 L/kg product). The companies with cotton, synthetic and blended fabric products consume the highest amount of water, varying between 64 and 250 L/kg product. The reason is that manufacturing processes of cotton, synthetic and blended fabric products include several steps that require more water. The data in Table 1.1 show that the water consumption of enterprises with low production capacity is higher than companies with high capacity. The same is valid for the enterprises with outdated machines and equipments, backward technologies, and weak management. For example with the same cotton products, consumption of water of the Hiep Thanh Company was only 38 L/kg product. The Song Tan Company consumed 415 L/kg product. The Hiep Thanh has modern equipment and technology with a capacity of 1,200 ton/year, while Song Tan operates with outdated machines and equipment, backward technologies and a low capacity (60 ton/year). Table 1.1 also shows that the volume of wastewater generated by the textile industry makes up more than 90% of the water consumption of the enterprise. The volume of wastewater is depended on the types of products, production processes, type of machines, scale of enterprise and amounts between 10 and 9,700 m^3/day.

Table 1.1: Volume of wastewater generated by 29 textile enterprises

Name of Company	Production capacity (ton/year)	Number of employees (persons)	Water supply (m^3/day)	Wastewater produced (m^3/day)	Specific water consumption (L/kg)
Knitted fabric					
Cong Thanh Co., Ltd	3,000	30	100	95	10
Tuyet Tran Co., Ltd	2,600	30	270	260	31
Vu Thinh Co., Ltd	1,500	30	80	77	16
Xuan Huong Weaving Company	1,500	60	70	60	14
Hong Tien Phat Co., Ltd	1,300	105	100	80	23
Hiep Phong Co., Ltd	800	10	26	22	10
Hoang Phong Co., Ltd	700	8	50	40	21
Tan Tien Cuong Co., Ltd	700	10	30	25	13
Tan Phu Cuong Co., Ltd	400	10	15	13	11
Duc Hung Co., Ltd	300	8	80	77	80
Duc Hoa Processing & Finishing Co., Ltd	300	17	40	34	40
Nguyen Ngoc Hai Co., Ltd	200	9	40	38	60
Thuan Phat Processing & Dyeing Co., Ltd	200	12	25	22	38
Hai Lien Processing Co., Ltd	150	14	25	22	50
Hoang Dung Processing & Finishing Co., Ltd	150	10	25	22	50
Tan Minh Co., Ltd	150	10	25	23	50
Huu Tai Co., Ltd	60	9	13	10	65
Cotton fabric					
Hiep Thanh Deying Company	1,200	30	150	140	38
Phat Thinh Co., Ltd	300	18	100	95	100
Hung Thinh Co., Ltd	250	25	40	35	48
Song Tan Textile Co., Ltd	65	15	90	85	415

Table 1.1: Volume of wastewater generated by 29 textile enterprises, continued

Name of Company	Production capacity (ton/year)	Number of employees (persons)	Water supply (m^3/day)	Wastewater produced (m^3/day)	Specific water consumption (L/kg)
Blended and synthetic fabric					
Nam Quang Co., Ltd	700	20	90	80	39
Nhan Thanh Processing & Finishing Co., Ltd	400	30	100	92	75
Cotton, synthetic, blended yarn and fabric					
Thanh Cong Company	10,000	5,500	10,000	9,750	165
Thang Loi Textile & Garment Joint Venture Company	4,200	3,300	2,500	2,300	179
Phuoc Long investment Joint Stock Company	4,200	800	900	800	64
Namtex Co., Ltd	3,000	460	2,500	2,200	250
Dong A Textile & Garment Company	2,800	1,300	2,200	2,000	236
28 Company- Agtex	1,950	4000	750	700	115

Source: Vietnam Textile and Garment Group; 28 Company-Agtex (2005)Viet (2003; 2006)

The composition of wastewater from 25 textile enterprises is shown in Table 1.2. The wastewater has a COD concentration that shows a wide fluctuation from 245-11,150 mg O_2/L. A high value of COD often originates from the cotton fabric manufacturing process (around 465-3,960 mg O_2/L) and from the knitting fabric process (around 705-11,150 mg O_2/L). For synthetic fabrics, concentrations of COD were significantly lower: 370-2140 mg O_2/L. Meanwhile concentrations of COD generated from large scale enterprises with equal products vary widely from 245-2,200 mg O_2/L. Besides COD, these wastewater streams contain dyestuffs (toxic organic chemicals), salts, and surfactants. The ratio of BOD_5/COD is found to be low: around 0.2-0.5. One of the important characteristics of dye wastewater is the fact that it contains color agents. The wastewater from small and medium-sized enterprises is often higher in color intensity (495-3,680 Pt-Co) than the color of wastewater from large scale enterprises which varies from 245-1,800 Pt-Co. Concentrations of heavy metals such as chromium, zinc, and copper are very low. The pH of the wastewater varies widely from 3.9 to 11.3.

The results in Table 1.2 indicate that the concentration of pollutants in the wastewater of small enterprises is higher than in that of the medium-sized and large enterprises. The explanation is that almost all small enterprises buy cheap chemicals from China and Taiwan which are low in quality. Moreover, the amount of dyestuffs and chemicals used in the manufacturing process is often based on management experiences. Wastewater from small scale textile enterprises usually has high pollutant concentrations, which contributes significantly to the amount of pollution to many canals and rivers.

Medium-sized and large scale enterprises have more often invested in modern equipment, good process control and buy good quality chemicals and dyestuffs. Consequently, the concentration of chemicals and dyestuffs in wastewater streams are lower.

Table 1.2: Composition of textile and garment industry wastewater

Name of company	Flow rate m^3/day	pH -	SS mg/L	Color Pt-Co	COD mg O_2/L	BOD mg O_2/L	N total mg/L	PO_4^{3-} mg/L	SO_4^{2-} mg/L
Knitted fabric									
Hong Tien Phat Co., Ltd	80	7.3	150	-	705	254	-	-	-
Tan Tien Cuong Co., Ltd	25	7.2	148	1,720	1,485	330	3.3	0.9	34
Duc Hoa Processing & Finishing Co., Ltd	34	9.7	82	1,740	780	205	1.2	0.4	371
Thuan Phat Processing & Finishing Co., Ltd	22	11.3	1,112	3,680	11,150	5,100	41	0.7	18
Hai Lien Processing & Finishing Co., Ltd	22	7.8	13	3,005	3,390	1,875	0.1	0.3	24
Hoang Dung Processing & Finishing Co., Ltd	22	7.2	26	1,635	1,870	690	7.0	0.5	12
Cotton fabric									
Song Tan Co., Ltd	85	6.6	95	1,500	1,320	420	1.1	0.4	35
Phu Hoang Gia Trading & Processing Co., Ltd	-	12.4	338	-	465	96	-	-	-
Du Phat Co., Ltd	-	11.2	102	-	3,230	1,435	-	-	-
Tan Tien Hao Trading and Processing Co., Ltd	-	6.7	105	-	1,145	467	-	-	-
Tien Dung Co., Ltd	-	6.5	354	-	3,960	1,290	-	-	-
He Chang Co., Ltd	60	6.9	170	565	1,750	510	37.0	0.3	601
Synthetic yarn and fabric									
Ching Fa Fishing Implements Manufacturing Co., Ltd	300	7.8	34	1,180	1,840	675	69.0	3.9	-
Kuljin Co., Ltd	100	4.6	175	1,560	2,140	1,250	5.8	0.5	-
Yuekun Co., Ltd	50	10.5	17	980	505	96	4.5	1.6	0.45
Gi - Tal Sewing Tread Co., Ltd	350	3.9	35	495	370	90	5.0	1.3	-
Blended and synthetic fabric									
Nam Quang Co., Ltd (Tan Binh)	80	6.5	40	2,000	525	281	1.1	0.2	-
Nhan Thanh Processing & Finishing Co., Ltd	92	9.0	336	495	5,975	2,800	8.3	0.2	150

Table 1.2: Composition of textile and garment industry wastewater, continued

Name of company	Flow rate	pH	SS	Color	COD	BOD	N_{total}	PO_4^{3-}	SO_4^{2-}
	m^3/day	-	mg/L	Pt-Co	mg O_2/L	mg O_2/L	mg/L	mg/L	mg/L
Cotton, synthetic, blended yarn and fabric									
Thanh Cong Company	9,750	7.6	960	1,025	400	210	4.8	1.2	-
Thang loi Textile Company	2,300	10.7	180	-	1,750	407	-	-	-
Namtex Co., Ltd	2,200	7.7	50	1,800	245	60	8.6	26.7	-
S.Y.Vina Ltd., Co.	2,200	7.7	134	905	446	94	20.0	2.4	-
Dong A Textile & Garment Company	2,000	9.7	648	-	2,200	450	-	-	-
Phuoc Long investment Joint Stock Company	800	6.3	98	-	245	89	-	-	-
28 Company- Agtex	700	10.9	40	1,380	1,200	510	4.2	0.9	302
TCVN 5945:2005 Industrial wastewater-discharge standards:									
Class C: water quality standards for industrial effluents discharged into sewer systems (often applied to industrial enterprises located inside an industrial zone)		5.0-9.0	200	-	400	100	60	8	
Class B: water quality standards for industrial effluents discharged into surface water resources which are not used for potable water production		5.5-9.0	100	50	80	50	30	6	-

Note: total nitrogen includes nitrogen organic, nitrate, nitrite, and ammonium.
Source: Vietnam Textile and Garment Group(VINATEX 2003); Viet (2003; 2006)

Air pollution

Gaseous emissions have been identified as the second largest pollution problem (after wastewater) for the textile industry. Air polluting sources come mainly from the operation of boilers using fuel oil (FO) or diesel oil (DO). The boiler operation usually generates sulphur oxides (SO_x), nitrogen oxides (NO_x) and hydrocarbons (HC). The air quality inside enterprises is relatively clean, as can be seen from the results of measurement presented in Table 1.3. The values of the analyzed parameters were lower than the permissible threshold values of the environmental health standards.

The composition of air pollution from chimneys of some textile enterprises is tabulated in Table 1.4. Inside the chimneys of boilers at the textile enterprises the concentration of most analyzed inorganic parameters is lower than the air quality required by industrial emission standards (TCVN 5939:2005). Only the concentration of sulphur dioxide (SO_2) is above standard for S.Y. Vina Ltd.Co. and for the 28 Company -Agtex.

Table 1.3: Air quality inside 12 textile enterprises

Name of enterprise	Noise dB	Particulates mg/m^3	NO_2 mg/m^3	SO_2 mg/m^3	CO mg/m^3
Knitting fabric					
Hong Tien Phat Co., Ltd	80-84	0.3	0.20	0.24	2.0
Tan Tien Cuong Processing and Finishing Co., Ltd	74-78	0.4	0.10	0.11	2.2
Duc Hoa Processing and Finishing Co., Ltd	79-81	0.1	0.05	BDL	1.1
Thuan Phat Processing and Finishing Co., Ltd	74-78	0.5	0.12	0.13	2.2
Hoang Dung Processing and Finishing Co., Ltd	77-87	0.4	0.05	BDL	BDL
Cotton fabric					
Song Tan Co., Ltd	73-80	0.1	0.10	0.06	0.8
Tien Dung Co., Ltd	74-75	0.3	0.15	0.12	1.6
Jinkyon Vietnam Co., Ltd	84-93	0.2	0.05	BDL	BDL
Van Phuc Thanh trading and processing Co., Ltd	73-79	1.1	0.07	0.10	1.1
Blended and synthetic fabric					
Nam Quang Co., Ltd (Tan Binh)	79-83	0.3	0.27	0.44	8.0
Nhan Thanh Processing and Finishing Co., Ltd	74-77	0.6	0.18	0.24	2.1
Cotton, synthetic, blended yarn and fabric					
Thanh Cong Company	-	-	0.06	0.07	3.8
Thang Loi Company	-	45.9	0.07	0.10	4.4
Phuoc Long investment Joint Stock Company	-	0.34	0.06	0.41	-
TCVS, 3733:2002/BYT Air Quality – environmental health standards inside factories	85	1	10	10	40

Source: Vietnam Textile and Garment Group(VINATEX 2003); Viet (2003; 2006);

BDL: below detection level

Table 1.4: Composition of industrial air pollution of five textile enterprises (in chimney)

Name of enterprise	Parameters				
	Temperature (^0C)	Dusts (mg/m^3)	SO_2 (mg/m^3)	NOx (as NO_2) (mg/m^3)	CO (mg/m^3)
Namtex Company	162	372	1,242	646	355
S.Y.Vina Co., Ltd .	193	124	2,486	342	169
28 Company- Agtex	-	175	2,585	366	27
Thanh Cong Company	255	-	800	175	150
Nam Quang Co., Ltd	270	150	341	27	25
TCVN 5939: 2005- Air quality industrial emission standards					
Class A: operational enterprise	-	400	1,500	1,000	1,000
Class B: new enterprise	-	200	500	850	1,000

Source: Viet (2003; 2006); Thanh Cong Company (2005); 28 Company- Agtex (2006)

Other significant sources of air emission in textile industry are related to resin finishing, printing, dyeing and fabric preparation. For instance, hydrocarbons (HC) are emitted from drying ovens and mineral oils in high temperature drying/curing. Acetate and formaldehyde are two major emissions of concern in the textile industry. According to VINATEX (2003) concentrations of these organic substances were low in manufacturing zones for most textile enterprises; for instance acetate was in the range of 0.03-4.30 mg/m^3, and hydrocarbons concentration was 0.01-4.71 mg/m^3.

In addition, particulate pollution (dust) is also one of the issues of concern for textile and garment production. The particulates originate mainly from yarn, weaving and sewing processes. In according with statistics of VINATEX (2003) for loose raw material, particulate in yarning and weaving process are 1.5-2% and 0.5-1%. Particulates generated from yarning, weaving and sewing processes are as follows (VINATEX 2003):

- Yarning process : 1.10-3.44 mg particulates/m^3
- Weaving process : 1.16-1.50 mg particulates/m^3
- Sewing process : 0.93-1.15 mg particulates/m^3

Solid waste

Solid wastes generated from the textile industry are primarily non-hazardous. It includes scraps of yarn and fabric, miss produced yarn and fabric, and packaging waste. All non-hazardous waste is separated at source and recycled in other enterprises. In accordance with decision No. 23/2006/QD of the Ministry of Natural Resources and Environment which lists hazardous waste, sludge generated by wastewater treatment systems of textile industry, chemical storage drums, and outdated chemicals and dyestuffs should be considered hazardous substances. Almost all hazardous waste, especially sludge, is not treated by professional companies. Total amounts of solid waste generated daily from textile enterprises, and the composition of sludge, are summarized in Tables 1.5 and 1.6.

Table 1.5: Amount of solid waste generated daily from 4 textile enterprises

Name of companies	Production capacity (ton/month)	Non-hazardous waste (kg/month)	Hazardous waste (kg/month)		Domestic solid waste (kg/month)
			Sludge	Total	
Thanh Cong Company	833	10,000	2,000	2,820	4,000
28 Company- Agtex	165	260	3,000	3,403	100
Phuoc Long Private Enterprise	25	5,200 (including ash from coal)	40	173	270
Hoang Dung Processing & Finishing Co., Ltd	12.5	200	40	75	120

Source: TCM (2007); HCM DONRE (2007); 28 Company- Agtex (2006)

Table 1.6: Composition of sludge from 3 textile enterprises

Parameters	Unit	Thanh Cong Company	Hoang Dung Processing & Finishin Co., Ltd	Phuoc Long Private Enterprises
Humidity	%	90	-	92
Cd	mg/ kg DM	BDL	7.71	3.78
Ni	mg/ kg DM	33.7	-	-
As	mg/ kg DM	0.12	0.99	2.36
Pb	mg/ kg DM	3.02	115	21
Cu	mg/ kg DM	318	-	-
Zn	mg/ kg DM	2.745	-	-
Cr total	mg/ kg DM	BDL	54	52
Fe	mg/ kg DM	1.456	-	-
Phenol	mg/ kg DM	0.12	0.29	0.01

Note: BDL: below detection level.
Source: TCM (2007); VUC (2006); HCM DONRE (2007)

Domestic (sanitary) waste

The textile industry attracts a large amount of employees. With more than 2 millions employees the sector employs up to 24% of the industrial workforce, of which 80% is female. One company has even over 5,000 workers. So, textile and garment enterprises are usually built in or close to residential areas. This adds domestic environmental pressures and hindrances to the industrial ones through large volumes of discharged domestic wastewater, domestic solid waste, and traffic jams from a large amount of commuters.

1.2.3 Conclusions

Of the three main waste streams from the textile industry, wastewater is the most problematic and polluting one. As it is often discharged directly, it affects directly surface water quality of local canals and rivers through its high concentration of pollutants and large flow rate. Sulphur oxides, and especially SO_2, have been identified as the second largest pollution problem, mainly originating from the operation of boilers. Industrial solid waste source has hardly and impact on the environment, with the exception of wastewater treatment sludge. Domestic wastes impact depends on the amounts.

1.3 Current environmental protection and management in the textile industry

1.3.1 The administrative environmental management system in Vietnam

The Ministry of Natural Resources and Environment (MONRE) is the top state management agency for national natural resource management and environmental protection. The National Assembly established MONRE in 2002. The tasks of MONRE cover seven main fields in connection with land, water resources, geology and minerals, environment, hydrometeorology, geo-information survey and mapping, and marine protection. The Vietnam Environment Protection Agency (VEPA) is one of the four agencies of MONRE. This agency assists MONRE in executing state management tasks regarding environmental protection. The major tasks and responsibilities of VEPA include areas such as: examination, supervision, prevention, mitigation and remediation of environmental pollution, degradation and incidents; improvement of environmental quality; conservation of biodiversity; environmental monitoring; application of clean technology; developing database statistics, information and reporting on environment; implementing integrated coastal zone management; and education to enhance the awareness of the community on environment. September 30th, 2008 the VEPA changed its name in to Vietnam Environment Administration (VEA) based on Decision No. 132/2008/QD-TTg of the Prime Minister. The establishment of VEA was an important step in the process of the planning agencies for environmental management of the State and marked the growth and development of the environmental sector of the country.

The Departments of Natural Resource and Environment (DONREs) are the state management agencies for natural resource management and environmental protection at provincial/city level. DONREs fall under the responsibility of city/provincial governments, called people's committees (PCs), and professionally under MONRE.

There are 64 provincial DONREs in Vietnam. DONREs activities consist of appraisal of environmental impact assessments; examination, supervision, inspection, remediation of environmental pollution, degradation and incidents; improvement of environmental quality; environmental monitoring; education to enhance the awareness of the community on environment. They also assist PCs on the master plans.

In all large cities/provinces with industrial development an Industrial Zones Authority (IZA) was established to carry out environmental management for industrial and export processing zones. The IZAs are established by PCs and have responsibility to examine and supervise enterprises in industrial zones for compliance with environmental protection; to resolve environmental disputes and problems caused by environmental accidents in the industrial zones, together with DONREs; to handle complaints of enterprises; and education and raising awareness of the employees.

Environmental Protection Divisions (EPD) at the district and community levels is the lowest state management agencies for natural resource management and environmental protection. The EPD belong to people’s committees at district level. Following the Law on Environmental Protection (2005) EPD’s responsibility and power are enhanced to effectively protect the environment. Tasks of the EPD include appraisal of environmental protection commitments; supervision and examination to comply with the regulation on environmental protection; resolving public complaints and environmental disputes. The environmental management structure in Vietnam is presented in Figure 1.3. When an enterprise is established, it has to carry out regulations of environmental protection, as summarized in Figure 1.4.

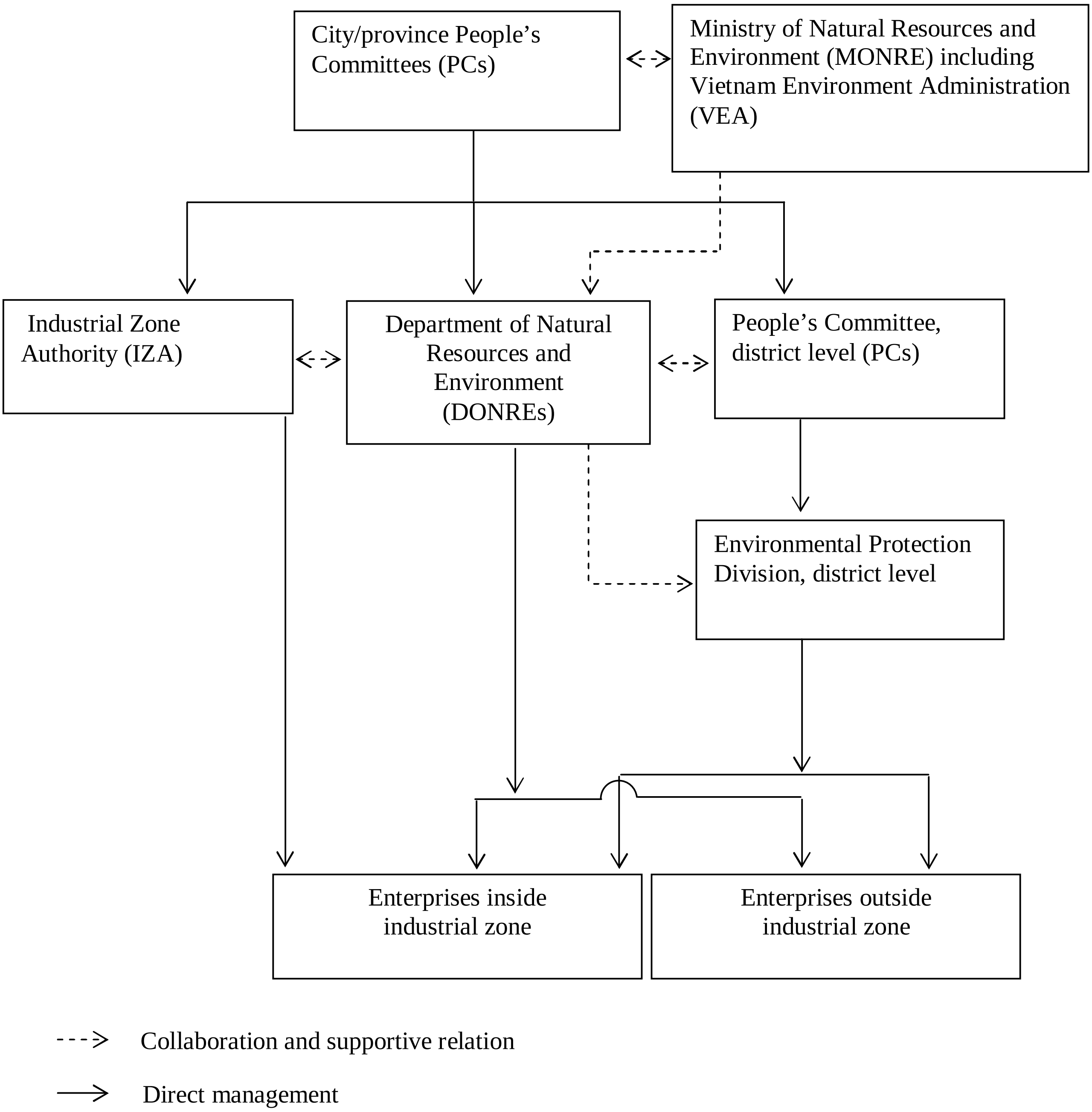


Figure 1.3: Environmental management structure in Vietnam

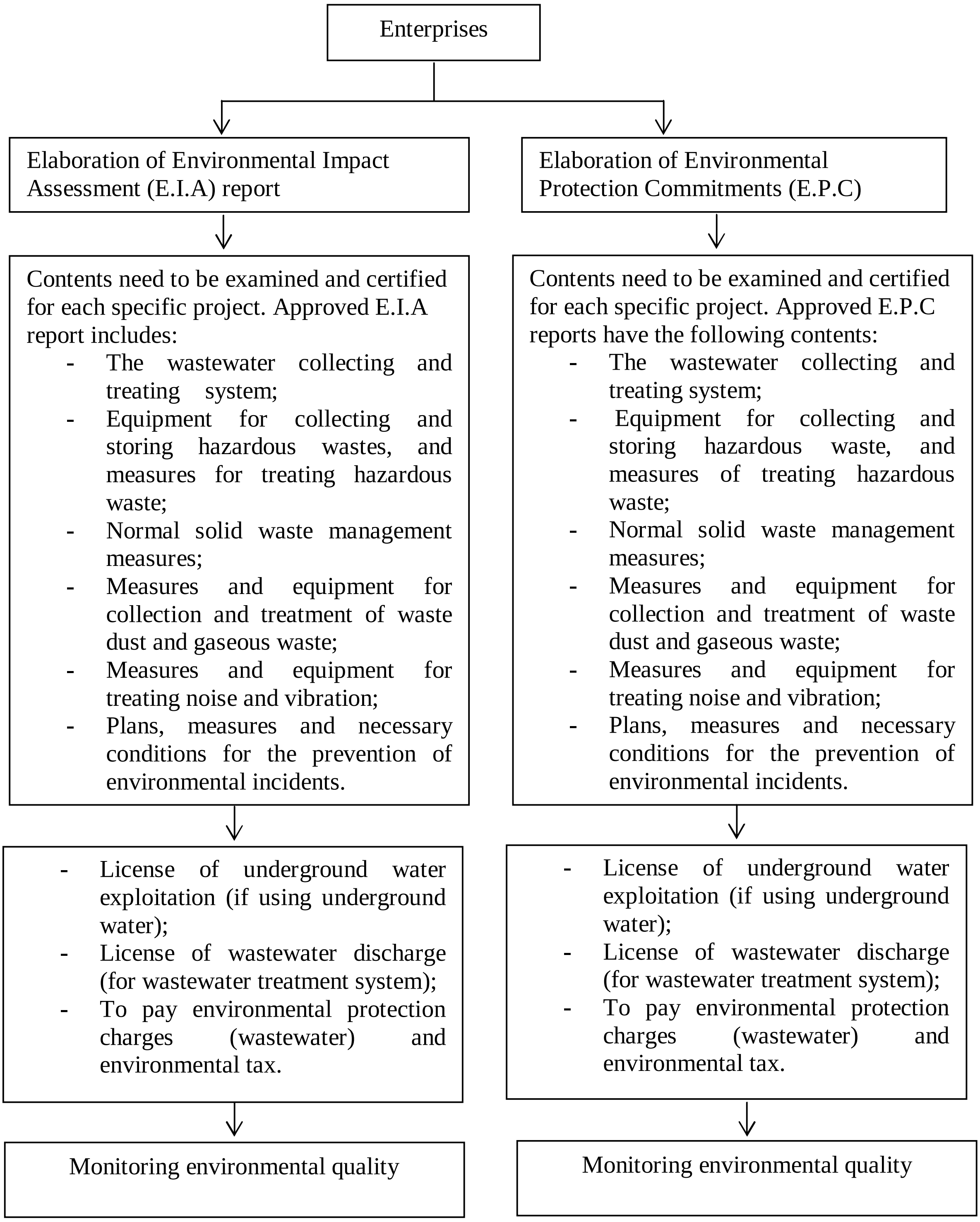


Figure 1.4: Environmental management procedures for new enterprises in Vietnam

Note: Enterprises must carry out EIA or EPC depending on capacity and type of industry. This is regulated based on Decree No. 80/2006/ND-CP from the Government, dated 9th August, 2006, and on detailed regulations and guidelines from the Law on Environmental Protection 2005.

1.3.2 Environmental protection policy

At the Earth summit on Environment and Development held in 1992 in Rio de Janeiro (Brazil) the Government of Vietnam passed the Declaration on Environment and Development and Agenda 21. Since then, Vietnam has further transformed its socio-economic development model and its system of environmental protection. Many important policies on management and utilization of natural resources and environmental protection have been developed and implemented. A system of law and national standards was enacted, meeting practical requests and needs for renovation in the country, such as a new labor code, a law on public health care and protection, a law on environmental protection, etc. Remarkable events in environmental protection in Vietnam from 1991-2009 are listed in Table 1.7.

Table 1.7: Remarkable event in Vietnam's environmental policy

Year	Remarkable events
1991	- The Law on Forest Protection and Development was promulgated, and the National environment protection and sustainable development plan for the period 1991-2000 was approved
1992	- Ministry of Science, Technology and Environment was established
1993	- National Assembly of Vietnam approved the law on environmental protection, the Veterinary Ordinance, the Law on Oil and Gas, the Ordinance on environmental protection and inspection - National Environmental Protection Agency was established by the Ministry of Science, Technology and Environment
1994	- Decree 175/CP for guiding the implementation of the Law on environmental protection was promulgated
1995	- National action plan on conservation of bio-diversity was promulgated. - Vietnamese Environmental Standards (1995) was promulgated, which include: Ambient air quality standards (TCVN 5937:1995); maximum allowable concentration standards of hazardous substances in ambient air (TCVN 5938:1995); surface water quality standards (TCVN 5942:1995); Ground water quality standards (5944:1995); industrial wastewater discharge standards (TCVN 5945:1995)
1996	- The Law on minerals and the Ordinance on radiation control and safety were approved. - Decree 26/CP regulating administrative infringement fines for environmental protection was promulgated. The decree focused on enterprise compliance with the Law on environmental protection

Table 1.7: Remarkable event in Vietnam's environmental policy, continued

Year	Remarkable events
1998	- Politburo of the Central Committee of the Communist Party instructed intensification of environmental protection activities in the national industrialization and modernization period. The Law on water resources was approved
1999	- Strategies for solid waste management at urban and industrial zones to 2020, and the regulation on hazardous waste management were approved
2002	- Ministry of Natural Resources and Environment was established
2003	- Some Vietnamese Standards were reformed: water quality and domestic waste (TCVN 6772:2001); water quality standards for industrial effluents discharged into sewers (TCVN 6980:2001); water quality standards for industrial effluents discharged into rivers protecting aquatic life (TCVN 6984:2001). According to these standards the concentration of pollutants is defined based on total waste load.
2004	- The national environmental protection strategies for the period up to 2010, with an outlook to 2020, were approved.
2005	- National Assembly of Vietnam approved the Law on environmental protection 2005 - Promulgation of Vietnamese Environmental Standards (2005)
2006	- Decree No. 22/2006/QĐ-BTNMT by MONRE on enforcement of five environmental standards, which include: ambient air quality standards (TCVN 5937:1995); maximum allowable concentration of hazardous substances in ambient air (TCVN 5938:2005); industrial air emission standards for inorganic substances and dusts (TCVN 5939:2005); industrial air emission standards for organic substances (TCVN 5949:2005); industrial wastewater discharge standards (TCVN 5945:2005) - Promulgation of decree No. 80/2006/NĐ-CP by the Government on detailed regulations and guidelines for implementation of some articles of the Law on Environmental Protection
2007	- Government Decree No. 59/2007/ NĐ-CP on the management of solid waste, 9 April - Government Decree No. 88/2007/ NĐ-CP on urban and industrial zone drainage, 28 May - Government Decree No. 174/2007/ NĐ-CP on environmental protection fee for solid waste, 29 November - Establishment of the environmental police force and Natural Resources & Environment Policy Institute

Year	Remarkable events
2008	- Decree No. 29/2008/ NĐ-CP of the government regulations on the establishment, operation, policy and State administration of industrial parks, export processing zones, economic zones and border economic zones, 14 March - Decision No. 16/2008/QĐ-BTNMT by MONRE on enforcement of eight environmental national technical regulations, including the national technical regulation on effluent of textile industry (QCVN 13:2008) - Ministry of Natural Resources and Environment Circular No. 08/2009/TT-BTNMT on environmental protection regulations for economic zones, high technological parks, industrial zones and industrial clusters, 17 July
2009	- Prime Minister Decision No. 1419/ NĐ-TTg on approval of industrial cleaner production strategies up to 2020, 7 September - Prime Minister Decision No. 2149/ NĐ-TTg on approval of national strategies for management of solid waste up to 2025 with orientation towards 2050, 27 December - Circular No. 25/2009/TT-BTNMT by MONRE on enforcement of national technical regulation on industrial emission of inorganic substances and dust (QCVN 19:2009); industrial emission of organic substances (QCVN 20:2009); National technical regulation on industrial wastewater discharges (QCVN 24:2009)

Although Vietnam has a well-developed system of policies and legal instruments, the system can not keep pace with the rapid development of industry, business, services, and population. Consequently, the natural environment has been seriously compromised in many areas and environmental pollution and deterioration has reached alarming levels. The making of Vietnam‘s environmental protection policy started later than in many other countries, and is still in its infancy and with incomplete implementation and enforcement. Hence, there is no balanced combination of three dimensions of development: economic, social and environmental protection. The problem reveals through the document of control and inspection of 285 enterprises in 2006 of the Vietnam Environmental Protection Agency (VEPA). According to this document, only 19% of the enterprises build wastewater treatment plants, and only 4% of the companies had wastewater treatment plants meeting the Vietnamese standards; only 16% of the enterprises had an air pollution treatment system, and 21% of the enterprises carried out monitoring of environmental quality; 5% of the enterprises had not yet made an Environment Impact Assessment report (VEPA 2007).

The explanation is that in Vietnam policies have been in favor of economic development and social stability, but have yet to pay full attention to sustainability in exploitation and utilization of natural resources. Too much emphasis on economic development, especially GDP growth, resulted in a severely deteriorated environment.

1.3.3 Relocation programmed

Most paper factories, food processing companies, textile enterprises and many other industries were established in Vietnam without planning, especially in big cities such as Hochiminh city, Ha Noi, and Bien Hoa. In Hochiminh city about 35,000 medium small enterprises are scattered throughout the city, often located in densely populated urban areas without any waste treatment system. To minimize environmental pollution from industrial activities and improving the living conditions of residents, Hochiminh city authorities developed in 2002 a policy of relocating polluting small enterprises to industrial zones outside Hochiminh city. The "Integration of relocation of polluted enterprises to Industrial Zones (IZ)" program was originally planned to run between 2002 and 2004. Until now, Hochiminh city has been the only city with a relocation program.

The main objectives of the relocation program in Hochiminh city included:
- To remove the seriously polluting enterprises into industrial zones or suburbs, where firms can use common wastewater treatment facilities;
- To rearrange existing production activities, and reorganize the licensing for new investment projects which consider the abatement of pollution in industry;
- To concentrate small scale enterprises of the same branch into clusters, in order to create large scale conglomerates. By doing so these small scale enterprises can share costs and develop an efficient organizational structure for environmental protection and better market competition;
- To further develop industrial zones in Hochiminh city.

According to a report of the Department of Natural Resources and Environment (DONRE) in 2006, this program was prolonged to 2006. Financial support was too small during the first years, there were problems with finding enough land for the relocation program (720ha), and infrastructure in the relocation zones was often not available. Up to the end of 2006, when the program finished, there were 1,402 highly polluting enterprises in the list of the relocation program, of which 1261 (90% of the 1,402 enterprises) achieved results:
- Relocation: 630 enterprises, (50% of the 1261 companies)
- Stopping the production: 463 enterprises (36.8%)
- Change of products produced: 127 enterprises (10%)
- Onsite application of remediation: 36 enterprises (2.8%)
- Requests for expanding the relocation time: 5 enterprises (0.4%)

Through this program, small and medium-sized textile enterprises moved to industrial zones or suburbs or stopped production. Large state-owned enterprises could not relocate to the industrial zones because these enterprises require quite some land, water and energy, which these industrial zones could not deliver. Therefore, they carried out onsite remediation, by investing in waste treatment systems. However, these enterprises still seriously pollute the environment in populated areas. One of the future strategies for the Vietnam's textile and garment industry is to invest in building a textile and garment industrial zone, with complete infrastructure including a water supply system, electricity, and centralized wastewater treatment plant. This would also improve their competitiveness in the world.

1.3.4 Current status of waste treatment in the textile industry

Wastewater treatment

A survey on the present situation of textile wastewater treatment technology was carried out for different sizes of enterprises. The results show that almost no wastewater treatment facility meets the industrial wastewater-discharge standards (TCVN: 5945-2005, class B) for both COD and color intensity. The reason is that textile wastewater changes strongly within a day, even per hour, making it very difficult to treat. Enterprises do not have the professional manpower to fine-tune the wastewater treatment operations. Beside, Vietnamese standards for color and COD are very strict. To meet color and COD standards (50 Pt-Co and COD 80 mg O_2/L) requires modern technology. Moreover, costs of wastewater treatment operation are high and increase production costs. Therefore, direct discharge of wastewater into sewers, canals or rivers occurs regularly. Lastly, the design of treatment systems does not meet the requirements because consulting companies hardly ever investigate properly the composition and volume of wastewater.

Textile wastewater treatment technology can be divided into: (1) physical/chemical treatment (coagulation), (2) a combination of physical/chemical treatment (coagulation) and biological treatment (aerobic treatment). The selection of technology will depend on the discharge standards to be achieved.

Enterprises located inside an industrial zone only have to meet the TCVN 5945: 2005 (industrial wastewater-discharge standards), class C (water quality standards for industrial effluents discharged into sewer systems). The standard is described in Table 1.8. The current wastewater treatment technology applied in most enterprises is presented in Figure 1.5.

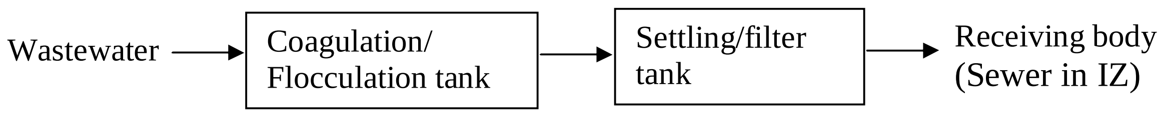


Figure 1.5: Standard wastewater treatment system for textile industry

The application of a coagulation process can only reduce suspended solids and colloidal particles resulting in a decrease in color of nearly 50%. Table 1.8 lists suspended solids of effluents of Nhan Thanh, Tan Tien Cuong, and Duc Hoa Co., Ltd. A site survey shows that the suspended solids in the effluent are still high, due to the short sedimentation period, which cannot ensure the total settlement of solids. The data in Table 1.8 also show that almost all effluents do not meet the discharge standards for COD, because the coagulation process does not sufficiently reduce the dissolved organic compounds. Sulfate concentration of effluents from some wastewater treatment systems was higher than influent, because alum sulfate was used as the coagulant. Among seven enterprises tested, only Hong Tien Phat Co., Ltd met the discharge standards due to a low influent concentration.

The enterprises located outside an industrial zone (or inside an industrial zone, which is not yet provided with a centralized wastewater treatment plant), need to meet discharge standards TCVN 5945:2005, class B: water quality standards for industrial effluents discharged into surface water resources which are not used for potable water production. The present situation regarding the wastewater treatment technology of Thanh Cong Company is described in Figure 1.6.

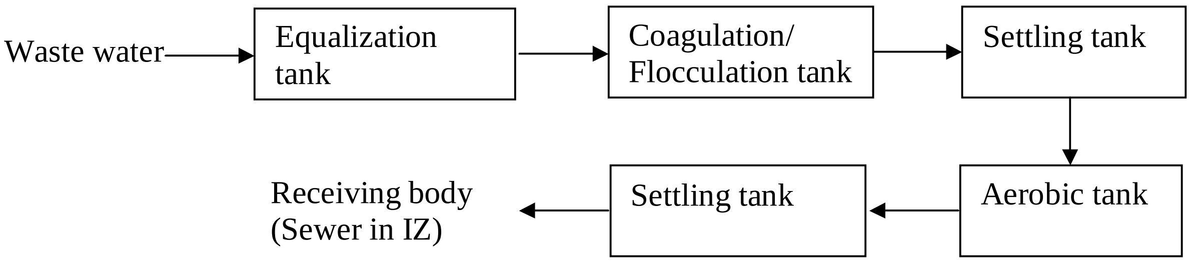


Figure 1.6: Advanced treatment wastewater treatment system combining physical/chemical treatment (coagulation) and biological treatment of Thanh Cong Company

However, with this treatment system the color intensity of the effluent does not meet the discharge standards (50 Pt-Co). It is very difficult to meet these standards with the present treatment technology. The data in Table 1.9 illustrate that with the applied treatment technology, COD can not decrease to below the allowable threshold (COD: 100 mg O_2/L).

Namtex Company and Houlon Corporation Vietnam are also equipped with a wastewater treatment system similar to the one mentioned in Figure 1.6. However, these are provided with an aerobic process before the coagulation process (Figure 1.7). However, after treatment the color and COD of the effluent still exceed the standard.

Composition of effluent from combined of physical/chemical and biological treatment systems or biological and physical/chemical treatment (following Figures 1.6 and 1.7) is presented in Table 1.9.

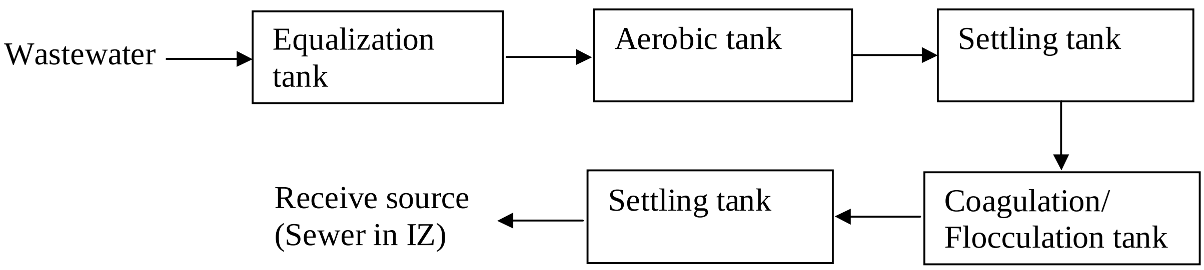


Figure 1.7: Advanced treatment wastewater treatment system combining biological treatment and physical/chemical treatment (coagulation) of Namtex Company and Houlon Corporation Vietnam (inside an industrial zone, which is not yet provided with a centralized wastewater treatment plant)

The wastewater treatment system of S.Y. Vina Co., Ltd with additional coagulation process as post treatment is described in Figure 1.8. The data of the S.Y. Vina Co., Ltd in Table 1.10, show that the effluent exceeds the discharged standards many times on color and COD, and thus post treatment may not improve treatment efficiency. The results show that the system is not operated properly.

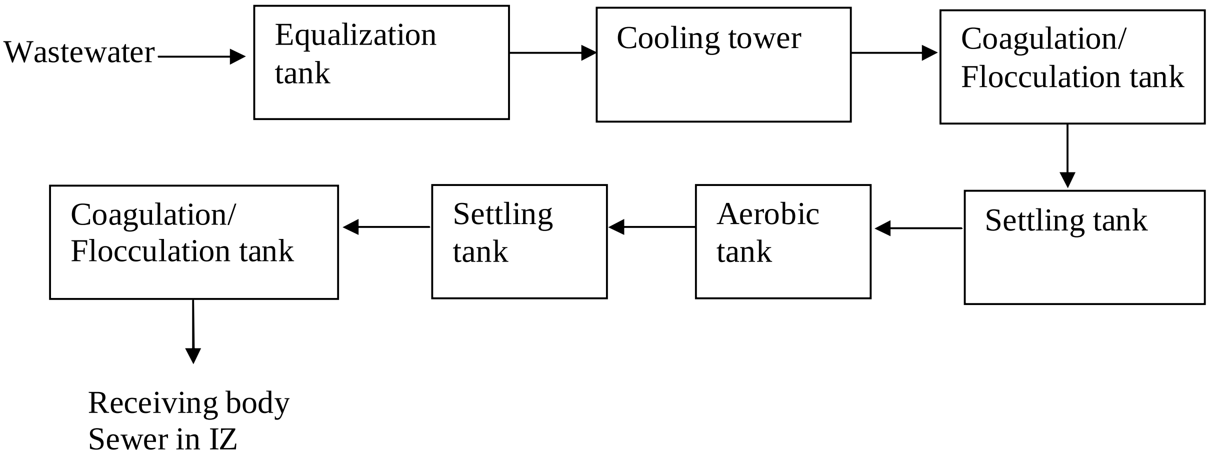


Figure 1.8: Wastewater treatment system of S.Y. Vina Co., Ltd (inside an industrial zone, which is not yet provided with a centralized wastewater treatment plant)

Table 1.8: Effluent qualities of wastewater treatment systems with coagulation process of companies inside an industrial zone (effluent should comply with class C discharge standards) and discharge standards. Effluent qualities of wastewater treatment systems with coagulation process of a company outside an industrial zone (effluent should comply with class B discharge standards) and discharge standards

Name of enterprises	Flow rate (m^3/day)	pH	SS (mg/L)	Color (Pt-Co)	COD (mg O_2/L)	BOD (mg O_2/L)	N_{total} (mg/L)	P_{total} (mg/L)	SO_4^{2-} (mg/L)	Note
Hong Tien Phat Co., Ltd	60	5.7	42	241	620	125	1.1	0.2	44	Before treatment
		5.4	96	50	122	35	4.5	0.2	123	After treatment
Song Tan Co., Ltd	90	6.6	288	1500	1320	420	1.1	0.3	35	Before treatment
		6.6	95	530	670	180	1.9	0.4	75	After treatment
Nhan Thanh Co., Ltd	80	9.0	336	495	5973	2800	8.3	0.2	150	Before treatment
		4.4	250	297	2288	1329	12.6	0.7	115	After treatment
Duc Hoa Co., Ltd	35	9.7	82	1739	780	205	8.0	0.4	371	Before treatment
		6.6	95	88	492	303	1.2	0.3	275	After treatment
Tan Tien Cuong Processing and Finishing Co., Ltd	30	7.2	148	1717	1483	330	3.3	0.9	34	Before treatment
		6.5	105	1667	1272	300	2.3	1.1	31	After treatment
Hoang Dung Co., Ltd	20	7.5	788	-	4725	1013	0.1	0.3	24	Before treatment
		7.0	62	-	1670	690	0.7	0.5	12	After treatment
He Chang Co., Ltd	90	6.9	170	565	1750	600	37	0.3	35	Before treatment
		6.6	53	132	1325	510	5	0.1	75	After treatment
28 Company -Agtex	700	11.9	38	688	772	152	13.7	2.8	0.06	After treatment (class B)
TCVN 5945:2005, Class B		5.5-9.0	100	50	80	50	30	6	-	
TCVN 5945:2005, Class C		5.0-9.0	200	-	400	100	60	8	-	

Table 1.8: Effluent qualities of wastewater treatment systems with a combination of coagulation and aerobic processes, and discharge standards, continued

Name of enterprises	Flow rate (m^3/day)	pH	SS (mg/l)	Color (Pt-Co)	COD (mg O_2/L)	BOD (mg O_2/L)	N_{total} (mg/L)	P_{total} (mg/L)	Surfactant (mg/L)	Note
Gi - Tal Sewing Tread Co., Ltd	350	3.9	35	493	372	90	5.0	1.3	0.437	Before treatment
		7.1	44	396	193	48	4.3	1.1	0.198	After treatment (class B)
Yue Kun Co., Ltd	50	10.5	17	998	505	96	4.5	1.6	0.450	Before treatment
		7.9	15	112	39	12	1.3	0.1	0.115	After treatment (class B)
Ching Fa fishing equipment Co., Ltd	400	7.8	34	1187	1840	645	69	3.9	0.138	Before treatment
		4.9	15	122	61	15	15	0.3	0.084	After treatment (class B)
Kukjin Co., Ltd	100	4.5	55	1170	2142	1250	-	-	-	Before treatment
		7.3	30	142	833	540	-	-	-	After treatment (class B)
TCVN 5945:2005, Class B		5.5-9.0	100	50	80	50	30	6		
TCVN 5945:2005, Class C		5.0-9.0	200	-	400	100	60	8	-	

Source: Viet (2003; 2006); 28 Company- Agtex (2006)

Table 1.9: Effluent qualities of wastewater treatment systems with a combination of aerobic and coagulation process, and discharge standards

Name of enterprises	Flow rate (m^3/day)	pH	SS (mg/l)	Color (Pt-Co)	COD (mg O_2/L)	BOD (mg O_2/L)	N_{total} (mg/L)	P_{total} (mg/L)	Surfactant (mg/L)
Thanh Cong Company									
Hualon corporation Vietnam	6,600	6.8-7.2	11-47	42-120	88-225	20-57	1.5-3.3	0.4-0.6	0.037-0.045
Namtex Company	2,500	7.8-8.0	11-32	613-1240	76-189	13-66	3.7-7.3	17.7-23.4	0.020-0.050
TCVN 5945:2005, Class B		5.5-9.0	100	50	80	50	30	6	-

Source: Thanh Cong Company (2005); 28 Company- Agtex (2006); Viet (2006)

Table 1.10: Effluent qualities of wastewater treatment of S.Y Vina Co. Ltd (coagulation, aerobic and coagulation post treatment process)

Name of enterprises	Flow rate (m^3/day)	pH	SS (mg/l)	Color (Pt-Co)	COD (mg O_2/L)	BOD (mg O_2/L)	N_{total} (mg/L)	P_{total} (mg/L)	Surfactant (mg/L)
S.Y. Vina Co., Ltd	2,200	7.3-7.7	33-134	658-903	252-446	60-94	4.6-19.7	0.2-2.4	0.006-0.015
TCVN 5945:2005, Class B		5.5-9.0	100	50	80	50	30	6	-

Source:Viet(2006)

Air pollution treatment

Almost all textile enterprises in and outside industrial zones are not equipped with an air wastes treatment system. Waste gasses are emitted directly (sometimes via a chimney) into the environment. Most chimneys have only height of 5-20 m. Few enterprises are equipped with treatment systems for exhaust gas from boilers. Such treatment systems consist of wet absorption with an alkali solution as absorbent (Figure 1.9). Particulate pollution is abated with a cyclone or filter bag.

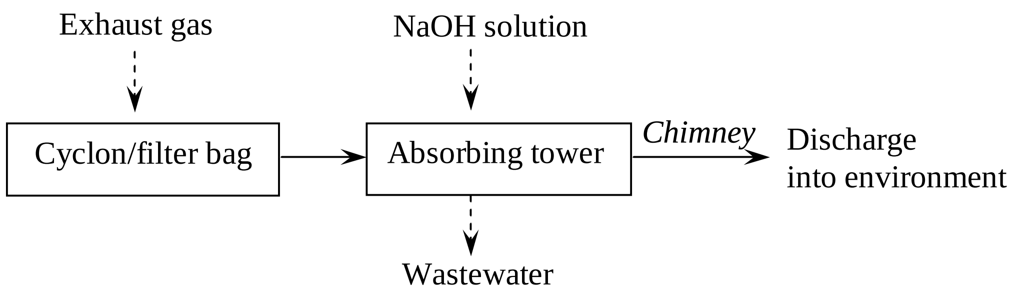


Figure 1.9: Air pollution treatment technology of textile enterprises

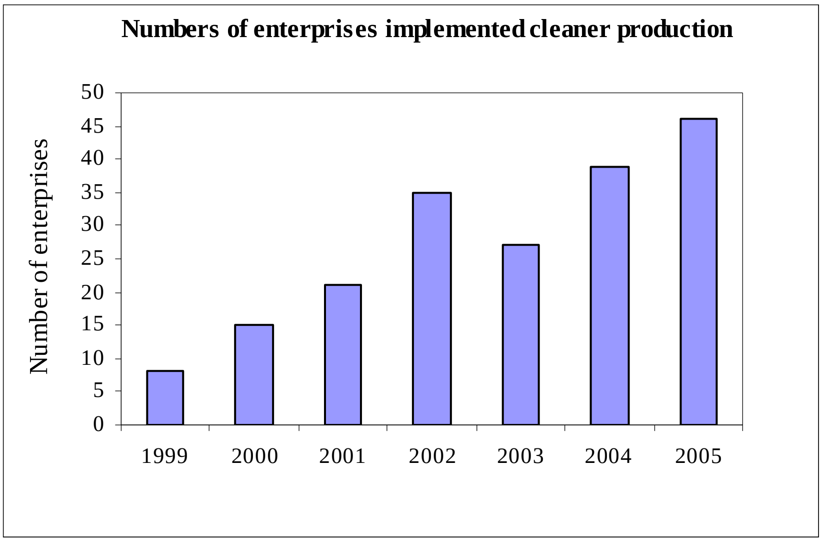
Solid waste treatment

Industrial production premises do classify domestic solid wastes and industrial solid wastes. The implemented treatment directions of solid wastes nowadays are:

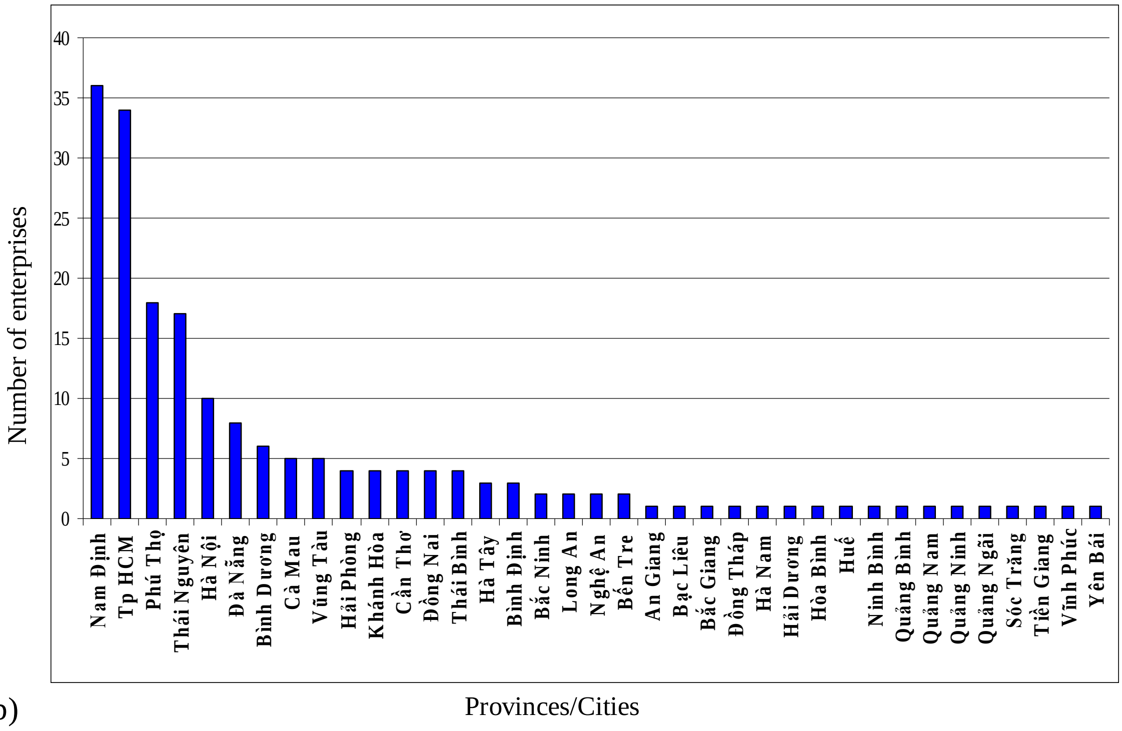
- Domestic solid waste is collected and treated (on contractual basis) by the Provincial/District Urban Environment Company.
- Industrial solid wastes, including non-hazardous and hazardous waste, which is not yet classified, is sold to companies buying scraps. Part of the industrial wastes is sold to recycling companies, while the rest of the industrial wastes are disposed together with domestic solid wastes.
- Most sludge from wastewater treatment system is collected by the Provincial/District Urban Environment Company and dumped at landfills. However, few enterprises contract a professional company for treatment of sludge.

1.3.5 Cleaner Production

The Government of Vietnam passed the International Declaration on Cleaner Production in 1999 and the National Cleaner Production Action Plan (2001-2005) was born in 2003. After seven years implementing cleaner production (CP), 200 enterprises of different industries and scale had joined the cleaner production demonstration projects. According to the Vietnam Environment Protection Agency- VEPA (2006) the number of textile enterprises that implemented CP was 34 (out of a total of 2,000 textile and garment enterprises). Figure 1.10 shows the limited number of enterprises that had implemented CP, compared to the total number of enterprises in Vietnam. Implementation of CP in Vietnam happens through demonstration projects, which is financed by international organizations or the government. At the end of demonstration projects all activities related to CP in these enterprises come to a stop.



(a)



(b)

Figure 1.10: (a) Number of Cleaner Production demonstration projects implemented each year; (b) and number of the enterprises implementing Cleaner Production in the various provinces/cities (VEPA 2006)

1.3.6 Application of ISO 14001 in textile industry and environmental protection performance of the textile industry

In recent years, textile and garment enterprises have replaced most obsolete equipment, and invested in purchasing modern equipment to produce high quality products for export. The EU, Japan, Canada and the US request textile products of high quality, and also an environmentally sound working environment. In order to exports textile products to these countries exporting enterprises have to treat waste (wastewater, air pollution, solid waste) and have to develop and certify an ISO14000 environmental management system. Through ISO 14000 certification, exporting textile and garment enterprises will improve market opportunities as well as environmental performance. Achieving ISO 14001 certification is now believed to be one of the key tasks of the textile and garment industry (VINATEX 2003). In Vietnam the number of enterprises with ISO certification has increased in recent years (Figure 1.11), and that is also true for the Vietnamese textile enterprises. It shows the benefits of ISO once companies have understood they have to invest to get a higher return.

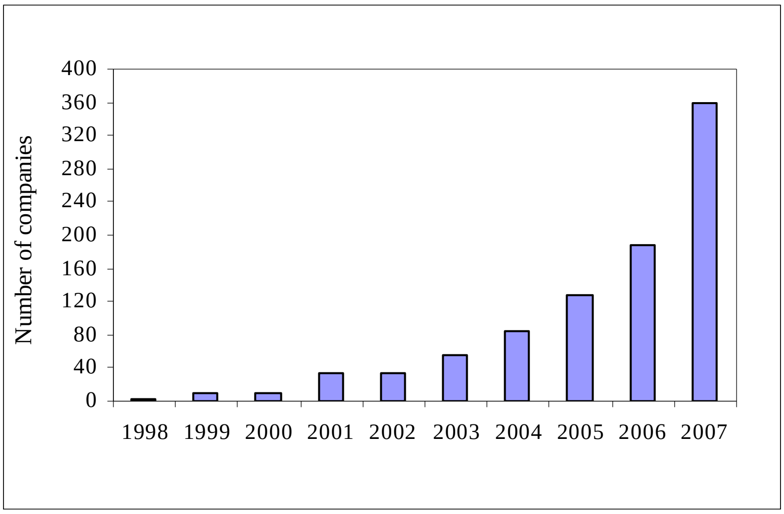


Figure 1.11: ISO 14001 certification application in Vietnam, 1998-2007 (source:http://www.iso.org)

1.4. Development strategies of textile and garment industry for 2015 to 2020

According to development strategies for the textile and garment industry for 2015 to 2020 (Dung 2008) targets of the textile and garment industry include:

- Developing the textile and garment industry to become one of the key export industries, satisfying the domestic consumption demand, creating employment, improving the competition ability, integrating stability in the region and in the world.
- The production growth rate should reach 12-14% and export growth should become 15% per year.

- Export turnover should reach 18 billion US$ in 2015 and 25 billion US$ in 2020 together with employment of about 2.75 million people in 2015 and 3 million people in 2020.

In correspondence with the above targets, this strategy means for the textile and garment industry the following:

- Development of the textile and garment industry in the direction of specialization and modernization, in order to create a leap in quality and quantity of products and move towards conditions that are stable, sustainable and effective.
- Overcoming the weaknesses of industry such as underdevelopment, inadequate and untimely supply of accessories, not paying proper attention to fashion design and trademark development.
- Taking exports as the target for the development, enlarge export markets, develop and maximize the domestic market. Concentrating on development of supporting industry, improving added value for products.
- Diversifying the ownership and enterprise types in the textile and garment industry, mobilizing all local and overseas resources to invest and develop textile and garment production.
- Developing the human resources in terms of quality and quantity, properly training managers, technicians, designers and skillful workers.

Environmental protection is recognized as an inseparable part in the development of the textile and garment industry to achieve sustainable development. The development strategy of textile and garment industry until 2015 towards 2020 with regard to the execution of the environmental protection programs is concentrated into issues below.

- Development of the textile and garment industry in association with protecting environment and transferring companies to labor rich (rural) environments;
- Moving the polluting enterprises (dyeing and weaving enterprises) out of the cities to Industrial Zones with complete infrastructure such as a water supply system, electricity and centralized wastewater treatment.
- Moving the garment enterprises to provinces with abundant workforce sources and favorable transportation.
- Encouraging implementation of Cleaner Production and environmental management system (ISO 14001), especially for large scale enterprises and enterprises exporting to the EU, Japan, US market, in order to improve the quality of their products, services and to have competitive production.

In the targets of the development strategy for the textile and garment industry from 2015 to 2020, there are many advantages to apply "Greening textile and garment industry in Vietnam", especially in the approach of an industrial ecology zone.

1.5 The objective and structure of the thesis

1.5.1 The objective

The textile industry is an industry in rapid development in Vietnam. Vietnam’s textile and garment industry has made a remarkable contribution to economic development, with more than 2 millions employees. However, its development has relied on low labor productivity; energy intensive production technology; high natural resource consumption; and release of large amounts of emissions. Although enterprises have built waste treatment facilities, actually almost all these facilities are operating inefficiently, resulting in serious environmental deterioration and human health problems. In Vietnam the textile industry is seen as one of the most polluting industries.

Many programs have been carried out to minimize pollution in the textile and garment industry and to move to more sustainability. However, these programs have almost always concentrated on one approach or technology or waste stream.

The objective of this thesis is to focus on the development and desk application of an integrated model combining pollution minimization and end-of-pipe technologies for individual enterprises as well as for combined enterprises in a (textile) industrial ecological zone. In order to achieve a sustainable development of the textile industry subsequent steps have to be analyzed; first, to maximize resource efficiency: second, to minimize and recycle waste; and finally, to treat remaining waste streams, especially wastewater.

Such an integrated approach has to look not just into technological options (whether they be resource efficiency, waste exchange or treatment systems) but also into the role private and public actors (can) play in the implementation of such technological options.

1.5.2 The structure of the thesis

The structure of thesis includes eight chapters as following:

Chapter 1: **General introduction on Vietnam textile & garment industry**
In this chapter the Vietnamese textile & garment industry development and strategies, together with environmental problems and current status of the industry’s environmental protection performance are introduced. Also the goals of the research are described.

Chapter 2: **Environmental protection in textile industry: concepts and methods**
The chapter presents concepts and methods of Cleaner Production, industrial ecology and end-off-pipe practices to minimize pollution from the textile industry to achieve sustainable development.

Chapter 3: **Physical /chemical processes: experimental research**
The chapter deals with the experimental data and assessment regarding the application of physical/ chemical (AOPs) processes to remove color of different dyes with the purpose to reuse the wastewater. The results are compared regarding treatment efficiency and economical costs in order to choose the best treatment method.

Chapter 4: **Combination of physical, chemical and biological processes: experimental research**

The chapter deals with the experimental data and assessment on the application of a combination of physical/chemical and biological treatment processes to completely remove color and COD of the textile wastewater. The results are compared regarding treatment efficiency and economical costs in order to choose the best treatment method to comply with strict discharge standards.

Chapter 5: **Separation of wastewater streams: experimental research**

The chapter gives the survey data and assessment on reuse ability of separated wastewater streams. The treatment technologies of each wastewater stream are compared regarding of economic and treatment efficiency.

Chapter 6: **Greening production in textile industry, a case study at Thanh Cong Textile and Garment Joint Stock Company**

This chapter describes application of an integrated approach combining pollution minimization and end-of-pipe treatment for a large state owned textile enterprise, evaluating achieved efficiencies.

Chapter 7: **Case study of Industrial Ecology at "Nhon Trach 2 Industrial Zone"**

This chapter deals with the modeling of efficient use of resources in and outside an existing textile industrial zone in order to close material cycles and to (re)use resources and waste as efficiently as possible.

Chapter 8: **Conclusions and recommendations**

Chapter 2

Environmental protection in the textile industry: concepts and methods

2.1 Introduction

Most industrial production processes generate waste, and so does the textile industry. The quantity and composition of waste depends on many factors such as industrial production scale, raw materials used, production management, technologies, the kind of products produced, and the capacity of treatment, reuse and recovery. Hence, within the textile production sector, different production plants will show different pollution profiles, so that the idea of "one solution fits all" will not work.

This chapter deals with environmental protection approaches for the textile industry in the world as well as Vietnam. Different circumstances require different (combinations of) approaches to effectively protect the environment. In introducing the various approaches, technologies and methods of environmental protection in this chapter, a distinction will be made in three main categories, dealt with in three subsequent sections. Section 2.2 introduces a variety of so-called end-of-pipe solutions and approaches; all focused on treating waste streams from textile production plants. Section 2.3 elaborates on cleaner production approaches and methodologies. Section 2.4 focuses on the more recent notion of industrial ecology, which looks at environmental protection beyond separate production units. Section 2.5 moves beyond technology and introduces the actors and institutions involved in implementing such environmental protection approaches. The final section elaborates on the methodology of the thesis.

2.2 End-of-pipe technology

To comply with regulation of national environmental agencies industries are forced to treat their waste (including the wastewater) before discharging it. End-of-pipe technology is applied to treat pollution from industrial activities, and ranges from simple to complex and advanced technologies. Many types of technological processes- alone or in combination - have been applied to remove pollutants from waste streams in various industries: physical (settling, filtering), physical/chemical (coagulation/flocculation), absorption, chemical (oxidation, neutralization), and biological (anaerobic, aerobic) processes.

End-of-pipe technology was the first approach to be widely used in industrial production processes for environmental pollution control, from the 1950s onwards first in the more developed parts of the world. But the building, operation and maintenance of these waste treatment systems add to production costs and thus affect the competitiveness of industries. Besides, such waste treatment processes form by-products. For instance, waste sludge is generated from wastewater treatment systems that treat wastewater wit heavy metals by coagulation or precipitation processes. Thus, end-of-pipe waste treatment measures are often only transferring contaminants from one medium to another medium. For example, domestic solid waste is dumped in landfills which will generate biogas and soil pollution.

Hence, also within end-of-pipe treatment technologies there is recently more attention to reuse and recycling waste: to improve the environmental performance, to reduce the financial burden of waste treatment, and to exploit resources. Innovative technologies have been applied to achieve better treatment efficiency and to solve some of the end-of-pipe technology’s shortcomings. Hence, end-of-pipe technology is increasingly becoming a suitable solution for environmental protection. As mentioned in chapter 1, the textile industry is seen as one of the most polluting industries, textile wastewater treatment has been extensively researched in laboratories, via pilot cases, and in practice. The various treatment processes studied can be divided into biological, physical/chemical, chemical, and other processes. Many of these processes are only functioning on a laboratory or pilot scale, including electrochemical and pair (double) extraction (which are not yet suitable to be applied for high organic concentrations and large volumes as textile wastewater). Until now, only a few technologies have been applied for wastewater from full scale textile industries. In this chapter, many treatment processes will be reviewed in depth, in term of cost, feasibility, practicability, stability, environmental impact. The reviewed technologies are:

- Change of color by pH adjustment
- Coagulation processes
- Advanced oxidation processes (AOPs)
- Membrane processes
- Biological process with anaerobic and aerobic processes
- Combination of different processes

2.2.1 Change of color by pH adjustment

Due to dyestuffs complex chemical structures, they are resistant to fading on exposure to light, water and many chemicals (Poots et al. 1976a; McKay 1979). According to Phyllips (1996), almost all dyestuffs contain one or more benzene rings or more complex aromatic compounds. The name aromatic compounds is derived from the fact that the rings are often a part of a substance with strong covalent bonds, and usually have a pleasant odor. In the chemical structure of dyestuffs, the groups that cause the color are called chromophore groups. The groups that increase the color intensity of the chromophore are called auxochrome groups. The modern viewpoint is that the chromophore group is a conjugated system of double bonds (Van der Zee et al. 2001; Van der Zee 2002). If light absorption of the chromophore is very small the substance would not be a dyestuff. Dyestuffs usually contain auxochrome groups which are acid or base groups, ionized and strongly polar. These auxochrome groups are fixed at two sides in the dyestuff molecule to form an electron fuse or attraction force within the dyestuff. Therefore, the color of dyestuffs can be affected by the pH. In fact, decolorization of a solution can occur within a narrow pH range. Some compounds undergo a color change or even become colorless in certain pH ranges. One of examples is the p-nitrogen phenolate ion, which is yellow in an acid solution and turns blue-yellow in an alkaline solution.

The pH is a prominent factor in wastewater treatment processes like the coagulation process as well as in the chemical oxidation. Chemical oxidation processes are effective only within a certain pH range. The Fenton’s reagent process, for example, has its optimal pH around 3-5, and the ozonation process efficiency is also pH dependent. The same is true for coagulation. To better understand the effect of only pH, and the pH in the physical/chemical and oxidation processes on color change, an experiment on the effect of pH on color intensity is described in chapter 3.

2.2.2 Coagulation/flocculation process

Coagulation/flocculation process are often applied to remove colloidal, suspended solids which are not directly removed by sedimentation, filtration, and flotation processes. The coagulation process involves the chemical destabilization of colloidal particles and the formation of larger particles through agglomeration of destabilized colloids into microflocs, progressing into bulky flocs that can settle.

The colloidal particle destabilization can be obtained by addition of a reasonable dosage of potential determining ions, electrolytes, hydrolyzed metal ions. These chemicals are called coagulants. Adding potential determining ions or electrolytes is in general not feasible in wastewater treatment because it needs a large amount to achieve a reduced zeta potential or change of the charge double layer. Hydrolyzed metal ions, however, provide good results in terms of treatment efficiencies and costs.

According to Metcalf and Eddy (2003), particle destabilization and removal by hydrolyzed metal ions, such as alum and iron, is a complex process. Process factors which can promote the coagulation/flocculation process are velocity gradient, reactive time, and pH (Lenntech 2004). The pH is a prominent factor in a coagulation process, the time and velocity gradient are related to the probability of the particles meeting each other. The dosage of coagulant/flocculant needed depends on the nature of the particles, and the pH and temperature of the wastewater. Factors such as pH, dosage of coagulant, temperature are often used in studies for coagulation process.

Typical coagulants and flocculants are aluminum sulfate, aluminum chloride, ferric chloride, ferric sulfate, ferrous sulfate, calcium hydroxide, sodium aluminum and pre-hydrolyzed metal salts such as poly-aluminum chloride and poly-iron chloride. Aluminum sulfate, ferric sulfate, ferrous chloride and poly-aluminum chloride are commonly used in coagulation process because they are commonly available, cheap, have high color removal efficiency.

There is an abundance of literature on the coagulation process as a textile wastewater treatment. The coagulation is found to be effective in the color removal of insoluble dyestuffs such as disperse, azoic, vat and sulphur dyes, but not or less not effective for the removal of soluble dyes (Olcay et al. 1996; Vandevivere et al. 1998; Oliver et al. 2000; Kao et al. 2001). In contrast, there are some studies that show that the coagulation process is efficient in the color removal of soluble dyes, such as reactive and acid dye (Stahr et al. 1980; Thakur et al. 1994), and unsatisfactory in the color removal of insoluble dyestuffs such as vat dyes (Mattioli et al. 2002).

Literature research reveals that in some cases the color removal in raw wastewater may be more efficient applying the coagulation process with aluminum sulfate. A good removal efficiency of 42% for COD was obtained with a combination of aluminum salt and lime (Altinbas et al. 1995). In general, the removal of heavy metals can also take place in a coagulation process (Abdel-Shafy et al. 1996; Mollah et al. 2001; Amuda et al. 2006). However, removal of recalcitrant organic matter, nutrients and salts is limited for the coagulation process (Vandevivere et al. 1998; Lefebvre and Moletta 2006).

Results of Stahr et al. (1980) show that an alum salt dosage in the range of 100 to 500 mg/l efficiently removes color for sulphur dyes, vat and acid dyes. Panswad and Wongchaisuwan (1986) discovered that magnesium carbonate combined with lime can remove over 90% of the color from a reactive dye wastewater. The same was found by Mehrotra et al. (1995) for sulphur dye, they reported a color removal of 90% using $MgCO_3$ at pH of 10.

Thakur (1994) reported that the coagulation process can remove color up to 90% from reactive dye wastewater with 50 ppm Fe^{3+} or Al^{3+} under acid condition. However, Marmagn and Coste (1996) found low removal efficiencies with the coagulation process of certain types of dyes such as reactive and acid dyes with the same coagulants.

Olcay et al. (1996) carried out coagulation studies for removing color from an acid dyeing bath. The achieved efficiencies were low with dosages of 1,000 mg aluminum, ferrous, and ferric salts per liter wastewater. Aluminum salt gave the highest removal efficiency of 55%, at a pH of 7.5, with ferrous salt this was 39% at a pH 9 and with ferric salt 12% at a pH 7.5. For wastewater which was collected from balance tank, containing reactive dyes (initial color 230 Pt-Co), 250 mg aluminum salt/L at pH 7.8 and 250 mg ferrous salt/L at pH 10.5 gave a high efficiency in terms of color and COD removal, the color removal efficiency was 91% (remaining color 20 Pt-Co) for ferrous coagulant and 83% for aluminum.

According to Tuba (2001) the coagulation process with aluminum and ferric salts for color and COD removal of wastewater from a cotton fabric manufacturing process (disperse and reactive dye) gave a color and COD removal efficiency of 45% and 68% for aluminum, and 43 % and 69% for ferric salts with the same dosage of 1,250 mg/L at pH 6. In a synthetic fabric manufacturing process using 4 types of dye: disperse, reactive, sulphur and termosol, aluminum salt with a dosage of 200 mg/L at pH 5 achieved a removal efficiency of 67% for color and 48% for COD.

According to Perkowski et al. (2000) a dosage of 100 mg Fe^{2+} at pH 8 removed 85% of the color and 35% of the COD per liter raw textile wastewater. Kao et al. (2001) indicated that most textile wastewater treatment systems, with a combination of a biological treatment and chemical coagulation in Taiwan could not produce an effluent that met the color standards (400 ADMI); the color removal efficiency of the coagulation step ranged from 40-70%.

According to Azbar et al. (2004), coagulation with 350 mg $FeSO_4$/L at pH 8.5 can only remove 50% of the color and 40% of the COD for wastewater generated from an acetate and polyester fiber manufacturing process.

Summarizing some of the findings of the literature on the coagulation process it is clear that the pH plays a prominent role in the removal efficiency of the coagulation process. The optimal pH for aluminum salt in the range of 5 to 7.8, for ferrous salt this is from 8-10. These pH values are suited for coagulation with aluminum and ferrous salt. The dosage of coagulant is varied depending on nature and concentration of dyestuffs. The aluminum sulfate dosage ranged from 100 to 1,250 mg/L to obtain color removal efficiencies of 43 to 91%, for ferrous sulfate this was 200 to 1,000 mg/L, achieving lower removal efficiencies than aluminum sulfate. A good removal efficiency of 35-91% for COD was obtained with the coagulation process.

One of the main drawbacks of coagulation process is the generation of large amounts of sludge (Mattioli 2002). In addition, the coagulation process adds a large amount of coagulant and pH adjustments solution into the wastewater, consequently this will increase the salt concentration (or electric conductivity) of the effluent. Reuse of water and dye and chemical recovery are still not applicable using the coagulation process as wastewater treatment. However, the coagulation process is used widely in textile wastewater treatment plants at present.

In short, the coagulation process may efficiently remove color and COD from textile wastewater at optimal conditions established in laboratory or pilot studies. The effect of pH, dosage and type of coagulant on the removal efficiencies for several types of textile wastewaters was investigated. The results are presented in chapter 3.

2.2.3 Advanced oxidation processes (AOPs)

Advanced oxidation processes (AOPs) are mostly based on the action of highly reactive radical species (especially the hydroxyl radical OH•) that can react with a wide range of compounds, including toxic or non-biodegradable compounds. The advanced oxidation processes are widely applied to treat many different types of wastewater. The three AOPs usually applied are: O_3, O_3/H_2O_2, and Fenton's reagent (Fe^{2+}/H_2O_2).

Ozone (O_3)

Ozone is one of the strongest oxidants with a high oxidation potential (E_0 =2.07V). The oxidation potential of ozone is higher than that of oxygen (E_0 =1.23 V) and hydrogen peroxide (E_0 =1.78 V), but lower than that of the hydroxyl radical OH• (E_0 =2.28 V). Ozone can oxidize many organic and inorganic matters in water and wastewater. The oxidation process may occur following two pathways:

- Direct oxidation by soluble molecular ozone $O_{3(aq)}$;
- Indirect oxidation by free radicals (mainly OH•) produced by the decomposition of ozone in solution.

The dissociation reaction of ozone produces oxygen and oxygen radical that are able to oxidize complex organic molecules to simpler organic molecules which are often more biodegradable (Lopez et al. 1998). Ozone reactions with organic matter in aqueous systems may occur via two pathways: direct attack by molecular ozone via cycloaddition or an electrophilic reaction; and indirect attack by free radicals (mainly OH•) produced from the decomposition of ozone(Hoigné and Bader 1976; Gurol and Singer 1982; Masten and Davies 1994; Von Gunten et al. 1995; Von Sonntag 1996; Beltrán et al. 1998).

The direct reaction between ozone and organic molecules is described as a bimolecular reaction. The apparent reaction rate is a first order reaction with respect to dissolved ozone concentration and a first order reaction with respect to the organic compounds (Hoigné and Bader 1976).

On the other hand, the indirect reaction between ozone and organic compounds occurs via hydroxyl radicals generated from ozone self-decomposition. The indirect reaction is described as a first order reaction with respect to the radical concentration, [OH•] and as a first order reaction with respect to the organic compound concentration. The equations of ozone decomposition mechanism are described by Staehelin (1983) and Hoigné (1998) as follows:

$$O_3 + OH^- \rightarrow O_2\bullet^- + HO_2\bullet \quad \text{(slow)} \qquad (2.1)$$

$$\left.\begin{array}{lll} HO_2\bullet & \leftrightarrow & H^+ + O_2\bullet^- \\ O_2\bullet^- + O_3 & \rightarrow & O_3\bullet^- + O_2 \\ O_3\bullet^- + H^+ & \leftrightarrow & HO_3\bullet \\ HO_3\bullet & \rightarrow & HO\bullet + O_2 \\ OH\bullet + O_3 & \rightarrow & HO_4\bullet \\ HO_4\bullet & \rightarrow & HO_2\bullet + O_2 \end{array}\right\} \text{(Fast)} \qquad (2.2)$$

The net reaction of ozone decomposition (eq. 2.2) is given below (eq. 2.3):

$$2O_3 \rightarrow 3O_2 \qquad (2.3)$$

The ozone process is a promising method for purification aiming for reuse of textile wastewater, resulting in direct environmental and economic benefits. The ozone process can be used to remove color, COD and detergents to an extent that is sufficient for water reuse in other production processes. The conditions that are necessary to achieve this level of purification are compatible with reasonable operation costs. Many researchers have investigated the ozonation process for treating textile wastewater. Results demonstrate that ozonation is very effective and fast process for decolorizing and can easily break the double bonds present in most dyes (Groff 1992; Tzitzi et al. 1994; Mattioli et al. 2002). In decolorizing, the application of ozone has been shown to be very effective for soluble dyestuffs such as acid, cationic, and direct dyes, while disperse and vat dyes (insoluble dyestuffs) were more resistant to ozone treatment (Marmagn and Coste. 1996). However, Namboodri et al. (1994) found that complete decolorization of red 13 and blue 60 disperse dyes was achieved in 40-60 seconds. According to Van der Zee et al. (2001) a concentration of 50-384 μg/L of halogenated alkenes and aromatic hydrocarbon (synthetic wastewater) could be reduced by 82% and 87% respectively, when applying an ozone dosage of 6 mg/L. In accordance with Kabdasli et al. (2002) the color of reactive dye can be completely removed by the ozonation process with a dosage of 1,890 mg O_3/L within 30 minutes. Ciardelli and Ranieri (2001) reported that a concentration of 30mgO_3/L is sufficient to reduce color up to 89-100% and the COD decreased 39-67% at a contact time of about 60 minutes. A higher ozone dosage did not give a further increase of the color removal efficiency.

Numerous laboratory-scale experiments have documented the feasibility of ozonating dyeing baths effluent and reusing the decolorized effluent several times with excellent color reproducibility. For instance, from a dye bath effluent, containing acid and reactive dye 1: 2 metal complex dye, the color was decreased by 76% within a reaction time of 2 minutes at pH 3, with a dosage of 111 mg O_3/L per minute (Sevimli and Kinaci 2002). For dye bath effluents of cotton and polyester production processes, the reactive time was extended to 60 minutes with a high ozone dosage of 2,400 mg/L. The color removal efficiency obtained was then 96% (Arslan et al. 2000). For dye bath effluents of cotton, synthetic, and blended fabric manufacturing wastewater an ozone dosage of 97 mg/L was needed with a contact time of 5 minutes to achieve a color removal efficiency of 68% (Orhon et al. 2002).

The ozone process can also be used as a post-treatment or polishing step of effluents to meet the discharge standards or for reuse.

The ozonation process produces a large quantity of potentially biodegradable by-products (Tzitzi et al. 1994; Lopez et al. 1998; Mattioli et al. 2002; Teo et al. 2002). For example, with application of a dosage of 2-111 mgO_3/L and a contact time of 30 minutes to textile wastewater, its ratio of BOD_5/COD increased from 0.52 to 0.75. Therefore, the ozone process can be employed as preliminary stage for subsequence biological degradation of toxic organic compounds.

The main advantage of the ozonation process is that the discoloration of the wastewater is achieved in a relatively short time and the process produces no sludge. In addition, ozone can also remove a large proportion of absorbable organic halogens (AOX) and inhibit and destroy foam properties of surfactants (Mattioli et al. 2002). No risks are associated with discharge of residual ozone because ozone is unstable and decomposes into water and oxygen.

As a preliminary stage for raw textile wastewater treatment, ozone is too expensive if all COD is to be oxidized, but it can be uses as a pre-treatment step to decolorize dyes and decompose toxic compounds. However, some of the ozonation products, especially aldehydes, are very toxic or carcinogenic (Lopez et al. 1998).

Application of ozone for the treatment of textile industry wastewater is characterized by high installation and operational costs. The estimated costs are between 0.11 and 0.27 €/ton textile wastewater, and could be as high as 0.55 €/ton for heavy polluted textile wastewaters (Kaulbach 1996). According to Boncz (2002) the cost of ozone production is about 3.5 €/kg and the amount of ozone needed for treatment is about 30-80 g/ton of wastewater. This relatively high cost of ozone generation mainly comes from the high consumption of energy. This is one the major drawbacks with the application of the ozonation process with treating textile wastewater.

Factors influencing the ozone process

The main factors that influence the ozone process are:

- Effect of pH
- Ozone dose and efficiency of ozone’s mass transfer process in water
- Effect of scavengers
- Effect of particles

Effect of pH

The pH affects significantly the formation of by-products and the efficiency of the oxidization process. According to Hoigné and Bader (1976) and Tuba (2001) direct oxidation by molecular ozone is the main pathway in acid environments, whereas the indirect oxidation by hydroxyl radicals is the main pathway in alkaline environments or with the presence of agents like H_2O_2, UV, and catalysts. The reactive oxidation rate increases due to the formation of free radicals according to eq. (2.1). Several researches (Hoigné and Bader 1976; Sotelo et al. 1989; Hoigné 1998; Elovitz et al. 2000; Boncz 2002) remark that free valence radical formation are the fastest at pH $\geq$ 8 and the treatment efficiency decreases at that pH due to the loss a large proportion of ozone through self-decomposing at high pH.

Ozone dose and efficiency ozone's mass transfer in water

Complete dissolution of ozone into the liquid phase depends on mass transfer. The mass transfer of ozone from the gas phase to the liquid phase can be ineffective when part of the supplied ozone is not dissolved in the liquid and remains in the gas phase. In order to reinforce the treatment efficiency, ozone is supplied to the wastewater in very fine bubbles. The consumption of ozone per unit of wastewater can be used to compare the treatment efficiency of this process among the different wastewaters.

When the reaction rate starts to reduce and by-products are created, the dissolved ozone concentration will increase up to a point where it will no further dissolve in the wastewater.

Therefore the ozone concentration in the gas phase increases. This is considered as an optimal endpoint for the ozone oxidation to avoid supplying excessive quantities of ozone.

Effect of scavengers

Textile wastewater contains in general a high concentration of several inorganic substances like Na_2CO_3, NaCl, and Na_3PO_4. These salts are known to be radical scavengers (Hoigné and Bader 1976; Neta et al. 1988; Acero and Von Gunten 2000). The scavengers react with OH• (see equation 2.4 and 2.5) wasting a certain amount of OH•. The lower OH• concentration decreases the efficiency of the oxidation process.

$$OH\bullet + CO_3^{2-} \rightarrow CO_3\bullet^- + OH^- \quad (k = 4.2.10^8\ M^{-1}s^{-1}) \quad (2.4)$$

$$O_2\bullet^- + CO_3\bullet^- \rightarrow CO_3^{2-} + O_2 \quad (k = 7.5.10^8\ M^{-1}s^{-1}) \quad (2.5)$$

Bicarbonate ions are also seen as scavenging radicals and are involved in ozone decomposition according to Tri and Trung (2005). The equation between OH• and HCO_3^- is given below:

$$OH\bullet + HCO_3^- \rightarrow HCO_3\bullet^- + OH^- \quad (k = 1.5.10^7\ M^{-1}s^{-1}) \quad (2.6)$$

In experiments aimed to measure the influence of chloride in the oxidation process, Liao et al (2001) discovered that the chloride ion had almost no effect on decomposition of ozone. The reaction between chloride ions and hydroxyl radicals is presented in equation 2.7.

$$OH\bullet + Cl^- \rightarrow ClOH\bullet^- \quad (k = 8.9.10^7\ M^{-1}s^{-1}) \quad (2.7)$$

The reaction rate constant (k) of the reaction between OH• and CO_3^{2-} (eq. 2.4) is much higher than the reaction rate constant of reaction between OH• and HCO_3^- (eq. 2.6). The textile wastewater usually has a very high (>8.3) or low pH (<4.5). At high pH the equilibrium between bicarbonate and carbonate will create the strong scavenger carbonate, causing a negative effect on the oxidation process. While at low pH the formed carbonic acid (H_2CO_3) does not scavengeh hydroxyl radicals. In order to avoid inhibition of carbonate and bicarbonate ions on the ozonation process, the pH is best adjusted to acid conditions. According to Boncz (2002) carbonate ions will be formed by the reaction of $CO_3\bullet^-$ and $O_2\bullet^-$ (eq. 2.5) since the reaction rate constant k is much higher than of that of the reaction presented in equation (2.4). As a consequence the presence carbonate ions in solution will increase the consumption of ozone and decrease the efficiency of AOPs.

According to Hoigne'(1998) carbonate and bicarbonate ions most often inhibit the ozonation rate, while phosphate and nitrate ions inhibit to a much lower degree. The reactions between NO_3^- and PO_4^{3-} with OH• are:

$$OH\bullet + NO_3^- \rightarrow OH^- + NO_3\bullet \quad (k < 5.10^5\ M^{-1}s^{-1}) \quad (2.8)$$
$$OH\bullet + PO_4^{3-} \rightarrow OH^- + PO_4\bullet^{2-} \quad (k < 1.10^7\ M^{-1}s^{-1}) \quad (2.9)$$

Influence of particles

Particles, including suspended solid and colloidal particles, present in wastewater significantly affect the ozonation process by decreasing contact between molecular ozone or hydroxyl radicals and dyestuffs. Besides, insoluble dyestuffs present as colloidal particles in wastewater could be oxidized to a soluble form by ozone or other oxidants in a treatment process resulting in an increase of the consumption of ozone or reaction time.

H_2O_2/O_3

The ozone mass transfer from the gas to the liquid phase can often be insufficient because the supplied ozone is not completely dissolved into the liquid phase. In such cases hydrogen peroxide addition may improve the conversion of ozone into radicals. In the H_2O_2/O_3 process only the indirect oxidation by free radicals OH• will occur which yields mostly nonselective oxidation of complex substances. Hydrogen peroxide is also seen as a precursor compound for the decomposition of ozone by means of HO_2^- (eq. 2.10). HO_2^- will increase the rate of radical formation as is given in the equation 2.11.

$$H_2O_2 + H_2O \leftrightarrow HO_2^- + H_3O^+ \quad (2.10)$$

$$HO_2^- + O_3 \rightarrow O_3\bullet^- + HO_2\bullet \quad (2.11)$$

In a subsequent reaction, the O_3^{-}• and HO_2• radicals will continue to form the hydroxyl radicals (2.2). A net reaction is represented by H_2O_2/O_3 as follows:

$$H_2O_2 + 2O_3 \rightarrow 2OH\bullet + 3O_2 \qquad (2.12)$$

Influence of H_2O_2 dosage

Similar as with ozonation, the H_2O_2/O_3 process is also affected by many factors like pH, colloidal particles, and the presence of scavenging substances as mentioned above. In addition, the H_2O_2 dosage significantly affects the H_2O_2/O_3 oxidation process. The required dosage of H_2O_2 dosage depends on the scavenger nature and concentration in the wastewater. However, H_2O_2 in excess can cause decreased oxidation efficiency because H_2O_2 can also act as a scavenger (eq. 2.13).

$$OH\bullet + H_2O_2 \rightarrow H_2O + HO_2\bullet \qquad (2.13)$$

Fenton's reagent

Fenton's reagent is seen as a quite effective method for decolorization and COD removal for several textile effluents. In the Fenton's reaction, free hydroxyl radicals (OH•) are formed from H_2O_2 addition in to an acidic environment (pH<5) containing iron ions (normally as Fe^{2+}). The main removal of COD and color in the Fenton's reaction has to be attributed to the oxidation process by the highly reactive radicals (such as hydroxyl radicals) and the coagulation process with $Fe(OH)_3$ co-precipitation. The reaction equations are mentioned below.

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + OH\bullet \qquad (2.14)$$

The reaction rate constant k_1 of reaction (2.14) is 63 $M^{-1}.s^{-1}$ (Gallard and De Laat 2001).

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + H^+ + HO_2\bullet \qquad (2.15)$$

The reaction rate constant k_2 of reaction (2.15) is $\leq 3*10^{-3}\ M^{-1}.s^{-1}$ (Pignatello 1992).

From the reaction rate constants k_1 and k_2 can be derived that in steady state [Fe^{2+}] will be 21,000 [Fe^{3+}] as is explained below.

$k_1[Fe^{2+}]\ [H_2O_2] = k_2[Fe^{3+}]\ [H_2O_2]$
$[Fe^{3+}] = k_1 / k_2\ [Fe^{2+}]$
$[Fe^{3+}] = 21{,}000[Fe^{2+}]$

In addition, the formed hydroxyl radical (eq. 2.14) can react again with Fe^{2+} and H_2O_2 as is shown in the reaction equation (2.16) and (2.17). Especially OH• can react with organic compounds and creates highly reactive organic radicals as show in equation (2.18).

$$OH\bullet + Fe^{2+} \xrightarrow{H+} OH^- + Fe^{3+} \quad (2.16)$$
$$OH\bullet + H_2O_2 \rightarrow H_2O + HO_2\bullet \quad (2.17)$$
$$OH\bullet + RH \rightarrow R\bullet + H_2O \quad (2.18)$$

The organic radicals R• are reduced or oxidized or di-merized as shown in equation (2.19), (2.20) and (2.21).

$$R\bullet + Fe^{2+} \rightarrow Fe^{3+} + RH \quad (2.19)$$
$$R\bullet + Fe^{3+\,(a)} \rightarrow Fe^{2+} + R^+ \text{ then } R^+ + H_2O \rightarrow ROH + H^{+\,(b)} \quad (2.20^{a+b})$$
$$R\bullet + R\bullet \rightarrow R_2 \text{ (di-mer)} \quad (2.21)$$

The radical $HO_2\bullet$ (eq. 2.17) can react with Fe^{2+} and Fe^{3+} according to the following equations:

$$HO_2\bullet + Fe^{3+} \rightarrow H^+ + O_2 + Fe^{2+} \quad (2.22)$$
$$HO_2\bullet + Fe^{2+} \rightarrow HO_2^- + Fe^{3+} \quad (2.23)$$

The hydroxyl radical produced in the Fenton's reaction, can completely decompose recalcitrant and hazardous organics into harmless components. Fenton's reagent is regarded as a quite effective and economical method for decolorization and COD removal of several dyestuffs (Kuo 1992; Bharat and Sanjeev 2007).

Factors influencing Fenton's reagent

There are four main factors that influence Fenton's reagent, which are pH, ratio of H_2O_2 and Fe^{2+}, temperature, and scavengers (inorganic anions).

Influence of pH

The pH can significantly affect the decomposition of H_2O_2 and solubility of iron. The solubility of iron ions depends on the environmental conditions. In an acid environment, Fe^{3+} is easily reduced to Fe^{2+} by H_2O_2 (eq. 2.15), with the advantage of hydroxyl radical (OH•) creation by reaction (2.14). At a high pH precipitation of Fe^{3+} as $Fe(OH)_3$ occurs faster than the reduction of Fe^{3+} to Fe^{2+} as according to reaction (2.15), H_2O_2 is then decomposed into oxygen and water. Results of Kuo (1992), Solozhenko et al. (1995), Shyh and Chang (1997), Park et al. (1999), Danilo et al. (2006); Bharat and Sanjeev (2007) show that the oxidation process with Fenton's reagent is optimal in a pH range of 2.8-4.0.

Influence of H_2O_2 : Fe^{2+} ratio

In Fenton's reagent, the concentration of H_2O_2 and Fe^{2+} influences the reaction rate as mentioned in equation (2.14). Fe^{2+} and H_2O_2 not only react to form hydroxyl radicals, OH•, according to equation (2.14) but also the reactions (2.16) and (2.17) occur wasting just formed OH•. Several studies have proposed the existence of an optimal H_2O_2: Fe^{2+} ratio for Fenton's reagent. However, literature results show large differences in the H_2O_2: Fe^{2+} ratio. According to Pérez et al. (2002), Solozhenko (1995), Ruppert et al. (1994), Bauer and Fallmann Bauer (1997), and Kuo (1992) the ratio of H_2O_2: Fe^{2+} varies from 0.15:1 to 400:1. Sevimli and Kinaci (2002) found with a dosage of 300 mg

H_2O_2/L and 250 mg/L ferrous sulfate (1.5:1) a color removal efficiency of 98 and 99.7% of synthetic wastewater containing respectively RO -16 and AR -337 dyestuffs. An increase in dosage to 500 mg H_2O_2/L, and 600 mg/L ferrous sulfate (0.8:1) obtained removal efficiencies of 91% for color and COD of a dye bath effluent with reactive and acid dyes. According to Kuo (1992) synthetic wastewater with 0.3 g of total dyestuffs/L (direct, disperse, basis, reactive, and acid dyes) and real wastewater gave similar results: a removal efficiency of 88-90% for COD and 97% for color. The dosages of H_2O_2 and ferrous sulfate were largely altered for each dyestuff: 292 up to 857 mg H_2O_2/L and 83 up to 500 mg ferrous sulfate/L (ratio 1.7:1 - 3.5:1).

Hsueh et al. (2005) found that the degradation degree of organic substances increases as H_2O_2 and ferrous dosage increases until an optimal dosage is achieved. An excess of H_2O_2, and Fe^{2+} could give the opposite results. The required H_2O_2 dose depends on the pollutant concentration, such as the COD load and color intensity of the wastewater. Schwarzer and Greor (1993) found that in practice, the mol ratio of H_2O_2 and COD is often in the range of 0.5-1.0. The optimal ratio of H_2O_2 and Fe^{2+} usually has to be determined in practice for each wastewater.

Influence of temperature

When temperature increases the efficiency of Fenton's oxidation is raised. This effect is most clear below 50^0C. However, if the temperature is above 50^0C the efficiency of the Fenton's reaction decreases because H_2O_2 decomposes to oxygen and water at higher temperatures. According to Kuo (1992), Solozhenko (1995), Sevimli and Kinaci (2002) decolorization of Fenton's oxidation is affected by temperature; the proper temperature is lower than 50^0C.

With application of Fenton's oxidation to wastewater with a high concentration of organic pollutants or wastewater at high temperature the H_2O_2 is either consumed and converted into CO_2 or lost due to evaporation. Both situations are not favorable for economical reasons. The temperature in range of 30-40^0C is the best.

Depending on the textile wastewater, Fenton's oxidation can efficiently (70-99%) decolorize almost all dyestuffs such as reactive, direct, metal complex, pigment, acid, base, disperse, and vat dyes (Kuo 1992; Groff 1992; Shyh 1997; Bharat and Sanjeev 2007). In comparison with the ozonation process, the Fenton's process is relatively cheap and results generally in high COD removal efficiencies of 50-88%. A drawback of Fenton's reagent application is that many kinds of chemicals are used, resulting in high operational costs. Besides, the amount of generated sludge with Fenton's reagent application adds costs for handling and disposal of this hazardous sludge.

Influence of scavengers

Salts like Na_2CO_3, NaCl, and Na_3PO_4 are often present at high concentrations in textile wastewater and are known radial scavengers. However, because the Fenton's reagent is applied at low pH (<5), these salts hardly affect the removal efficiency of Fenton's reagent. At low pH the carbonate, bicarbonate is converted into CO_2. Chloride ions are also reported to have a very small radical scavenging effect.

2.2.4 The recovery of valuable products (membrane technology)

Membrane technology is receiving more and more attention and will likely play a key role in the industry's ongoing efforts to minimize water usage. Its advantages include reduction of the volume of wastewater, and recovery and recycling of valuable components from the wastewater streams or recovery of thermal energy from hot wastewaters, apart from producing effluents that meet discharge standards. In addition, this process occupies has only a small area requirement.

According to Stephenson et al.(2000), a membrane can be thought of as a material through which one type of substance can pass more readily than others, thus presenting the basis of a separation process. Membrane processes are filtration in which the pore size of the membrane is of molecular dimensions. These pore sizes are controlled and determined during the manufacture of membrane material. According to Afarias and Farias (1997) microfiltration (MF) membranes have pore sizes that are capable of separating colloidal particles from dissolved polymers. Ultra-filtration (UF) membranes separate polymers and colloidal matter from soluble low molecular weight molecules. Nano-filtration membranes allow the partitioning of divalent ions from monovalent ions. Finally, reverse osmosis (RO) membrane only water permeates and the presence of colloidal particles will cause fouling of the membranes.

Most commercial membranes are made with an asymmetric cross section, with the smallest hole facing the feed solution and an open structure downstream. This feature prevents the membrane pores from blocking as would occur in a depth filter. Unlike ordinary filters, membrane processes are operated with a strong cross-flow that is tangential to the membrane surface. The membranes can usually be chemically cleaned to a nearly new condition. Typical membrane life is two to three years depending on characteristics of wastewater (Sójka-Ledakowicz et al. 1998; Ciardelli et al. 2001; Koyuncu et al. 2004; Zheng and Liu 2006).

Processes to recover water, auxiliary chemicals and energy of textile dyestuffs wastewater have been used widely in the recent years because of a potential shortage of water. Since 1986 Separem has developed membrane processes for reuse of textile effluents. Membrane processes may be applied to different textile wastewater streams like washing, dying, bleaching, printing, finishing wastewater, etc.

Membrane processes can treat varying flows of wastewater, from a few cubic meters to thousands of cubic meters per day. Membrane techniques have been employed in South Africa for removal of reactive dyes. With adaptation of the reactive dyeing process the permeate from the membrane separation process, containing some of the auxiliary chemicals, could be reused. In order to recycle these chemicals, specific rejection characteristics are demanded of the membrane process used, which in this case was based on nano-filtration membranes (Erswell et al. 1988). Koyuncu (2002) evaluated the suitability of nano-filtration membranes for separating COD, color and electric conductivity increasing matter from textile effluent containing acid, disperse, and metal complex dyes at a flow of 1,200 m^3/day. The overall removal efficiency of COD, color and conductivity was higher than 97%. The ingoing feed COD was about 550-720 mg/L, the effluent COD was lower than 10 mg/L at an applied pressure of 10 bar. The COD of the permeate decreased with increasing cross membrane pressure and increased with increasing recovery. Almost a complete color removal was achieved with the nano-filtration application, color intensity decreased to 10 Pt-Co. This significant reduction in color and COD makes reuse of the permeate in other processes of the textile production processes possible. Total estimated treatment costs would be 0.81 US$/$m^3$. According to Buckley (1992), a full scale nano-filtration facility treating reactive dye liquors from a medium sized (200 m^3/month) cotton dye process applying a conservative design flux of 10L/m^2h, should recuperate the capital investment within three years. The amount of electrolytes (sodium chloride or sodium sulfate) discharged would be decreased by more than 90%. Afarias and Farias (1997) demonstrated on pilot scale a combination of ultra-filtration and nano-filtration, enabled repeated recycling of water and salts for starting a bath for new dyeing.

Soluble dye classes like acid, metal complex, direct, basic or cationic and reactive dyes can be separated by reverse osmosis. A return on investment costs within three years for ultra filtration/reverse osmosis (RO) membrane treatment of 1,000 m^3/day of textile wastewaters was calculated based on reduced costs of salts, water, and sewer services (Ciardelli et al. 2001). The reverse osmosis plant was constructed with two stages, each comprising six spiral wrap elements. The quality of the produced permeates compared favorably with tap water. In dyeing trials 200,000 m of fabric was dyed using the reverse osmosis permeate with no discernible effect on the dyeing quality (Buckley 1992).

However, the application of membrane technologies remains limited. Membrane treatment produces a highly concentrated waste streams and the treatment of these by current methods such as evaporation or discharge into the ocean are either economically or environmentally unacceptable. Another important drawback is that the capital costs of the membrane process are high. The costs of treating or preventing membrane fouling are also high. Additionally a reasonable level of expertise is required. It can be concluded that this technology is currently not suitable for the textile industry of Vietnam.

2.2.5 Biological processes

Biological removal of dyestuffs is based on microbial biotransformation of dyes. Two biological processes are applied to treat textile wastewater: anaerobic (UASB) and aerobic (activated sludge) processes. The aerobic activated sludge process is widely used in textile wastewater treatment. A combination of an anaerobic and aerobic process is applied to remove the pollutants completely. The anaerobic process is the first step to reduce the molecular dyes into aromatic amines (color removal) and the second aerobic step is used as a polishing step to meet requirements.

Aerobic process

Conventional suspended activated aerobic sludge and attached sludge processes are widely used for textile wastewaters. The activated sludge process performs very well for BOD removal but is almost ineffective for color removal (Altinbas et al. 1995; O'Neill et al. 1999; Hu 2001; Panswad et al. 2001; Mattioli et al. 2002). The color removal occurs mainly as adsorption on the sludge (Mattioli et al. 2002). The mechanism of dye removal includes two phases. The first phase involves rapid adsorption of the dye onto mycellial pellets and the second slow phase involves biodegradation. According to Van der Zee (2002) the electron withdrawing nature of the azo dye linkages is blocking oxygen attack resulting in ineffective in dye removal. Thus the aerobic process alone can not achieve an effluent color that meets discharge standards. A combination of the aerobic process with other techniques is often applied for achieving these standards. In presence of specific oxygen catalyzed catalytic enzymes, some aerobic bacteria are able to reduce azo compounds and produce aromatic amines (Stolz 2001).

One of the drawbacks of the activated sludge system is that it produces a large amount of sludge, which has to be further treated, increasing operational costs. Another drawback of the aerobic process is the large energy consumption for aeration. In addition, the aerobic process is not suited for enterprise with small areas availability because a large area is needed for an aerobic treatment facility.

Anaerobic process

Azo dyes account for 60-70% of all used dyestuffs and pigments in processing textile. Most decolorization of azo dyes occurs when the chromophore bond in molecule is cleaved. Under anaerobic conditions this cleaving generates intermediates such as aromatic amines and decolorization of dyes does not mean a significant reduction of COD (Hao 2000). The exact mechanism of the anaerobic azo dye reduction is not clearly understood yet and mechanisms are proposed (Gingell and Walker 1971; Haug et al. 1991; Carliell et al. 1995; Razo et al. 1996; Kudlich et al. 1997; Van der Zee et al. 2000).

Although many anaerobic microorganisms are capable cleaving chromophores and auxochromes bonds of some dyes, only few can mineralize dyes to CO_2 and H_2O, most likely due to the complex structure of the dyes. A precondition for the reduction of azo dyes is the presence of a co-substrate acting as an electron donor (Nigam et al. 1996). Many different co-substrates are suitable electron donors, ranging from tapioca to sugars and volatile fatty acids (Carliell et al. 1995; Nigam et al. 1996; Donlon et al. 1997; Chiwekitvanich et al. 2000; Van der Zee et al. 2000; Willetts and Ashbolt 2000).

The rate of azo-reduction depends on the type of co-substrate and/or on the chemical structure of the azo dyes. Azo dye reduction leads to formation of aromatic amines and these were found to accumulate under anaerobic conditions (Brown and Laboureur 1983; Field et al. 1995).

Cervantes et al. (2001b) reported soluble COD and color removal efficiency of about 85%, at steady state conditions at a loading rate of 5.3 g COD/L.day, using 100 mg AO7/L (acid orange 7) as substrate in an upflow anaerobic sludge bed (UASB) reactor. Athanasopoulos (1992) also used an UASB on laboratory scale treating the desizing and scouring wastewater from a cotton blending factory. The maximum COD loading rate was 2.5 g COD/L.day with COD removal ranging from 60-90%.

An anaerobic pre treatment offers several potential advantages such as better removal of color, AOX, and heavy metals (through precipitation).

Compared with aerobic systems that need expensive aeration and have problems with bulking sludge, anaerobic treatment may present a cheaper alternative. This gives the anaerobic digestion process a potential economic advantage. The anaerobic process has the capacity for high organic loading rate and low nutrient wastewater treatment and with the possibility of reductive dye decolourisation. Anaerobic treatment is a promising technology for integrated wastewater treatment in the textile industry.

A major drawback of anaerobic process is the formation of aromatic amines, which are more toxic to the environment than the azo dyes. Another drawback is the odor from anaerobic degradation of organic mater. In treating textile wastewater a biological system needs to be capable to deal with the varying composition of the wastewater which can change rapidly. In addition, some dyes are quite toxic to microorganisms. The low bacterial yield in anaerobic systems, compared to aerobic systems, could in practice show a decrease of removal efficiencies on real textile wastewater. To degrade dyestuff into aromatic amines the hydraulic retention time needs to be high. The aromatic amines tend to accumulate in an anaerobic system.

Combined anaerobic and aerobic processes

The combination of anaerobic and aerobic process has proven its effectiveness in research studies. The first step is the anaerobic process to reduce the molecular dyes into aromatic amines (color removal) and the aerobic step polishes the anaerobic effluent to meet requirements. Jianrong et al. (1994) achieved for a high strength effluent of dye manufacturing plant a 90% COD reduction and 96% color reduction in a laboratory scale UASB reactor at a HRT of 8 hours, followed by an activated sludge reactor at a HRT of 6 hours.

Zaoyan et al. (1992) operated a large pilot plant ($24m^3$/day) for 9 months at a textile dyeing mill which used reactive dye and other dye class on polyester/cotton fabric. The treatment consisted of two multi stage rotating biological contactors. The anaerobic process, with a HRT of 7 hours and an organic loading rate of 2 g COD/day.m^3 was followed by the aerobic polishing step. The combined anaerobic/aerobic system achieved a color removal efficiency of 72%. The aerobic system alone showed a color removal efficiency of <60%. The final effluent of the combined treatment system was still deeply colored. Both the single and the combined system achieved 78% COD removal efficiency; the remaining COD was 150 mg/L, a 95% BOD_5 removal efficiency (13 mg/L) and 70% anionic surfactants removal efficiency (0.7 mg/L). In general, the sequential anaerobic/aerobic systems are not capable to produce effluents that satisfy regulations.

2.2.6 Combined physical-chemical, chemical, and biological processes

Difficulties with treatment of textile wastewater are assumed to be caused by the complex composition of textile wastewater with its wide variety of dyestuffs, auxiliary, and basic chemical used in the textile manufacturing processes. The use of an individual treatment process may not completely decolorize, degrade organic matter and remove other chemicals in the textile wastewater, because each treatment process can only remove some compounds from the wastewater. In order to meet discharge standards, a combination of physical, physical-chemical, chemical, and biological techniques has to be developed. A combined physical/chemical and aerobic treatment or aerobic and physical/chemical treatment has proved its effectiveness in research studies and in practice. However, with more strict standards for color and COD it is difficult to achieve an effluent that meets these standards. For instance, combining an aerobic process with a subsequent chemical oxidation process like ozone or the Fenton's reagent process, the aim is to remove readily biodegradable compounds with biological process, and remove the non-biodegradable or toxic compounds with the chemical oxidation. Sequential treatment by chemical oxidation and aerobic treatment also offers a feasible measure. The chemical oxidation step improves the biodegradability of refractory organic compounds and decolorization of the dyestuffs and breaks down toxicant matter into less toxic matter. The subsequent aerobic treatment can then obtain a high efficiency. A process comprising pre-treatment with precipitation/flocculation, biological treatment and a post-treatment unit with reverse osmosis can recover 80% of wastewater, chemical and energy from effluent of textile enterprises (Gaeta and Fedele 1991). For treatment of effluent from textile enterprises, an application involving activated sludge oxidation, sand filtration, ultra filtration and reverse osmosis can achieved reuse wastewater without problems since the quality of water presently used in textile wet processes (Ciardelli et al. 2001). The choice for a combined treatment scheme depends on the composition, discharge standards, economic conditions, and on the purpose of reuse of the recycled wastewater.

2.2.7 Separating wastewater streams

In the textile industry, almost all processes generate high volumes of wastewater. The amount and composition of the wastewater depends on the process, machine and the type of fiber (cotton, polyester, nylon, blends of cotton/polyester). Quantity and composition of the wastewaters vary widely with amounts ranging from 40-300 m^3 per ton product (Boncz, 2002) in which 75% of the total water consumption is related to rinsing processes. Most rinsing steps are high in consumption of water and produce low pollution concentrations. Wet processes of the textile industry include three main steps: preparation, dying and finishing. The preparation step uses basic chemicals like acid, base and detergents. Different dyes, salts and chemical auxiliary are used for the dying step. Some types of organic matter like softeners and surfactants are applied in the finishing step. The difficulties with the treatment of wastewater and the high costs mainly arise from the presence of a mixture of all these components in the wastewater stream, making a single treatment process ineffective to reach discharge standards. A combination of several treatment processes is necessary to achieve an effluent that satisfies the requirements of environmental regulation. In a complete treatment system, however, all pollutants have to pass through the whole system although each step of the combined process is designed to remove some compounds from the wastewater. Separating wastewater streams is applied with the purpose to achieve high treatment efficiency due to the effects of undesirable compounds for that specific separate treatment process. The separation of wastewater streams enables treating each wastewater stream in an optimal way. The reuse of wastewater (rinsing wastewater) or recovery of chemicals (special basic chemicals, and salts) can reduce production costs.

A drawback of wastewater separation in an enterprise is that the investments for a draining system is expensive, complicated. Operation of several and diverse wastewater treatment systems is not easy and it needs expertise.

2.3 Cleaner production

At present, the end-of-pipe technology is not the sole solution to protect the environment against industrial pollution. Pollution and waste prevention at the source is an equally important environmental strategy for industry to reduce the adverse impacts of production on the environment, often brought together under the notion of cleaner production. Cleaner production has been recognized as a desirable strategy, both environmentally and economically. The concept originated in Europe during the 1970s, in an effort to promote "low and no waste" technology, and was later combined with ideas of sustainable development at a company level (Fresner 1998). Later, in the 1990s cleaner production became especially important for developing countries that are rapidly expanding their industrial production, as it was believed to present an opportunity to invest relatively cheaply in environmentally sound production now, rather than later paying heavily for waste treatment operations. Experiments in Western Europe and developing countries demonstrated that in the long run, pollution prevention through waste minimization or cleaner production are more cost effective and environmentally sound than traditional end-of-pipe pollution control measures. The European Commission (1998) reported "Cleaner technologies for Waste Minimization" has shown that it is feasible and economic to apply cleaner production in food products, beverage manufacturing, pulp & paper mills, textile and clothing production and wood and furniture manufacturing. In order to stimulate the development and implementation of cleaner production many developing countries established Cleaner Production Centers in the 1990s. According to the Vietnam Cleaner Production Center and Vietnam textile industry group- VNCPC and VINATEX (2002), Vietnam's textile industry has an enormous potential to apply cleaner production, with more efficient energy and raw material use, lower emission levels and reduction of production costs. It is estimated that 30-50% of all current wastes and emissions from the Vietnamese textile industry can be prevented at the source by the use of environmentally sound and economically profitable cleaner production procedures.

2.3.1 Cleaner production theory

The Cleaner Production Program of the United Nations Environmental Program UNEP defined cleaner production (CP) in 1996 as: "The continuous application of an integrated preventive environmental strategy applied to processes, products and services in order to increase efficiency and reduce risks to humans and environment" (UNEP 1996). The Australian cleaner production programme defined cleaner production slightly different, but with the same connotation: "a strategy to continuously improve products, services and processes to reduce environmental impacts and work towards ecologically and economically sustainable development"(Environmental Australia 1997). There are differences between cleaner production concepts in different countries (Maica 1996). However, from an environmental point of view most of these definitions have major similarities: cleaner production helps to efficiently use raw materials and energy, eliminate toxic raw materials, and reduce the quantity and toxicity of all emissions and wastes. Other concepts similar to cleaner production are waste minimization, pollution prevention, and green productivity; these concepts share some fundamental ideas with cleaner production. The goal of cleaner production is to minimize environmental impacts by changing either the way goods or services are produced (process technology) or the products themselves (product design).

Environmental risks are reduced as the total amount of waste generated and the harmful substances are reduced. In addition, cleaner production is also seen as one of the building blocks of an industrial ecology approach (see below). Therefore, cleaner production has gained in importance in industry and in governmental policy to control pollution. It is important to stress that cleaner production is not only simply a question of changing equipment, but it is also a matter of changing management, attitudes, know-how, and improving the manufacturing process as well as the product composition.

Cleaner production can be applied to any manufacturing processes and ranges from relatively easy operational changes to more comprehensive transformations of product design and production processes. Cleaner production can be divided into three main groups/strategies, to be elaborated below:

- Waste reduction at source
- Recycling
- Product modification

2.3.2 Waste reduction at source

The fundamental idea of cleaner production is going to the source of pollution and maximizes pollution reduction at that place. This practice of waste reduction at the source is comprised 5 main options (EPA 1997; VNCPC 2002; VNCPC and VINATEX 2002): good housekeeping, better process control, material substitution, equipment modification, and new process technology. These will be described in more detail below.

Good housekeeping

Good housekeeping includes the relatively most simple strategy and set of measures within the cleaner production approach. It does not require outlays or high technology. The options and measures of good housekeeping do not require advanced technological innovations or drastic rescheduling of productions/product designs, but involve regular maintenance of pipes, valves, pumps; the closing of water taps; and turning off equipment when not used to avoid leakage and loss of water, energy and raw materials. Through good housekeeping practices, companies can improve production efficiency, prevent pollution without changing industrial processes and products, and reduce production costs. For the textile industry, good regular maintenance and housekeeping can reduce 10-20% water and energy usage (VNCPC and VINATEX 2002). In good housekeeping, the role of employees is a decisive success factor. So training and incentive programs are key success elements in good housekeeping, and good communication lines between departments in a company prove essential.

Many options found in cleaner production practices are good housekeeping measures. For instance, the report on the Consultative group cleaner production project with 13 companies in Styria, Austria, showed that 50% of all cleaner production options are not technical measures, but related to organization and good housekeeping (Fresner 1998). According to the Vietnam Cleaner Production Center, VNCPC (2004), 26% of cleaner production options carried out in the Vietnamese textile industry could be labeled as good housekeeping.

Better process control

Better process control measures optimize production conditions to achieve efficient consumption of raw materials and minimize waste generation. Optimizing process control via scheduling dyeing operation to minimize machine cleaning, proper maintenance of production equipment, identification of unnecessary washing of both grey materials and equipment (EPA 1997), and dyeing recipe optimization leads to a reduction of both chemical consumption and pollution load to the drain during the production process. This improves production efficiency and maintains low operation costs. Influential process control factors for dyeing processes include temperature, time, pressure, pH, processing speed; these all have to be monitored and regulated to optimize dying conditions. Bortone et al. (1997) claims that it is possible to reduce water consumption in wet processes with 5-10%, simply with changes in such operation procedures.

Material substitution

Material substitution changes toxic raw and auxiliary materials for less harmful ones, or ones that can be used more efficiently, or raw materials that can be recycled internally or externally. One of the purposes of material substitution is to prevent more pollution material ending up in the wastewater and thus to reduce the emission of pollutants to the environment. Opportunities for material substitution vary substantially among enterprises, because of differences in process conditions, products and raw materials (EPA 1997). For example, hydrochloride, which is used during the bleaching processes, is substituted with hydrogen peroxide to reduce total dissolved solids and improve fabric quality before dyeing. This reduces the emission of toxic materials to the environment. Another example: reactive dyes, a low fixation dye (60-90%), and the use of low quality salts, can be substitutes for dyes with high fixation (90-95%) and high quality salt. This results in a reduction in the consumption of salt from 0.63 to 0.45 kg/kg fabric (Narayanaswamy and Scott 2001). The material substitution can be carried out easily because it does not require large investments and it significantly reduces toxic chemical emissions.

Equipment modification

Equipment modification retrofits or modifies the existing equipment and introduces automation in production processes, to minimize raw material loss, water use and energy use (EPA 1997; Bortone 1997). In many cases, modifying equipment can provide source reduction by reducing the ratio of water and chemicals to textile goods (EPA 1997). Options for modifying equipment include installing automated dosing systems and dye machine controllers.

New process technology

This solution installs modern equipment in terms of enhanced resource productivity, which as a result reduces waste and emission, and establishes best practice techniques. With the application of new process technology the consumption of water and energy can be decreased significantly, and the potential for saving on raw materials and improving product quality is large. An example of a new production process is the replacement of winch for soft flow (jig) technology. The typical bath liquor to fabric ratio for winch dyeing varies from 17:1 to 14:1, and for soft flow dyeing it varies from only 7:1 to 5:1. Thereby it reduces water consumption by respectively 30% and 50%. Another example is to install a new boiler with a higher efficiency, which will reduce the energy consumption with 10-20%. However, new process technology options usually require higher investments than other cleaner production options.

2.3.3 Reuse/Recycling

Generated waste streams from production process can be recycled/re-used on-site or off-site an enterprise. Recycling/reuse is an excellent way for an enterprise to save costs, reduce waste, and often save energy. On-site recycling/reuse uses waste from one process and reuses it in the same or another production process. A simple example of the on-site reuse is wastewater of the last washing phase from a dyeing process that is reused in earlier washing phases. Out-site recycling/reuse puts external recycling networks to work to achieve less (or even zero) emission. For instance, wasted solvents can be collected and sold to enterprises that separate these solvents from a waste stream, purify them and sell them to other consumers. Although the recycling/reuse activities do not directly prevent pollution, these activities might be seen as effective measures to minimize pollution entering the environment.

2.3.4 Product modification

Product modification changes the characteristics of products. Products become less polluting, their lifetime may be expanded, and/or they are easier to repair. Product modification is a fundamental part of cleaner production. This practice includes two parts:

- Changes in products through the improvement of product design, such as its shape and material composition. This option can include large savings on consumption of materials, and reduction in the use of hazardous chemicals.
- Changes in product packaging in order to minimize pollution.

An example of product modification is to design products with light color instead of dark color; or replacing plastic packing for recycled cardboard.

2.3.5 Benefits of cleaner production/pollution prevention

The success of cleaner production brings benefits for the company and for society. The benefits for the company relate to: reduction of costs spent on production, improvement of the working environment, and compliance with environmental regulation. In addition, with a cleaner production approach the company can open new market opportunities, for instance by creating favorable conditions for the implementation of accredited environmental management systems (e.g. ISO 14001), which will give companies better access to export markets. The benefits for society include improved environmental quality and sustainable development. According to UNEP(1997), application of cleaner production can decrease the amount waste produced by a company with 10-30%. Case studies from various countries give evidence of such successes. Petek and Glavic (1996) reports on successful waste minimization measures in textile enterprises in Denmark, where good housekeeping, better process control, and equipment modification, reduced the pollution load with 25% (15,3000 m^3/year) in wastewater, 24% (7,300 kg/year) for dyes, and 14% for textile auxiliary and basic chemicals (73,800 kg/year). The production costs of textile could be reduced with 6 % after the implementation of clear production. Fresner (1998) showed that cleaner production was also successful in the Austrian textile industry. The application of good housekeeping, on-side recycling/reuse, material substitution, and better process control helped to reduce water use with 20%, limited the discharge of large volumes of wastewater and chemicals into environment, and saved a company 200,000 US$ per year. Implementation of cleaner production in Indian hosiery clusters (containing eight integrated hosiery mills) saved production costs between 8-10 cents per T-shirt. The quantity of water and energy consumed was reduced between 30-50% through new process technology. Beside these economic benefits, the application of cleaner production improved the environmental performance of the eight Indian mills (Sakurai 1995). Cleaner production is also gaining importance in China. Every year China publishes a list of best practical techniques for cleaner production and takes administrative and economic measures to urge enterprises to apply and implement cleaner production (Warren et al. 1999). A dyeing and finishing factory located in Taichung County, China, had implemented a cleaner production program with new process technology, recycling/reuse, and better process control options. This factory gained 10.7% additional profit each year, mainly by reducing water, energy and chemical consumption (Sakurai 1995). Kamipai Textile Company is classified as a large textile factory in Indonesia. With the application of cleaner production options such as good housekeeping, new process technology, and on-side recycling/reuse it reduced 30% of water and 20% of energy consumption (Sakurai 1995).

These benefits are also true for the textile industry in Vietnam, as illustrated in Table 2.1. According to annual report of Vietnam Cleaner Production Center (2006) the number of textile enterprises that implemented cleaner production between 1999 and 2004 was 34, out of a total of 2,000 Vietnamese textile and garment enterprises. These Vietnamese demonstration projects show that implementation of cleaner production by applying simple low-cost options brings not only economic benefits by reducing costs with 50-80 US$/ton product, but also obtain environmental benefits by decreasing the pollution load. Figure 2.2 shows the division of CP options adopted at 34 textile enterprises in Vietnam. Better process control and good housekeeping were the most often implemented options, with 45% and 26% respectively. New process technology is rarely implemented as cleaner production measure, with only 5%.

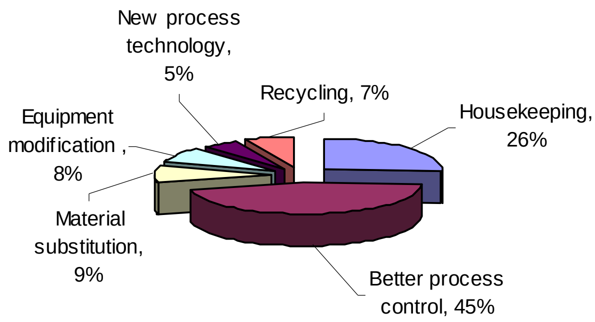


Figure 2.1: Distribution of cleaner productions options for textile industry in Vietnam (CP program for Textile industry (1999-2004) (VNCPC and VINATEX 2002)

Table 2.1: The benefits of cleaner production in textile industry in Vietnam, compared to world averages

Items	Vietnam	In the world
Water supply	5-35 %	30-50%
Chemical	2-33 %	-
Fuel	6-52%	-
Electricity	3-57%	20-50%

Source: Vietnam cleaner production Center (2006), Sakurai (1995), Maica (1996)

2.3.6 Barriers and constraints of cleaner production

Although cleaner production can bring many benefits, a number of barriers and constraints prevent wide spread implementation of cleaner production programs and measures. These barriers and constraints fall into four categories: financial, attitudinal, institutions and policy, and technological constraints (Visvanathan and Kumar 1999; Frijns 2000).

Many practices of cleaner production in the world show that one of the important constraints is lack of finance (Visvanathan and Kumar 1999; Frijns 2001). In the various case studies and practices cleaner production unavailability of capital to invest in new equipment or systems often becomes a significant obstacle to cleaner production implementation. Because options related to new technology processes often require large investments, these are particularly vulnerable to financial constraints. Only large companies can afford to invest sufficient funds for such options; small and medium-sized enterprises suffer most from financial constraints.

The attitude of the factory manager towards cleaner production is a fundamental factor in the adoption of cleaner production. The perception of leaders is a prerequisite for a successful cleaner production project; they too often resist change and innovation. And many managers still live by the misconception that prevention measures only cost money. In addition, the attitudes of employees have significant influence on success as well as maintenance of a cleaner production program.

Generally, in developing countries there is often a lack of institutional framework and supportive policies to effectively promote the application of cleaner technology in production. Sometimes economic supporting tools exist (such as financial funds, low interest rates, tax reduction) but these are insufficient to encourage enterprises to massively apply cleaner production. In addition, standards and regulations on environmental performance promote rather the implementation of end-of-pipe technologies than cleaner production approaches.

Cleaner production is a process that takes time as it involves technological changes. Technical constraints impede the ability of a company to develop, and implement cleaner production programs. These include absence of readily available cleaner production technologies that can be adopted directly, and the lack of expertise on cleaner production within the company.

In Vietnam

As reported by Nhan (2006), although a number of demonstration projects have been implemented with financial support from international organizations (such as UNEP, UNDP, UNIDO), the implementation of cleaner production is still limited in Vietnam. This is expressed in the number of enterprises that implemented cleaner production. Until 2007, seven years after the cleaner production declaration, only 200 enterprises have implemented a cleaner production program in Vietnam. In Vietnam, the following barriers for cleaner production implementation can be noticed.

Many cleaner production projects in Vietnam are not successful, because these projects are initiated by the Vietnam Cleaner Production Center (VNCPC) or the Ministry of Industry and Trade and supported with initial finances and consultants from international organizations or the government. The reason that companies join such demonstration projects is that they see these projects as a way to improve environmental protection without spending money. But once the (financial) support stops these companies are no longer interested. In addition, a weak link with and poor coordination between policies results in poor application of cleaner production and more environmental friendly technology. In its evaluation of the implementation of the National Plan on the Environment and Sustainable Development for the period 1991-2000, the Ministry of Science, Technology and Environment MoSTE stated that "existing economic policies are not actually environmental friendly and technological policies are not really linked with environmental protection and the enforcement". While other documents like the strategy on environmental protection 2010 and national orientations towards 2020 (Khai 2003) or the Vietnam Agenda 21 of Government (Dung 2004) presented pollution prevention and cleaner production as key solutions for environmental protection, once coming to specific programs and measures, the role of cleaner production is often much less prominent. In addition, the Law on Environmental Protection is still focused on waste treatment rather than on waste minimization. In the recent decree of the Government No 23/2005/CT-TTg, dated 21 June 2005, on strengthening hazardous waste management, the principle of hazardous waste minimization was mentioned only once. With the prevalence of command-and-control environmental policy at present and a lack of state capacity in enforcement of environmental laws, it is not encouraging for companies to implement cleaner production.

While existing policies on cleaner production remain insufficient, cleaner production is not yet a legal requirement for new industrial projects and investments. For example, application of cleaner production is voluntary and not part of compulsory regulation, such as environmental impact assessment, monitoring of environmental quality, or the building of wastewater treatment plants. A company that receives an ISO certification can enter new exports markets (certainly for textile and garment). For the domestic market, a company with the certification of "high quality Vietnamese goods'' will also attract more customers. But the application of cleaner production is not followed by larger domestic markets, or a wider penetration in the world market.

Lack of finances is also an important constraint for cleaner production in Vietnam. In order to replace existing technologies and machines large amounts of money are required, which textile companies often can not afford. The existing economic support in Vietnam (via financial funds, low interest rates, tax reduction and exemption) has failed up till now to encourage large numbers of enterprises to apply clean and environmental friendly technology. For example, the environmental protection funds, with each a total capital of between ten billion VND and hundred billion VND, can not afford financial support of new process technologies. Besides, administrative procedures to access financial support are complicated and cumbersome (Khoa 2006).

Attitudes of factory managers strongly resist change and innovation in industrial processes and practices. Distrust and disinterest in alternative processes are widespread and managers of small and medium-sized enterprises – and even of large enterprises – show reluctance to change. Managers usually hesitate to seek outside assistance also out of commercial confidentiality, especially in the textile industry. Results of interviews with fifty textile company managers in March 2007 show that they did not receive any relevant information from cleaner production programs; most of them never heard of the concept of cleaner production or they still thought prevention measures only cost money (An 2007). In addition, the low education level of employees – a characteristic of Vietnam's textile and garment industry – has a significant negative influence on success as well as maintenance of cleaner production programs at the enterprise level.

2.4 Industrial ecology

2.4.1 Variations of the concept of industrial ecology

The ideas that have shaped industrial ecology began to emerge 40 years ago, and it has been strongly developed in the recent decade. There are many definitions of industrial ecology. Erkman (1997) and Frosch and Gallopoulous (1989) define industrial ecology as industrial components that link together to minimize the impact of the industrial system on the environment, by optimizing the material and energy flows going through the industrial system. Industrial ecology is about how to make the industrial system compatible with the way natural ecosystems function. According to the definition of industrial ecology from Graedel and Allenby (2003), industrial ecology is the way in which humanity can deliberately and rationally approach and maintain sustainability. The concept requires that an industrial system environmentally optimizes the total material cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy and capital. As mentioned by Van Koppen and Mol (2002) industrial ecology is regarded as a broad concept, encompassing industrial ecosystems as well as approaches that pursue environmental improvement along the lines of life cycle management, design for environment, and service economy.

2.4.2 Basic principles of industrial ecology

Regarding Yang and Lay (2004), there are three basic elements in industrial ecology. First, energy requirements should be minimized, as should waste generation and the consumption of scarce resource. Second, industrial wastes and discarded products should be used as input to industrial – or other production – processes, in a way analogous to the cycles of nutrients by various organisms in ecological food webs. Last, the system should be diverse and resilient in order to absorb and recover from unexpected shocks**.** In most instances, either entirely new industries or significant modifications of existing industries are developed. Within the broad framework of industrial ecology three concepts are often mentioned and used: industrial metabolism, industrial symbiosis, and industrial ecosystem.

The industrial metabolism refers to the entire material and energy flows going through an industrial system. Industrial metabolism is studied through essentially analytical and descriptive approaches (based on the material-balance principle), and aims at understanding the circulation of material and energy flows linked to human activities (Erkman 1997). Manhan (1999) also shows that industrial metabolism can be examined at factory, industry, and global level. In a similar way, Van Koppen and Mol (2002) define the concept of industrial metabolism as the analysis of material flows in systems of production and consumption.

Industrial symbiosis engages traditionally separate industries in a collective approach, involving systems of physical exchanges of materials, energy, water and/or by-product for mutual advantage. The key to industrial symbiosis is collaboration and the synergistic possibility offered by geographic proximity (Chertow et al. 2004). Industrial symbiosis is part of industrial ecology. The concept resembles symbiosis in nature, a biological term referring to “a close sustained living together of two species or kinds of organism (Encyclopaedia Britannica 1992).

An industrial ecosystem is a synthetic analogue of a natural ecosystem, with connection through the flow of materials and energy between the various firms/production units (Sagar and Frosch 1997). In an industrial ecosystem, the interdependency among firms is based primarily on the use of waste materials and waste energy from some industries and turns that into raw materials for others. To mature as an industrial ecosystem, it must go beyond the use of waste materials and energy, explicitly addressing other considerations, including design and construction. Constructing industrial ecosystems is seen as a concrete strategy for developing closed loop systems locally, in industrial parks or regions (Ernest and Evans 1995). Van Koppen and Mol (2002) mentioned that industrial ecosystems are characterized as communities of companies and other organizations that collaborate to achieve enhanced environmental and economic performance or greater eco-efficiency. Models for operational industrial ecology suggest simple design principles, for example:

- Closing material loops, avoiding upsets to the metabolism of the natural system (toxics elimination and pollution prevention), dematerialization, and thermodynamically efficient energy utilization. (Tibbs and Hardin 1992; Lowe 1994; Ehrenfeld 1995);
- Moving from linear through-put to closed loop material and energy use (Ehrenfeld and Gertler 1997);
- Cascading energy use and the use of industrial by-products as feedstock (Ehrenfeld and Gertler 1997).

2.4.3 Application of industrial ecology

The idea of industrial ecology has been applied in case studies in different countries in the world. Each of them brings experiential lessons to improve industrial ecology in the future. Some industrial ecology projects have been implemented successfully, of which the Kalundborg industrial park in Denmark, and the industrial ecosystem project in the Rotterdam harbor area, the Netherlands, are among the early success stories (Gertler and Ehrenfeld 1996). Kalundborg involves the exchange of waste, by-products, and energy among firms situated closely together, among which a power station, oil refinery, pharmaceuticals & enzymes, plasterboard firms, and several energy users within the municipality. The Kalundborg industrial ecology project brings more efficient use of material, energy, resource and elimination of waste, and increased both economic and environmental benefits. It has become a pioneer to pushing industrial ecology in practice. Another often cited example is the industrial ecosystem project (INES) in the Rotterdam harbor area, the Netherlands. In this industrial area many refineries and chemical firms are located, which reuse waste streams and by-products and exchange energy from each other.

According to Baas (1998) the INES project showed the efficiencies to reduce the use of energy, water and bio sludge significantly. From the INES projects, the following experiences are drawn: (1) pollution prevention and cleaner production are important elements of industries ecology; (2) the diversity in composition of industrial ecology is importance; (3) an informal network among participants joining the project contributes to the success of the project.

Heeres et al.(2004) compared six Eco-industrial park development projects, three located in the Netherlands and three in the United States. The Dutch EIP projects proved more successful than their US counterpart. The experiences drawn from these projects are that heavy government involvement are no impulse to interest companies for EIPs; on other hand the successfulness of such projects usually largely depends on spontaneous offers of companies. These projects do show that planed EIP development is a long term process. The central lesson from these and other case studies (such as EIPs in Germany, and in the state of Queensland, Australia) is that one needs to consider carefully the system boundaries and the role of local and regional public authorities (Baas and Boons 2004; Korhonen 2004; Roberts 2004; Sterr and Ott 2004; Von Malmborg 2004).

The case studies and international experiments on industrial ecology extend to the Asian region. The paper of Chiu and Young (2004) informs us of examples of industrial ecology in Asian developing countries. They present a strong argument that Asian developing countries could adopt industrial ecology as a long term strategy to combine national development, economic growth, and sustainable development. The case of Singapore's Jurong Island comprises food and beverage outlets, convenience stores, a medical clinic, and recreational enterprises (Yang and Lay 2004). In Guangxi Guangxi city, China, the industrial symbiosis consist of interlinked production of sugar, alcohol, cement, compound fertilizer, and paper and includes recycling and reuse. For this case, Lowe et al. (2007) show that application of actor network analysis (customer, supplier, communities, research and training institutes, and government) contributes to putting industrial ecology successfully to work.

In Vietnam, industrial ecology is still a new concept. This concept has been introduced to Vietnam by Phuong (2002), Dieu (2003), Khoa (2006) and Nhat (2007). Through a number of case-study analyses of industrial ecology, it is suggested that Vietnam could adopt industrial ecology to combine environmental improvement and economic development of enterprises and the many industrial zones and parks. But Nhat (2007) also uses the concepts for different small and medium-scale argo-industries in the tanning, slaughter and seafood processing sector. An early successful application of the industrial ecology concept for a Vietnamese industrial park was developed by Dieu and colleagues (2003; 2005). The environmental friendly industrial park project was carried out at Bien Hoa, Dong Nai Province. Exchange of by-products among companies inside and outside the park was analyzed and the necessary networks were identified.

2.5 Actor networks

As noted above most industrial ecology studies and analyses, and also many of the cleaner production and end-of-pipe studies, are preoccupied with substance flows and technological innovations in industrial systems. Usually the actors and institutions that have to implement environmental innovation receive marginal attention. By the same token, most of these studies see major barriers for implementation related to these actors and institutions. It is against this background that network studies have been introduced in cleaner production and industrial ecology studies.

Network models have the advantage of combining both the structural properties of institutions and the interactions between actors constructing a network. Networks can be characterized as social systems in which actors engage in more or less permanent, institutionalized interactions. There appear several analytical network models in literature, also with respect to environment-informed transformations in economic sectors. Most of them are rather constructed on an ad hoc basis, following directly from one or a limited number of empirical studies. A triad-network model (Mol 1995) is a more systematic way of analyzing actors and institutions around industrial systems under environmental reform. While earlier studies did concentrate on the role of governments and policy networks, or the contribution of entrepreneurs and value chains, this triad network model brings together three interdependent networks in industrial innovations: a policy network, an economic/industrial network, and a societal network. The triad network model enables us to systematically analyze the actual and potential contribution of different actors and their related institutions to environmental reforms in industries and industrial systems.

The triad-network model is a conceptual model for analyzing the extent to which an ecological 'perspective' penetrates and transforms the social practices predominately governed by three basic perspectives in modern society: political, economic and societal. The triad-network model combines these three analytical perspectives with three networks around given social practices: an economic, a policy and a societal network. Each of the three interdependent networks constitutes thus a combination of a specific analytical perspective, distinctive institutional arrangements and a restricted number of interacting (collective) actors, which are considered to be most important regarding that perspective. Applied for industrial transformation and industrial ecology, the following networks are distinguished:

Within policy networks, interactions and institutional arrangements between state organizations and industry are primarily governed by political-administrative rules and resources. Other interactions and institutional arrangements are also inspired by and can be analyzed from this perspective, although they will then prove to be more peripheral. Policy network studies analyze the interdependencies between these actors, the 'rules of the game' which put these policy networks to work, the resources dependencies (regarding power, money, knowledge, information etc.) between the various actors and agents dominant in these policy networks, the common or diverging world view along which communication and joint strategies are developed or not, etc. There exists a considerable amount of literature (e.g. in neo-corporatism and policy community studies) that provides evidence of the usefulness of such analyses of the transformations and continuities in these interdependent network actors (Grant et al. 1988; Marsh and Rhodes 1992; Smith 1993; Mol 1995).

Economic networks basically focus on economic interactions via economic rules and resources between economic agents in and around the industrial park, chain or sector that form the object and unit of analysis. Although the intellectual background of economic network analyses are mainly to be found in industrial organization theory, institutional economics and organizational sociology, the basic concepts differ only partially from those in policy network analyses. Economic network studies analyze the relationships between the firms, the network structures in terms of power and resource dependencies, and the economic processes of continuity and transformation. They look at (i) the vertical interactions from raw material producer up until the final consumer and beyond, (ii) the horizontal relations between competitors and on the level of the industrial branch association providing some collective interest representation, and (iii) regional relations and interactions in restricted geographical areas. The relations with conventional industrial ecology analyses of the material flows in geographical areas or production-consumption chains (e.g. LCA) are evident, but in the network studies the emphasis is rather on the non-material dimensions of the park/chain/network (economic relations, power, information monopoly and exchange, knowledge, control, ownership, etc.). Håkansson (1988), Martinelli (1991) and Grabher (1993) are relevant volumes that provide valuable conceptual tools for analyzing these economic networks in detail.

Thirdly and finally, societal networks aim at identifying relations between an industry, a chain, an industrial sector or an industrial park the one hand, and civil society organizations and arrangements associated with what is usually called 'the life world' on the other. It is the rich tradition of (new) social movement research that provides the conceptual tools to analyze the interaction patterns, and their continuity and transformation, between on the one hand environmental and consumer organizations and on the other industrial firms. In general, interactions between the NGOs and the industry in question take place in three dimensions: direct, indirect, and via state agencies. In Vietnam real independent environmental NGOs as we know them in Europe or the U.S. do not exist. So, at present strong NGO pressure, which forces significant changes in industrial production, can not be expected. But more diffuse civil society impact on environmental reform might be present, via the media or via unorganized citizens.

2.6 Research methodology

2.6.1 Research strategy and case study selection

In order to achieve the objectives stated in Chapter 1, the research strategy in this research focuses especially on practical experiments and case studies. The practical experiments are especially used for acquiring additional technological knowledge on waste treatment options, as building blocks for constructing our textile industry model. The most important characteristics of a case study approach are to study in depth a relatively small number of research units, rather than an overall research on multiple cases. This was especially used to operationalize and test an industrial ecology model for the textile industry.

In time, the research strategy encompasses three major components: (1) development of theoretical frameworks and models (end-of-pipe, cleaner production, industrial ecology, waste exchange networks, actor networks) that can be interpreted as building blocks to be combined in reducing the textile's environmental impacts; (2) the collection, analysis, and assessment of production processes, characteristics of waste streams, technological options, organizational models for textile industry. Laboratory and field experiments, literature research, assessments of environmental performances and economic costs provide us with practical information on the contribution of theoretical models for the current textile industry in Vietnam. (3) Constructing optimal models of environmental performance of two textile case studies in contemporary Vietnam, in which end-of-pipe, cleaner production and industrial ecology ideas are combined into an optimal model for a stand alone textile company and a textile industrial park.

At present, there are more than two thousands textile companies in Vietnam, of which more than 50 companies are large ones. Although in number the large companies are small (2.5% of all textile plants), they significantly affect the environment by discharging high concentrations and significant volumes of wastewater, air pollution and solid waste. In addition, large textile enterprises involve three stages of processing (spinning, weaving and finishing) with many products, while medium-sized and small enterprises often only include one or two stages (dyeing and/or finishing) with few products. The Thanh Cong Textile and Garment Company is chosen as the first case study, as it is representative for large textile companies in Hochiminh City. The willingness of the company to cooperate on this research was a vital argument in selection. Without company cooperation such a research cannot be carried out.

According to development strategy of the Vietnam Textile and Garment Industry Group (2005) the building of three textile and garment industrial zones is planned. The aim of these industrial zones is to create an efficient organizational structure for environmental management, to increase competition on the market, and to minimize pollution. To analyze the possibilities for environment improvements in a group of textile companies, research on one industrial zone is carried out. Nhon Trach 2 industrial zone in Dong Nai is selected as the second case study. In this industrial zone a significant number of textile companies are located, making it a potential interesting case for designing an industrial system.

2.6.2 Methods of data collection and analysis

Basic information on the contribution of end-of-pipe treatment processes, cleaner production and waste exchange possibilities have been collected through analysis of secondary data and via laboratory and pilot scale experiments. These latter methods were directed to specific treatment technologies. Laboratory and pilot scale experiments on the treatment of real textile wastewater are used to gain additional knowledge on the potential contribution of different approaches to reduce the environmental pollution of textile production processes.

For building the model around the two case studies primary and secondary data were collected and analyzed. First primary data on a large number of textile industries in Vietnam were collected, such as on manufacturing processes, environmental pollution situation, and environmental performance through interviews and on-site measurement and investigation (by survey, sampling and analysis of air pollution, wastewater, solid waste of textile enterprises). The investigated enterprises were mostly located in Le Minh Xuan industrial zone, district 6, 11, Tan Binh, and Tan Phu in Hochiminh city, Nhon Trach 2 industrial zone in Dong Nai. After visiting several enterprises, more detailed primary data were collected of the selected enterprise and industrial zone through sampling, measurement and analysis of material flows of the selected enterprises. This enabled us to construct a mass balance and calculate the exchange of energy and material flows between enterprises inside and outside the industrial ecology model.

Interviews were another source of primary data. Personal in-depth interviews (face to face) with managers and personnel of the selected companies were made. Information related to manufacturing, compliance with laws on environmental protection, and company development strategies came from interviews with actors in the networks surrounding the case studies. In order to further analyze the role of different actors in the policy, economic and social networks, experts of the Vietnam Textile and Garment group (VINATEX), the Vietnam Environment Administration (VEA), MONRE, DONRE of Dong Nai and Hochiminh city, authorities of the industrial zones of Dong Nai and Hochiminh city (Hepza) have been interviewed. In addition, in-depth interviews and discussions with experts and consultants at institutes, universities, and research centers such as the Polytechnic University in Ha Noi, Van Lang University in Hochiminh city, the Center for Environmental Technology and Management

(CENTEMA), and the Vietnam Cleaner Production Center (VNCPC) have been carried out for generating ideas and checking options.

Secondary data were collected for different phases of this research from various sources, among which: annual statistics from the General Department of Statistics; the annual; reports of VINATEX and reports of the Vietnam Textile and Apparel Association (VITAS); monitoring data on environmental quality from several environmental authorities; annual monitoring reports on environmental quality from the selected companies and industry; national and international scientific literature.

Chapter 3

Physical/chemical processes: experimental research

3.1 Introduction

The textile industry causes serious pollution for the environment due to the large quantity and high concentration of pollutants in wastewater, when discharged untreated. The pollution originates from the textile enterprise's use of various dyestuffs and auxiliary chemicals in the production process, which end-up in significant quantities in the wastewater. The remaining dyes in the textile industry effluent usually have a high color intensity and organic matter concentration. Almost all dyes are difficult to degrade and decolorize due to their complex structure and synthetic origin. The choice of a treatment method for textile wastewater will depend on the used class of dyestuff and of the specific discharge standards. The color is considered as one of the key parameters in the treatment of textile wastewater.

The removal of color from a solution can occur according to four main mechanisms. Firstly some compounds undergo color change and even become colorless at certain pH ranges. Secondly decolorization can occur when colored compounds are adsorbed in flocs produced by a coagulation process. Thirdly the chromophore/auxochrome bond is broken without the actual break-up of the major fragment of the original dye molecule. Finally, the addition of a bleaching agent could decolorize wastewater. However, if a bleaching agent is used part of the color disappearance might not be due to full degradation of dyestuffs. Besides, their by-products could be more toxic than the original compound.

In order to understand more clearly the color removing mechanisms, the color removal processes for textile wastewater will be studied in this chapter. A general introduction is given in section 3.1. The change of color at various pHs is discussed in section 3.2. Section 3.3 describes the removal of color by means of physical/chemical treatment processes (coagulation processes). Section 3.4 presents the study on the removal of color by chemical treatment processes (advanced oxidation processes). Finally, in section 3.5 some conclusions are presented.

3.2 Change of color by pH adjustment

3.2.1 Introduction

The pH is one of the important factors that affect the efficiency of treating wastewater by coagulation or advanced oxidation processes, especially with regard to color removal from textile wastewater. Some compounds undergo color change and even become colorless at a certain pH range. For instance a color indicator substance such as phenolphthalein is colorless at pH 4.5 and becomes pink at pH 8.3. If wastewater pH adjustment alone can cause decolorization is still not fully known. Therefore the effect of pH on color removal in textile wastewater was studied for four types of wastewater: (1) disperse & reactive dyes, (2) vat dyes, (3) disperse & acid dyes and (4) a mixture of several wastewater streams from other steps of dyeing and finishing processes (= mixed wastewater). The following studies are presented and discussed:

- Assessing the change of color for the four wastewater streams at pH 1, 2, 3, 4, 5, 6, 7 and 10, using sulphuric acid to adjust the pH;

- Assessing the effects of different types of acids (HCl and H_2SO_4) on the color change.

3.2.2 Materials and methods

Apparatus

- pH meter: the pH was determined with a pH meter model MP220, manufactured by Mettler Toledo, Switzerland. The pH range is from 0 to 14 (±0.01).
- Magnetic stirrer with heating facility: made by WWR, USA, model 375. The maximum heating temperature was 55^0C, the maximum stirring speed was 2,000 rpm with a magnetic stir bar.
- The spectrophotometer was a GENESYS*20 made by Hach, USA with a wavelength range of 390 to 900nm.
- Low speed centrifuge: model FUHUA 80-2, made in China. The maximum rotational speed was 4,000rpm with a relative centrifugal force of 1,795g. The low speed centrifuge has the following specifications:

  - Volume of centrifugal tube : 10 ml
  - Number of tubes : 12 tubes
  - Diameter of centrifugal tube : 2 cm

Chemicals

Two types of acids were applied to assess the effect of the different acid types on the color removal efficiency of the four wastewater streams (disperse & reactive dyes, vat dyes, disperse & acid dyes, and mixed wastewater).

- HCl 5%;
- H_2SO_4 10%.

The acid solutions of 5-10 % were prepared by diluting concentrated acid (HCl 35% and H_2SO_4 98%) with demineralized water. The used H_2SO_4 and HCl were of pure grade from Merck.

Analytical methods

Measurement of color was performed according to the single-wavelength method (APHA 1995). Color intensity is determined by comparison of the sample with a known platinum-cobalt solution as a standard. In all experiments the color intensity was measured with a spectrophotometer at a wavelength of 455nm. The color intensity is expressed as Pt-Co. The color intensity was also determined at three further wavelengths: 436 nm (yellow), 525 nm (red) and 620 nm (blue) and was then expressed as absorption.

If the color exceeded 500 Pt-Co units, the sample was diluted until the color intensity was within the linear region of the absorption-concentration curve.
The pH was determined by a pH meter.

Procedure for pH variation tests

The pH variation experiments were performed in 250 ml beakers using samples of 150 ml of wastewater. The sample was mixed with a magnetic stirrer during pH adjustments. Acid solution was added to the sample with a burette. At the end of experiment the sample was left to settle for 30 minutes after which the supernatant was collected for determination of the color intensity and turbidity.

In this study the influence of centrifuging the wastewater samples, prior to addition of acid solutions, was also examined to compare the influence of suspended solids on color removal by changing the pH. The applied centrifuge speed was 3,000 rpm for 5 minutes.

Type of wastewaters

Wastewaters used for the experiments were provided by the 28 Company-Agtex in Vietnam. The main products of this company are cotton, blended cotton & polyester (T/C), synthetic fabrics, and blended wool. With a complete production system ranging from yarn twisting, weaving, dyeing and finishing, sewing to finished products, the company has a full set of modern technology and equipment. The dyeing process is applied according to the cold pad batch method and exhaust batch method (dyeing batch) at high pressure.

From the cold pad batch process with main textile products G.TC.219 fabric (35% cotton and 65% polyester), wastewater containing disperse & reactive dyes and with P.TC. 277 fabric (25% cotton and 75% polyester), wastewater containing vat dyes were used for investigation.

For the dyeing batch process with G.TW.538 L5 fabric (blended wool), disperse & acid dye wastewater samples were used to perform experiments.

Mixed sample is wastewater containing a mixture of several wastewater streams from other steps in the dyeing and finishing process, which was collected at the equalization tank.

The wastewater samples were stored at 4^0C and left to warm to room temperature (25-28^0C) before experiments.

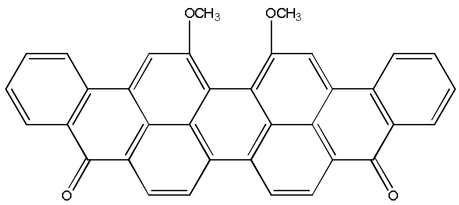
A flow scheme of the cold pad batch and the dyeing batch processes together with collection points of the wastewater samples is given in section 5.5.2 of chapter 5.

Characteristics and structure of some dyestuffs

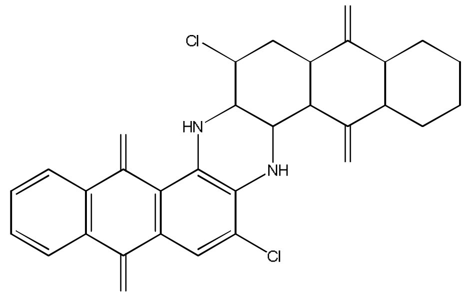
In order to understand the mechanism of the chemical reactions in decolorization of dyestuffs, the general characteristics of vat, disperse, reactive and acid dyestuffs used in the manufacturing processes of the 28 Company-Agtex are described in more detail.

Vat Dyes

Vat dyes are usually very insoluble in water and most organic solvents. The vat dyes need to be introduced in a soluble form to the fabric to impregnate the fibers. The fixation of the dye within the fiber is achieved by changing the dye into the insoluble form. Most commonly, the soluble form of the vat dye is a reduced form, the colorless leuco form. This leuco form is as an enol soluble in alkaline solution and is applied to the fabric in this form. Sodium dithionite is currently the favored reducing agent. Oxidation of leuco form is applied to bring back the dye in its insoluble form. The vat dyes are primarily used for cotton, rayon, but are also used for acrylics, modacrylic and nylon. Vat dyes have a high degree of fixation (80-95%) resulting in a small amount of unfixed dyes ending in the wastewater. Only a few vat dyes contain aromatic organic halogen (AOX) components and heavy metals in their structure. A low concentration of vat dyes in wastewater will cause no toxicity to microorganisms, but can be toxic to some aquatic organisms. The structures of some vat dyes used in the manufacturing process of 28 Company-Agtex are given in Figure 3.1. Wastewater with these dyes was used in the experiments.



C.I. Vat green 1

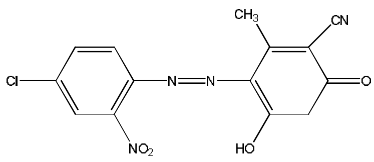


C.I. Vat blue 6

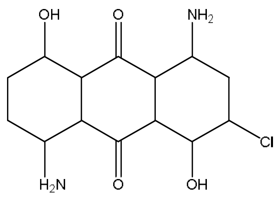
Figure 3.1: Structure of two vat dyes

Disperse dyes

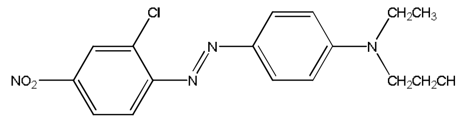
The disperse dyes are substantially insoluble in water. General characteristics of disperse dyes are small, planar and non-ionic molecules, with attached polar functional groups like $-NO_2$ and -CN. Their shape makes it easier to slide between the tightly-packed polymer chains of the fabric, where the polar groups improve the water solubility by enhancing the dipolar bonding between dye and polymer and affecting the color of the dye. Disperse dyes are usually applied as a dispersion of finely divided dye in a soap solution in presence of some solubilizing agent such as phenol, cresol, or benzoic acid. The process suffers from the fact that usually the absorption of dye into the fiber is slow and is best carried out at elevated temperature in pressure vessels. Disperse dyes can be used to dye polyester, nylon, triacetate, and acrylic fibers. Disperse dyes have a high degree of fixation (90-95%) resulting in a small amount of unfixed dyes ending in the wastewater. Structures of some disperse dyes which are used in the production process of the 28 Company-Agtex are presented in Figure 3.2. Wastewater with these dyes was used in the experiments.



C.I Disperse Yellow 211



C.I Disperse Blue 56

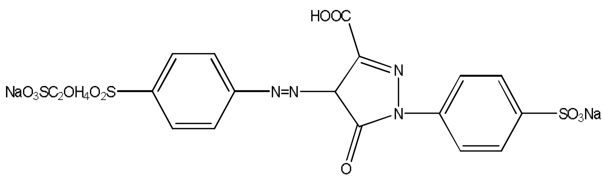


C.I Disperse Yellow 211

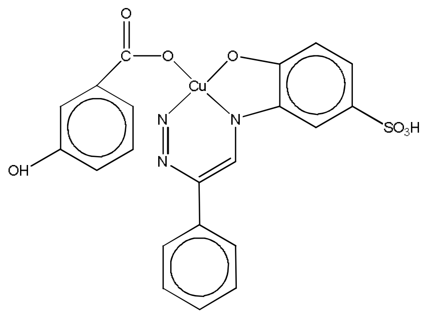
Figure 3.2: Structure of three disperse dyes

Reactive dyes

Reactive dyes are soluble in water and belong to a class of highly colored organic substances. Reactive groups in reactive dyes react chemically to form covalent bonds with OH, NH_2 or SH groups in fibers. The dye structure is often a heterocyclic aromatic ring with most commonly a vinyl sulphone reactive group. Reactive dyes are applied mostly to cellulose fibers, cotton, rayon, and linen. Some are appropriate for use on wool. In the dyeing process with reactive dyes, hydrolysis of reactive groups is an undesired side reaction that lowers the degree of fixation. The fixation degree of reactive dyes is 60-70%. Figure 3.3 gives the structure of some reactive dyes which are used in the production process of the 28 Company-Agtex. Wastewater with these dyes was also used in the experiments.



C.I. Reactive Yellow 14

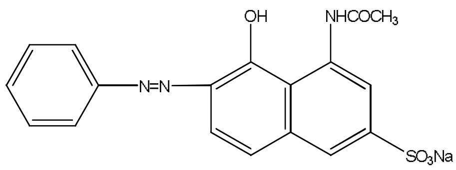


C.I. Reactive yellow C-2RR

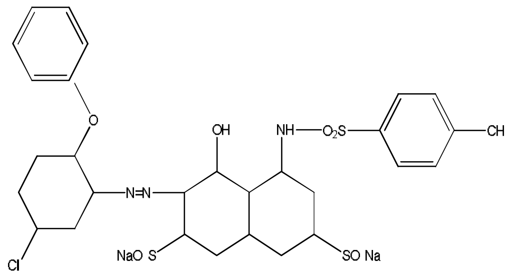
Figure 3.3: Structure of some reactive dyes

Acid dyes

Most acid dyes are azo dyes, antharaquinone or triarylmethane containing compounds. Acid dyes are water soluble anionic dyes. When acid dyes are applied in acid solutions they react chemically with alkaline groups (NH_3) in the fabric’s fiber structure and form ionic bonds. Because wool has both acid and alkaline groups in its structure, acid dyes can be used quite successfully on wool. These dyes are also utilized for dyeing nylon and to a lesser extent for acrylics, some modified polyesters, polypropylene, and spandex. The acid dyes are used in an acid medium containing acetate or sulphuric acid to set the color. Acid dyes cannot be used on cellulose fiber because these are susceptible to damage from the acid. The acid dyes are non-caustic, in many cases non-toxic. Acid dyes have a high degree of fixation from 80 to 95%. Regarding acid dyes two factors of concern for the environment are: the amount of acid solution and the unfixed dyes that will end-up in the wastewater at the end of process. Figure 3.4 give the structure of some acid dyes which are used in the production process of the 28 Company-Agtex. Wastewater with these dyes was also used in the experiments.



C.I. Acid Red 249



C.I. Acid red 1

Figure 3.4: Structure of two acid dyes

Composition of wastewater streams

Table 3.1 presents the composition of the textile wastewater streams of two processes: the cold pad batch and dyeing batch. The table shows that concentration of pollutants in the wastewater from the dyeing batch is higher than in the wastewater of the cold pad batch process. For example, the color of the wastewater from the dyeing batch is more than 2 to 3 times intensive and the COD 10 to 15 times higher in comparison with effluent of the cold pad batch. In addition, two parameters also have to be considered for treating textile wastewater: temperature and pH. The temperature of the wastewater varies between 45 to 60^{0}C and the pH of the wastewater is very high or low depending on types of used dyestuffs. A low pH (pH 5) of the wastewater is due to acid conditions of the dyeing batch process with acid dyes, while a high pH (pH 11) is due to the alkaline medium used in dyeing with disperse & reactive dyes, and the vat dye in the cold pad batch. The mixed wastewater is constituted by several wastewater streams from other steps in the dyeing and finishing processes. As a result the COD and color of the mixed wastewater is higher compared to cold pad batch wastewater and is lower compared to the wastewater of the dyeing batch process.

Table 3.1: Composition of the textile wastewater streams of the 28 Company-Agtex

Parameters	Unit	Disperse & reactive dyes wastewater (from cold pad batch process)	Vat dyes wastewater (from cold pad batch process)	Disperse & acid dyes wastewater (from dyeing batch process)	Mixed wastewater (from equalization tank)
Temperature	^0C	50	50	60	45
pH	-	10.9	11.0	5.1	10.9
COD	mg O_2/L	320	280	4,060	1,195
BOD_5	mg O_2/L	74	73	865	510
Alkalinity	mg $CaCO_3$/L	420	500	-	-
Turbidity	FAU	180	170	330	125
Color intensity	Pt-Co	1,345	1,360	3,095	1,390
Color		Red	Blue	Green	Brown
Absorbance at					
λ = 436 nm		0.430	0.430	0.956	0.400
λ = 525 nm	-	0.465	0.245	0.350	0.245
λ = 620 nm		0.175	0.230	0.240	0.180

Source: Loan (2006)
Note: (-): not measured

3.2.3 Results and discussion

Effect of pH adjustment on the four wastewater streams from textile production processes containing disperse & reactive dyes, vat dyes, disperse & acid dyes, and mixed wastewater was investigated. Besides the pH variation the type of acid was tested for best color removal.

Disperse and reactive dyes (red wastewater)

Using H_2SO_4 10% to adjust pH

Disperse and reactive dyes wastewater has a high pH of 8.4. For centrifuged and non centrifuged wastewater samples the pH was adjusted from 8.4 to 7, 6, 5, 4, 3, 2, and 1, corresponding to used volumes of acid of 0.8, 2.6, 2.9, 3.5, 15.2 and 120 ml/L respectively. Figure 3.6 shows the results of color change as a function of pH adjustments for centrifuged and non-centrifuged samples. The non-centrifuged samples show a maximum color removal efficiency of 31% at a pH value of 5; the color reduced from 1,140 Pt-Co to 780 Pt-Co. Note that color reduction at lower pH's was also caused by dilution of the sample with the acid solution.

Centrifugation of samples resulted in a significant color reduction without pH decrease, the color reduced from 1,140 to 820 Pt-Co corresponding to a removal efficiency of 28%. Results of pH change on the centrifuged samples were similar to the non-centrifuged ones. At pH 1 the color removal efficiency achieved a maximum of 44%. However, again a large volume of acid solution was added to the sample (120 ml acid solution per liter sample, a dilution of 12%) to adjust the pH to 1.

The results in general show that a slight reduction in color was found with decrease of the pH. The shape of the curves of both experiments was similar as can be seen in Figure 3.5. However, the maximum efficiency in color reduction of the centrifuged samples was higher than for the non-centrifuged ones. The higher color intensity of the non-centrifuged samples could be caused by the turbidity, whereas with centrifuged samples the effect of turbidity was prevented.

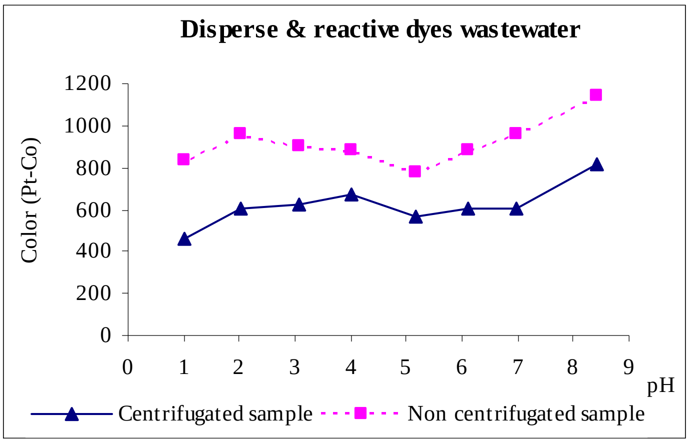


Figure 3.5: Effect of pH on color intensity of disperse & reactive dyes wastewater (red wastewater). H_2SO_4 was used for decreasing the pH of wastewater

Using HCl 5% to adjust pH

The experiments with the disperse & reactive dyes wastewater was repeated using 5.2, 7.2, 30, and 200 ml HCl/L to adjust the pH to 6, 4, 2, and 1 for centrifuged and non-centrifuged samples. Figure 3.6 shows that centrifuged and non-centrifuged samples gave the same results. The color slightly reduced at lower values of pH. The color removal efficiency was in the range of 14-27% for centrifuged samples, and 14-40% for non-centrifuged samples. Maximum efficiency was achieved at a pH value of 1. However, at that pH a large volume of acid was added to the samples (200 ml acid 5% for a liter of sample, a dilution of 20%). The results show the same tendency as in case of the use of H_2SO_4 to decrease pH.

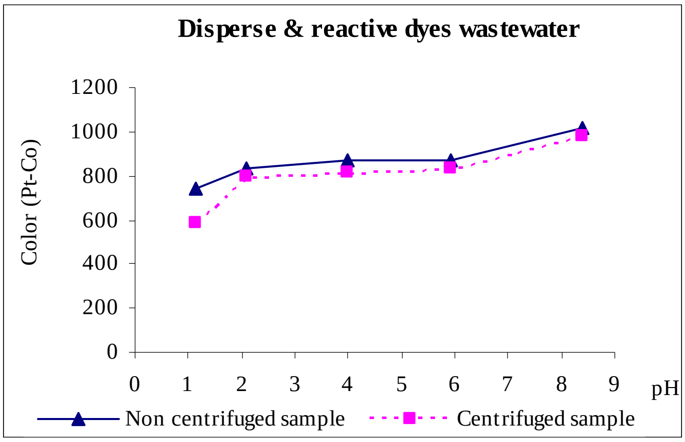


Figure 3.6: Effect of pH on color intensity of disperse & reactive dyes wastewater. HCl was used to decrease the pH of wastewater

Figure 3.7 presents a comparison between the effects of different acids on the color intensity. In brief, the influence of the type of acid on change of color was not significant in the case of non-centrifuged samples. In the case of centrifuged samples it is observed that for disperse & reactive dyes wastewater a higher color removal efficiency is obtained with the use of H_2SO_4.

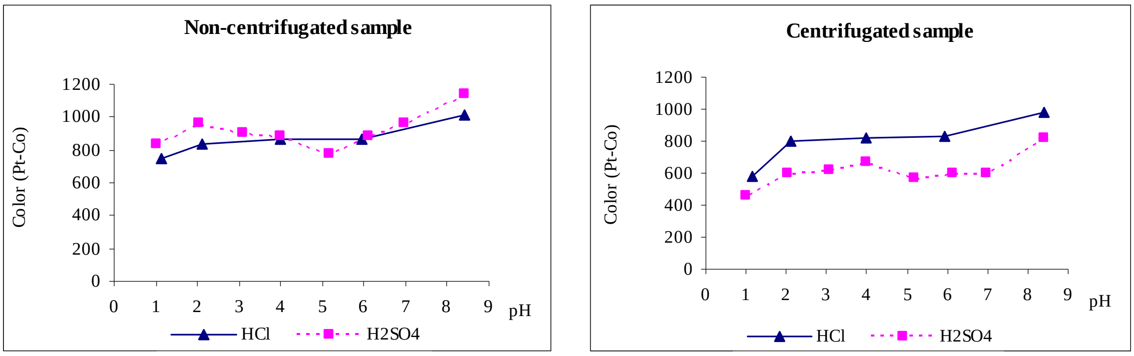


Figure 3.7: Effect of type of acid on color intensity of centrifuged and non-centrifuged wastewater with disperse & reactive dyes wastewater

Vat dyes (blue wastewater)

As can be seen from the previous experiments there is only a slight difference in color removal efficiency between the use of H_2SO_4 and HCl acid. Therefore, the experiments with vat dyes wastewater samples were only performed with H_2SO_4.

Similar to the disperse & reactive dyes, dyeing with vat dye in alkaline medium results in a wastewater with a high pH (10.3). The pH was adjusted to 8, 6, 4, 3, 2, and 1 using the addition of acid volumes of 0.16, 0.18, 0.30, 0.34, 2 and 8 ml/L of sample respectively. As can be seen in Figure 3.8 the color did not change much with change in pH. The maximum removal efficiency achieved was only 9%.

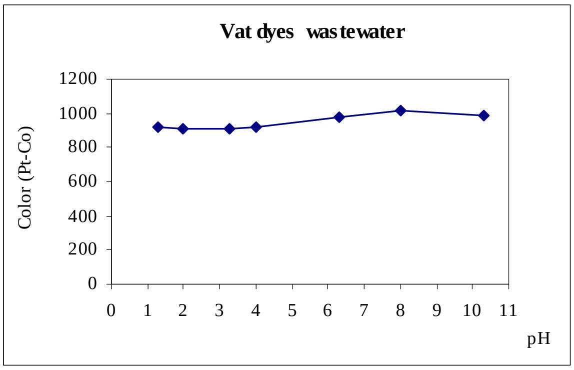


Figure 3.8: Effect of pH on color intensity of vat dyes wastewater. H_2SO_4 was used to decrease the pH of wastewater

Disperse and acid dyes (green wastewater)

As mentioned above, the dyeing batch with disperse and acid dyes are operated at acid conditions. Therefore the discharged wastewater usually has a low pH (5.7). The experiments were carried out with centrifuged and non-centrifuged samples. The pH was adjusted to 4, 3, 2 and 1 using 3.2, 5, 12.8, and 110 ml of H_2SO_4 (10%) per liter sample respectively. From Figure 3.9 it can be seen that the change of color intensity with change in pH of both experiments had a similar shape. There was a little difference in color change between centrifuged and non-centrifuged samples. The maximum removal efficiency was only 14-16% at a pH of 1. This was probably due to dilution of the sample with a large volume of added acid (200 ml per liter sample). These results also indicate that pH adjustment does not have a significant effect on the color intensity of disperse & acid dyes wastewater.

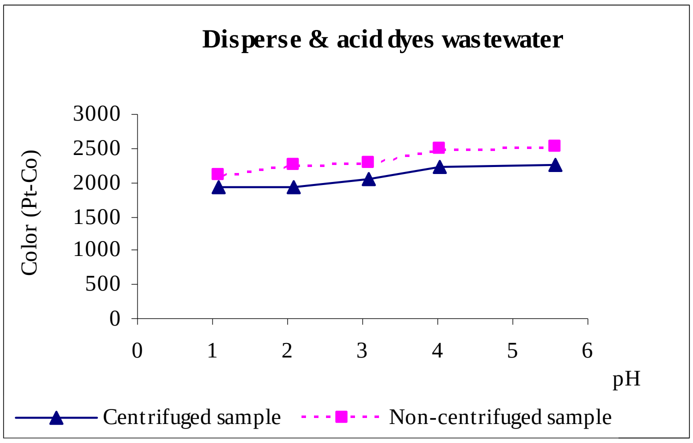


Figure 3.9: Effect of pH on color intensity of disperse & acid dyes wastewater. H_2SO_4 was used to decrease the pH of wastewater

Mixed wastewater

Similar to the previous experiments, the experiments with mixed wastewater were carried out with centrifuged and non-centrifuged samples. The pH of the mixed wastewater was 10.4. The pH was adjusted from 10.4 to 7, 6, 4, 3, 2, and 1 using 0.22, 0.32, 0.42, 0.48, 1.42 and 8 ml H_2SO_4 (10%) per liter sample respectively. Figure 3.10 shows the effect of pH on the color intensity for both samples. At pH 4 there was no difference between centrifuged and non-centrifuged samples. For non-centrifuged samples, at pH 7 the color removal efficiency achieved showed the highest value (33%). At pH 1 and 2, the color intensity was 1,405 and 1,425 Pt-Co and exceeded the initial wastewater's color of 1,390 Pt-Co. Comparable results were also found for centrifuged samples.

At pH values of 1 and 2 formation of flocs in the non-centrifuged wastewaters occurred. The formed flocs were very small in size. They did not settle and were causing an increase in turbidity of the sample. At pH of 1 the highest turbidity was found (130 FAU). The sample at pH 1 was filtered or centrifuged after which the color intensity was measured. Filtration reduced color to 230 Pt-Co (efficiency 83%). The color intensity of the centrifuged sample was 1,100 Pt-Co (efficiency 20%). These obtained data show that a filtration process (pore size 20 µm) can remove small particles much more efficient than centrifugation (at 3000 rpm).

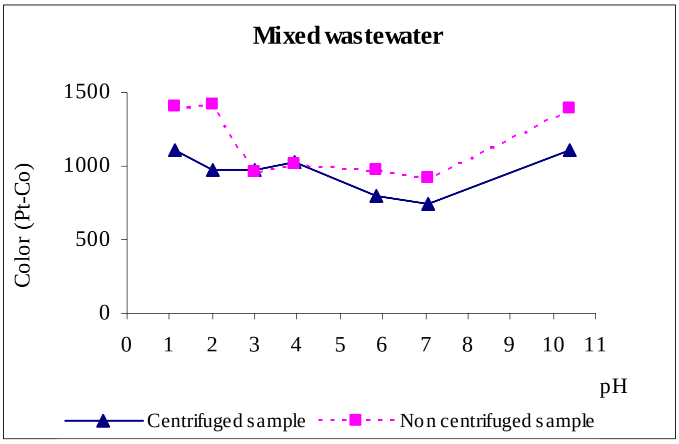


Figure 3.10: Effect of pH on the color intensity of centrifuged and non-centrifuged samples of mixed wastewater

3.2.4 Conclusions

In brief, the color intensity of disperse & reactive dyes, vat dyes, and disperse dyes was hardly affected by change of pH, even when the pH was changed in a wide range from 10 to 1. Only with the disperse & reactive dyes wastewater a significant efficiency in color removal was achieved (44 %), but this can be partly attributed to the dilution of wastewater with a large volume of acid solution. The results obtained with centrifuged and non-centrifuged samples are not very different. The effect of different acids (HCl and H_2SO_4) on the change of color was more or less the same. Addition of relatively large amount of H_2SO_4 promotes the coagulation/flocculation process resulting in the formation of small flocs. A centrifugation process can remove these flocs. In this case a reduction of color intensity of maximal 44% is possible. However, this is not a feasible option for reducing color intensity because of the large quantity of acids that must be used. In addition, a large amount of chemicals has to be used to adjust the pH back to a reasonable level for the next step of the textile wastewater treatment. It was further found that for mixed wastewater a filtration process (pore size 20 µm) is much more efficient to remove small particles than a centrifugation process.

3.3 Coagulation/flocculation process

3.3.1 Introduction

The chemical coagulation/flocculation process is usually applied as a pre-treatment step to improve the performance of a biological wastewater treatment, as a polishing or as a main step for color removal in textile wastewater treatment, and in some cases for effluent reuse.

There is a lot of studies and practice to remove color from the textile wastewater by chemical coagulation/flocculation (Nicolaou and Hadjivassilis 1992; Altinbas et al.

1995; Cooper 1995; Lin and Peng 1996; Marmagn and Coste 1996; Reid 1996; Sarasa et al. 1998; Vandevivere et al. 1998; Mattioli et al. 2002). However, these studies also gave different results which are sometimes also contradicting. In order to better understand the coagulation/flocculation process for a wastewater containing one of the four investigated dyestuffs mentioned previously, experiments with typical coagulants such as aluminum sulfate, poly aluminum chloride, and ferrous sulfate were executed to check the literature and find economically suitable solutions for color removal. The reasons for selecting these coagulants were: aluminum sulfate is a relatively effective coagulant in color removal, available and very cheap; ferrous sulfate is cheaper than ferric sulfate; and poly-aluminum chloride has characteristics of pre-hydrolyzed metal salts. The objectives of the experiment were:

1. To determine the effect of the types of coagulants on the color removal efficiency. Three types of coagulants/flocculants were applied: aluminum sulfate $Al_2(SO_4)_3.18H_2O$ poly-aluminum chloride (PAC), and ferrous sulfate $FeSO_4.7H_2O$.
2. Using the above mentioned types of coagulants to assess the removal of color for four different wastewater streams (disperse & reactive dye, vat dye, disperse & acid dye, and mixed wastewater) by a coagulation/flocculation process in dependence of pH and amount of coagulant.
3. To determine the optimal pH. The pH was varied from 4 to 8 when using $Al_2(SO_4)_3.18H_2O$; from 6 to 9 when using PAC and from 9 to 11 when using $FeSO_4.7H_2O$ at a constant dosage of coagulants for each wastewater type: aluminum sulfate: 900 mg/L, ferrous sulfate: 1,000 mg/L and poly-aluminum chloride: 900 mg/L. The pH was adjusted with H_2SO_4 or NaOH solutions.
4. To determine the optimal dosage of coagulant. The dosage of coagulant was varied from 400 to 1,200 mg/L for $Al_2(SO_4)_3.18H_2O$ and PAC, and from 400 to 1,800 mg/L for $Fe_2SO_4.7H_2O$. The experiments in which the effect of type and amount of coagulant were executed at optimal pH which was determined from pH optimization experiments.
5. Using the above mentioned coagulants/flocculants to determine the effect of temperature on the coagulation/flocculation process. The textile wastewater usually has a high temperature, therefore cooling of the wastewater is the first step in the textile wastewater treatment process. The effect of temperature was measured at three levels: 30, 40 and 50^0C.

3.3.2 Materials and methods

Apparatus

Jar test equipment, model JLT6 (Velp Scientifiza, the Netherlands), was used in the experiments to determine optimal pH and to determine the optimal dosage of coagulant. The jar test apparatus comprises of 6 beakers for samples, stirred simultaneously by 6 mixers. The type of mixer was a flat blade propeller. The rotation speed could be varied from 10 to 300 rpm. The jar test set-up is presented in Figure 3.11.

The spectrophotometer was a GENESYS*20 made by Hach, USA with a wavelength range of 390 to 900nm. The pH meter was model MP220, manufactured by Mettler Toledo, Switzerland. The conductivity meter was model Sension 5 manufactured by Hach, USA.

Figure 3.11: The JLT6 Jar test set-up

Chemicals

The coagulant/flocculation experiments were performed with three selected coagulants. The coagulation solutions were prepared by dissolving 5-10 % powder of the three coagulants in water. The pH adjustments were made by the addition of H_2SO_4 or NaOH (5-10%). The H_2SO_4 or NaOH solutions were prepared from concentrated H_2SO_4 (95-98%) or NaOH (98%) pellets and demineralized water to obtain the desired 5-10% concentration. All coagulants used in the coagulation experiments were commercial available chemicals, and the H_2SO_4 and NaOH were of pure grade.

Analytical methods

COD, BOD_5, and alkalinity were determined according to Standard Methods for the Examination of Water and Wastewater (APHA 1995):

- COD: closed reflux, titrimetric method.
- BOD: 5-day BOD test (at 20^0C).
- Alkalinity: titration method with standard acid solution.
- Color was measured with a spectrophotometer at a wavelength of 455 nm, and was expressed in Pt-Co. Turbidity was measured by a spectrophotometer at a wavelength of 450 nm, and was expressed in FAU (Formazin Attenuation Unit).
- The pH was determined with a pH meter. This pH meter could measure in the range between 0 to 14 pH units with accuracy of ±0.01.
- Temperature was measured with a thermometer (0-100^0C).
- The electrical conductivity (EC) and total dissolved solids (TDS) were measured with a conductivity meter. The conductivity range is 0-1999 µS/cm and total dissolved solids range is 0-50,000mg/L.

Coagulation/flocculation test procedure

The experiments were performed in 6 beakers with a volume of 1,000 ml. Each beaker contained 500 ml of wastewater. The beakers with wastewater were placed in the jar test equipment set-up, and the stirring was turned on. The dosages of coagulant and pH adjustment solutions (H_2SO_4 or NaOH) were added to the wastewater at the same time. To determine an optimal pH, the dosage of coagulant was kept constant, and the values of pH were changed. For determination of an optimal dosage of coagulant, the pH was kept constant and the dosages of coagulant were changed. Based on literature and field evaluation it can be concluded that, instantaneous rapid mixing of coagulants is a critical aspect (Metcalf & Eddy, 2003). Typical mixing times for aluminum sulfate and ferric sulfate for coagulation of colloidal particles is less 1 minute and sweep floc precipitation requires 1 to 10 minutes (Metcalf & Eddy, 2003). Therefore, first, complete mixing of chemicals and wastewater was carried out with a rapid mixing velocity of 100 rpm for 1 min. Then the mixing velocity was decreased to 30 to 40 rpm (slow mixing) and stirring continued for 30 minutes for flocculation. At the end of the reaction, flocs were left to settle for 30 minutes before samples of the supernatant were collected for the determination of pH, color, turbidity, total dissolved solids, and COD. The total time period of one experiment was about 60 minutes.

Type of wastewaters

The wastewater was provided by the 28 Company-Agtex in Vietnam as presented in section 3.2.2. Four types of wastewater streams were used as described in section 3.2.1. Wastewater samples were stored at 4^0C and left at room temperature prior to the start of the batch experiments.

3.3.3 Results and discussion

The coagulation processes of the four wastewater streams containing different dyestuffs were tested with three types of coagulants. The optimal pH and coagulant dosage for each wastewater stream is discussed in more detail below. The optimal pH and dosage of a coagulant were chosen according to the highest efficiency in color removal achieved for each type of wastewater.

Effect of coagulant

Aluminum sulfate $Al_2(SO_4)_3.18H_2O$

As mentioned in chapter 2, section 2.2.3 the most appropriate pH conditions for the coagulation process with aluminum sulfate are in the range of pH 5-8. In this experiment, the coagulant dosage was kept constant at 500 mg/L for disperse and reactive dyes wastewater, 900 mg/L for vat dyes and mixed wastewater, and 1,000 mg/L for disperse and acid dyes wastewater. The pH was varied between 5 and 8. The effect of the pH on the color removal efficiency for the four wastewater streams is presented in Figure 3.12. For the vat dyes and the mixed wastewater the optimum pH was 5. For the disperse and reactive dyes wastewater the optimal pH was 6. For the disperse and acid dyes wastewater the optimum pH was 7. For the disperse & acid dyes wastewater it was observed that at pH 5 and 6 the wastewater samples showed a very high turbidity, resulting in very low color removal.

At optimal pH the coagulant doses were varied from 200-2,000 mg/L depending on the concentration of remaining dyestuffs in the wastewater. In Figure 3.13 the effect of the aluminum sulfate dosage on the color removal efficiency for the four wastewater streams is presented. A dosage of ≥ 500 mg/L provided a significant color removal efficiency for disperse and reactive dyes and vat dyes wastewater. At a dosage of 600 mg/L a color removal efficiency of 98% was achieved for vat dyes wastewater. Disperse and acid dyes wastewater shows a maximum color removal efficiency of 80% with a coagulant dosage of more than 1,600 mg/L. For mixed wastewater a color removal efficiency comparable to that of disperse and reactive dyes and vat dyes wastewater was found (90%, final color 105 Pt-Co). The COD removal efficiencies at the optimum coagulant dosages for color removal were 81% for mixed and disperse and reactive wastewater (final COD 230 mg O_2/L), and for vat wastewater 84%. For disperse and acid wastewater only 53% COD removal efficiency was found.

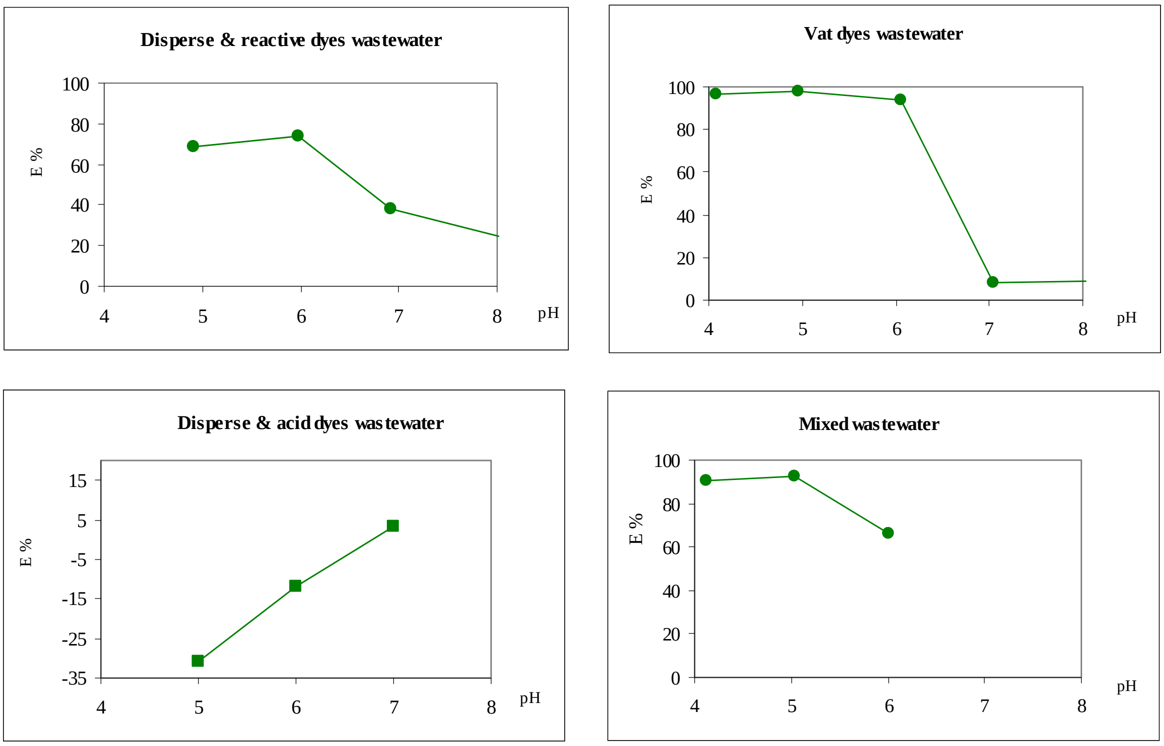


Figure 3.12: Effect of pH on the color removal efficiency (E%) for the four wastewater streams with constant coagulant dosage of 500 mg/L $Al_2(SO_4)_3.18H_2O$

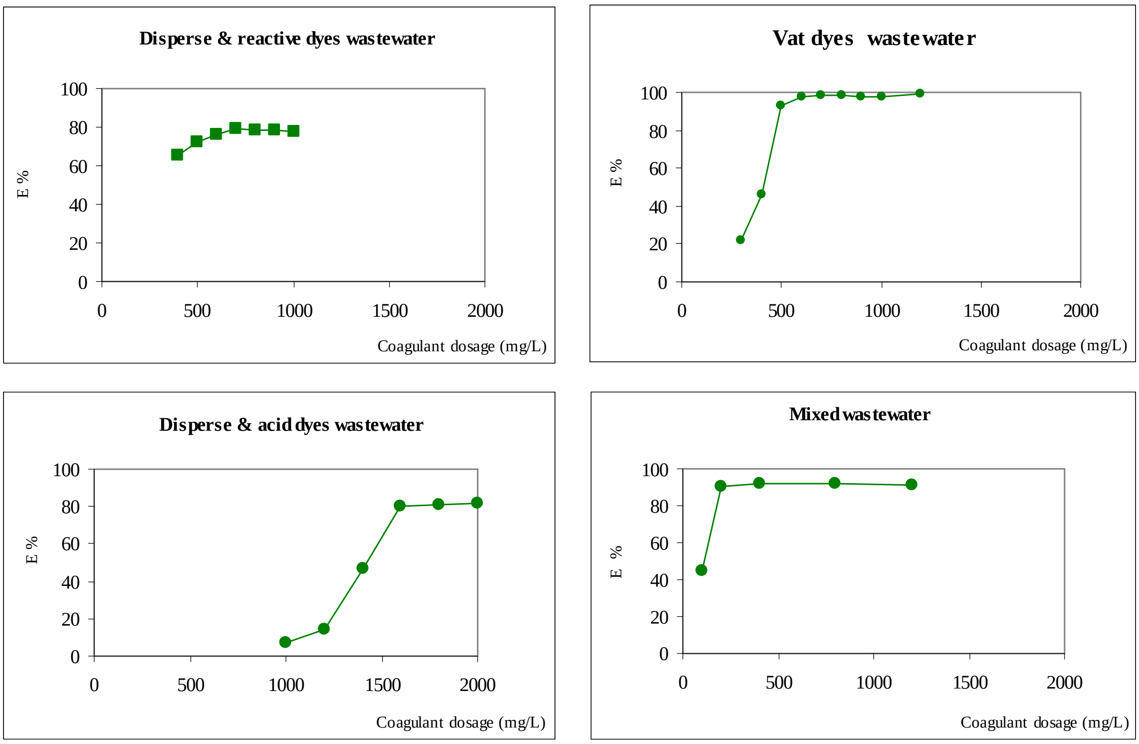


Figure 3.13: Effect of $Al_2(SO_4)_3.18H_2O$ dosages on the color removal efficiencies (E%) of the four wastewater streams at optimal pH

As reported by Mattioli et al. (2002) one of the disadvantages of a coagulation/flocculation process is the increase of the ratio of the electric conductivity (EC) and total dissolved solids (TDS) of the wastewater. This is caused by the addition of chemicals (coagulant and solution for pH adjustment) to the wastewater to achieve optimal conditions. Sometimes this will cause an exceeding of the discharge standard of TDS. In the pH optimizing experiment, the dosage of coagulant added to the sample was a constant dosage. The pH of the sample was changed from 4 to 8 using H_2SO_4 (10%). The volume of used H_2SO_4 was depended on the requirement of pH adjustments and ranged from 1.8 to 3.3 ml.

This study found that after the coagulation process the EC of all of the samples was slightly reduced in comparison with original sample. For instance, in the case of vat dyes (blue wastewater) the EC of original sample was 1876 µS/cm. In the optimal pH experiment the EC reduced to 1852 µS/cm at pH 4, 1768 µS/cm at pH, 1744 µS/cm at pH 6, 1720 µS/cm at pH 7, and 1704 µS/cm at pH 8. The reduction is very small and can be explained by the fact that a part of the soluble materials can be removed by coagulation/flocculation (absorption on flocs).

The results of the optimal coagulant dosage experiments were similar to the optimal pH experiments. In these experiments the amount of coagulant that was added varied from 300-1,200 mg/L. Using 3.0 to 3.6 ml H_2SO_4 (10%) in order to decrease the pH to an optimal value of 5 has hardly any effect on the EC of the samples. This proves that the influence of adding coagulants and the adjustment of pH on the EC is very low. Therefore, effluents from coagulation/flocculation can meet the Vietnamese standards for EC. The absence of an increase in EC can be explained from the solubility of aluminum hydroxide as a function of pH. This relationship is presented in Figure 3.14. The minimum aluminum solubility is at pH 6.

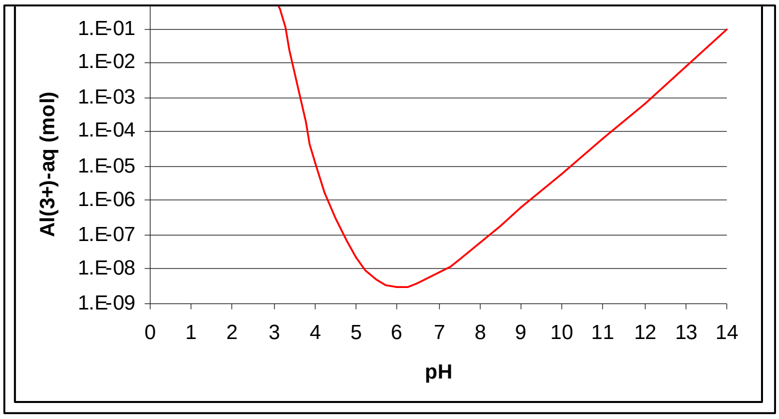
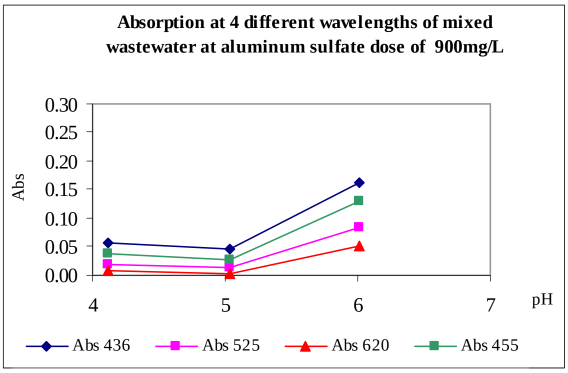


Figure 3.14: The solubility of aluminum hydroxide [$Al_2(OH)_3$] as a function of pH

The color measurement was carried out by two methods in the coagulation experiments with mixed wastewater using aluminum sulfate as coagulant. The first method is based on a comparison of color standards (Pt-Co) at a wavelength of 455 nm (single method). The second method is based on the light adsorption at different wavelengths: 436 nm (yellow), 525 nm (red) and 620 nm (blue). In Figure 3.15 the effect of the two methods on the absorption of mixed wastewater is shown. The absorption of original mixed wastewater at 455 nm was the lowest in comparison with the 3 other wavelengths. After the coagulation process the shape of the curves was similar. The absorption decreased with increasing dosage of coagulant; the color removal efficiency was more or less the same at all used wavelengths: 91% at 455 nm (Pt-Co), and 94 % at 436 nm, 525 nm and 95% for 620 nm. As mentioned in chapter 2, the Vietnamese standard color limit allowance uses Pt-Co as a unit, therefore the single method with unit of Pt-Co was chosen to measure color for all experiments.



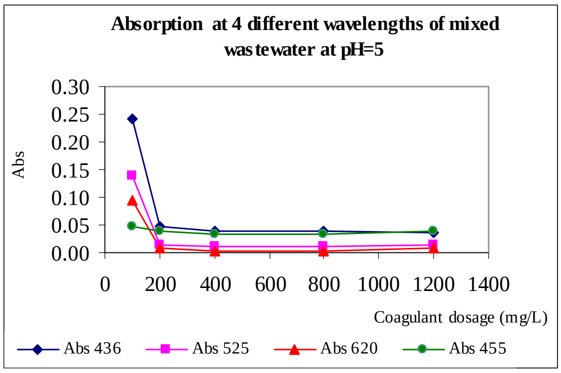


Figure 3.15: Measured absorption at 4 different wavelengths for mixed wastewater as a function of pH and the dosage of $Al_2(SO_4)_3.18H_2O$

Poly aluminum chloride (PAC)

Two wastewater streams (disperse & reactive dyes and vat dyes) were coagulated with PAC. At a constant coagulant dosage of 500 mg/L the color removal efficiency at pH values varying from 6 to 8.6 for disperse & reactive dyes wastewater and from 6 to 9 for vat dyes wastewater were investigated.

For disperse & reactive dyes the highest color removal efficiency (64%) was obtained at a pH value of 6.5. For vat dyes the best color removal efficiency (96%) was obtained at pH 8.0.

At optimal the pH of 6.5 for disperse and reactive dye wastewater the optimal PAC coagulant dosage was 800 mg/L with a color removal efficiency of 77%. For vat dyes wastewater at optimal pH 8.0 an increase in coagulant dosage from 600-900 mg/L resulted in an increase in the color removal efficiency from 55 to 96%. The color removal efficiency hardly changed when the dosage of coagulant was further increased from 1,000 to 1,200 mg/L.

The COD removal efficiency of vat dyes and disperse & reactive dyes wastewater were more or less the same: 74 and 76% at optimal conditions (For vat dyes wastewater was at pH 8.0 and dosage of 900mg/L. For disperse & reactive dyes wastewater was at pH 6.5 and dosage of 800mg/L).

The color removal efficiency for vat dyes wastewater was in general higher than for disperse & reactive dyes wastewater. In Figure 3.16 and 3.17 the effect of pH and the coagulant doses on the color removal efficiency are shown.

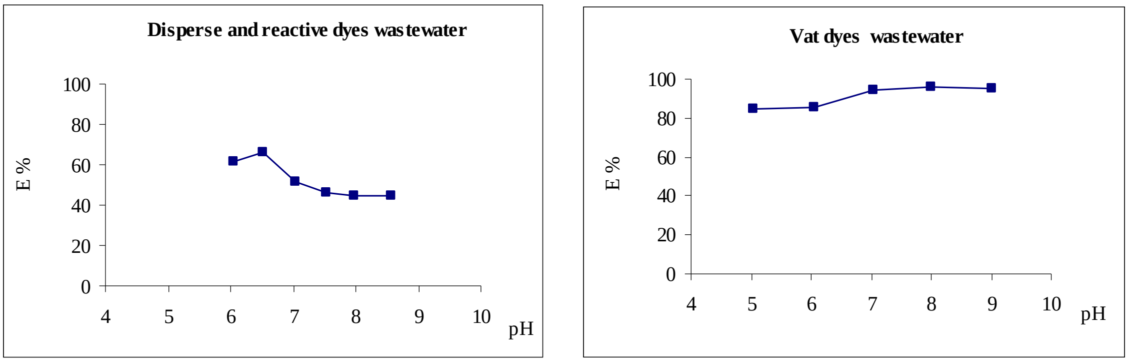


Figure 3.16: The effect of pH on the color removal efficiency (E%) of disperse & reactive dyes and vat dyes wastewaters with a constant coagulant dosage of 500 mg PAC/L

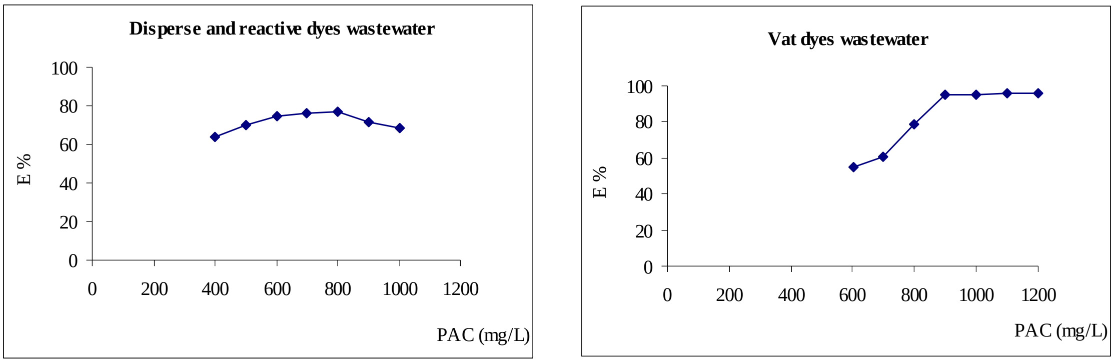


Figure 3.17: Effect of PAC dosage on the color removal efficiency (E%) of disperse & reactive dyes and vat dyes wastewaters at fixed pH value of 6.5 (disperse & reactive dyes) and 8.0 (vat dyes)

Ferrous sulfate ($FeSO_4.7H_2O$)

In this experiment, three wastewater streams were used: disperse & reactive dyes, vat and disperse & acid dyes wastewater. The effect of pH is represented in Figure 3.18. In these experiments a fixed coagulant dosage of 700 mg/L for disperse & reactive dyes wastewater and 1,000 mg/L for vat dyes and disperse & acid dyes wastewater was applied. The best results were obtained at pH 9 for disperse & acid dyes, vat dyes, and at pH 11 for disperse & reactive dyes wastewater. It was observed that at pH 8 the vat dyes wastewater got very turbid, and the color of the wastewater became darker, so that the color intensity strongly increased resulting in negative removal efficiency. Similar results were found for disperse & acid dyes wastewater at pH 11.

The effect of $FeSO_4$ dosages at optimal pH on the color removal efficiency for the three wastewater streams is presented in Figure 3.19. The optimal dosage for disperse & reactive dyes wastewater at fixed pH of 11 was 800 mg/L resulting in a color removal efficiency of 78% and a COD removal efficiency of 84%. For vat dyes wastewater the effect of $FeSO_4$ dosages on the color removal efficiency was tested at the optimal pH of 9. The optimal dosage for vat dyes wastewater was 1,600 mg/L with a color removal efficiency of 94% and a COD removal efficiency of 76%. For disperse & acid dye wastewater, the highest color removal efficiency was 64% with a $FeSO_4$ dosage of 1,000 mg/L at pH of 9. From the three wastewater streams tested with respect to the $FeSO_4$ as coagulant vat dyes wastewater showed the highest removal efficiency for color and COD.

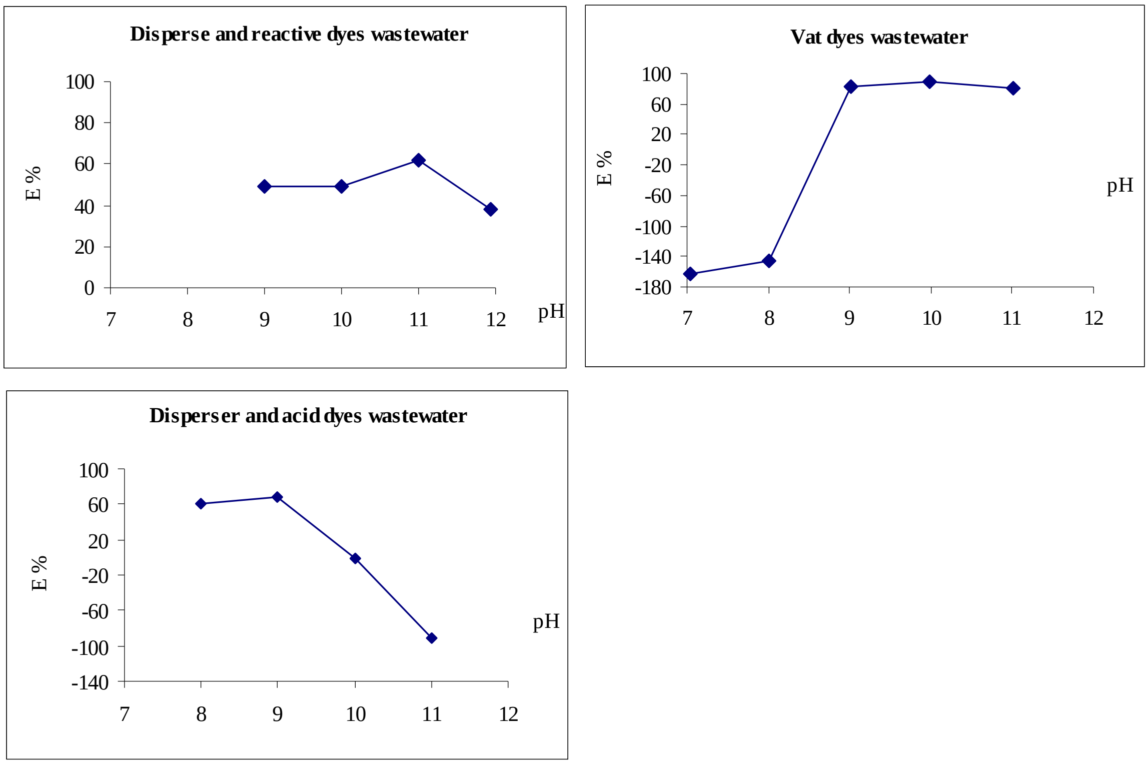


Figure 3.18: The effect of pH on the color removal efficiency (E%) at fixed coagulant dosage

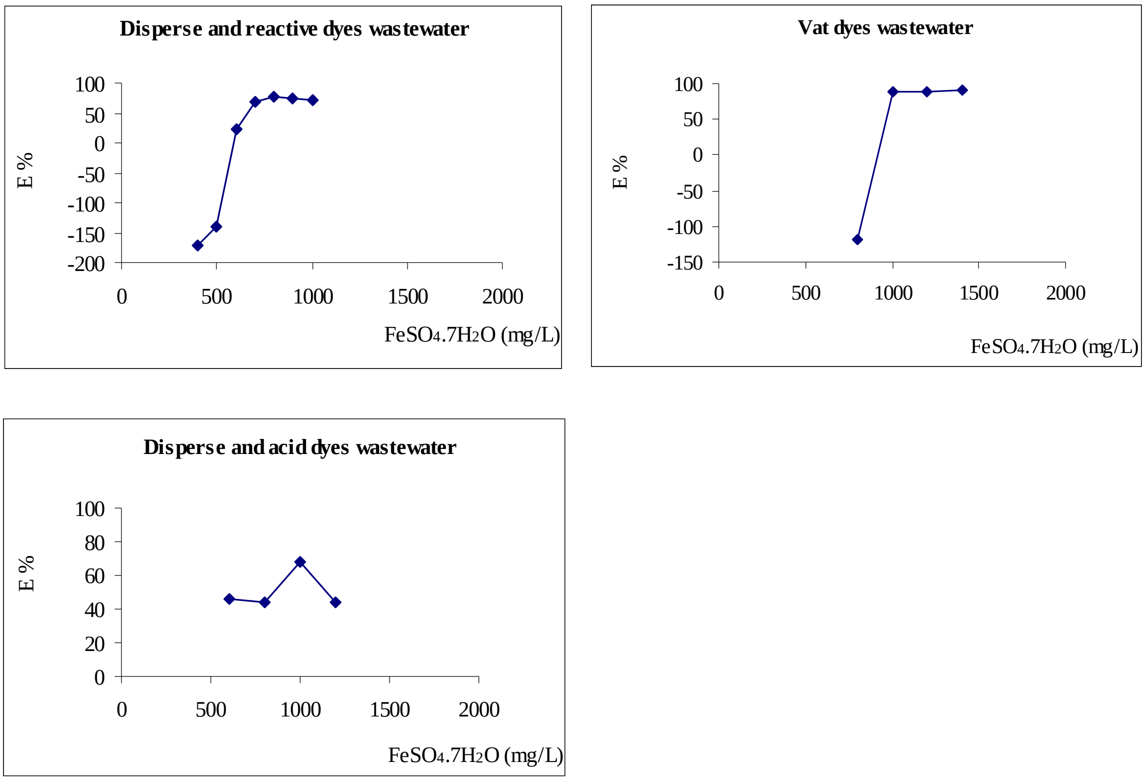


Figure 3.19: Effect of $FeSO_4$ dosage on the color removal efficiency (E%) at optimal pH values

Comparison of coagulation experiments

The results with respect to the removal of color and COD from the four wastewater streams used in the coagulation experiments are summarized in Table 3.2. A comparison of color removal efficiency of the four wastewater streams using three coagulants of $Al_2(SO_4)_3$, PAC and $FeSO_4$ is presented in Figure 3.20. It is clear that in general coagulation processes achieved a high removal efficiency of color and COD. The results were the same as reported by some studies (Grau 1991; Lin and Lin 1993; Tünay et al. 1996; Kabdasli et al. 2000).

Table 3.2: Summary of optimal test results of the coagulation/flocculation process

Coagulants	Wastewater streams	Initial pH	Optimum pH	Optium dosage (mg/L)	Color removal E (%)	COD removal E (%)
$Al_2SO_4.18H_2O$	Disperse & reactive dyes	10.9	6.0	700	79	81
	Vat dyes	11.0	5.0	600	98	78
	Disperse & acid dyes	5.1	7.0	>1600	80	53
	Mixed wastewater	10.9	5.0	600	90	81
PAC	Disperse & reactive dyes	10.9	6.5	800	76	74
	Vat dyes	11.0	8.0	900	95	74
$FeSO_4.18H_2O$	Disperse & reactive dyes	10.9	11.0	800	78	84
	Vat dyes	11.0	10.0	1600	96	76
	Disperse & acid dyes	5.1	9.0	1000	64	63

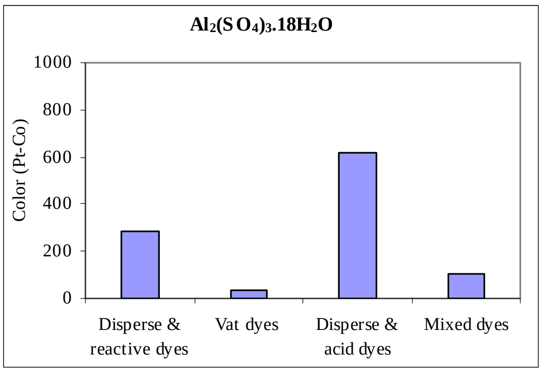
For **disperse & reactive dyes** wastewater, the efficiency of aluminum sulfate, ferrous sulfate, and poly aluminum chloride is more or less similar. The maximum color removal efficiency was around 76-79% and the COD removal efficiency ranged from 74-84%. However, the remaining color after coagulation was in the range of 285-310 Pt-Co which is too high to meet the Vietnamese regulation discharge standard of color (50 Pt-Co) with only one treatment step. The explanation could be that the untreated wastewater contains a larger amount of reactive dyes than disperse dyes, based on the typical fixation aspects of these dyestuffs. The fixation of disperse dyes is about 90-95% and for the reactive dyes this is 60-90%. The coagulation process was more effective in color removal of the insoluble disperse dyes and less for the soluble reactive dyes. Even though the amount of remaining reactive dyes in the wastewater was higher than the disperse dyes, the color removal efficiency that could be achieved was 79%. This proved that also soluble reactive dyes could be removed by an adsorptive mechanism of soluble reactive dyes on the flocs which were formed in the coagulation/flocculation process. Among the three tested coagulants aluminum sulfate achieved the highest color removal efficiency. For disperse & reactive dyes wastewater the estimated operational costs for achieving optimal conditions for aluminum sulfate was 0.2US$/$m^3$ wastewater.

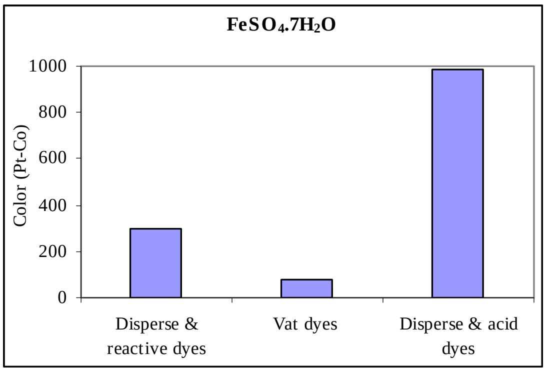
For **vat dyes** wastewater the results show that the coagulation process was also a very effective means of color and COD removal, especially for color removal. The aluminum sulfate gave the highest color removal efficiency (98%) reducing the color down to 30 Pt-Co, the lowest value achieved with the four types of wastewater. The COD removal was 78% (62 mg O_2/L). The estimated operational costs are 0.27US$/$m^3$ wastewater. Use of PAC and $FeSO_4$ coagulants also achieved a high efficiency (95 and 96%) but needed more coagulant: PAC 900 mg/L and $FeSO_4.7H_2O$ 1,600 mg/L. The vat dyes are only applied in the dyeing and finishing process of P.TC 277 fabric. The remaining vat dyes in the wastewater of this process were about 5% of the initial dye concentration. These remaining vat dyes are relatively insoluble and therefore they could be completely removed by a coagulation process.

The coagulation process with ferrous sulfate of **disperse & acid dyes** wastewater gave the lowest color removal efficiency (64%) compared to the color removal efficiency of the other wastewater streams (disperse & reactive dyes, vat dyes, and mixed wastewater). Although a high dosage of coagulants (2,000 mg $Al_2(SO_4)_3.18H_2O$/L or 1,200 mg $FeSO_4$/L) were used a noticeable color remained. This can be explained by considering the composition of the wastewater. This still contained a high concentration of acid dyes after the coagulation process. Before coagulation the wastewater contained 5-10% of the initial amount of the disperse & acid dyes. After the coagulation step, disperse dyes could have been removed almost completely by the coagulation process but acid dyes could not. As mentioned in chapter 2, acid dyes are highly soluble dyes, which are less efficient to be removed with the application of a coagulation/flocculation process. Costs were not calculated for the application.

For **mixed** wastewater, coagulation with aluminum sulfate showed a high removal efficiency for color (92%) and for COD (81%). The used dosage was lower (400 mg/L) than for the three other wastewater streams. This might be because at the equalization tank the concentrated wastewater streams were diluted by other less polluted wastewater streams, and as a consequence, it could be easier to reach the optimal conditions for the coagulation process. For mixed wastewater, the estimated operational costs to achieve optimal conditions for aluminum sulfate was 0.15US$/$m^3$ wastewater.

At optimal pH, but with a lower than optimal dosage of coagulant, the color increased resulting in less or negative removal (see graph 3.13 d) efficiency. The reason is that insufficient coagulant amount has been added to destabilize colloidal particles or to reduce the surface charge, in which case the coagulation process may not yet occur. As a result, a less effective efficiency of color removal was achieved compared to optimal conditions.





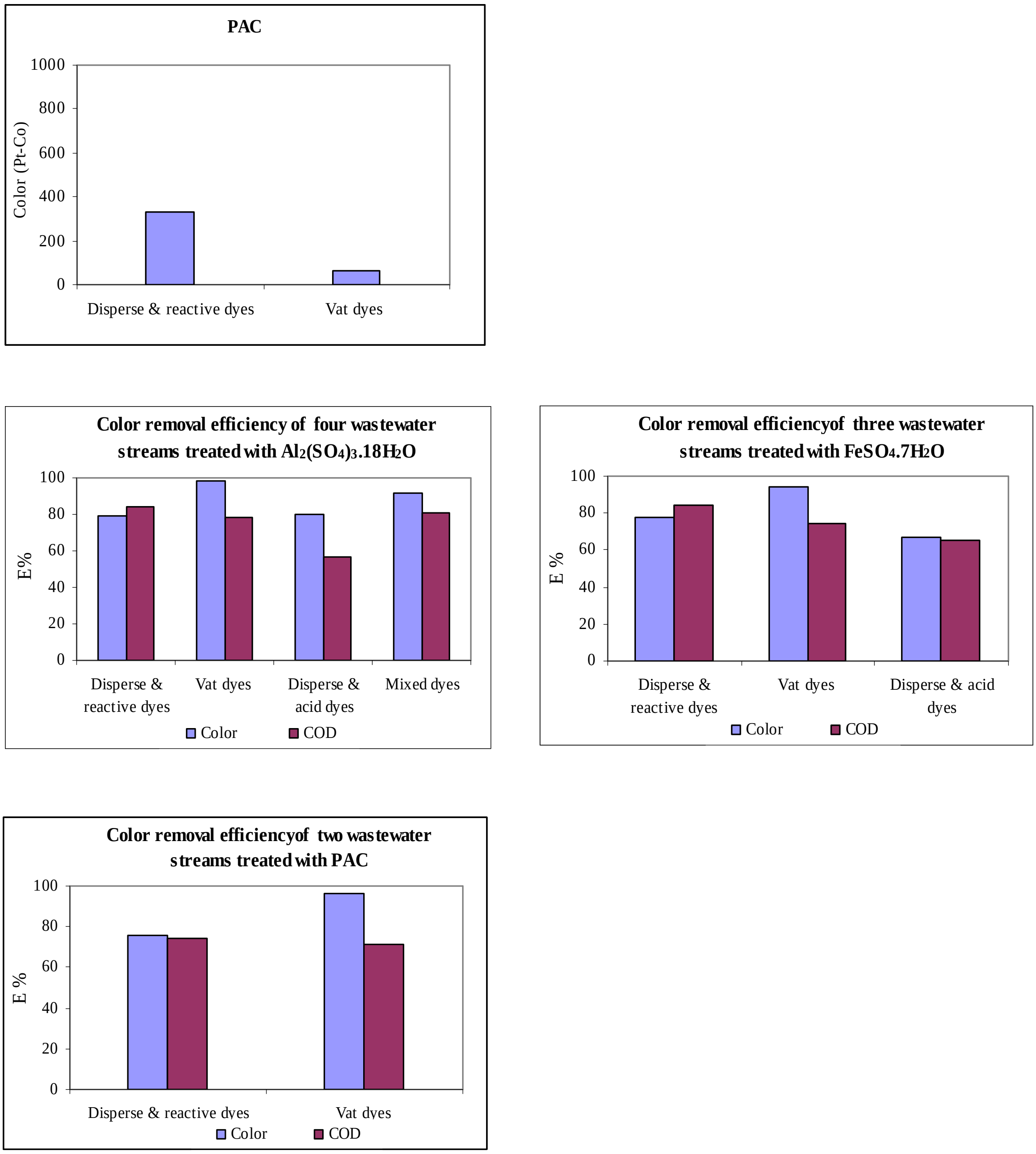


Figure 3.20: Comparison of color intensity and removal efficiency of color and COD of wastewater streams using three types of coagulants of $Al_2(SO_4)_3$, $FeSO_4$ and PAC at optimal conditions

Effect of temperature on the coagulation/flocculation process

In the experiments aimed to evaluate the effect of temperature on the coagulation/flocculation process mixed wastewater was used at the optimal pH of 5 and dosage of aluminum sulfate of 400 mg/L.

In Figure 3.21 the effect of varying the temperature on the color removal efficiency of the coagulation process is shown. Results show that within the studied temperature range of 30-50^{0}C there was only a small effect on the color removal efficiency. So cooling down of the wastewater to ambient temperatures is in general not necessary for textile wastewater.

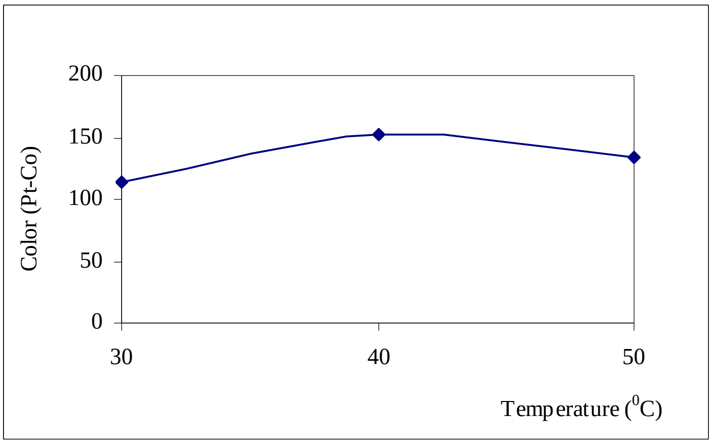


Figure 3.21: Effect of temperature on the color of mixed wastewater, at optimum aluminum sulfate dosage and pH

3.3.4 Conclusions

The results of the experiments clearly showed that the coagulation process is a very effective means for color removal of disperse & reactive dyes, vat dyes, and mixed wastewater. This study indicated that experimentally found optimal pH values are in agreement with literature data. Optimal pH varies between pH 5 and about 7 for aluminum sulfate, between 6.5 and 9 for poly aluminum chloride, and between 9 and 11 for ferrous sulfate. These experiments revealed that pH affects the coagulation process significantly. With proper pH control it was possible to achieve high color removal efficiencies at smaller coagulant dosage. As can be seen from section 3.1 only pH adjustments did not have a significant effect on the efficiency of color removal.

As already mentioned it was found in literature that the dosage of coagulant found to achieve a high color removal efficiency was in the range from 200-1,500mg/L. In this study, the color removal with high efficiency can be obtained with optimal coagulant dosages in a range from 400-1,000 mg/L. The dosage of used coagulants will depend on the characteristics and concentration of remaing dyestuffs in the wastewater. Adding more coagulant than the optimal dosage achieved little improvement in the color removal efficiency. Although coagulation processes can remove a significant amount of color and COD in textile wastewater, only a coagulation step by it self can not meet the discharge standards. In agreement with reports of some studies (Stahr, 1980; Takur, 1994) this study also found that the coagulation process did not only remove insoluble dyestuffs but also soluble dyestuffs by the absorption mechanism, especially reactive dyes. In addition the coagulation process does not increase in EC of wastewater which is one of the important factors in wastewater reuse and in meeting discharge standards. Temperatures in the range between 30 and 50^0C have a small effect on the coagulation process. A drawback of coagulation processes is that it generates sludge which has to be treated further and that it will increase the operational costs of a wastewater treatment system.

Among the three studied coagulants (aluminum sulfate, poly aluminum chloride, and ferrous sulfate) aluminum sulfate is relatively the most effective coagulant in color removal. It is also the cheapest coagulant at present.

3.4 Advanced oxidation processes

3.4.1 Introduction

In order to meet the strict discharge standards for color (50 Pt-Co) and COD (80 mg O_2/L) or to make reuse of the effluence possible, advanced oxidation processes (AOPs) could be considered to satisfy these strict standards. According to literature (Churchley 1994; Tünay et al. 1996; Liakou et al. 1997; Shyh and H. M. Chang 1997; Vandevivere et al. 1998; Ledakowicz et al. 2001; Karahan et al. 2002; Mattioli et al. 2002; Baban et al. 2003; Lucas et al. 2007) the AOPs represent the most widely used chemical methods for treatment of textile wastewater and the application of AOPs are found to be effective in the decolorization, COD reduction, and enhancing the biodegradability of textile wastewater. The AOPs can be applied as a pre-treatment step to convert complex organic molecules (non-biodegradable) into simple molecules which often represent more biodegradable substrates (Oliver et al. 2000; Chamarro et al. 2001) or as a polishing step in wastewater treatment systems to meet the strict discharge standards or reuse standard (Lin and Liu 1994; Tzitzi et al. 1994; Strickland and Perkins 1995; Churchley 1998; Sigge et al. 2001). However, some literature data also show different results due to differences in the complexity of the wastewater. The purpose of this part of the research was to find a suitable AOPs practice for color and COD removal of textile wastewater. More specifically the object of this study focused on investigation of efficiency of three AOP methods for five types of textile wastewater streams and the effect of temperature on the AOPs color removal efficiency.

The goal was to assess the removal of color for five types of wastewater streams (disperse & reactive dyes, vat dyes, disperse & acid dyes, acid dyes, and mixed wastewater) with the three AOPs which have been used widely in the practice of color removal. These AOPs are the application of O_3, O_3/H_2O_2, and Fenton’s reagent.

O_3

Regarding the application of O_3 as reported in literature it is observed that many textile wastewater studies (Matsui et al. 1981; Gaehr et al. 1994; Sarasa et al. 1998; Wu et al. 1998) have focused on the color removal applying ozone at difference pH values. At values of pH>8 indirect reactions between ozone and organic compounds occur via hydroxyl radicals. In an acid environment, ozone will directly react with the organic compounds. The direct ozonation of dyestuffs is a much faster reaction than the reaction of radicals. Several results show that a pH in the range of 3 to 11 only slightly affects the efficiency of color and COD removal (Namboodri et al. 1994; Perkins et al. 1995; Kabdal et al. 2002; Selcuk and Meric 2006). In addition, adjustment of pH to a very high or low pH will increase the electric conductivity of effluent and operational costs of wastewater treatment system. In the experiments described in this paragraph, ozonation was carried out at the original pH of five raw wastewater streams in which four wastewater streams are collected from the 28 Company-Agtex and one artificial wastewater at two pH values: artificial wastewater containing only dye at pH 5 and artificial wastewater with dye, salts, and lubic-Co (lubricant used for dyestuff fixation enhancement) at pH 11.2.

As mentioned in literature (chapter 2), the optimal dosage of ozone that results in a complete decolorization ranged from 30-2,400 mg O_3/L. For artificial wastewater the ozone dosage necessary for decolorization is in general lower than for real wastewater. From literature results it can be concluded that application of a large ozone dosage is not feasible because ozonation is very expensive. In our experiments the applied ozone dosage was relatively low and was varied in a range from 20-200 mg O_3/L for artificial wastewater and 30-600 mg O_3/L for real wastewater depending on characteristics and color intensity of each wastewater stream.

The presence of particles (suspended solids or colloidal particles) in wastewater is one of the important factors that will affect the efficiency of AOPs. However, only few literature data for effect of particles have been published. Textile industries, as mentioned in chapter 2, usually use a high concentration of several inorganic salts in the dyeing process. The remaining salt concentration in wastewater is important for the effect of ozone on impurities in textile wastewater. Therefore, in this study the effects of particles and of salts on the performance AOPs were experimentally evaluated using artificial wastewater, and subsequently with real wastewaters. The experiments with particle free wastewater were carried out with filtered or centrifuged wastewater. Two types of salt, (NaCl and Na_2CO_3) were used in the experiments. Lubic-Co (particles) was used to investigate the influence of particles on the oxidation process. Lubic-Co is an additive in textile processing that consists of small particles and is present in real textile wastewater. In the experiments, the removal efficiency of suspended solids, total COD (COD_{total}), particulate COD (COD_{part}), dissolved COD (COD_{dis}), suspended solids COD (COD_{ss}) and colloidal COD (COD_{col}) were investigated.

O_3/H_2O_2

As already mentioned in chapter 2, an optimal H_2O_2/O_3 mol ratio of 0.5 was reported in literature. However, this ratio can drastically change due to the wastewater composition, especially by the presence of scavengers in the wastewater. In order to assess the effect of the mol ratio of H_2O_2/O_3 on the removal efficiencies of the chosen parameters, the experiments were carried out at the optimal ozone dosage and varying the dosage of H_2O_2 between 140 to 280 mg/L.

Fenton' reagent

In literature an optimal pH range between pH 3 and 5 for Fenton's reagent is reported (Kuo 1992; Sevimli and Kinaci 2002). In order to assess the effect of pH, the experiments were performed at pHs varying in the range between 2 to 5, at a fixed H_2O_2 and Fe^{2+} dosage.
For determination of the optimal dosage of hydrogen peroxide, the experiment was performed at hydrogen peroxide dosages varying between 30 and 2,260 mg H_2O_2/L, depended on the characteristics of the wastewater streams.
For determination of optimal iron dosage the iron (Fe^{2+}) dosage was varied between 20 and 223 mg Fe^{2+}/L at optimal pH and H_2O_2 dosage.

Assessment the effect of temperature on AOPs

Textile wastewater usually has a high temperature, and a pretreatment step is used to decrease the temperature of the wastewater before it is treated in a next treatment step (Oliver et al. 2000; Kabdal et al. 2002). This cooling step adds operational costs for the wastewater treatment plant. To assess the influence of temperature on the color removal, experiments at temperatures 30, 40, and 60^0C were performed, at optimal conditions (established previously) for ozone oxidation and Fenton's reagent.

3.4.2 Materials and methods

Apparatus

O_3 experiments

The reactor used in the experiment consisted of a double walled glass cylinder with an inlet for ozone supply, outlet for ozone discharge and pH measurement. The total volume of reactor was 1.5 L. The reactor had an internal diameter of 9 cm and a height of 24 cm. The ozone was introduced through a stainless steel diffuser. A stirrer, at a speed of 60 rpm, was used for the homogeneous distribution of the ozone in the wastewater. The ozone was supplied by an ozone generator. Teflon tubing and connectors were used. The set-up is shown in Figure 3.22.

Two ozone generators were used for the experiments. The first ozone generator (Sorbios, model GSG 001) was fed with pure oxygen gas (HoekLoos, the Netherlands). A concentration of 1.1% v/v ozone in the gas mixture was used, at a controlled feed rate of 17.7 L/hr. The second generator was a Dozomax model (Vietnam), at a controlled feed rate of 11.7 L/hr, and a capacity of 1 g O_3/hr, using dry air. In order to mix the ozone and wastewater, a magnetic stirrer was used during the experiments. The magnetic stirrer (model 375 of VWR , USA) had a speed control up to 2,000 rpm.

O_3/H_2O_2 experiments

The oxidation experiments with O_3/H_2O_2 were carried out with the same reactor system as used in the O_3 experiments. In these experiments, the hydrogen peroxide dosage was injected into the reactor through one of the inlet of the reactor.

Figure 3.22: Ozone reactor set-up

Fenton's reagent experiment

A jar test apparatus model JLT6 (Velp Scientifiza, the Netherlands) was used in the Fenton's reagent experiments for the determination of the optimal pH, dosage of H_2O_2, and dosage of catalyst (Fe^{2+}). The jar test set-up used was the same as in the coagulation experiments. The set-up is presented in Figure 3.11.

Chemicals

The chemicals used in the experiments are pure grade and were obtained from Merck:

- Hydrogen peroxide 30% (H_2O_2) was used in Fenton's reagent, and in the ozone experiments.
- Ferrous sulfate ($FeSO_4.7H_2O$) was used in Fenton's reagent experiments.
- $Na_2S_2O_3$ and KI were used in the determination of the ozone concentration by titration.
- Na_2CO_3 and NaCl were used to assess the effect of scavengers in AOPs.
- H_2SO_4 or NaOH solutions made from concentrated H_2SO_4 (95-98%) or NaOH (98%) pellets and diluted with demineralized water to obtain the desired concentration of 5-10%. These were used for pH adjustment.

Analytical methods

The analyses were performed according to Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

The COD was measured with the closed reflux, titrimetric method, five types of COD were determined as follows:

- Well mixed total (raw) wastewater samples were used for measuring the total COD (COD_{total}).
- The supernatant of the raw wastewater after filtration with pore size of 1.2 µm was used as sample for the measurement of the particulate COD (COD_{part}).
- The supernatant after filtration with pore size of 0.45 µm was used for measuring the dissolved COD (COD_{dis}).
- The suspended solids COD (COD_{ss}) and colloidal COD (COD_{col}) were calculated as follows:
  $COD_{ss} = COD_{total} – COD_{part}$;
  $COD_{col} = COD_{part} - COD_{dis}$.
- BOD: 5-day BOD test at 20^0C.

Alkalinity was determined by titration with a standard acid solution.

Color intensity of a Vietnamese wastewater was measured with a spectrophotometer (Hach GENESYS*20) at a wavelength of 455 nm. The color is expressed in Pt-Co units. For wastewater of the UCO textile factory, Belgium, the color intensity was determined by scanning for the best absorbance within wavelength range of 200 to 700 nm with a UV-vis spectrophotometer. The dominant wavelength for that wastewater was 616 nm. For determining the color intensity of artificial wastewater from a recipe of the GVA textile Company in Aalten, the Netherlands the same procedure was performed. The dominant wavelength was 416 nm.

Turbidity was measured with a spectrophotometer (Hach GENESYS*20) at a wavelength of 450 nm, and is expressed in FAU (Formazin Attenuation Unit).
Residual hydrogen peroxide (0.1 - 6%) was determined with the iodometric titration method or with a “Nanocolor Peroxid 2” test kit. The principle of the iodometric titration method is that H_2O_2 oxidizes iodide to iodine in the presence of acid and molybdate as a catalyst. The formed iodine is titrated with a standard thiosulfate solution, with starch as an indicator. The “Nanocolor Peroxid 2” kit uses change in color intensity, measured with a spectrophotometer, as a measure for the amount of H_2O_2.

The ozone concentration of samples was monitored by means of a Varian DMS 100 spectrophotometer, at a wavelength of 259 nm. The ozone concentration was also determined with the iodide method (KI method). In this method the ozone oxidizes iodide to iodine in an acid environment (pH=2). The formed iodine is titrated with a standard thiosulfate solution, with starch as an indicator.

The pH was determined with a pH meter model MP220, manufactured by Mettler Toledo – Switzerland, which measures between pH 0 and 14 with accuracy ±0.01.
The electrical conductivity (EC) was measured with a conductivity meter model Sension 5 manufactured by Hach, USA, with a range of 0 – 1999 µS/cm.
The temperature was measured with a thermometer (0-100^0C).

Type of wastewaters

The experiments were performed with textile wastewaters from three sources. The first was collected from the 28 Company-Agtex in Vietnam. The composition of these wastewaters is mentioned in section 3.1.2. The second wastewater was obtained from the UCO textile factory, Belgium. The last one, an artificial wastewater, was prepared according to a recipe of the GVA textile Company in Aalten, the Netherlands. This artificial wastewater was used to study the effects of salts and particles on the performance of AOPs. Table 3.3 and 3.4 present composition and some of the characteristics of wastewater from dyeing process of the UCO textile factory and artificial wastewater of GVA textile Company. The artificial wastewater includes a reactive dye -blue navy- (16.3 mg /L), commercial name RB 171 reactive dye, and auxiliary chemicals such as sodium chloride (20 g/L), sodium carbonate (5 g/L), and lubic-Co (0.6 ml/L). Lubic Co is the source of the suspended solids in the wastewater. As can be seen in Table 3.3 the concentration of suspended solids in the sample with reactive dye, salts and lubic-Co was 290 mg/L while the concentration of the suspended solids in the two remaining samples was 0 mg/L. In addition, Lubic-Co is the main the cause of COD in the artificial wastewater samples. The reactive dye and lubic-Co were supplied by the Aalten textile Company. The dosage of used dye in experiments was calculated using the typical fixation percentage of 70% for a reactive dye and 30% the dye was discharged into the wastewater. The other chemicals were added following a recipe for a real dyeing batch.

Table 3.3: Some characteristics of artificial wastewater of the GVA textile Company, the Netherlands

Type of artificial wastewater	Characteristics			
	Absorbance at wavelength 416 nm	pH -	COD mg O_2/L	SS mg/L
Only reactive dye: 16.3 mg/L	0.301	5.1	23	0
Reactive dye: 16.3 mg/L Salts: 20 g NaCl/L and 5 g Na_2CO_3/L	0.317	11.2	47	0
Reactive dye: 16.3 mg/L Salts: 20 g NaCl and 5g Na_2CO_3/L Lubic-Co: 0.6 ml/L	0.347	11.2	395	290

Variation in the dyeing wastewater quality depends on type of dye used and production capacity. The dyeing process wastewater of the UCO textile factory (Belgium) had mostly a dark color like dark blue and black. The color was the main pollutant of the wastewater generated from the dyeing process. The absorbance of this sample was 2.85 at wavelength of 616 nm. The results presented in Table 3.4 show that the ratio of BOD/COD was very low at around 4%. The pH of sample was slightly acidic.

Table 3.4: Dyeing process wastewater composition, using acid dye (UCO textile factory, Belgium)

Parameters	Unit	Results
pH	-	4.6
Absorbance (616 nm)	nm	2.85
SS	mg/L	530
COD_{total}	mg O_2/L	6,380
COD_{ss}	mg O_2/L	570
COD_{col}	mg O_2/L	120
COD_{dis}	mg O_2/L	5,690
BOD	mg O_2/L	250
Chloride	mg/L	1,040
N-NH_4^+	mg/L	5.14
N-NO_2^-	mg/L	0.30
N-NO_3^-	mg/L	0.30
P-PO_4^{3-}	mg/L	4.03

Source: Bisschops and Spanjers (2002)

O_3 experiments

One liter of raw wastewater was used for each of the experiments. The gas phase and wastewater were mixed by a magnetic stirrer. In this study, the effect of ozone dosages between 20 and 600 mg/L was investigated at the original pH of the wastewater. Both the ingoing and outgoing ozone concentration were determined to quantify the ozone consumption during the experiment. In the KI method the residual ozone was absorbed in a 2% potassium iodide solution (KI). Samples of the treated wastewater were collected at the regular time intervals of 5, 30, 60, 120, and 240 minutes for the determination of pH, color, turbidity, alkalinity, and conductivity. The COD was only determined at optimal conditions. The pH was measured continuously during the experiment. The influent and effluent from some experiments were centrifuged at a speed of 4,000 rpm to remove particles. The supernatant was used for analysis.

O_3/H_2O_2 experiments

Oxidation by O_3/H_2O_2 was performed in a similar way as in the ozone experiments. Two experiments were carried out at optimal ozone concentration and at different hydrogen peroxide concentrations. The hydrogen peroxide concentration was varied between 140 to 280 mg/L. After the ozone generator was turned on, the experiments were started by injecting 0.425 μL or 0.850 μL of 30% hydrogen peroxide solution into the reactor. The total reaction time of each experiment was about 240 minutes. At regular time intervals of 5, 30, 60, 120, and 240 minutes samples were collected to determine the pH, color, suspended solids, residual hydrogen peroxide, and COD.

Fenton's reagent experiments

The experiments with Fenton's reagent were carried out using the jar test apparatus. Six beakers of volume 1,000 mL with 500 mL of wastewater per beaker were used for all experiments. The dosages of oxidant and pH adjustment solutions (H_2SO_4 or NaOH) were added into the wastewater simultaneously. The jar test was conducted with 1 minute rapid mixing at 100 rpm, followed by 30 min slow mixing at 30 rpm to allow completion of the reaction. Then the samples were left to settle for 30 minutes before the supernatant was collected for the determination of the pH, color, turbidity, EC, and COD. The complete time period of the assay was about 60 minutes.

3.4.3 Results and discussion

Effects of salts, particles on the O_3 process efficiency for treating artificial wastewater of the Aalten textile company, the Netherlands

The wastewater characteristics are listed in Table 3.3. For artificial wastewater containing dye, the absorbance of the sample slightly increased after addition of NaCl, Na_2CO_3, and lubic-Co compared to the sample containing only reactive dye. The main increase of absorbance came from adding lubic-Co. The absorbance of only reactive dye in the sample was 0.301, 0.317 after adding salts, and 0.347 after adding lubic-Co.

The absorbance of only reactive dye in the sample was 0.301, 0.327 after adding salts, and 0.347 after adding lubic-Co. Results showed that reactive dye (RB 171) did not cause a high COD in the wastewater (23 mg O_2/L). The high COD was usually due to auxiliary chemicals like lubic-Co: 395 mg O_2/L (wastewater containing reactive dye, salts and lubic-Co). In Figure 3.23 the color intensity (absorbance) of the wastewaters is plotted against the ozone dosage for the artificial wastewater with only reactive dye, with reactive dye and salts, and with reactive dye, salt and lubic-Co. From this figure the effect of salts and lubic-Co on the color removal in the wastewater by ozonation can be derived. Although the experiments with only reactive dye and reactive dye plus salts were performed at different pHs, results indicate that complete decolorization of the wastewaters occurred within 20 minutes. The absorbance decreased from 0.500 to 0.055 (with an absorbance of 0.055 the wastewater was almost colorless). The explanation might be that the mechanism of the decolorization in these experiments occurred due to direct attack of the dye molecules by molecular ozone for the wastewater containing only reactive dye (pH of 5.1), and indirectly by hydroxyl radicals for the wastewater containing reactive dye & salts (pH 11.2). This proves that sodium chloride and sodium carbonate did hardly affect the ozonation process. These results are in agreement with the results found by Schmelling 1997; Sotelo 1989; Hoigne' 1998; Liao 2001; Tanaka 2002, and Boncz 2002.

However, the complete decolorization of artificial wastewater containing reactive dye, salts, and lubic-Co was about 240 minutes. This shows that particles (expressed in terms of lubic-Co) had a large effect on time and dosage of ozone needed for color removal. Instead of the 20 minutes with dosage of 11.3 mg O_3/L needed for complete decolorization (absorbance $\approx$0.06) of the reactive dye and reactive dye & salts samples, the sample containing reactive dye, salts and lubic-Co took 240 minutes with dosage of 121.2 mg O_3/L to obtain a final absorbance of 0.10.

Although the ozonation process had a treatment efficiency of 99 % in terms of color removal, the COD appeared to be unaffected. The COD removal efficiency was 11% for wastewater that contained reactive dye & salts, 18% for wastewater containing dye, salts & lubic-Co, and 21% for wastewater with only dye. In order to completely remove COD with ozone, a large amount of oxidant is needed. This is very expensive and regarded unfeasible. Lubic-Co is the source of the suspended (colloidal) particles in wastewater. These particles can not be removed by centrifugation. Figure 3.24 shows that the absorbance behavior of wastewater samples containing reactive dye, salts, and lubic-Co did not change with centrifugation. The lubic-Co colloidal particles inhibited the contact between ozone and soluble pollutants and consumed (partially) ozone. This explains why the wastewater containing dye, salts, and lubic-Co took more than 4 hours for complete decolorization in comparison with the 20 minutes for the wastewater without lubic-Co.

During the ozonation experiment, the pH of the wastewater with only reactive dye changed considerably from 5.1 to 3.7 within the 20 minutes reaction time. This was not the case for the wastewater containing reactive dye & salts and reactive dye, salts & lubic-Co. The pH values of these wastewaters were more or less the same (from 11.2 down to 11.15) after 240 minutes reaction time. The reason for that is that the acids generated during the experiments were neutralized by the buffering effect of the salts present in reactive dye & salts and reactive dye, salts & lubic-Co wastewater. This result shows that the ozonation process causes a decrease pH of unbuffered wastewater.

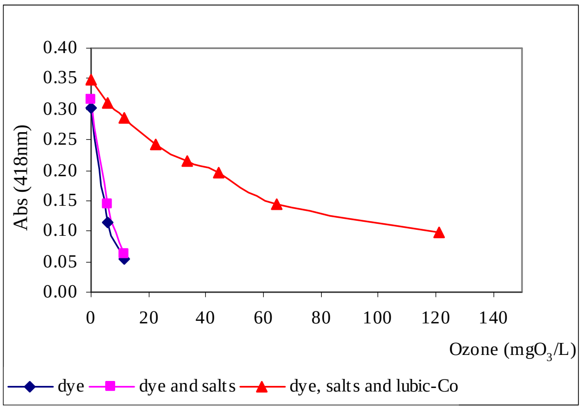


Figure 3.23: Effect of ozonation dosages (≈ ozonation time) on the color intensity of artificial wastewaters containing reactive dyes, reactive dyes & salts or reactive dyes & salt & lubic-Co

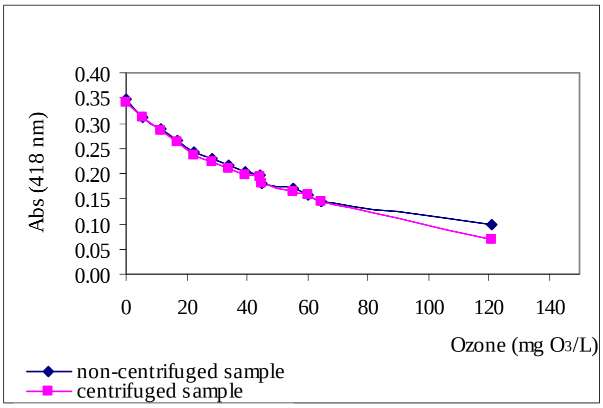


Figure 3.24: Effect of ozonation dosages (≈ ozonation time) on the color intensity of centrifuged and non-centrifuged artificial wastewaters containing reactive dyes & salts & lubic-Co

O_3/H_2O_2 process for treating artificial wastewater of the Aalten textile company, the Netherlands

In Figure 3.25 the effect of ozonation dosage (proportional to the ozonation time) on the color intensity of artificial wastewaters containing reactive dyes, salts, and lubic-Co is illustrated. Parameter is the added amount of H_2O_2. From the figure it will be clear that the color intensity of the wastewater is much more and faster reduced using only O_3 than with O_3/H_2O_2. The efficiency of the process with O_3 and H_2O_2 hardly changed even when the H_2O_2 dosage was increased two times. Hoigne' et al. (1998) states that when hydrogen peroxide is added to the solution (wastewater) it may improve the solubility of the ozone in the liquid phase, and consequently improve the conversion of ozone into radicals resulting in an increase of the efficiency. Figure 3.26(a) and (b) depict the outgoing, ingoing and consumption of ozone in the absence and presence of hydrogen peroxide for artificial wastewater containing reactive dye, salts, and lubic-Co at a pH value of 12. Results indicate that the mass transfer of the ozone in the liquid phase was increased when H_2O_2 was present, since the concentration of the outgoing ozone is almost zero during the experimental time of 240 minutes. The obtained results prove that adding H_2O_2 improves the solubility of the ozone in the liquid phase. Although consumption of ozone in the O_3/H_2O_2 experiment increased, the color removal efficiency decreased. This decreased efficiency can be explained by the destruction of hydroxyl radicals by the excess of H_2O_2. The residual H_2O_2 was 5.9 when 140 mg/L H_2O_2 was applied and 13.9 mg/L for a dosage of 280 mg/L. The H_2O_2 can act as a scavenger following the equation:

$OH\bullet + H_2O_2 \rightarrow H_2O + HO_2\bullet$ (Walling 1975)

This experiment demonstrated that there is probably an optimum ratio of $H_2O_2:O_3$ and this optimal ratio of $H_2O_2:O_3$ has to be determined in practice for each wastewater. The pH hardly changed during the experiment (pH 11.2) because the generated acid products during the treatment process were buffered by the high concentrations of Na_2CO_3 in the sample. The ozone remains in the favorable pH range for effective degradation of the wastewater.

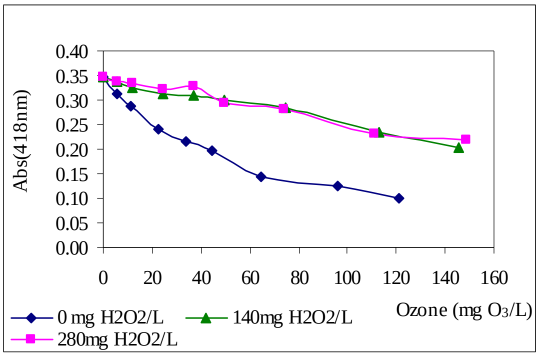
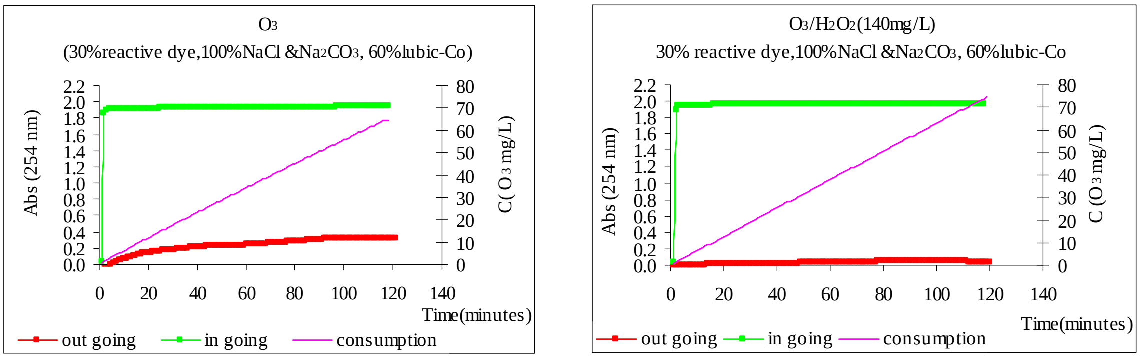


Figure 3.25: Effect of ozonation dosage (≈ ozonation time) on the color intensity of artificial wastewaters containing reactive dyes, salts, and lubic-Co without and with 140 or 280 mg H_2O_2/L



(a) (b)

Figure 3.26: Consumption of ozone C (mg O3/L) and absorbance of ozone at wavelength 254 nm applying (a) O_3 or (b) O_3/H_2O_2 for artificial wastewater containing reactive dyes & salts & lubic-Co

Table 3.5 summaries the COD, BOD and suspended solids concentrations before and after ozonation of the artificial wastewaters. Total COD reduced unsignificantly in both experiments. There was a conversion COD_{ss} and COD_{col} into COD_{dis} resulting in a decrease of the COD_{ss} and COD_{col} and an increase in COD_{dis}. The suspended solids concentration increased due to the formation of Na_2CO_3 precipitate. Moreover the oxidation process using O_3 or O_3/H_2O_2 could not or hardly improve the biodegradability of artificial wastewaters. On the contrary, results of Selcuk and Meric (2006) and Mattioli et al. (2002) showed that a combination of O_3/H_2O_2 could improve color removal and biodegradability of effluents. Therefore an experiment was performed only applying ozone (Table 3.5).

Table 3.5: COD, BOD and suspended solids concentrations before and after ozonation for artificial wastewater

Parameters	Unit	Only reactive dye	Reactive dye, salts and lubic-Co Before O_3 treatment	Reactive dye, salts and lubic-co After O_3 treatment	After O_3/H_2O_2 treatment
COD_{ss}	mg O_2/L	-	15	0	0
COD_{col}	mg O_2/L	-	255	150	159
COD_{dis}	mg O_2/L	22	205	291	287
COD_{total}	mg O_2/L	22	475	441	446
BOD	mg O_2/L	-	320	320	255
SS	mg/L	0	290	356	376

O_3 process for treating real textile wastewater of UCO textile factory, Gent (Belgium)

Acid dyes wastewater

The wastewater from the dyeing & finishing step of the UCO textile factory, Gent (Belgium) had a high color intensity (black), COD and suspended solids content, a low pH of 4.6, and a very low BOD/COD ratio. At the dominant wavelength of 616 nm for measuring the wastewater's color absorbance of the color intensity was 2.85. In Figure 3.27, the effect of ozonation on the color intensity of filtered and not filtered acid dyes wastewaters is shown. Results indicate that the color intensity of the unfiltered wastewater slightly decreases (15%) after 240 minutes ozonation. However, just filtering reduced the absorbance of wastewater sample approximately 85% compared to the unfiltered raw wastewater, from 2.85 down to 0.42. The efficiency of color removal from the filtered wastewater with ozonation increased (efficiency 62% at dosage of 107.6 mg O_3/L, and 83% at dosage of 226 mg O_3/L). However, the corresponding COD reduction was almost negligible for both filtered and not-filtered samples.

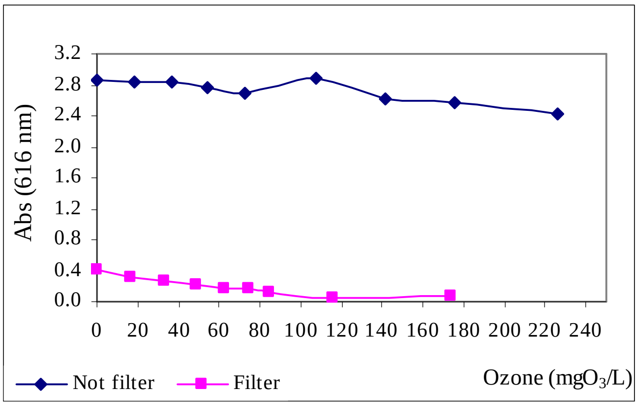


Figure 3.27: Effect of ozone dosage (≈ ozonation time) on the color intensity of filtered (pore size 1.2 µm) and unfiltered acid dye wastewaters of the UCO textile factory, Gent (Belgium)

Disperse & reactive dyes, vat dyes, disperse & acid dyes, and mixed wastewaters from 28 Company-Agtex, Vietnam

Unfiltered wastewater streams

The effects of ozone dosage on the color intensity and removal efficiencies of three unfiltered wastewater streams of the 28 Company-Agtex are shown in Figure 3.28 (a), (b), and (c).

For disperse & reactive dyes wastewater (Figure 3.28 a) the color removal efficiency increased with increased ozone dosage. At 30 mg O_3/L the color intensity dropped from 1,345 to 775 Pt-Co corresponding with a removal efficiency of 43%. At an ozone dosage of 200 mg O_3/L the remaining color was 305 Pt-Co (77% color removal efficiency). Ozonation decreased the pH from 8.6 to 7.9 for the disperse & reactive dyes wastewater and the electrical conductivity hardly changed, even at the highest ozone dosage.

As is shown in Figure 3.28(b), the color removal efficiency of the vat dye wastewater was quite low compared to disperse & reactive dyes wastewater. The highest color removal efficiency achieved was only 27% at a dosage of 200 mg O_3/L. Ozonation decreased the pH from 11 to 9.0 for the vat dyes wastewater and the electrical conductivity of the wastewaters hardly changed, even at the highest ozone dosage.

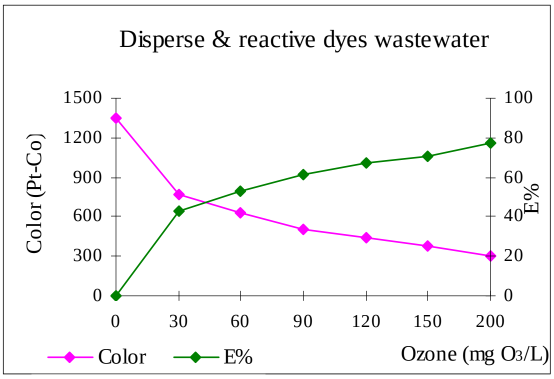
The results of the experiments with disperse & reactive dyes and vat dyes wastewater indicate that even at the highest applied ozone dosage (200 mg O_3/L) the achieved color removal did not meet the Vietnamese discharge regulations regarding color of 50 Pt-Co.

Because the color intensity and COD of the mixed wastewater was higher than that of the disperse & reactive dyes and vat dyes wastewater the applied ozone dosage for the mixed wastewater was increased from 20 to 600 mg O_3/L. The results in Figure 3.29(c) show that with dosages up to 50 mg O_3/L the color intensity hardly changed. Up to 100 mg O_3/L the color removal efficiency was only 5%, at 200 mg O_3/L it was 16%, and reached 57% at a dosage of 600 mg O_3/L. The decrease of the pH was the highest for the mixed wastewater: from 10.8 to 7.0.

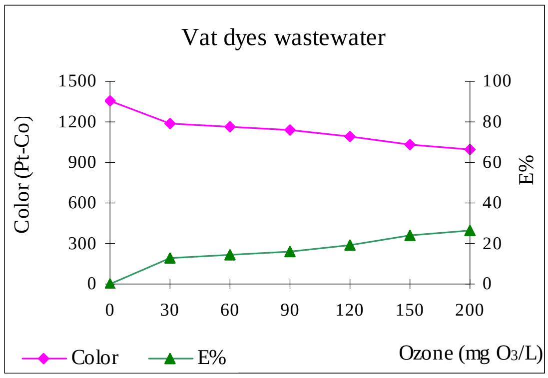
The color removal efficiency of the disperse & reactive dye was higher than that of vat dyes, and mixed wastewater. Complete decolorization of the three wastewater streams with applied maximum amounts of ozone was not achieved probably due to the influence of the initial high color intensity, the presence of particles, or the high COD.

Results show that turbidity decreased with increased the ozone dosage. Some of the dyestuffs in the wastewaters of these experiments were insoluble dyestuffs such as the disperse dyes and vat dyes. They are present in the wastewater as colloidal particles or suspended solids which caused the turbidity of wastewater samples. The results show that very probably the insoluble dyestuffs can be converted to a soluble form by the oxidation process with ozone. This is the reason why the turbidity was decreased for all experiments. Figure 3.29 shows the effect of ozone dosage on the alkalinity of both disperse & reactive dyes and vat dyes wastewaters. The alkalinity of the disperse &

reactive dyes wastewater decreased significantly at an ozone dosage of 30 mg O_3/L, from 400 to 110 mg $CaCO_3$/L, and it remained almost constant as the ozone dosage increased further. There is a relationship between the alkalinity consumption and the highest color removal efficiency (43%) at 30 mg O_3/L and pH 8.6 with disperse & reactive dyes wastewater. The indirect oxidation by radicals can probably break the bond of the choromorphore group in the dyestuff to form acid products such as HCOOH, CH_3COOH, oxalic acid, H_2CO_3, ect. These acids caused the consumption of the alkalinity in the wastewater.



(a)



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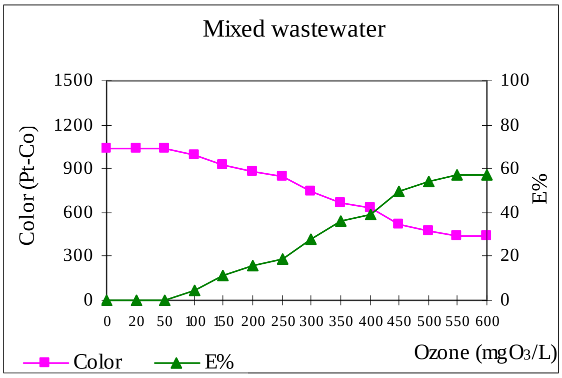


(c)

Figure 3.28 (a), (b), (c): The effect of ozone dosage on color intensity and color removal efficiency E% of three raw unfiltered wastewater streams

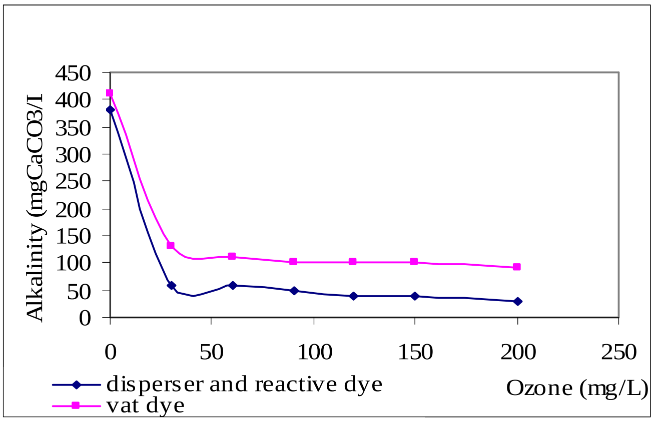


Figure 3.29: The effect of ozone dosage on the alkalinity of two real wastewater streams

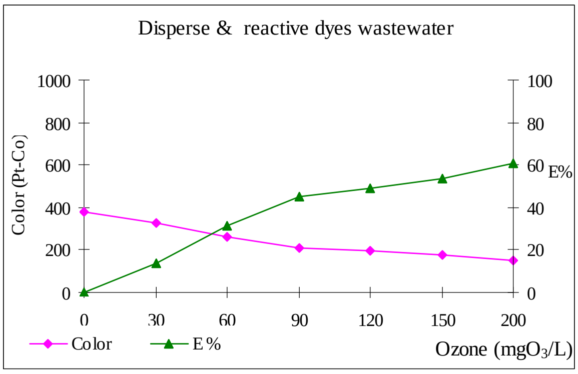
Filtered wastewater streams

To study the effect of particles (suspended solids) on the efficiency of the ozonation process the experiments reported above were repeated, but this time the particles of three wastewater streams were removed by filtration using a sand filter.

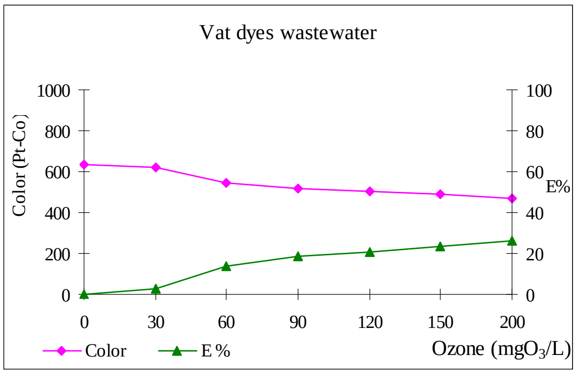
The filtration step by itself reduced also the value of some parameters of the raw wastewater. This was especially true for the color intensity which then decreased 20% for disperse & acid dyes and the mixed wastewater, 53% for vat dyes wastewater and 72% for disperse & reactive dyes wastewater. In comparison with non-filtered and filtered wastewater, the color removal efficiency of filtered wastewater by the ozonation process was the same (26%) for the vat dyes wastewater (with ozone dosages of 200 mg/L) and it increased from 55% (unfiltered) to 72% (filtered) for mixed wastewater (with ozone dosages of 500 mg/L). However, the color removal efficiency decreased for disperse & reactive dyes wastewater from 77% (unfiltered) to 61% (filtered). Figure 3.30 (a), (b), (c), and (d) shows the effect of ozone dosage on the color intensity and color removal efficiency for the filtered wastewaters.

Results show that increased ozone dosage reduces the color intensity of the four filtered wastewaters. Among the four wastewater streams, disperse & acid dyes wastewater had the highest color removal efficiency at a ozone dosage of 200 mg O_3/L, namely 79%, followed by the disperse & reactive dyes wastewater with a color removal efficiency of 61%, which was higher than the color removal efficiency of mixed wastewater (52%) and vat dyes wastewater (26%) at the same ozone dosage (200 mg O_3/L).

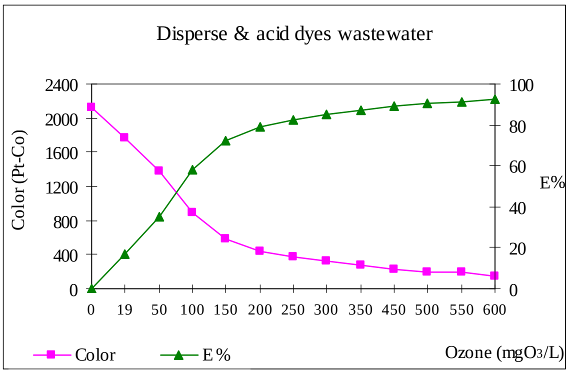
In these experiments with effect of ozone dosage in reduction of the color intensity of four wastewater streams, the pH of all experiments decreased with increasing ozone dose. The change in pH was only substantial with mixed wastewater which pH decreased from 11.4 to 9.0.



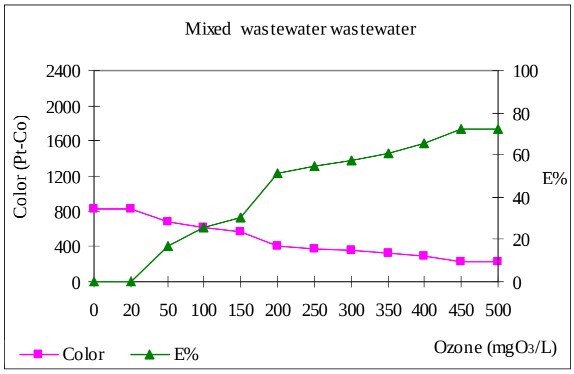
(a)



(b)



(c)



(d)

Figure 3.30: (a), (b), (c), and (d): The effect of ozone dosage on color intensity and removal efficiency of four filtered wastewater streams

The different color removal efficiencies of the four wastewater streams is due to the type of fixation process of the different dyestuffs in the dyeing process resulting in the different concentrations of dyestuffs in the wastewater, pH (the pH of disperse & reactive, vat, mixed and disperse & acid dyes wastewater was 8.1, 8.5, 11.2, and 5.9), and dependent on the characteristics of dyestuffs. The vat dyes wastewater contained insoluble vat dyes as colloidal particles. These colloidal particles could not be removed by the filtration step with the result that the ozone process hardly had an effect on the filtered sample. For disperse & acid dyes wastewater at acid conditions (pH 5.9), ozone should become a direct oxidation agent rather than an indirect one. Direct oxidation by molecular ozone is known to be efficient for decolorization of dyestuffs by breaking the double bond in the dyestuff molecule. At high pH values (disperse & reactive, vat, and mixed wastewater) the indirect oxidation by means of hydroxyl radicals is in general less efficient in color removal of dyestuffs than molecular ozone. The oxidation with molecular ozone is much more selective than oxidation by hydroxyl radicals. Table 3.6 (a) and (b) presents the color removal efficiencies of four filtered and non-filtered wastewater streams with ozone.

Table 3.6 (a): Color removal efficiency (E%) of filtered and non-filtered disperse & reactive dyes and vat dyes wastewater with ozone

	Disperse & reactive dyes wastewater		Vat dyes wastewater	
Ozone	E %		E %	
mg/L	Non- filtered	Filtered	Non- filtered	Filtered
0	0	0	0	0
30	43	14	13	3
60	53	31	14	14
90	62	45	16	19
120	68	49	19	21
150	72	53	24	23
200	77	61	27	26

Table 3.6 (b): Color removal efficiency (E%) of disperse & acid dyes and filtered and non-filtered mixed wastewater with ozone

	Disperse and acid dyes wastewater		Mixed wastewater	
Ozone	E %		E %	
mg/L	Non- filtered *	Filtered	Non- filtered	Filtered
0		0	0	0
20		17	0	0
50		35	0	17
100		58	5	26
150		73	11	31
200		79	16	52
250		83	19	55
300		85	28	58
350		87	36	61
400		88	39	65
450		89	50	72
500		91	54	72
550		91	57	-
600		93	57	-

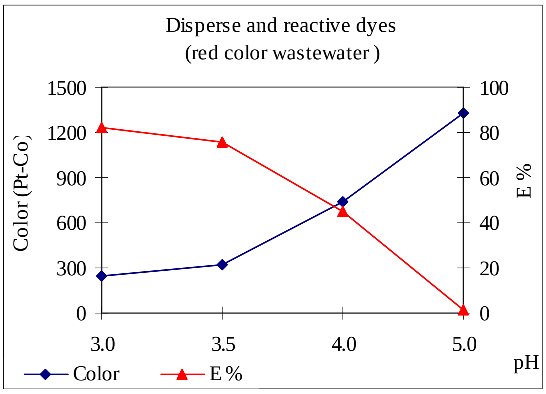
*Note: * Not tested*

The results are in agreement with literature which states that the ozonation process is very effective for treatment of acid and reactive dyes (soluble dyes) while disperse and vat dyes (insoluble dyes) are more resistant (Marmagne et al. 1996; Oliver et al. 2000). In addition, the ozonation process was found to be more efficient in the removal of color compared to removal of COD. This can be explained from the chemical characteristics of the azo-linkage of the dyes. The azo-linkage is the part easiest oxidized within the molecular structure of the dyestuffs, and therefore the transformation of the azo-linkage leading to decolorization, is the preferred reaction. In these cases, the decolorization does not mean the degradation or mineralization of organic dye molecules. Thus, the COD is reduced insignificantly even at a complete decolorization of textile wastewaters (Oliver et al. 2000). The experiments also show that the oxidation process did not improve the degree of the biodegradability expressed as BOD. There was no change in BOD after the ozonation treatment.

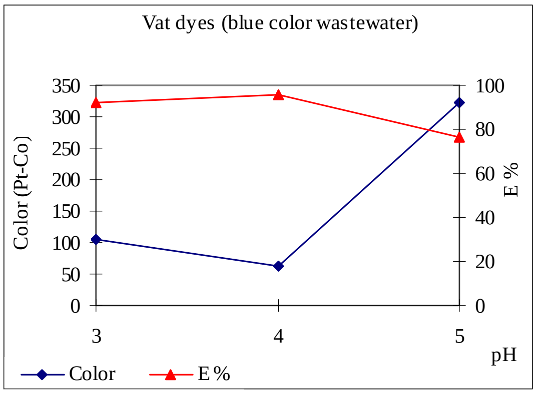
Fenton process for treating four wastewater streams

Optimal pH

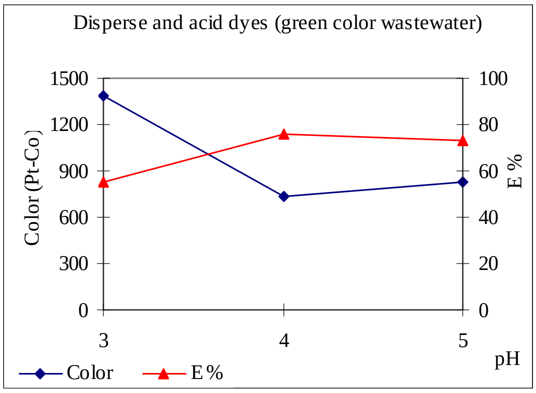
The optimal pH for color removal with Fenton's reagent was determined by varying the pH of the wastewater in the range between pH 2 and 5. Figure 3.31 (a), (b), (c), and (d) show the effect of pH on color intensity and color removal efficiency for four wastewaters. The H_2O_2 and Fe^{2+} dosages differed per wastewater. The applied dosages of H_2O_2 and Fe^{2+} were calculated from the concentration of dyestuff in wastewaters. For disperse & reactive dyes and mixed wastewater the maximum color removal efficiency was obtained at pH 3 as shown in Figure 3.31 (a) and (d). For vat dyes and disperse & acid dyes wastewater the highest color removal efficiency was obtained at pH 4 (figure 3.31 (b), and (c)). These results are in agreement with results found in literature (Solozhenko et al. 1995; Kang and Hwang 2000). The Fenton process usually occurs in an acid environment at a pH <5. Figure 3.32 shows the electric conductivity (EC) as a function of pH in experiments with Fenton's reagent of disperse and reactive dyes, and vat dyes wastewater. The EC of all samples increased with an increasing dosage of H_2SO_4 used for the pH adjustments of the wastewaters. The EC was the highest at pH 2 due to the large amount of used H_2SO_4. The increase of the EC at pH 2 was twice as high compared to the increase of EC at pH of 3, 4, and 5.

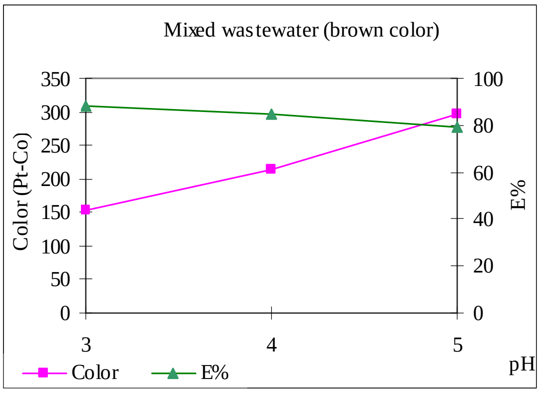


(a) Dosage of 133 mg H_2O_2/L and 20 mg Fe^{2+}/L



(b) Dosage of 133 mg H_2O_2/L and 60 mg Fe^{2+}/L





(c) Dosage of 2,640 mg H_2O_2/L and 324 mg Fe^{2+}/L (d) Dosage of 1,160 mg H_2O_2/L and 222 mg Fe^{2+}/L

Figure 3.31 (a), (b), (c), and (d): The effect of pH on color intensity and color removal efficiency (E%) of the four wastewater streams treated with the Fenton's reagent

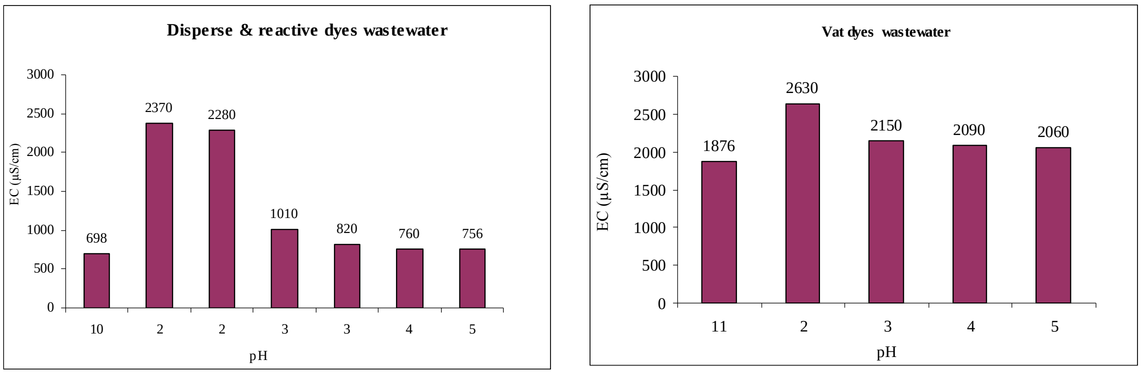


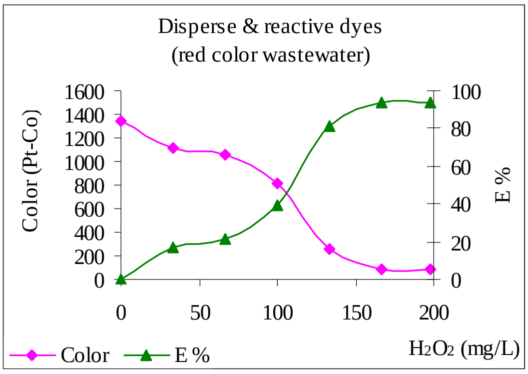
Figure 3.32: The electric conductivity as a function of pH of two wastewater streams

Optimal amount of H_2O_2

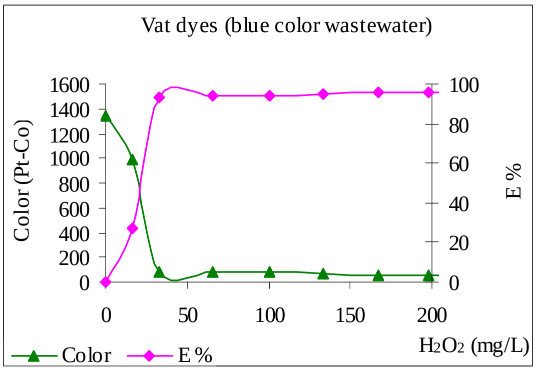
The determination of the optimal H_2O_2 dosage in the application of Fenton's reagent was performed at optimal pH. In Figure 3.33 (a), (b), (c) and (d) the effects of H_2O_2 dosage on the color intensity and color removal efficiency for four wastewater streams is shown. From these figures it is clear that the H_2O_2 dosage reaches a critical point with maximum color and turbidity removal efficiency. Increasing this critical dosage of H_2O_2 did hardly change the efficiencies. Figure 3.33(b) shows that for vat dyes wastewater a color removal efficiency of 94% was obtained at a dosage of 33 mg H_2O_2/L, the remaining color was 85 Pt-Co. The maximum efficiency found for this wastewater was 96%: the remaining color was 50 Pt-Co which meets the color discharge standard of Vietnam. The disperse & reactive dyes wastewater needed a fivefold dosage of H_2O_2(167 mg H_2O_2/L) compared with vat dyes wastewater to achieve the same color removal efficiency of 94% (Figure 3.33 a). The mixed wastewater shows a similar pattern as the vat dyes wastewater, but to achieve a high removal efficiency a high dosage of 200 mg H_2O_2/L was necessary. At this dosage of 200 mg H_2O_2/L the color removal efficiency is 85% and it hardly changes at further increase of the H_2O_2 dosage from 400 to 1,500 mg H_2O_2/L. Disperse & acid dyes wastewater required a very large dosage of H_2O_2 (2,640 mg/L) to reduce the color intensity from 3,100 to 735 Pt-Co, corresponding with a color removal efficiency of 76%. The color removal efficiency hardly improved at further increase of the H_2O_2 dose to 2,900 mg H_2O_2/L. The explanation might be that oxidation by hydroxide radicals is in general less selective than the oxidation by molecular ozone for the color removal of dyestuffs. The disperse & acid dyes wastewater contains a variety of organic compounds from dyeing process and finishing including dyestuffs and other compounds which cause a high COD concentration and color intensity in the effluent. In reaction with Fenton's, the reagent amount of formed hydroxide radicals is not sufficient to oxidize most of the compounds in the wastewater and the hydroxide radicals can not selectively oxidize dyestuffs. The result is that a high color intensity remained after oxidation process.

At the end of the experiments, executed at optimal conditions, the residual H_2O_2 was determined for each wastewater stream. The residual H_2O_2 was 11.9 mg/L for the disperse & reactive dyes wastewater, 11.1 mg/L for the vat dyes wastewater, 25 mg/L for the disperse & acid dyes wastewater, and 0.01 mg/L for the mixed wastewater.

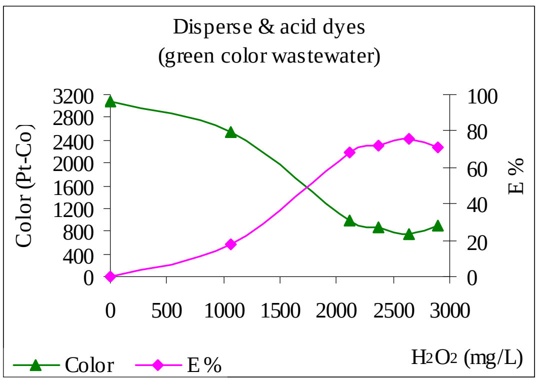
In brief, when the H_2O_2 dosage has achieved a critical concentration, further increasing of the H_2O_2 dosage hardly affects the efficiency. The results demonstrate that the type of used dyestuffs in the wastewater plays a crucial role in the consumption of H_2O_2.



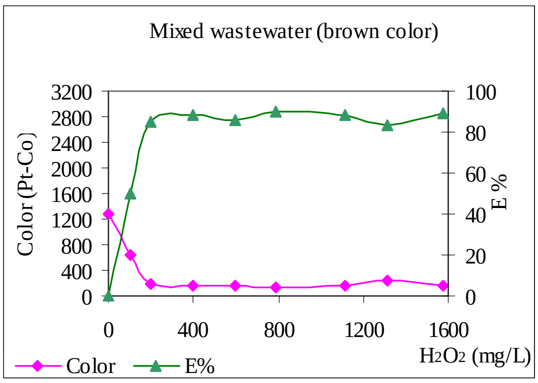
(a) pH 3 and 20 mg Fe^{2+}/L dosage



(b) pH 4 and 60 mg Fe^{2+}/L dosage



(c) pH 4 and 325 mg Fe^{2+}/L dosage



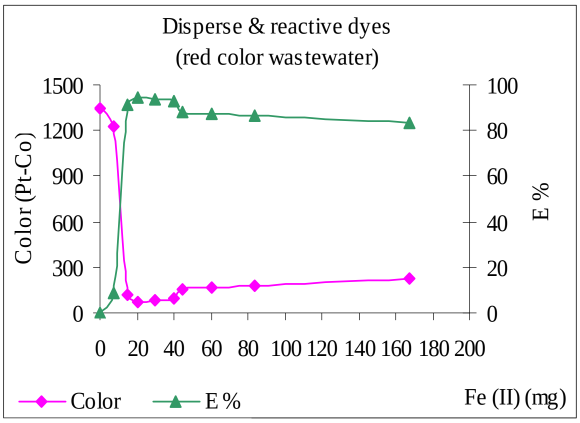
(d) pH 3 and 222 mg Fe^{2+}/L dosage

Figure 3.33: The effect of H_2O_2 dosage on the color intensity and color removal efficiency at set Fe^{2+} concentrations and pH for four wastewater streams

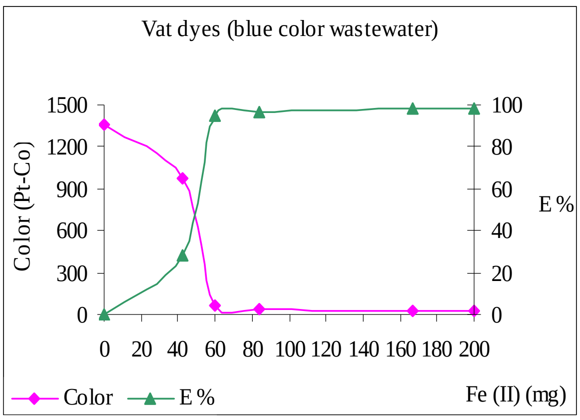
Optimal Fe (II) dose

The determination of the optimal ferrous dosage was performed at optimal pH and H_2O_2 dosage. Figure 3.34 (a), (b), (c) and (d) shows the effect of Fe^{2+} dosage on the color intensity and color removal efficiency of the four wastewater streams. Results of the disperse & reactive dyes wastewater are presented in Figure 3.34 (a). Increasing the ferrous dosage from 7.6 to 20 mg Fe^{2+}/L decreased the color and turbidity, and achieved a maximum color removal efficiency of 94% at 20 mg Fe^{2+}/L (color intensity 75 Pt-Co). The color increased slightly as the ferrous dose was increased further, because the excess of Fe^{2+} can increase the color intensity. For vat dye wastewater (Figure 3.34 (b)) increasing the ferrous dosage decreased the color intensity and turbidity also: a color removal efficiency of 95% was obtained at 60 mg Fe^{2+}/L (70 Pt-Co). The maximum color removal efficiency was 98% (45 Pt-Co). For the disperse & acid dyes wastewater increasing ferrous dosage also enhanced the color and turbidity removal efficiency (Figure 3.34 (c)). In order to reduce the color intensity from 3,100 to 595 Pt-Co, being the highest efficiency (81%) for this wastewater, a ferrous dosage of 350 mg Fe^{2+}/L was used. Although achieved color removal efficiency was very high at 81 %, the color intensity was still far away from meeting the discharge standard for color (50 Pt-Co). For mixed wastewater the color intensity decreased slightly at an iron dosage of 40 mg Fe^{2+}/L due to the formation of fine flocs. These flocs caused increase of color, as increasing the ferrous dosage from 80-111 mg Fe^{2+}/L the color intensity decreased and achieved a maximum color removal efficiency of 84% (145 Pt-Co at a dosage of 111 mg Fe^{2+}/L). Increasing the ferrous dosage further did enhance the color removal efficiency but not much: the color removal efficiency was 90% (145 Pt-Co) at a dosage of 141 mg Fe^{2+}/L. The experiments show that the ferrous dosage affects decolorization.

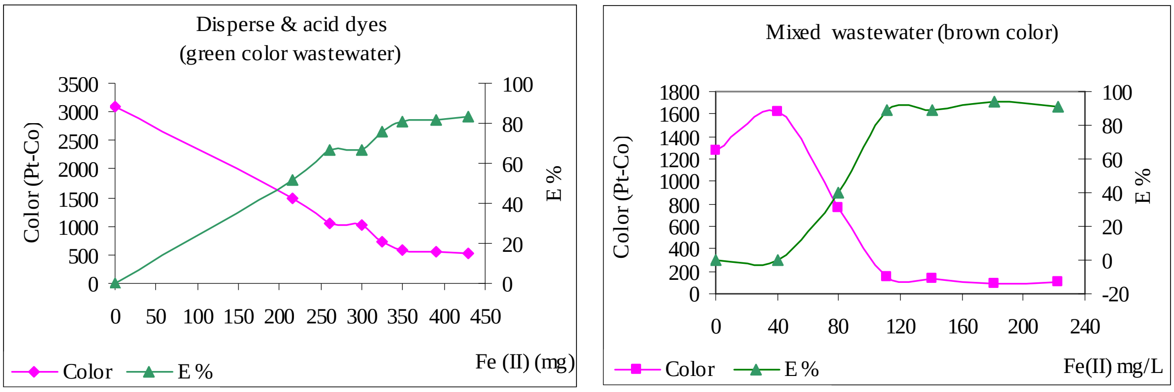
When the ferrous dosage reaches a critical level further increase has hardly any effect on the color removal efficiency. The EC of disperse & reactive dyes and vat dyes wastewater increased with increasing ferrous dosage as can be seen from Figure 3.35. This was also the case for mixed wastewater.



(a) pH 3 and 167 mg H_2O_2/L dosage



(b) pH 4 and 167 mg H_2O_2 /L dosage



(c) pH of 4 and 2640 mg H_2O_2/L dosage (d) pH 3 and 788 mg H_2O_2/L dosage

Figure 3.34: The effect of Fe^{2+} dosage on the color intensity and color removal efficiency at optimal H_2O_2 dosage and pH for four wastewater streams

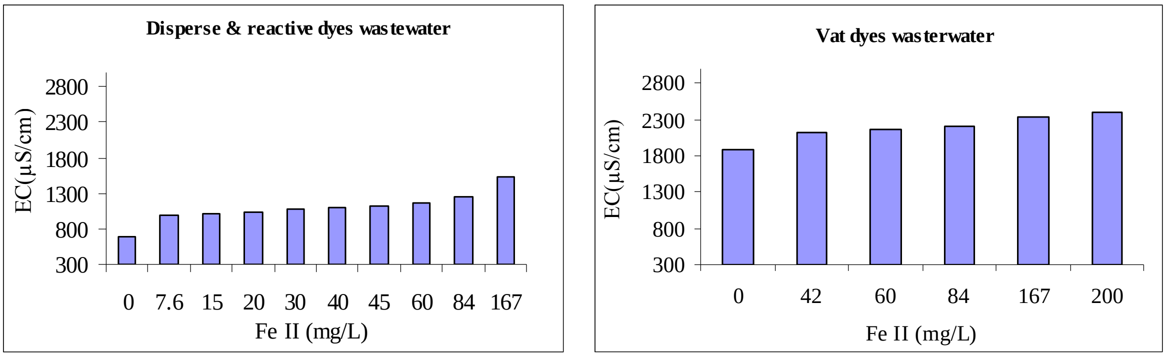


Figure 3.35: EC as a function of Fe^{2+} dosage for disperse & reactive dyes and vat dyes wastewater

At optimal conditions the achieved COD removal efficiency ranged from 52 to 90%. Treated vat dyes wastewater showed the highest COD removal efficiency of 90%. The COD decreased from 290 to 29 mg O_2/L. The disperse & reactive dyes wastewater reached a COD removal efficiency of 88%: the COD decreased from 320 to 40 mg O_2/L. The mixed wastewater reached a COD removal efficiency of 79%: the COD decreased from 320 to 40 mg O_2 /L. The disperse & acid dyes wastewater reached a COD removal efficiency of 52%: the COD decreased from 4060 to 1967 mg O_2 /L, at a large dosage H_2O_2 and Fe^{2+}.

The residual iron concentration was analyzed after each experiment for three wastewater streams at optimal conditions. The total residual iron concentration was 0.35 for vat dyes, 0.91 for disperse & reactive dyes, and 4.69mg Fe_{total} /L for mixed wastewater in which Fe^{3+} made up more than 50% of the total iron. These result shows that if optimal conditions are applied, an additional removal step for residual iron is not necessary because the iron concentration was under the Vietnamese discharge standard for total iron (5 mg Fe/L).

Comparing the effectiveness of Fenton's reagent and coagulation with $FeSO_4$ on the removal efficiencies, the Fenton's reagent proved to be better in terms of color and COD removal for the four wastewater streams. The reason is that the reaction of Fenton's reagent induces simultaneous both processes: the oxidation process with the formation of hydroxyl radicals and the coagulation process with the formed $Fe(OH)_3$.

Table 3.7 shows for the three types of investigated wastewaters the results of the final color intensity and COD after treatment with the Fenton's reagent and after the coagulation process with $FeSO_4$.

Table 3.7: A comparison of removal efficiencies of the Fenton's reagent process and the coagulation process

Parameters	Fenton's reagent			Coagulation with $FeSO_4$		
	Reactive & disperse dyes	Vat dyes	Disperse & acid dyes	Reactive & disperse dyes	Vat dyes	Disperse & acid dyes
Color (Pt-Co)	75	26	595	300	75	990
COD (mg O_2/L)	40	29	1670	52	74	1720
Amount chemicals H_2O_2 (mg/L) $FeSO_4$ (mg/L)	 167 100	 167 100	 2, 640 1730	 0 800	 0 1,600	 0 5,000

Comparison of the color removal efficiencies of the Fenton's reagent process and the ozone oxidation process for the different wastewaters is shown in Figure 3.36. It shows that the Fenton's reagent process gives a better efficiency. This can be explained by the mechanism of the Fenton's reaction. Both the oxidation and coagulation process occur simultaneously using Fenton's reagent. The effect is that colloidal particles can be removed by the coagulation process. In the ozone oxidation process no specific mechanisms is induced for the removal of colloidal particles present in mixed wastewater, vat dyes wastewater, and acid dyes wastewater. The result is a low removal efficiency.

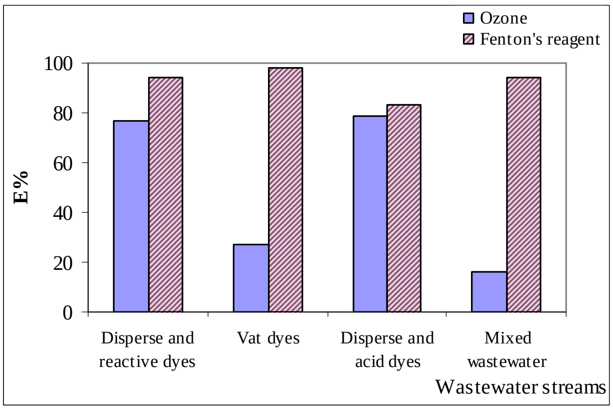
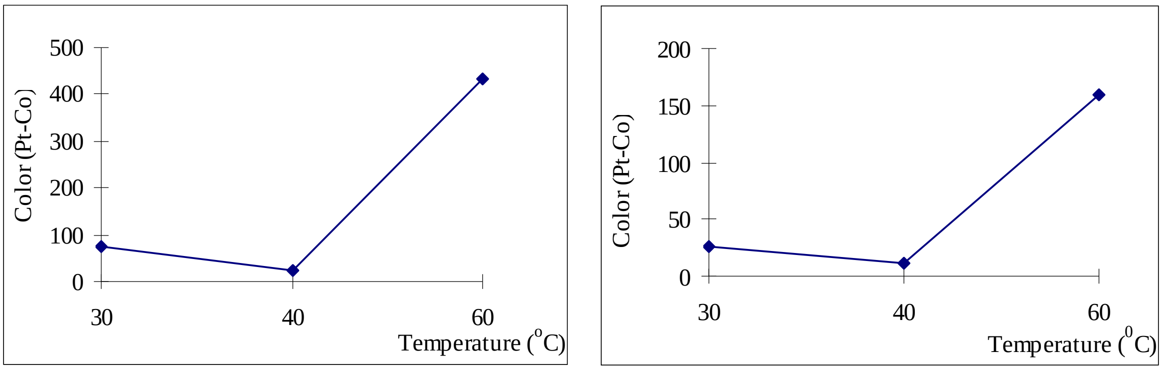


Figure 3.36: The color removal efficiency (E%) of the Fenton's reagent and ozone process for four wastewaters

Temperature effect on the Fenton's reagent process

To determine the effect of temperature on the performance of the Fenton's reagent process, disperse & reactive dyes and vat dyes wastewater were investigated. Three temperatures were investigated: 30, 40 and 60^{0}C. The results are shown in Figure 3.37(a) and (b). With both wastewater streams the optimal temperature at which the removal efficiency of color was the highest was 40^{0}C. The remaining color of disperse & reactive dyes wastewater was 25 Pt-Co at 40^{0}C. The color intensity increased to 435 at 60^{0}C. Similar results were obtained for the vat dyes wastewater. The remaining color at 40^{0}C was 12 Pt-Co. The color intensity increased to 159 Pt-Co at 60^{0}C. The explanation is that with increasing temperature from 30^{0}C to 40^{0}C the reaction rate can increase. The H_2O_2 almost completely reacted to form hydroxyl radicals and no residual H_2O_2 was detected after the reaction at 40^{0}C and 60^{0}C. The experiment at 30^{0}C showed a residual H_2O_2 concentration of 11.9 mg H_2O_2/L. When the temperature was increased to 60^{0}C a part of the H_2O_2 can decompose to O_2 and H_2O, causing a H_2O_2 deficit, resulting in a lower formation of hydroxyl radicals as well as in an higher remaining iron concentration in comparison with the experiments at a temperature of 30^{0}C and 40^{0}C. These experiments demonstrated that the temperature can affect the color removal efficiency when applying Fenton's reagent. However, these results are not in agreement with literature. According to Sevimli and Kinaci (2002), the effects of temperature on the oxidation by Fenton's reagent was very limited and the color removal efficiency did not change significantly.



(a) Disperse & reactive dyes wastewater (b) Vat dyes wastewater

Figure 3.37 (a) and (b): The effects of temperature on final color intensity at application of the Fenton's process for two types of wastewaters

3.4.4 Conclusions

The AOPs can be a feasibility solution to the problem of decolorizing textile wastewaters. The results obtained from studies with O_3, O_3/H_2O_2, and Fenton's reagent proved that when wastewaters contained a relatively high color concentration (such as disperse & reactive dyes, vat dyes, disperse & acid dyes, acid dyes, and mixed wastewater), the application of the Fenton's reagent process as a pretreatment step was better than the O_3 or O_3/H_2O_2 process in terms of color removal and especially in terms of COD removal. With the application of Fenton's reagent, the coagulation and oxidation process occur simultaneously. Therefore Fenton's reagent seems quite effective for the treatment of soluble and insoluble dyestuffs used in the textile industry. The achieved efficiencies were high for color and COD removal, except for the acid dyes wastewater which had a low COD removal efficiency. These experiments confirmed that with the application of the Fenton's reagent process, the strict standards of color and COD (Color: 50 Pt-Co and COD: 80 mg O_2/L) for wastewaters contaminated with dyestuffs such as vat dyes, and disperse & reactive dyes and for mixed wastewaters can be met.

In this study it was also found that in practice the Fenton's reagent process is economically not feasible when applied as a pre-treatment step for textile wastewaters with a high COD concentration. This was the case with the acid dyes wastewater (COD: 6,380 mg O_2/L) and disperse & acid dyes wastewater (COD: 4,060 mg O_2/L). The treatment process is economically unfeasible due to the considerable amount of H_2O_2 and Fe^{2+} necessary to decolorize these wastewaters. Disadvantage of the use of Fenton's reagent are the large amount of sludge which is generated. However, the quantity of sludge produced from the Fenton's process was less compared to the coagulation process. For example, the amount sludge generated with Fenton's reagent was about 27 ml (after 30 minutes settling) per liter of wastewater and 230 ml/L with the coagulation process with $FeSO_4$ for the vat dyes wastewater. In addition, wastewater treated with Fenton's reagent (pH is about from 3 to 5) needs pH adjustment before discharge into the environment or before a next treatment process is applied. Another disadvantage is that the remaining soluble iron after the Fenton's reagent reaction needs also to be removed to meet the Vietnamese discharge standards. These disadvantages related to the use of Fenton's reagent can be reduced by maintaining optimum dosages to minimize consumption of chemicals by an automatic control system.

The effects of salts concentration (NaCl and Na_2CO_3) on the ozone process found in this study were similar to those in literature, as mentioned by Hoigne' (1998), Tanaka (2002), Boncz (2002). A high concentration of these salts did not affect the decolorization of artificial wastewater or the ozone dosage needed. However, in literature the effect of colloidal particles (suspended solids) on AOPs, especially in the ozone process, has not been considered yet. From literature, it can be observed that insoluble dyes such as vat dye, disperse, and sulphur dye could not be removed efficiently by application of ozone. In general the literature hardly mentions the effect of particles on AOPs. The results of the experimental work show that colloidal particles in wastewater (lubic-Co) in artificial and vat dyes wastewater) affected significantly the consumption of ozone and extended the retention time for reaction. Thus the ozone process efficiency is highly sensitive to wastewaters containing a large amount of particles. The experiment with insoluble vat dyes wastewater demonstrates this clearly. This wastewater showed the highest removal efficiency with the Fenton's reagent process and showed the lowest removal efficiency with the ozone process. The results also show that the decolorization of textile wastewater with the ozonation process was related to the pH. Under acidic conditions direct oxidation by O_3 takes place and the decolorization occurs because the chromophore bond of the dyestuffs is broken by attack of the O_3 molecule. For instance, filtered disperse & acid dyes with an original pH of 5.9 achieved the highest efficiency at the same ozone dose of 200 mg O_3/L in comparison with other filtered dyestuffs wastewaters at alkaline conditions (disperse &

reactive dyes at pH 8.6 and vat dyes wastewater at pH 11). The results showed that the ozonation process had less effect on COD decrease. The COD removal efficiencies were in the range of 5-17%. Similar results were found in literature.
The advantages of the ozone process are that the ozone process did not require any additional chemicals for pH adjustment. Also the electric conductivity hardly changed with the ozone process and there was no sludge formation. As mentioned in chapter 2, the amendment of hydrogen peroxide to the ozonation process may improve mass transfer of the ozone in the liquid phase by an increase of the hydroxyl radicals amount, resulting in an increased decolorization efficiency. However, the experiments indicated that the radical reactions were not effectively promoted by the addition of hydrogen peroxide at high pH (11). In fact the efficiency decreased with the addition of hydrogen peroxide. Hence an optimal ratio of H_2O_2:O_3 exists depending on the composition of the wastewater, which has to be determined in practice for each type wastewater. The experiments described in this chapter showed that temperature affects the efficiency of color removal for AOPs. This is in contrast with literature data. Galindo and Klat (1998) and Masschelein (2002) reported no effect of temperature on the decolorization by AOPs treating textile wastewaters. The experimental work on the effect of temperature in AOPs showed that the Fenton's reagent had the highest color removal efficiency at 40^0C. Textile wastewater usually has a high temperature (40-50^0C), thus application of the Fenton's reagent process as pretreatment step at high temperature is a suitable method, since the wastewater cooling step is unnecessary.

3.5. Costs

The selection of a wastewater treatment process has also to be assessed from an economical point view. Figure 3.38 shows the operational fees of the studied methods.

For disperse & reactive dyes wastewater (Figure 3.38 (a)) the Fenton's reagent was the most optimal treatment method in terms of costs: 0.2 USD/m^3. These costs only include chemicals and energy. The Fenton's reagent was also the most optimal treatment in terms of high color and COD removal efficiency (color intensity in effluent: 75 Pt-Co, COD in effluent: 40 mg O_2/L). The coagulation process also showed a good costs result (0.2-0.3 USD/m^3), however, the color removal efficiency was only 76-79%. In addition, a large amount of sludge was generated with the coagulation process, which will increase the operational costs due to handing and treating the sludge (147 USD/ton sludge). The ozone process has operational costs which are 2.5 times higher compared to the costs of the Fenton's reagent process, and it showed also a lower color removal efficiency.

For the vat dyes wastewater the Fenton's reagent also was the cheapest option. The estimated costs were 0.2 USD/m^3 for a very high removal efficiency of 98% for color and 90% for COD. These two parameters met the Vietnamese discharge standards. The coagulation process of vat dyes wastewater achieved a color and COD removal of 95-96% with operational costs in the range of 0.4-0.5 USD/m^3.

The disperse & acid dyes wastewater which had a high color intensity and a high COD required substantial amounts of chemicals and showed a high energy consumption for all studied treatment methods. This resulted in operational costs of 0.5-0.7 USD/m^3 for the coagulation process and 1.7 USD/m^3 for treatment with Fenton's reagent, and 1.8

USD/m^3 for the ozone process. Although the removal efficiencies with ozone, Fenton's reagent, and the coagulation process were high (ozone: 79%, coagulation: 68-81% (used three coagulants), Fenton: 83%), the color was far from meeting the discharge standards.

For treating the mixed wastewater the coagulation process with aluminum sulfate was the best option in terms of costs: 0.2 USD/m^3, with a high removal efficiency of 95% for color and 81% for COD. The same result of color removal efficiency was obtained with Fenton's reagent, but the 88% COD removal efficiency by the Fenton's reagent process was in general higher than with the coagulation or the ozonation process. Estimated costs are 0.5 USD/m^3 for application of Fenton's reagent. Since the mixed wastewater was comprised of many types of wastewater streams from the manufacturing process and diluted it was easier to treat and needed fewer chemicals.

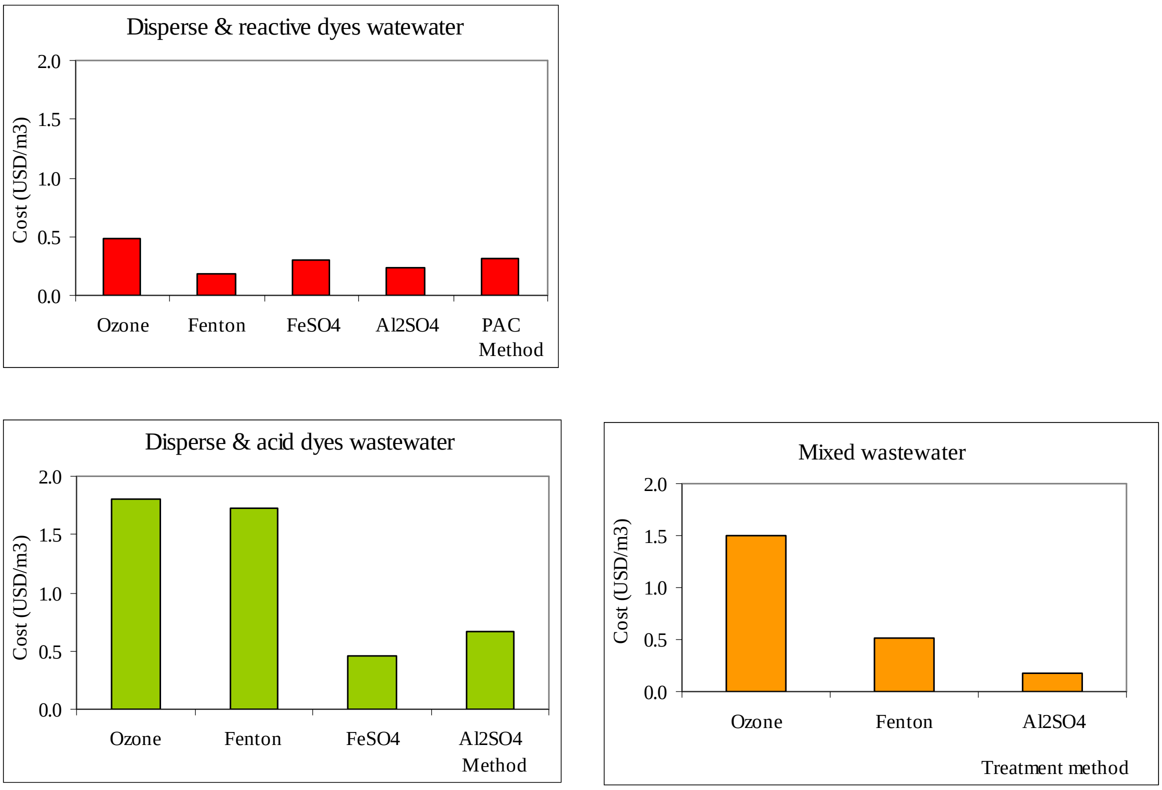


Figure 3.38: Comparison of treatment methods regarding costs of the coagulation processes and AOPs of four wastewaters

3.6. General conclusions of physical/chemical processes

The results of pH change, application of a coagulation step or application of AOPs for the four wastewater streams investigated are summarized in Figure 3.39. The Fenton's reagent is the most effective method for color removal of the four types of wastewater (disperse & reactive dyes, vat dyes, disperse & acid dyes, and mixed wastewater), especially for the vat dyes wastewater. The application of Fenton's reagent at the elevated temperatures of textile wastewater is a promising method for treatment of the main dyestuffs used in the textile industry such as vat, disperse, reactive, and acid dyes.

The Fenton's reagent method is not economically effective with wastewater streams with a very high COD concentration. Thus, applying separate collection of different wastewater streams will result in a higher economic efficiency because biodegradable compounds present in wastewater can be treated separately by a biological technology. This biological technology does not require addition of chemicals like Fenton's reagent, therefore the operational costs might be lower.

Some conclusions can be drawn for the coagulation process for the four types of wastewater streams. The experimental results show that the coagulation process yields high color removal efficiencies. Among the three studied coagulants, aluminum sulfate was the most effective with respect to color removal of the four types of wastewaters. The aluminum sulfate seems a promising coagulant in terms of costs and availability. The insoluble vat and disperse dyes can be completely removed by the coagulation process or by Fenton's reagent. Both the coagulation process and Fenton's reagent proved to be more efficient in removal of color and COD for the textile wastewater containing a mixture of soluble and insoluble dyes. The results also revealed that a part of the soluble dyes can also be removed by the coagulation process due to adsorption in flocs.

Change of only the pH did not cause a destruction of color of dyestuffs. However, the application of pH change is significantly affecting the performance of the coagulation processes and AOPs.

There are some differences between literature and this study regarding the results of ozone treatment. As mentioned in chapter 2 in literature the difference of the color removal efficiencies in a low and high pH environment was limited for the ozone process. However, from our results it is clear that the direct oxidation by molecular ozone is much more selective than the oxidation by hydroxyl radicals. For instance, with a filtered sample of disperse & acid dyes wastewater with an original pH of 5.9 the highest removal efficiency was achieved at the same ozone dose (200 mg O_3/L) compared to disperse & reactive dyes at pH 8.6 and vat dyes wastewater at pH 11.

The study also showed that particles (colloidal particles or suspended solids) affect negatively the ozone process with respect to the required dosage of chemicals and the required treatment time. The ozone process has almost no removal effect for vat dyes wastewater. This study revealed that the ozone process as a pre-treatment step is not suitable for insoluble dyes wastewater streams. If the wastewater contains a high concentration of suspended solids or colloid particles, a filtration or coagulation step has to be applied before applying the ozone process. The ozone process can be applied to treat insoluble dyes such as disperse dyes and vat dyes. However, this will consume a large amount of ozone, because ozone will oxidize insoluble dyes to soluble ones, and then break the chroromphore bonds. The ozonation process as the first step for decolorizing or enhancing biodegradability of raw textile wastewater is therefore not effective.

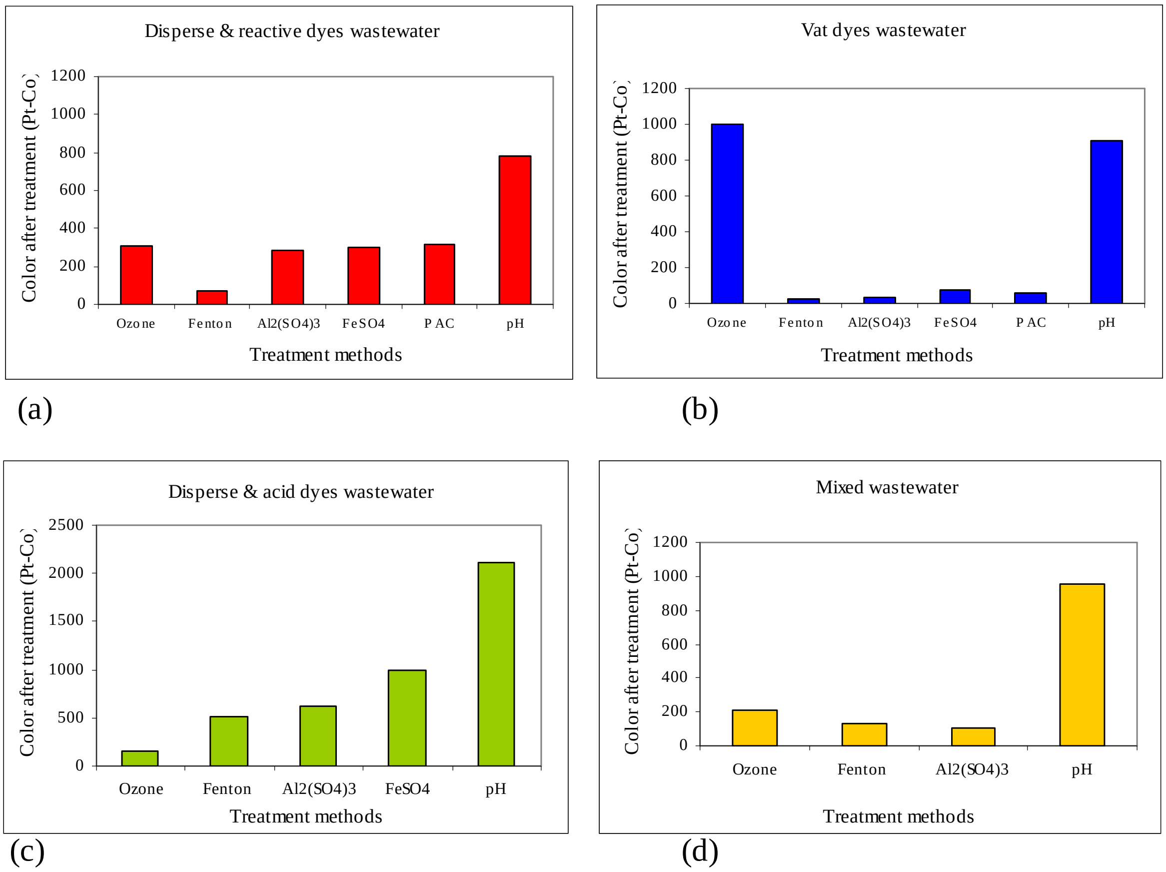


Figure 3.39 Comparison of treatment methods regarding color intensity after the coagulation processes or AOPs of four wastewaters

Chapter 4

Combination of physical, chemical and biological processes: experimental research

4.1 Introduction

The textile industry generates a large volume of wastewater with complex composition. Various organic compounds (sizing and desizing agents), surfactants, bleaching chemicals, different dyestuffs, salts, and many other chemicals can be found in textile wastewater. Difficulties with the treatment of textile wastewater mostly arise with the simultaneous presence of all these compounds in the wastewater. Results of the experimental research (chapter 3) show that physical/chemical processes like pH variation, coagulation, and AOPs, for treatment of textile wastewater have limited success as an individual treatment process. Each of these processes could only remove one or a few types of pollutants from the wastewater with the consequence that the effluents could not meet all the discharge regulations for discharge on surface water. The research also proved that chemical coagulation as a pre-treatment step and an effective process for high strength raw textile wastewaters. The economic feasibility of each process, however, was limited as a result of the relatively high costs of these processes, as was the case when AOPs were applied to achieve complete wastewater COD oxidation. It was also clear from the experiments in chapter 3, that it is better to apply AOPs, especially the ozone process, as a final treatment process or following chemical coagulation.

A survey of over 50 wastewater treatment facilities of textile enterprises in Vietnam shows that in practice only one coagulation step or coagulation in combination with a biological process (activated sludge process) is usually applied as treatment. However, almost none of the produced effluents could meet Vietnamese standards for industrial wastewater discharge (TCVN 5945:2005) for the parameters color and COD. According to Kao et al (2001) wastewater treatment technology (biological and coagulation/flocculation technologies) of 75 textile wastewater treatment facilities in Taiwan currently failed to effectively remove color from wastewater. Almost all these textile enterprises need to install a post treatment like AOPs for a complete color removal. Vandevivere et al. (1998) observed that the coagulation process is wide spread and an effectively process for color removal in textile wastewater. A combination of coagulation and biological processes can sometimes meet the discharge standards. Vandevivere et al. (1998) mentioned that ozone can decolorize most dyestuffs, but is less efficient with non-soluble dyestuffs and high strength raw textile wastewater. Nowadays (chapter 2), the aerobic process is widely used for the removal of COD and a part of the color of textile wastewater.

Other technologies such as adsorption, reverse osmosis, electrochemical treatment are researched on laboratory and pilot scale for textile wastewater treatment. Nevertheless, practical applications of these technologies are limited. From literature it can concluded that textile wastewater treatment currently has problems meeting effluent discharge regulations or to produce effluent fit for reuse at feasible costs. Therefore it is necessary to study an optimal post treatment for application after the coagulation and/or aerobic process.

To achieve this aim, six process combinations were studied: (1) coagulation and Fenton’s reagent; (2) coagulation and ozone; (3) activated sludge and coagulation; (4) activated sludge and ozone/hydroxide peroxide; (5) activated sludge and Fenton’s reagent; (6) activated sludge, coagulation and ozone. From the results of the experimental research, an optimal scheme for textile wastewater treatment technology will be selected based on the technical performance and costs.

4.2 Materials and methods

4.2.1 Equipment

Jar test apparatus

A jar test apparatus, model JLT6 (Velp Scientifiza) was used in the coagulation and Fenton's reagent experiments, to determine:

- Optimal pH;
- Optimal dosage of coagulant;
- Optimal dosage of H_2O_2;
- Optimal dosage of Fe^{2+}.

The specifications of the jar test apparatus are described in the chapter 3, section 3.2.2 (coagulation experiments).

Ozone reactor

In this experiment, the same reactor system was used as in the ozone experiments described in chapter 3, section 3.3.2. The ozone reactor is presented in Figure 3.12. The ozone was generated from dried air with an ozone generator: model Dozomax, with a flow rate of 11.7 L/hr. The capacity of the ozone generator was 1g O_3/hour.

Aerobic reactor

Total volume of reactor was 5 liters; the working volume of the reactor was 3.5 L. The reactor was made of glass. In the activated sludge reactor air was supplied by an air pump (model Resun, made in China) with a capacity of 60 L/min. The air was fed to the reactor through an air diffuser system (pumice stone) installed at the bottom of the reactor. The activated sludge batch reactor is illustrated in Figure 4.1.

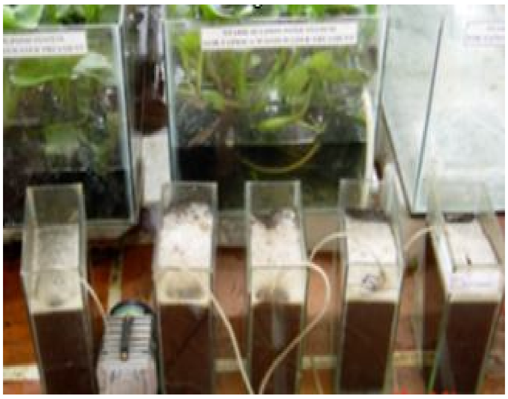


Figure 4.1: Activated sludge batch reactor set-up

4.2.2 Chemicals

- From the results in chapter 3, aluminum sulfate $Al_2(SO_4)_3.18H_2O$ was found the most effective coagulant for color removal, therefore it was also used in the experiments described in this chapter.
- H_2O_2 30% solution and ferrous sulfate $FeSO_4.7H_2O$ were used in Fenton's reagent and the ozone/ H_2O_2 experiments;
- $Na_2S_2O_3$ and KI were used in the determination of the ozone concentration;
- pH adjustments were made with H_2SO_4 or NaOH solutions which were prepared from concentrated acid (H_2SO_4 95-98%) or NaOH (98%) with demineralized water to obtain the desired 5-10% concentration.

The H_2O_2 30%, $FeSO_4.7H_2O$, $Na_2S_2O_3$ and KI were from Merck. H_2SO_4 (95-98%), NaOH (98%) were pure grade and from Guangdong Guanghua chemical factory Co., Ltd, China. The $Al_2(SO_4)_3.18H_2O$ was from Tan Binh chemical company in Vietnam.

4.2.3 Analytical methods

All analytical methods used for the experiments are described in chapter 3 section 3.3.2; with the exception that of the residual hydrogen peroxide and ozone were determined by the iodometric titration method.

4.2.4 Wastewater

In this study, all experiments were performed with real textile wastewater which was obtained from the 28 Company-Agtex located in the GoVap district, Hochiminh City, Vietnam. The scheme of the production process applied in this company together with the used chemicals and dyestuffs is described in section 5.5.2 (chapter 5). The samples were collected from the equalization tank of the wastewater treatment facility. The samples were stored at 4^0C. Table 4.1 presents the composition of the mixed wastewater. The main characteristics of the wastewater are a high pH, high color intensity, and high levels of COD and BOD.

Table 4.1: The composition of mixed wastewater

Parameters	Unit	Results
pH	-	10.9
COD	mg O_2/l	1,200
BOD_5	mg O_2/l	510
Color intensity	Pt-Co	1,390
Turbidity	FAU	123
Absorbance at wavelength		
436 nm		0.401
525 nm		0.244
620 nm		0.180

4.2.5 Experimental procedures

Coagulation/flocculation process with aluminum sulfate

The experiments were performed in six beakers with a volume of 1,000 ml. The jar test equipment holds 6 beakers and each beaker contained 500 ml of wastewater. After the jar test mixer was turned on, the dosages of coagulant and pH adjustments solutions (H_2SO_4) were added to the wastewater at a same time. Based on literature information and practice, instantaneous rapid mixing of metal salts is one important criterion. Typical mixing times for coagulation of colloidal particles are less than 1 minute and sweep floc precipitation is in range of 1-10 minutes (Metcalf and Eddy 2003). Therefore complete mixture of chemicals and wastewater was carried out with a rapid mixing velocity 100 rpm for 1 min. Then the mixing velocity was decreased to 30-40 rpm (slow mixing) and continued stirring for 30 minutes. After the mixing steps the formed flocs were left to settle for 30 minutes before samples of the supernatant were collected for determination of pH, color, turbidity, and COD. Time period of the assay was about 60 minutes.

The experiments were performed in the same fashion as described in chapter 3 section 3.2.2. Each experiment included two steps:

- The first step was to determine the optimal pH value. The pH values tested were 4, 5, and 6 at a constant dosage of 400 mg $Al_2(SO_4)_3.18H_2O$/L;
- The second step was to determine the optimal $Al_2(SO_4)_3.18H_2O$ dosage. The aluminum dosages tested were 200, 400, 800, 1,200, and 1,600 mg/L at the optimal pH determined previously.

Fenton's reagent process

The set-up of the experiments was the same as for the coagulation experiments. The used volume of wastewater was 500 ml. The H_2O_2 and the H_2SO_4 for pH adjustments were added to the wastewater at the same time. The pH was adjusted from 2 to 5. After the additions rapid-mixing for one minute at 100 rpm was followed by 60 minutes slow mixing at 30 rpm to the complete reaction. At the end of the reaction, the samples were left to settle for 45 minutes before samples of the supernatant were collected for determination of pH, color, turbidity, and COD. The experiments were:

- To determine the optimal pH. The values of pH were varied from 2 to 5 with 10% H_2SO_4, at a H_2O_2 dosage of 265 mg/L and 23 mg Fe^{2+}/L. The pH that provided the best color and COD removal efficiencies was considered optimal.
- At the optimal pH value, the H_2O_2 dosage was varied: 265, 400, 530 mg/L, at a constant dosage of 23 mg Fe^{2+}/L. The H_2O_2 dosage that provided the best color and COD removal efficiencies was considered optimal.
- At the optimal pH and H_2O_2 dosage, the Fe^{2+} dosage was varied: 8, 16, 24, 32 mg/L. The Fe^{2+}dosage that provided the best color and COD removal efficiencies were considered optimal.

Ozone process

Three experiments were performed with the ozone process. Firstly, with the combination of coagulation and ozone treatment, one liter of coagulated (settled) wastewater was used. In this experiment, two pH values (5 and 8) were studied at the same ozone dosage of 67.3 mg O_3/L. Secondly, with the combination of activated sludge and O_3 and O_3/H_2O_2 treatment, one liter of activated sludge effluent was filtered before it was put into the O_3 reactor. Different ozone dosages were studied, varying from 30 to 600 mg/L at pH 7.9 (pH of activated sludge effluent). Finally, with the combination of activated sludge, coagulation and ozone treatment, one liter of coagulated wastewater was studied with varying ozone dosages of 0 mg O_3/L up to 80 mg O_3/L at pH 5. During the ozone reaction, samples were collected at the regular time intervals of 5, 30, 40, 50, 60, 120 minutes or samples were collected after complete decolorization was obtained. The samples were left to settle for 30 minutes and the supernatant was used for the determination of pH, color, and turbidity. At the highest color removal efficiency the COD of the settled sample was determined. The ozone content of ingoing and outgoing sample of the ozone reactor was measured. The ozone dosage that provided the best color removal efficiency was considered optimal.

Aerobic process

The aerobic biodegradability of the mixed wastewater was determined in batch experiments. A volume of 3.5 L wastewater was used for each experiment. Air was supplied by an air pump with a capacity of 60 L/min. During the experiment, the dissolved oxygen concentration was kept at 2-3 mg O_2 /L. The pH of the wastewater was adjusted to 7.0-7.5 with 5% H_2SO_4. Textile wastewater usually has a low concentration of nitrogen and phosphorous. Therefore the wastewater was supplemented with nutrients such as $NaHPO_4$ and NH_4Cl in a ratio of COD:N:P = 150:5:1. Sludge from an activated sludge tank treating textile wastewater in Vietnam was used as seed sludge in the experiment. The sludge was fed to the reactor so that the suspended solids (SS) concentration was 3,000-3,500 mg/L. After constant conditions were reached, the reactor was sampled hourly for 10 hours. These samples were centrifuged for 3 minutes at 4,000 rpm before pH, color, and COD were determined. The tested wastewater treatment combinations are listed in table 4.2 with reference of the sections where the results are discussed.

Table 4.2: Tested treatment and treatment combinations on mixed wastewater and paragraph numbers

Section	Treatment (combination)
4.3.1	Coagulation + Fenton’s reagent
4.3.2	Coagulation + O_3
4.3.3	Activated sludge
	Activated sludge + coagulation
	Activated sludge + O_3
	Activated sludge + O_3/H_2O_2
	Activated sludge + Fenton’s reagent
	Activated sludge + coagulation + O_3

4.3 Combination of physical, chemical and biological processes

4.3.1 Combination of coagulation and Fenton's reagent processes

Coagulation/flocculation process

Figure 4.2 shows the effect of pH on the color intensity and color removal efficiency in the coagulation process. At pH 5, the best color removal efficiency of 92% was obtained corresponding with remaining color intensity of 105 Pt-Co.

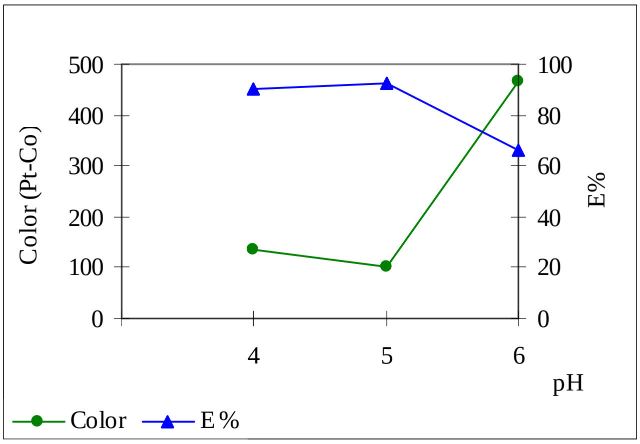


Figure 4.2: Effect of pH on the color intensity and color removal efficiency obtained in the coagulation process of mixed wastewater at an aluminum sulfate dosage of 400 mg/L

The effect of aluminum sulfate dosages on the color intensity and removal efficiency in the coagulation process showed that an increase in dosage of coagulant resulted in a decreased color intensity (Figure 4.3). At both dosages 400 and 800 mg/L of aluminum sulfate the color removal efficiency was the same. The highest was 92% with a remaining color of 105 Pt-Co. However, at an aluminum sulfate dosage of 400 mg/L, the residual COD was the lowest (230 mg O_2/L), which equals a COD removal efficiency of 81%. As optimal aluminum sulfate dosage 400 mg/L was chosen. Increasing the dosage up to 1,200 mg/L hardly changed the efficiency.

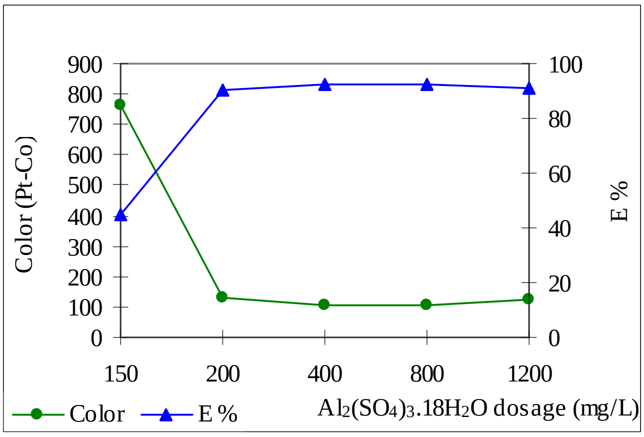


Figure 4.3: Effect of aluminum sulfate dosages on color intensity and removal efficiency in the coagulation process of mixed wastewater at the optimal pH

Table 4.3 summarizes the results obtained from the coagulation process with aluminum sulfate. Although a high color removal efficiency of 92% was achieved and a COD removal efficiency of 81%, a coagulation process alone can not meet the TCVN 5945:2005 for color and COD (color of 50 Pt-Co and COD of 80 mg O_2/L). The experiments confirm again that the coagulation process is indispensable as a treatment for textile wastewater because it can significantly decrease COD and color.

Table 4.3: Results of the coagulation process with aluminum sulfate

Items	Unit	Raw wastewater	Coagulation process
$Al_2(SO_4)_3 .18\ H_2O$	g/L	-	0.4
H_2SO_4 with concentrated 98%	ml/L	-	0.31
Experimental temperature	^oC	30	30
pH	-	10.8	5.0
COD	mg O_2/L	1,200	232
BOD_5	mg O_2/L	510	-
Color intensity	Pt-Co	1,390	105
Turbidity	FAU	123	11

Fenton's reagent process applied as post treatment process after the coagulation process

Optimal pH

The wastewater treated by the coagulation process was further post treated with Fenton's reagent. Determination of optimal pH for the Fenton's reagent was carried out by varying pH values between 3, 4 and 5. Figure 4.4 shows the effect of pH on the color intensity and removal efficiency with Fenton's reagent. The results show that applying Fenton's reagents the color intensity increased at all tested pH values. As a consequence

Fenton's reagent after coagulation gave a negative efficiency in comparison with original sample. The reason was that color-producing complex compounds were formed by oxidation processes of hydroxyl radicals. The other reason was that oxidized dissolved iron ions formed color-producing complex compounds. The color removal was found to be more or less independent of the pH. Within the three tested pH values pH 4 was considered the optimal pH which gave the lowest color intensity (150 Pt-Co). This pH was selected to determine optimal dosage of H_2O_2 and Fe^{2+}.

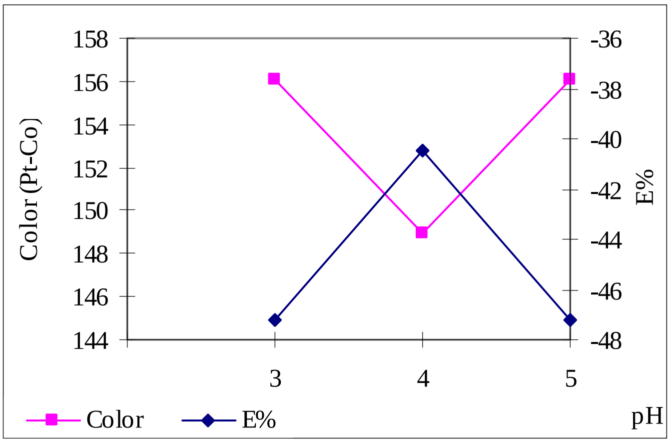


Figure 4.4: Effect of pH on the color intensity and removal efficiency in the Fenton's reagent process treating coagulated mixed wastewater. Used dosages in the Fenton's reagent process: 265 mg H_2O_2/L and 23 mg Fe^{2+}/L

Optimal H_2O_2 dosage

Figure 4.5 shows the effect of H_2O_2 dosage on the color intensity and removal efficiency of coagulated mixed wastewater. The obtained results were the same as with the optimal pH experiment: increasing the dosages of H_2O_2 from 130 to 530 mg/L the color hardly decreased. At a H_2O_2 dosage of 400 mg/L the color intensity deteriorated the least and was more or less the same as the sample before the H_2O_2 addition (105 Pt-Co). Therefore this dosage was chosen to be applied in the experiment for determining the optimal ferrous dosage.

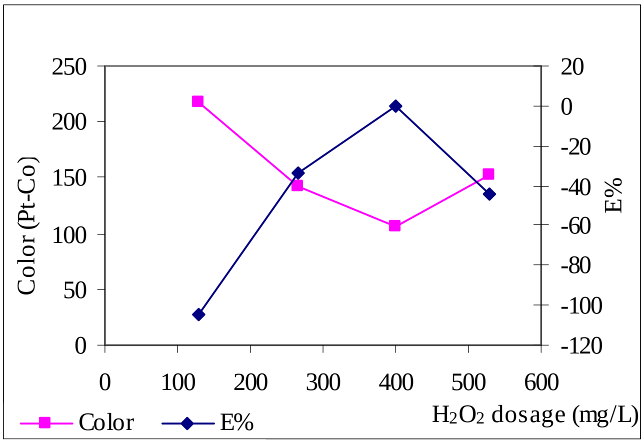


Figure 4.5: Effect of H_2O_2 dose on the color intensity and removal efficiency of coagulated mixed wastewater at pH 4 and 23 mg Fe^{2+}/L dosage

Optimal Fe $^{2+}$ dose

In this experiment, the effect of ferrous (Fe^{2+}) dosage was tested. From Figure 4.6 can be seen that the optimal ferrous dosage was at 8 mg/L: the corresponding color intensity was 74 Pt-Co (removal efficiency 30%). At higher ferrous dosages of 16, 24, and 32 mg/L, the color intensity increased. The explanation might be that ferrous in the sample is oxidized by the H_2O_2 to form red rust which caused higher color intensity than in samples with a low iron dosage. Another explanation can be that iron-organic complex compounds are formed when ferrous is overdosed. Kang (1997) found similar results and reported that the color removal efficiency increased with increasing ferrous doses and after reaching a maximum efficiency at the optimal ferrous dosage, the color removal efficiencies drop at higher ferrous doses. At the optimal ferrous dosage of 8 mg/L the residual total iron that remained in the filtered sample was 3.4 mg/L, of which 1.5 mg/L was Fe^{2+} and 1.9 mg/L was Fe^{3+} (56% Fe^{3+} and 44% Fe^{2+} of total iron). The decrease of total iron concentration might be caused by the ferrous coagulation process which might occur simultaneously during the oxidation process.

Combining the results of all optimalization experiments with Fenton's reagent for treating coagulated mixed wastewater, it can be concluded that the optimal conditions of Fenton's reagent were at pH 4 with a H_2O_2 dosage of 396 mg/L and a Fe^{2+} dosage of 8 mg/L. The resulting remaining color intensity was then 75 Pt-Co and 150 mg O_2/L for COD. This means that after treatment with the Fenton's reagent at optimal conditions, the color and COD of the treated wastewater was still higher than the Vietnamese standards for discharge industrial wastewater (TCVN 5945:2005, class B) for color intensity: 50 Pt-Co and COD: 80 mg O_2/L.

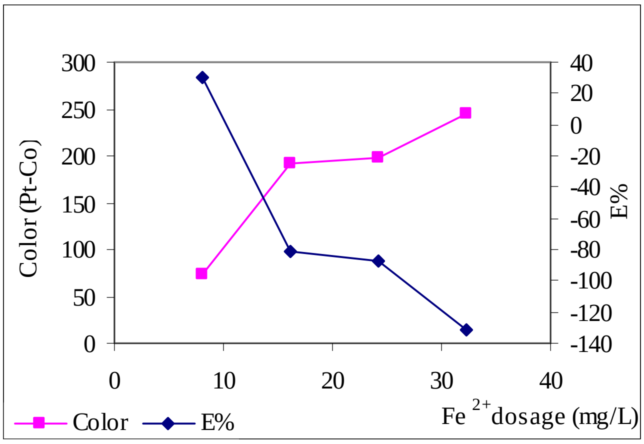


Figure 4.6: Effect of iron dosage on color intensity and removal efficiency of coagulated mixed wastewater at pH 4 and 396 mg H_2O_2/L

The optimal conditions for the coagulation and Fenton's reagent processes are summarized in Table 4.4. The treatment of the raw mixed wastewater with the coagulation process proved to be very effective for COD and color removal, achieving a high removal efficiency of 92% for color and 81% for COD. However, the subsequent post treatment with the Fenton's reagent process yielded limited success probably due to the formation of color producing complex compounds such as iron-organic complexes and rust particles and a coloring of the wastewater due to dissolved iron. The combination of coagulation and Fenton's reagent processes treating raw mixed wastewater could not reach the TCVN 5945:2005, class B for color and COD in the effluent (color: 50 Pt-Co, COD: 80 mg O_2/L), but it did meet the QCVN 13:2008/BTNMT, class B for color (150 Pt-Co, COD 150 mg O_2/L).

Table 4.4: The optimal conditions and combined results of the coagulation and Fenton's reagent processes treating raw mixed wastewater

Items	Unit	Raw wastewater	Coagulation process	Fenton's reagent	TCVN 5945:2005 Class B	QCVN 13:2008 Class B
$Al_2(SO_4)_3$	g/L	-	0.4	-	-	-
H_2SO_4 98%	mL/L	-	0.30	-	-	-
Fe^{2+}	mg/L	-	-	8	-	-
H_2O_2 30%	mL/L	-	-	0.4	-	-
NaOH	mg/L	-	-	4	-	-
Temperature	^oC	30	30	30	40	40
pH	-	11.0	5.0	4.0	5.5-9.0	5.5-9.0
COD	mg O_2/L	1,200	232	150	80	150
BOD_5	mg O_2/L	510	-	-	50	50
Color	Pt-Co	1,390	105	75	50	150
Turbidity	FAU	123	11	9	-	-

Note: Industrial wastewater-discharge standards (TCVN 5945:2005) and National technical regulation on the effluents of Textile Industry (QCVN 13:2008/BTNMT) in which Class B gives the allowed threshold value of effluent discharges into water resources which are not used for potable water production

4.3.2 Combination of coagulation and ozone processes

Coagulation processes

The results of the coagulation process are given in section 4.3.1 (coagulation/flocculation process). The supernatant of the settled effluent of the coagulation process was used as influent for the ozone process.

Ozone process

The supernatant of the coagulated wastewater was treated with the ozone process at pH 5 and 8.2. Table 4.5 summarizes the results.

At pH 5.0 (pH after coagulation) a 25 minutes reaction time with ozone achieved a color removal efficiency of 54% (remaining color 50 Pt-Co). The COD was reduced to 100 mg O_2/L corresponding with a removal efficiency of 53%. The O_3 consumed was 30.3 mg/L which was 50% of the initial O_3 dosage of 67.3 mg/L. The pH decreased from 5.0 to 4.3 at the end of the experiment.

At the same experimental conditions but now at pH 8.2 the results showed that the color removal was lower than at pH of 5. The maximum efficiency was only 27%, the remaining color was 75 Pt-Co. However, the COD removal reached the same efficiency (53%) as at pH 5, but the consumed amount of O_3 was higher than at pH 5.0 (41.6 mg O_3/L). After reaction with ozone the pH also decreased from 8.2 to 7.4 at the end of the experiment.

Table 4.5: Results of treatment with ozone of coagulated mixed wastewater at different pH values

Items	Unit	Raw wastewater	Coagulation process	Ozone process	
				pH = 5	pH = 8.2
$Al_2(SO_4)_3$	kg/L	-	0.4	-	-
H_2SO_4 98%	L/m^3	-	0.30	-	-
O_3 initial	mg/L	-	-	67.3	67.3
O_3 consumed	mg/L	-	-	30.3	41.6
O_3 residual	mg/L	-	-	37.0	25.7
pH	-	10.9	5.0	-	-
pH after ozone	-	-	-	4.3	7.4
Time	minutes	-	-	25	25
COD	mg O_2/l	1,200	232	100	100
Color	Pt-Co	1,390	105	50	75
Turbidity	FAU	123	11	5	8

In the combined treatment of coagulation and ozone the coagulation step removed almost all suspended solids and colloidal particles from the wastewater. Therefore the effect of particles was eliminated for the ozone process. The results showed that coagulated wastewater was completely decolorized in 25 minutes by the ozone process. The color removal of coagulated wastewater by the ozone process was higher at pH 5 than at pH 8 at the same ozone dosage of 67.3 mg O_3/L and the same reaction time. As mentioned in chapter 2, the degradation of organic compounds by ozone can follow two main pathways: direct oxidation by molecular ozone and indirect oxidation by means of hydroxyl radicals.

The obtained results demonstrated that direct oxidation at low pH of 5 by molecular ozone was very effective towards the decolorization of dyestuffs compared to oxidation with the hydroxyl radical formed at a high pH value of about 8. Oxidation by molecular ozone is much more selective than oxidation by hydroxyl radicals for dyestuffs which incorporate one or more double bonds or a specific region with a high π -electron density.

The conclusion is that a combination of coagulation and ozone can be applied for the treatment of textile wastewater with mixed disperse, reactive, vat, and acid dyes to meet QCVN 13:2008/BTNMT, class A and B for color (50Pt-Co and 150Pt-Co). This combination gave better results than the combination of coagulation and Fenton's reagent for color removal. With the application of the ozone process as post-treatment after a coagulation/flocculation process was better than as a pre-treatment step (see chapter 3) with respect to the amount of ozone needed to reach the Vietnamese environmental regulation for color. This can be attributed to the removal of particles prior to ozonation. However, the COD after combined coagulation and ozonation remains above the limit allowed according to TCVN 5945: 2005, class B and QCVN 13:2008/BTNMT, class A with a maximum threshold for COD of 80 mg O_2/L (TCVN 5945:2005, class B) and 50mg O_2/L(QCVN 13:2008/BTNMT, class A). It does however meet the value given by QCVN 13:2008/BTNMT, class B with a maximum threshold for COD of 150 mg O_2/L.

4.3.3 Combination of biological, physical, and chemical processes for treatment of mixed textile wastewater

Biological processes are widely used for the treatment of textile wastewaters. The biological process used in the textile industry of Vietnam as well as in the world is the aerobic activated sludge process. As mentioned in literature (chapter 2), the aerobic activated sludge process performs very well regarding BOD removal but is almost ineffective regarding color removal.

As can be seen from the composition of textile wastewater (Table 4.1) the BOD/COD ratio was around 0.4, therefore a (aerobic) biological process can be applied as a pre-treatment for the treatment of the mixed wastewater. The combination of activated sludge and different post treatment processes were studied in order to select the best combination with respect to color and COD removal in the treatment of textile wastewater.

Combination of activated sludge and coagulation process

Activated sludge process

The treatment time was varied to study its influence on the COD and color removal. Figure 4.7 shows the effect of the treatment time on the color intensity and COD of mixed wastewater. Within 4 hours of activated sludge treatment the $COD_{centrifuged}$ of the wastewater decreased and after that remained more or less constant: the $COD_{centrifuged}$ decreased from 1,180 to 345 mg O_2/L. This corresponds with a COD removal efficiency of about 70-76%. According to Mattioli, 2002; Hu, 2001; Panswad, 2001; O'Neill, 1999; Altinbas and Jiang, 1994, the activated sludge process performed very well on BOD removal but was almost ineffective in color removal. This does not correspond to the experimental results found in this study. In order to reduce effect of turbidity, influents and effluents were centrifuged before measuring the color. The color decreased from 995 to 530 Pt-Co after 9 hours activated sludge treatment, the color removal efficiency after 7 hours was 43% (565 Pt-Co) and 47% at 9 hours. The explanation for these results might be that the color removal in the biological process was mainly through adsorption on the sludge. It was noticed that the color of the sludge changed to dark brown (the color of the wastewater). In addition, a part of the dyestuffs could be degraded in the aerobic process by scission of the double bonds with the consequence a reduction of the color intensity. The biological process is indispensable in the treatment of textile wastewater to reduce the consumption of chemicals for the subsequent coagulation or chemical oxidation processes, since the textile wastewater contains biodegradable compounds.

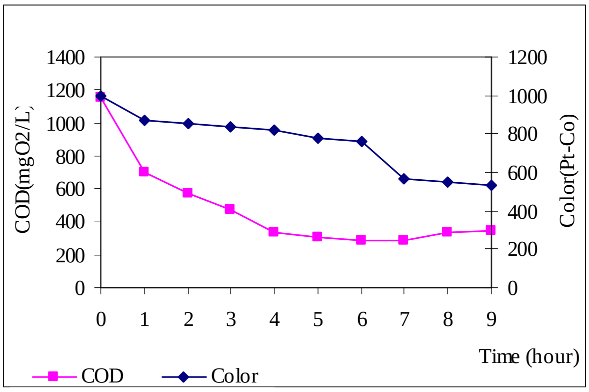


Figure 4.7: Effect of activated sludge treatment time on the COD and color intensity for mixed wastewater

Combination of activated sludge and coagulation process

The activated sludge effluent was settled for 30 minutes, and then the supernatant was treated with the coagulation process. In chapter 3 many experiments are described with the aim to determine the optimal pH and dosage of coagulant for the coagulation process of textile wastewater. Aluminum sulfate was considered the best coagulant. Figure 4.8 and 4.9 show the effect of pH and aluminum sulfate dosage on color intensity and removal efficiency of the supernatant of 30 minutes settled coagulated effluent of an activated sludge process. The best pH range for the coagulation process was between 4.0 and 5.0 and the optimal aluminum sulfate dosage was 400 mg/L. The achieved color removal efficiency was 90% with a remaining color of 110 Pt-Co. The COD decreased from 345 to 40 mg O_2/L, corresponding to a removal efficiency of 88%. Increasing the aluminum sulfate dosage from 400 to 1,200 mg/L hardly changed or slightly increased the color removal efficiency at an aluminum sulfate dosage of 1,600 mg/L. After the coagulation process the color intensity and COD meet the discharge regulation QCVN 13:2008/BTNMT, class B, but the color intensity still needs treatment to reach the allowable threshold of 50 Pt-Co for TCVN 5945: 2005, class B.

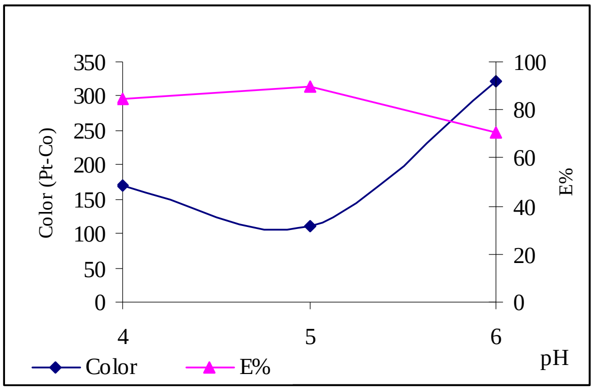


Figure 4.8: Effect of pH on the color intensity and removal efficiency (E%) in the coagulation process with a dosage of 400 mg/L $Al_2(SO_4)_3.18H_2O$ of aerobic activated sludge effluent

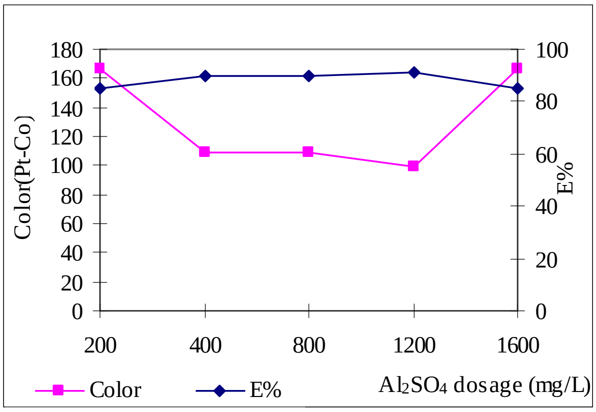


Figure 4.9: Effect of $Al_2(SO_4)_3.18H_2O$ dosage on the color intensity and removal efficiency E% in the coagulation process of activated sludge effluent at optimal pH 5

Combination of activated sludge with O_3, and activated sludge with O_3 /H_2O_2

Combination of activated sludge and O_3

The results show that the effluent of combined activated sludge and coagulation treatment did not yet achieve the discharge regulation class A regarding color. In the following experiment the combination of activated sluge and an O_3 process is tested. The activated sludge effluent was filtered before treatment with ozone.

In Figure 4.10 the effect of ozone dosages varying from 0 to 450 mg/L on color removal of the effluent of the activated sludge process is shown. The color was reduced from 1,100 to 205 Pt-Co with a maximum efficiency of 82%. When the ozone dosage was increased from 42 to 250 mg/L, the color removal efficiency increased. Increasing ozone dosages between 250 and 374 mg/L the color hardly changed. At ozone dosages of 42 and 84 mg/L the color intensity reduced fast, and between 125-374 mgO_3/L the color reduction was less. This was explained by the fact that the pH of the effluent of activated sludge treatment is 7.8-7.9.

Under these alkaline conditions the ozone may dissociate leading to the formation of hydroxyl radicals and then both molecular ozone and hydroxyl radicals are present simultaneously in the solution. According to results of ozone experiments in section 3.3.4 of chapter 3, the molecular ozone is much more selective in the decolorization of dyestuffs than the hydroxyl radicals. According to Boncz (2002), from a chemical point of view the azo-linkage of dyestuffs is the easiest to oxidize. In this case, molecular ozone was selected to oxidize the azo-linkage of the dyestuffs or the double bond in dyestuffs resulting in color reduction of the wastewater which was faster in the first stage of the ozone process.

As known, oxidation by hydroxyl radicals is faster but less selective than oxidation by molecular ozone. The hydroxyl radicals can react with organic compounds and create organic radicals with high reactivity, and subsequently can be demineralized as presented in equation 22 of chapter 2. In addition these hydroxyl radicals can also oxidize inorganic compounds present in textile wastewater.

It was observed that although the wastewater was filtered before ozonation, after finishing the ozone oxidation experiment several particles appeared in the sample. This caused an increase of ozone consumption without a decreased of the color.

The pH changed slightly during the reaction with ozone. The pH was reduced from 7.9 to 7.5 as presented in Figure 4.11. The combination of the activated sludge and ozone process did not result in an effluent that could meet the discharge standard for color and COD.

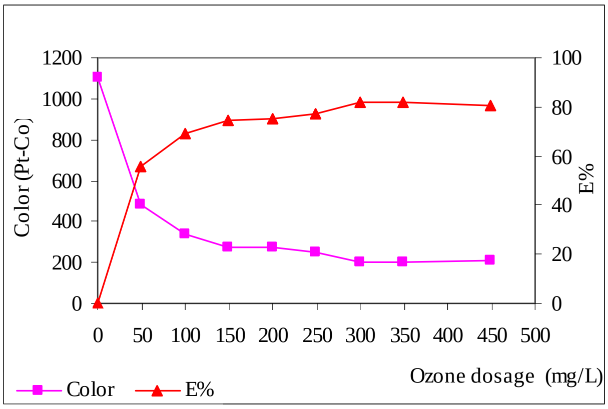


Figure 4.10: Effect of the ozone dose on the color intensity and removal efficiency on filtered activated sludge effluent from mixed wastewater

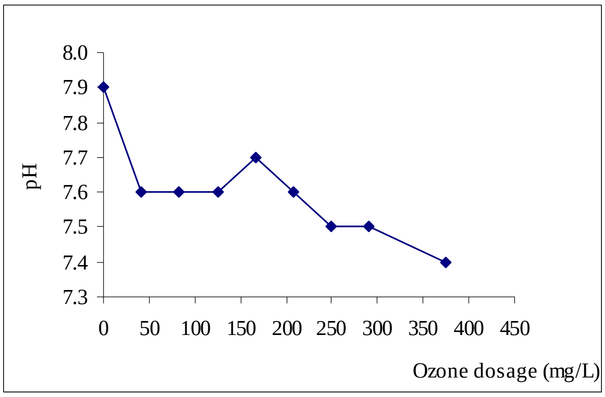


Figure 4.11: Change of pH by ozone treatment of filtered activated sludge effluent from mixed wastewater

Combination of activated sludge and O_3/H_2O_2 processes

In order to improve the color removal efficiency, the O_3/H_2O_2 process was applied to filtered activated sludge effluent from mixed wastewater. The optimal ozone dosage was chosen from the previous experiment (250 mg/L). According to literature mentioned in chapter 2, a ratio of 1 H_2O_2 to $2O_3$ is more or less optimum, therefore a H_2O_2 dosage of about 125 mg/L was used. Figure 4.12 shows the effect of O_3/H_2O_2, and the O_3 processes on the color intensity. There is little difference between applying O_3 and O_3/H_2O_2 to the wastewater. For the O_3/H_2O_2 process at an ozone dosage of 250 mg/L, the color removal was higher resulting in a remaining color of 205 Pt-Co and corresponding to a color removal efficiency of 81%. However, the sample became turbid and many particles appeared after finishing the experiment, similar to the previous O_3 experiment. During the reaction the pH hardly changed and remained at pH 7.7. According to theory (chapter 2), the O_3/H_2O_2 process with the formation of hydroxyl radicals (OH^*) can improve the color and COD removal efficiency; however this experiment showed different results. The efficiency did not change even at high hydrogen peroxide additions (chapter 3, ozone experiments). The hydrogen peroxide addition to the O_3 process did not improve the oxidation of dyestuffs with respect to the color and COD removal. Hydrogen peroxide is known as a scavenger of hydroxyl radicals. The hydrogen peroxide excess can cause the opposite effect intended. It is difficult to determine the optimal hydroxide peroxide dose in the O_3/H_2O_2 process. Therefore the O_3/H_2O_2 combination is not considered a suitable system to apply in textile wastewater treatment because of the lack of efficiency improvement.

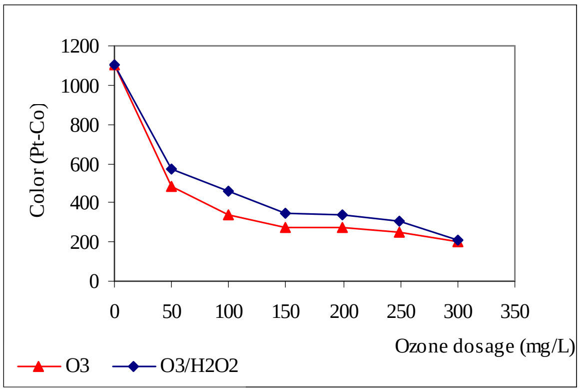


Figure 4.12: Effect of ozone doses in O_3/H_2O_2 and O_3 processes on the color intensity of filtered activated sludge effluent from mixed wastewater

Combination of activated sludge and Fenton's reagent

The settled effluent from mixed wastewater treated by the activated sludge process was treated with Fenton's reagent. Figure 4.13 shows the effect of pH on the Fenton's reagent process regarding color intensity and removal efficiency. The results clearly demonstrate that the best pH for Fenton's reagent is pH 3.0, which is in agreement with the values found in literature (chapter 2). At optimal pH the color removal efficiency was 78%, with a remaining color of 245 Pt-Co. The effect of H_2O_2 dosage is shown in Figure 4.14. With H_2O_2 dosages of 462 and 528 mg/L the color removal efficiency was 81%, higher than at dosages of 198, 264, 330, 396, 594, and 660 mg/L. The remaining color was about 205-210 Pt-Co. The optimal H_2O_2 dosage was 462 mg/L. This dosage was used in the experiment for the determination of the optimal Fe^{2+} dose. Figure 4.15 presents the effect of the Fe^{2+} dose in Fenton's reagent on the color intensity and removal efficiency. The maximum color removal efficiency was 77% at a Fe^{2+} dosage of 32 mg/L. Further increase of Fe^{2+} dosages increased the color removal efficiency, but not much. Increasing the Fe^{2+} dosage from 30 to 36 mg/L resulted in a decrease on removal efficiency from 77% to 71%. The reason was that the excess Fe^{2+} was oxidized to ferric hydroxide which increased the color intensity of the wastewater. The optimal conditions for Fenton's reagent for treating the effluent from an activated sludge process were pH 3, 462 mg H_2O_2/L and 32 mg Fe^{2+}/L. The effluent of the combined activated sludge and Fenton's reagent process at these optimized conditions achieved a color intensity of 255 Pt-Co and a COD of 260 mg O_2/L. Thus this treatment combination could still not produce effluents that met the discharge regulations.

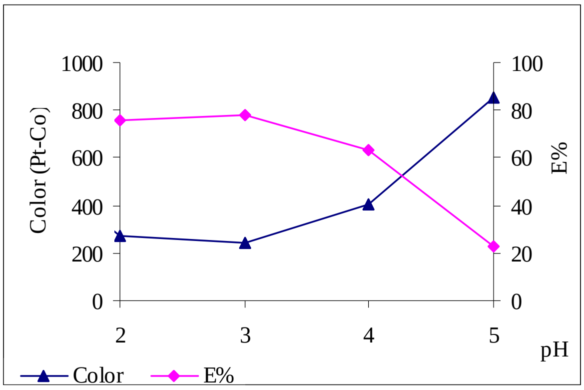


Figure 4.13: Effect of pH on color intensity and removal efficiency (E%) in the Fenton's reagent process of activated sludge effluent from mixed wastewater

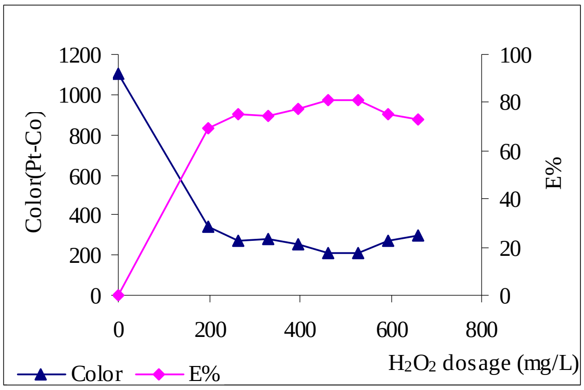


Figure 4.14: Effect of H_2O_2 dosage on color intensity and removal efficiency (E%) in the Fenton's reagent process of activated sludge effluent from mixed wastewater

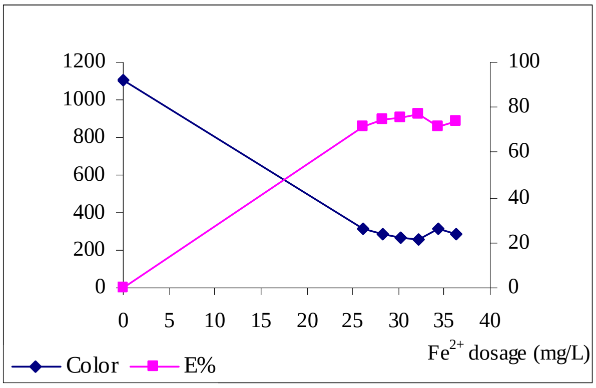


Figure 4.15: Effect of Fe^{2+} dosage on color intensity and removal efficiency (E%) in the Fenton's reagent process of activated sludge effluent from mixed wastewater

Combination of activated sludge, coagulation and ozone process

Because the effluent from the combined activated sludge process and coagulation process did not meet the discharge regulations, an experiment was carried out in which the combined activated sludge process and coagulation process was followed by a treatment with ozone. The results found in chapter 2 and section 4.3.2 indicated that at low pH (after coagulation the pH is about 5) molecular ozone dominates the color removal of textile wastewater. The effect of ozone dosage on color intensity and removal efficiency of settled activated sludge and coagulation effluent at pH 5 is shown Figure 4.16. When the ozone dosages were increased the color and COD removal efficiencies increased. With an ozone dosage of 62 mg/L the color removal efficiency was the highest (72%). The remaining color of the effluent was 45 Pt-Co and the COD was 30 mg O_2/L.

Table 4.6 summarizes the obtained results of the three combined processes treating mixed wastewater. With optimal ozone dosage the effluent meet the discharge regulation or might be reused in another process of the textile manufacturing process. The results demonstrated that the ozone process was very effect as a post- treatment or polishing step.

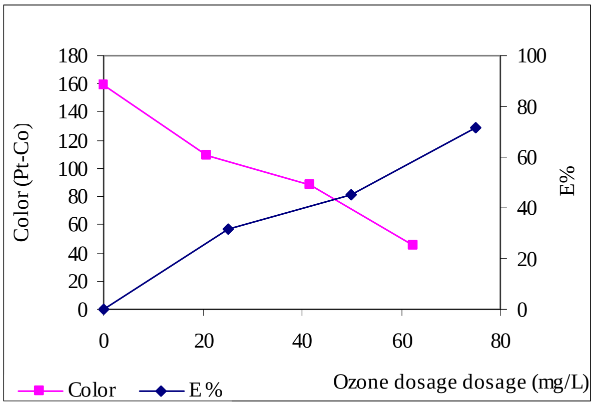


Figure 4.16: Effects of ozone dosages on color intensity and removal efficiency of settled activated sludge and coagulation process effluent from mixed wastewater

Table 4.6: Results of subsequent treatment of mixed wastewater with activated sludge, coagulation and ozone processes

Parameters	Unit	Raw wastewater	After activated sludge treatment	After coagulation process treatment	After ozone process treatment	TCVN 5945:2005 Class B	QCVN 13:2008 Class B
pH	-	10.9	7.8	5.0	4.3	5.5-9.0	5.5-9.0
COD	mg O_2/L	1,200	335	40	30	80	150
Color	Pt-Co	1,110	560	110	45	50	50
Turbidity	FAU	123	102	16	5	-	-

4.4. Costs

The survey of many textile companies in Vietnam showed that the main problem with the treatment of the textile wastewater is the operational costs. The estimated costs for treating one cubic meter of textile wastewater with different processes are illustrated in Figure 4.17, 4.18, and 4.19.

The operational costs are comprised of labor, electricity, and chemicals based on Vietnamese conditions. From the results is clear that a single treatment process would not give an effluent that meets the discharge regulation or would be too expensive if set to achieve the discharge regulation. The coagulation & ozone and the coagulation & Fenton’s reagent processes can be applied to textile wastewater to meet QCVN 13:2008/BTNMT, class B. However, the combined coagulation & Fenton’s reagent process would have higher operational costs as well as a lower efficiency than coagulation & ozone.

A comparison of a combination of coagulation & ozone processes (physical and chemical processes) and a combination of the biological, coagulation, and ozone processes (biological, physical, and chemical processes) in this study shows that the best results were achieved using a combination of biological, physical, and chemical processes. This treatment combination is capable to achieve a high degree of efficiency, it meets the QCVN 13:2008/BTNMT, class A and B as well as TCVN 5945:2005, class B. It allows the reuse/recycling wastewater and it has low operational costs.

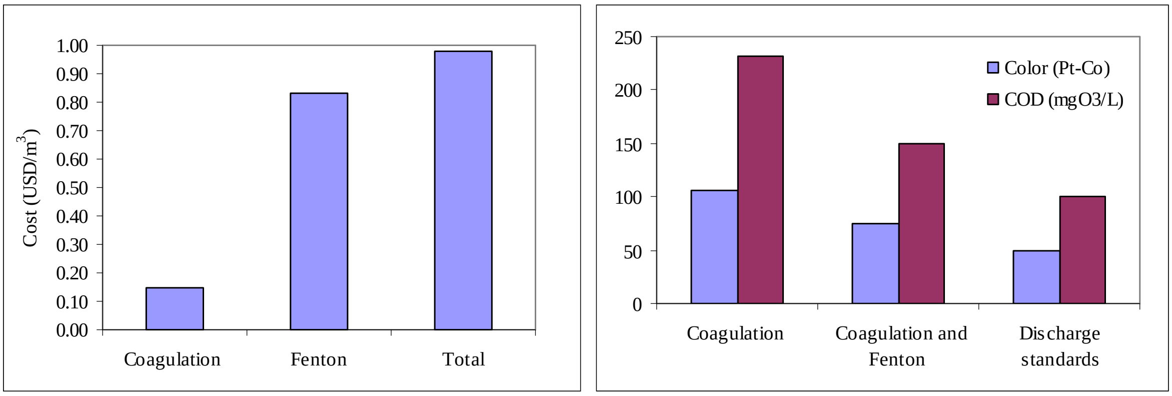


Figure 4.17: Operational costs and remaining color intensity and COD with the combined processes of coagulation and Fenton’s reagent treating mixed wastewater

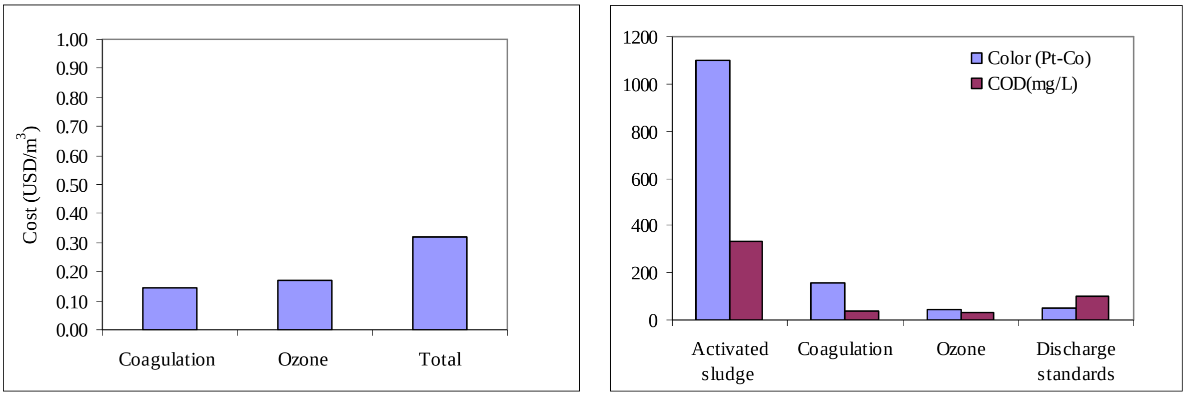


Figure 4.18: Operational costs and remaining color intensity and COD with the combined processes of coagulation and ozone treating mixed wastewater

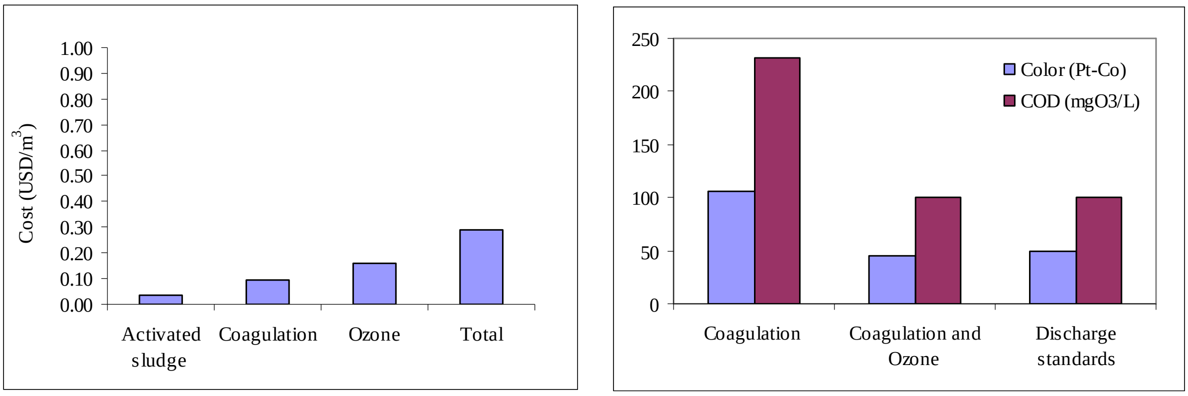


Figure 4.19: Operational costs and remaining color intensity and COD with the combined processes of activated sludge, coagulation and ozone treating mixed wastewater

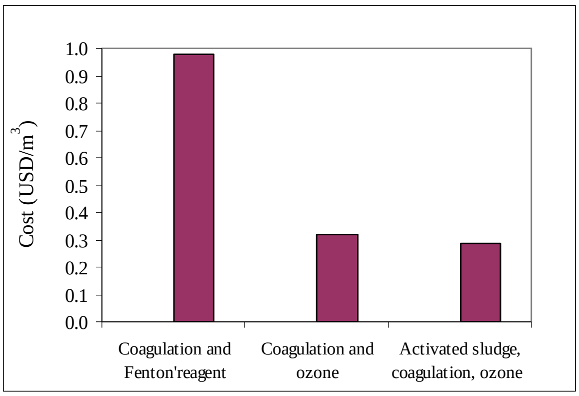


Figure 4.20: Operational costs of the different treatment combinations

4.5 Conclusions

From the results obtained several conclusions can be drawn. It is clear that a single treatment processes would hardly meet the discharge regulation, or in order to meet the discharge regulation a single treatment would be too expensive. The treatment of textile wastewater with the combination of an activated sludge, coagulation, and ozone process yielded the best color and COD removal efficiency at the lowest costs compared to all other tested combinations. In this system the biological process as the first step was designed to remove biodegradable compounds. This first step reduced the chemicals consumption in the next processes. The coagulation process was the next step; this step eliminated the effect of colloidal particles on the ozone process. The low pH of 5 helps the ozone to selectively oxidize the azo-linkages of dyes leading to easier decolorization. In Table 4.7 a comparative summarization is offered of all tested treatment combinations regarding pH, COD, color intensity and turbidity.

Of the treatment combinations of coagulation + Fenton's reagent and coagulation + ozone, the combination of coagulation + ozone gave a higher color removal efficiency and the operational costs are three times lower than the combination of coagulation + Fenton's reagent (0.97 USD/m^3). The most successful decolorization of the textile wastewater was at low pH by the molecular ozone mechanism; the preferential reaction for color removal in textile wastewater. Two schemes for textile wastewater treatment are proposed and described in Figure 4.21 and 4.22. With application of the first scheme (Figure 4.21) the effluent of textile wastewater industry can meet the discharge regulations for discharging into surface waters which are used for potable water production (QCVN 13:2008/BTNMT, class A). The second scheme (Figure 4.22) may be applied when discharging effluent into surface waters which are not used for potable water production (QCVN 13:2008/BTNMT, class B). In addition the second scheme is a suitable solution for companies with limited area like the 28 Company-Agtex located in Hochiminh City. With application of the first scheme, the effluent can be reused in other processes of textile manufacturing or for the purpose of irrigation. The results proved that a combination of physical and chemical processes is more expensive compared to the combination of biological, physical, and chemical processes.

Table 4.7: Comparison of parameters of the different applied treatment methods on raw mixed wastewater

Parameters	Unit	Raw wastewater	Combination of physical and chemical methods		
			Coagulation	Coagulation and Fenton's reagent	Coagulation and Ozone
pH	-	10.9	5.0	4.0	4.0
COD	mg O_2/L	1,200	232	150	100
Color	Pt-Co	1,390	105	75	50
Turbidity	FAU	125	11	9	5

Parameters	Unit	Activated sludge	Combination of biological, physical, and chemical methods				
			Activated sludge + coagulation	Activated sludge + Fenton	Activated sludge + Ozone	Activated sludge + O_3/ H_2O_2	Activated sludge +Coagulation +Ozone
pH	-	7.8	5.0	3.0	7.5	7.7	4.3
COD	mg O_2/L	335	40	260	270	275	30
Color	Pt-Co	1,100	110	253	205	205	45
Turbidity	FAU	125	16	24	20	20	5

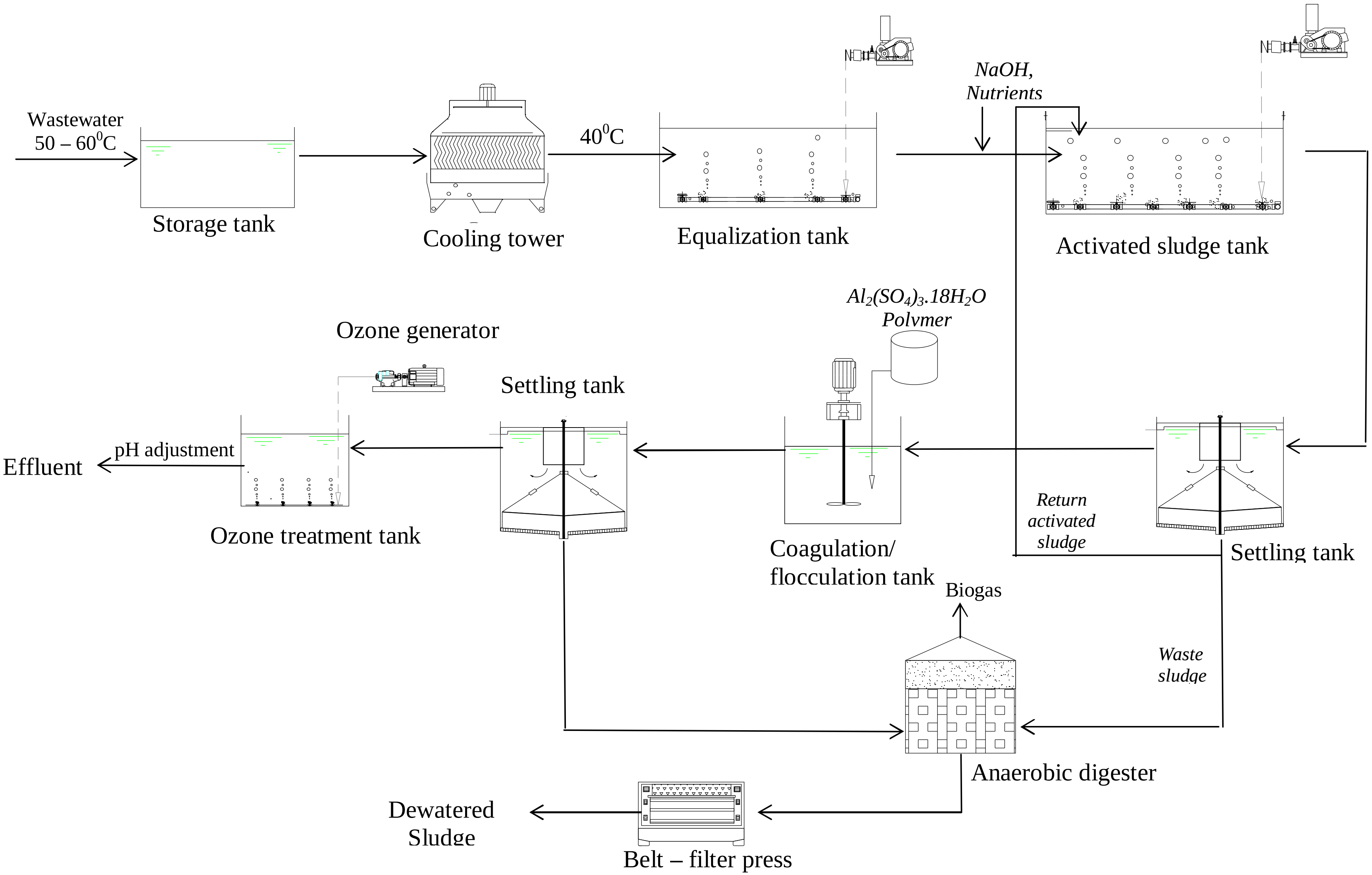


Figure 4.21: Flow chart of proposed textile wastewater treatment system based on the combination of the activated sludge, coagulation and ozone process for meeting an effluent quality within regulation QCVN 13:2008/BTNMT, class A

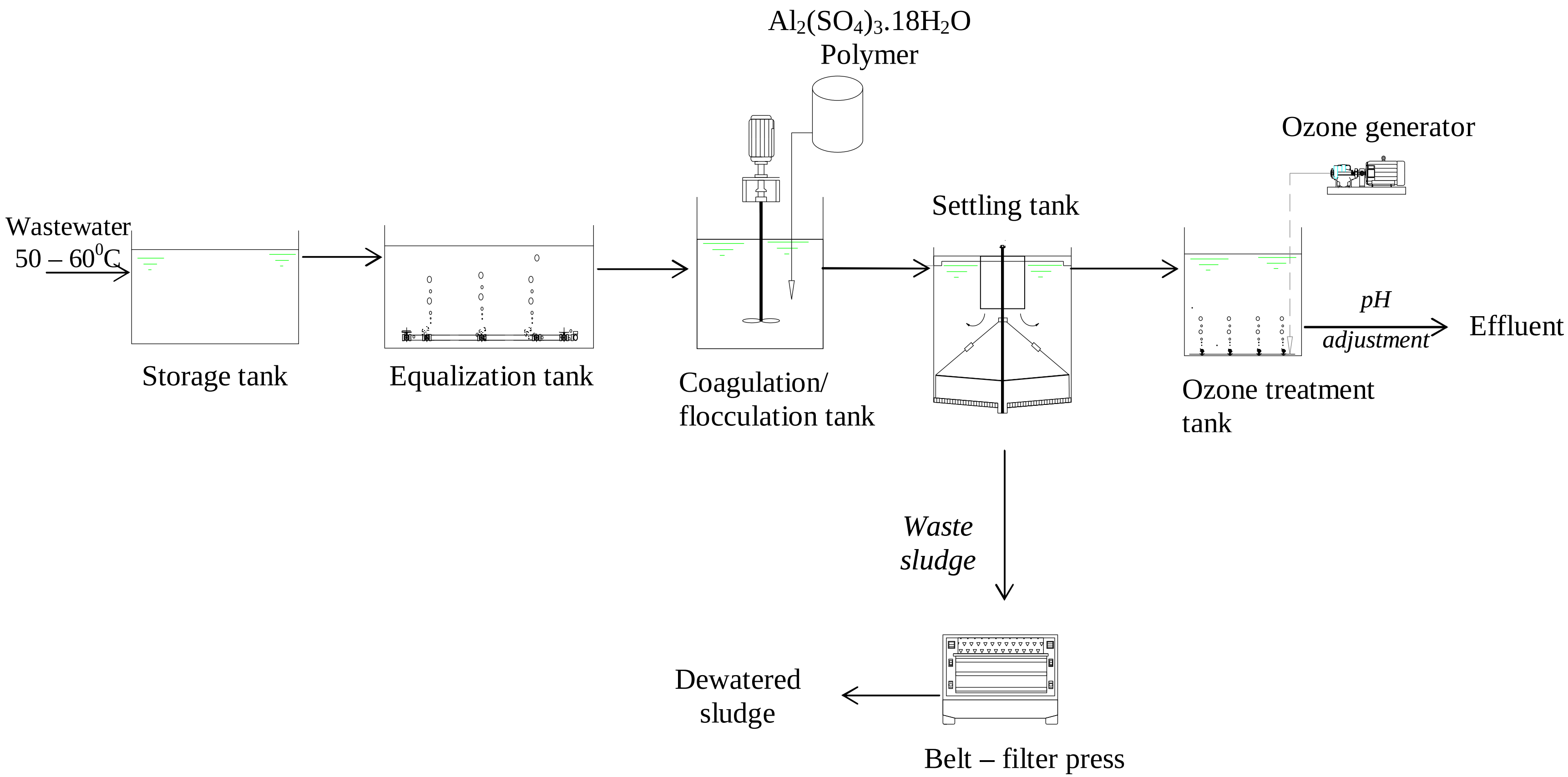


Figure 4.22: Flow chart of textile wastewater treatment system based on the combination of the coagulation and ozone process for meeting an effluent quality within regulation QCVN 13:2008/BTNMT, class B

Chapter 5

Separation of wastewater streams: experimental research

5.1 Introduction

In textile industry, wet processes usually generate a large volume of wastewater. Volume and composition of the wastewater depend on the manufacturing process, type of machines and characteristics of fiber or fabric (cotton, polyester, nylon, blended of cotton/polyester, etc.). According to Boncz (2002) quantities and composition of the textile wastewater vary widely and amounts range from 40 to 300 m^3 per ton product. The survey results of the textile industry in Vietnam showed that the volume of wastewater that was discharged was in the range of 10 to 415 m^3 per ton product (Loan 2004). In general, three quarters of the total water consumption is related to the washing processes (Loan, 2004). After each scouring, dyeing, printing and finishing step many rinsing sequences are required (Mattioli et al. 2002). As reported by Groves et al. (1978) an average 60 to 90% of total water consumption in wet processes is for rinsing purposes. Almost all wastewaters generated from washing steps show lower pollutant concentrations (COD, BOD, nutrients) than water from other steps of the wet processes (Loan 2005). The wet processes include three main steps: preparation, dyeing and finishing. In the preparation step several organic substances, surfactants and inorganic matter are used. Many different dyes, salts and auxiliary chemicals are used for the dyeing step. Organic substances such as sizing, softeners and surfactants are applied in the finishing step. The difficulties with the treatment of textile wastewater mostly arise from the presence of all the components mentioned above, mixed in the wastewater stream. In order to meet the requirements of environmental regulations, a combination of several treatment processes should be applied. In a textile wastewater treatment system all the pollutants have to pass through the whole system, although each treatment step of the system is designed for removing only one category of compounds of the wastewater. Therefore, the construction and operational costs of the textile wastewater treatment system has become a financial burden for the textile companies. For that reason a separation of wastewater streams is studied with the purpose to achieve high treatment efficiency at lower costs and to avoid influences of undesirable compounds in the different treatment processes. The aim of this study is to assess the possibilities for wastewater separation in a textile company to facilitate reuse and reduce chemical consumption as much as possible to promote sustainable development.

5.2 Methodology

The methods utilized for this study are data collection, site surveys, observations and sampling for analysis. The data collection was the first step in which primary data such as the geographical and administrative location, the type of manufacturing processes and environmental performance were gathered through visiting the 28 Company-Agtex. This company was located in GoVap district, Ho Chi Minh City, Vietnam. The primary data collection was done to identify the impacts of the company's production processes on environment and ability to reuse water. In order to understand the manufacturing process in more detail "face to face" interviews and site surveys were done. The secondary data give information about the local discharge standards and requirements for reuse of water in the production process of the company. The second step was sampling and measuring the quantity and quality of the wastewater from each step in the wet processes of the 28 Company-Agtex. This step was performed to assess the ability for wastewater source separation with reuse and/or treatment in the company.

5.3 Experimental procedures

At each step of the batch and continuous dyeing processes, the amounts of all inputs (water, chemicals and dyestuffs) used at the 28 Company-Agtex were recorded. Outgoing samples were collected and analyzed in order to assess the quality of water and wastewater for the implementation of separation of wastewater streams. The analyzed parameters include temperature, pH, color intensity, turbidity, suspended solids, COD_{total}, $COD_{dissolved}$, SO_4^{2-}, PO_4^{3-}, NH_4^+, and N-org.

5.4 Analytical methods

All analytical methods used are described in chapter 3. The determinations of alkalinity, suspended solids, SO_4^{2-}, PO_4^{3-}, NH_4^+, N-org were performed according to the Standard Methods for the Examination of Water and Wastewater (APHA 1995).

5.5 Results and discussion of the wastewater situation at the 28 Company-Agtex

5.5.1 Environmental performance of the 28 Company-Agtex

The 28 Company-Agtex is a typical large scale state-owned company in Vietnam. The production capacity of the company is 8,000,000 m^2 of fabric/year (28 Company-Agtex, 2007). The main products are cotton, blended cotton and polyester (T/C) and blended wool fabrics. With a complete production system ranging from yarn twisting to weaving, dyeing, finishing, sewing and finished products, the company has a full set of modern technology and equipment which include yarn machines, continuous dyeing process (pad-stream machine), batch dyeing process (Jet machine), etc. The company also pays attention to the environmental impact throughout the manufacturing process. For this environmental commitment the enterprise received certificates of the international standard organization, such as ISO 9001:2000 and ISO 14001:1996. In order to qualify for the ISO 14001:1996 certificate, the enterprise invested in a wastewater treatment system with a capacity of 700m^3/day, with a combination of coagulation and filtration processes as described in Figure 5.1. In this treatment system, chemical coagulation was applied as the main process for effluents treatment, followed by a filtration process as post treatment to polish the effluent. As mentioned earlier the coagulation process alone can not meet the discharge standards, especially regarding COD and color. Also the results from measuring effluent of wastewater treatment facility of the 28 Company-Agtex demonstrated this (Table 5.1). The effluent did not meet the discharge standards TCVN 5945:2005 class B as well as QCVN 13:2008, class B with three parameters: the BOD was three times higher then the standard given in TCVN 5945:2005 and regulation QCVN 13:2008; the COD was nearly eight times higher than the standard given in TCVN 5945:2005 and five times higher than the regulation given in QCVN 13:2008, also the pH exceeded the standards. Textile wastewater usually contains a high concentration of auxiliary chemicals (organic compounds) and remaining dyestuffs. However, the chemical coagulation/flocculation process can only remove part of the organic matter. In spite of the high operational costs the effluent can not meet the standards. When the operational costs of wastewater treatment make up from 15-30% of the production costs the consequences are problematic for the company (28 Company-Agtex, 2007).

Table 5.1: Composition of treated wastewater of the 28 Company-Agtex

Parameters	Unit	Treatment system effluent	TCVN, 5945:2005 class B	QCVN13:2008 class B
pH	-	11.9	5-9	5.5-9.0
Suspended solids	mg/L	38	100	100
COD	mg O_2/L	770	80	150
BOD	mg O_2/L	150	50	50
Total nitrogen	mg N/L	13.7	30	-
Total phosphor	mg P/L	2.8	6	-

Source: Quality assurance and testing center 3-Quatest 3 (2006); TCVN 5945:2005; QCVN13:2008

Vietnamese industrial wastewater discharge standard, QCVN13:2008: National technical regulation on the effluents of Textile Industry; class B is water quality standards or regulations for industrial effluents discharged into surface waters which are not used for potable water production

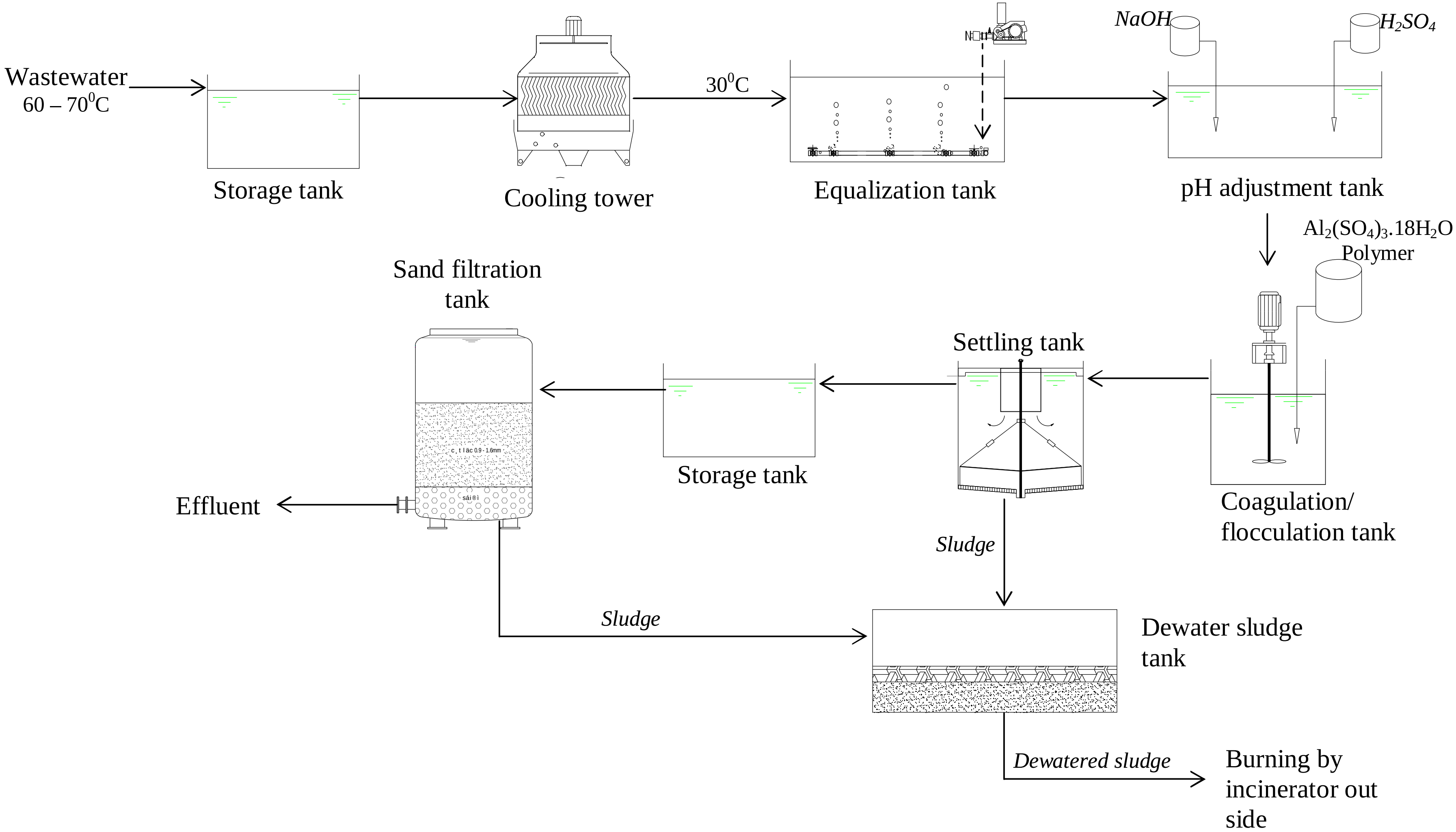


Figure 5.1: Flow chart of the textile wastewater treatment facility of the 28 Company- Agtex

5.5.2 Manufacturing process of the 28 Company-Agtex

The 28 Company-Agtex applies two main methods: batch and continuous operation. Both methods produce an effluent containing similar chemical constituents, namely the exhaust dye and other auxiliary chemicals. However, the concentration of exhaust dyes in the effluent streams of the two methods can vary considerably. Details of each method are described below.

Batch dyeing process

An example of a general batch dyeing process with generated wastewater streams is described in Figure 5.2. In this process a high amount of organic waste (expressed as COD) can be produced in the dyeing and finishing steps. The dyeing step is characterized by a high specific water consumption, auxiliary chemicals, and dyestuffs resulting in a relatively high volume of wastewater with a high color intensity, and poor biodegradability. The effluent from the finishing step (sizing) can have a high COD with a high level of biodegradable compounds but the effluent volume is low. Therefore, only the dyeing process was selected for this study. Figure 5.3 shows in more details the dyeing process of blended fabric code G.TW.538 L5 that is made of 35% cotton and 65% polyester and dyed using disperse and acid dyes. This process includes three stages listed below.

- The bleaching stage: this stage includes three steps: bleaching, neutralizing, and washing. The purpose of the bleaching stage is to enhance the following dye application and the luster and appearance of fabrics.
- The dyeing stage: the auxiliary chemicals and dyestuffs are added in the dyeing batch. The dyeing process is carried out at ± 120^0C and at a pressure of 3 atmospheres for 60 minutes. After dyeing, the pressure is decreased from 3 to 1 atmosphere, together with decreasing the temperature to 80^0C. Most of the water is then discharged into the sewer system.
- The washing stage: the purpose of this stage is to remove the residual dyestuffs and chemicals in the fabric. The washing stage consisted of cold washing, hot washing with chemicals, and finally hot washing.

Figure 5.3 also shows the sampling points at which remaining concentrations and quantities of wastewater after each step are determined. In the dyeing process, the auxiliary and neutralization chemicals and dyestuffs were prepared according to the requirements of the color and type of fabric. A recipe of the dyeing process of the fabric with code G.TW.538 L5 is summarized in Table 5.2.

Table 5.2: The recipe of dyeing process of fabric G.TW.538 L5

Items		Quantity (kg)	Use purpose
Chemical A	Miralan HTW new	12.358	Auxiliary chemical
	CH_3COONa	6.179	Auxiliary chemical
	Sera gal p-lp	6.179	Increases uniform color for the dyeing process
	CH_3COOH	6.179	Neutralization
	Invalon DAM	4.943	Increases uniform color for the dyeing process
	Albegal SET (Ethoxylated alcoholic fat)	6.179	Increases uniform color for the dyeing process
Chemical B	Terasil Blue 3RL – 02	1.761	Dyeing with disperse dyestuff
	Terasil Red 5G	0.605	Dyeing with disperse dyestuff
	Terasil Yellow 4G	3.522	Dyeing with disperse dyestuff
	Lanaset Green B	0.587	Dyeing with acid dyestuff
	Lanaset yellow 2R	1.977	Dyeing with acid dyestuff
Chemical C	Vitex SP 59	12.358	Washing chemical
Chemical D	Biolit 2090	6.179	Bleaching chemical
	Na_2CO_3	3.090	Auxiliary chemical
Chemical E	CH_3COOH	3.090	Neutralization chemical

Source: The 28 Company- Agtex (2006)

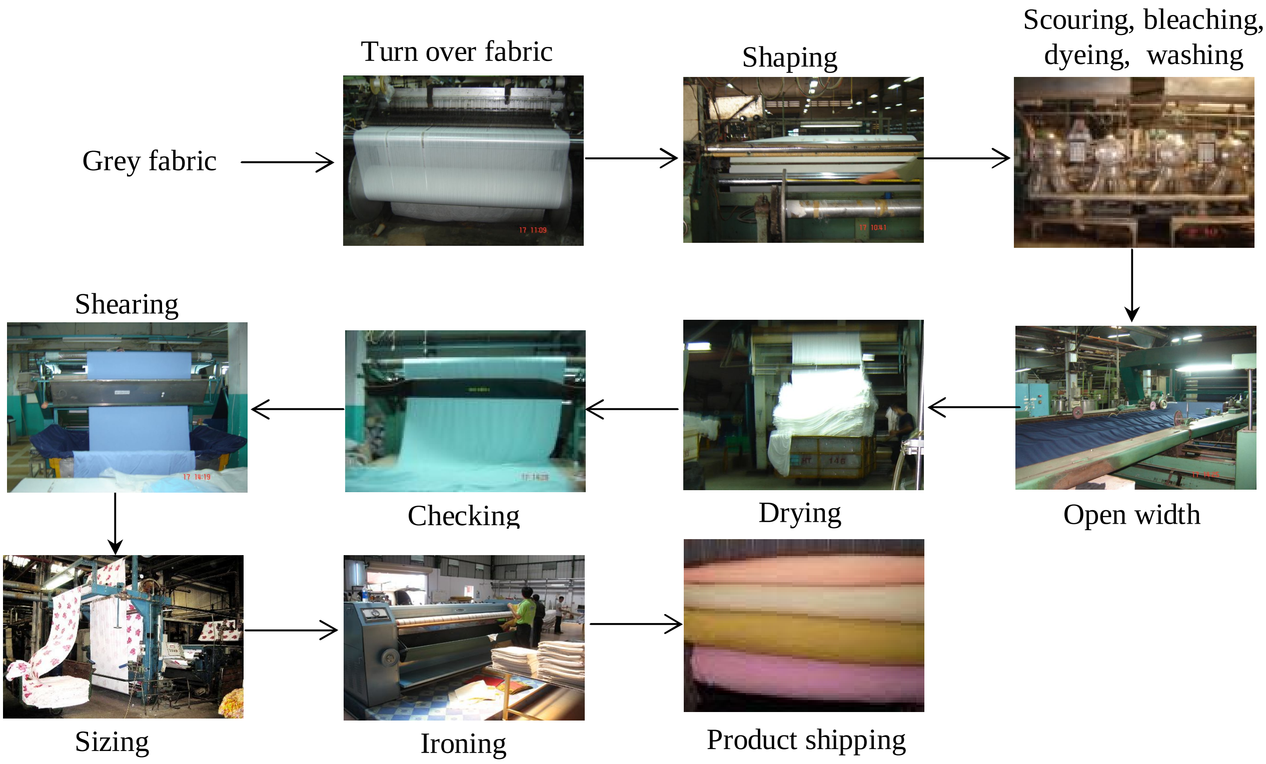


Figure 5.2: Flow chart of a dyeing batch process

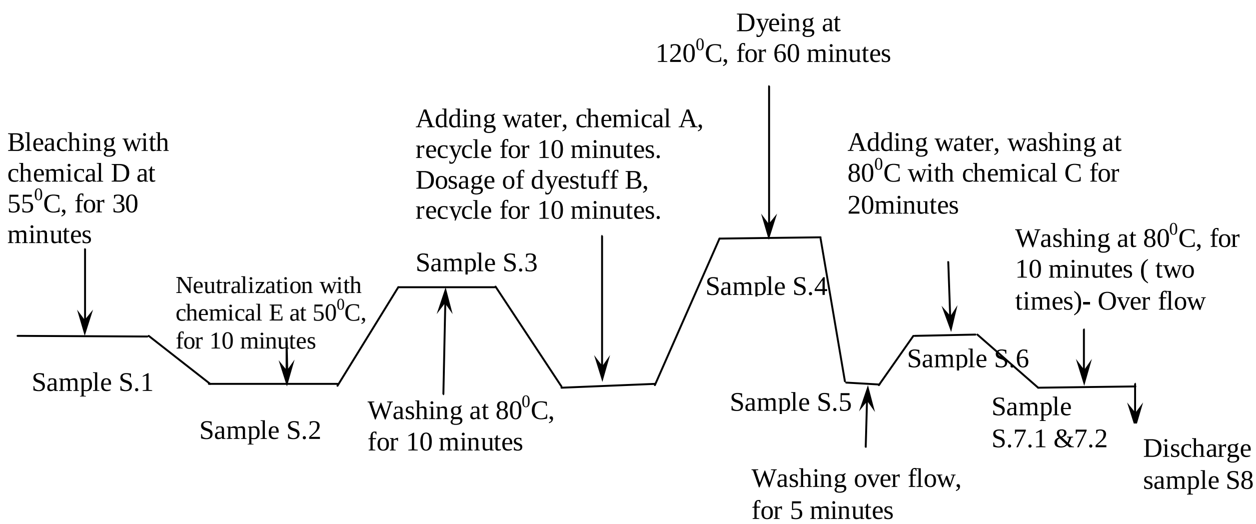


Figure 5.3: Flow chart of the dyeing process of blended fabric with code G.TW.538 L5 and sampling points

According to literature (chapter 2) the concentration of the main pollutants in batch dyeing process wastewater is usually higher than the concentrations in the wastewater from the continuous dyeing process.

Table 5.3 shows the composition of wastewater streams from the batch dyeing process for product G.TW.538 L5. The dyeing process was carried out with a Jet machine at high pressure. The quantity of blended fabrics in each dyeing batch was 620 kg (about 1,605 m^2) with a total water consumption of 52 m^3. The wastewater after the dyeing step (sample No. 4) has the highest concentration of pollutants, with a volume of about 5m^3/batch. The color intensity exceeded 78 times and the COD about 64 times the discharge standards. The low pH (4.6) of the wastewater was due to the requirements of dyeing process with acid dyes. All the washing wastewater after the dyeing step (samples 5 to 8) contained lower concentrations of pollutants compared to the bleaching, neutralizing and dyeing wastewater. For example, the COD of samples 5 to 8 gradually decreased from 6,400 to 1,520, 1,320, 240, and 95 mg O_2 /L, the color intensity also decreased, from 3,950 to 825, 1,020, 615, 235 and 60 Pt-Co. The bleaching and neutralizing steps produced high amounts of organic waste: 1,800 mg O_2/L after the bleaching step and 2,080 mg O_2/L after the neutralize step. From the recipe of dyeing process of the G.TW.538 L5 product it is clear that the organic wastes produced in both these steps are highly biodegradable compounds. After the neutralizing step the COD of the subsequent washing step (sample 3) decreased from 2,080 to 390 mg O_2/L and the color intensity from 120 to 27 Pt-Co. The total volume of wastewater generated from the dyeing process was about 47 m^3 (90% of the total water use) in which there was about 5 m^3 (10%) that did not need treatment (sample 8), 5 m^3 (10%) wastewater with a high pollution content in terms of color intensity and COD which really did need treatment (sample 4), and 37 m^3 (80%) with a low color intensity and biodegradable COD (remaining samples). The wastewater with biodegradable COD and low color intensity is can be pretreated with a biological process, which can result in a decrease of operational costs. From the results in chapter 3, ozone proved to be effective in the decolorization of high strength colored wastewater, generated from the dyeing step with disperse and acid dyes.

Figure 5.4 presents the operational costs and remaining color intensity after coagulation and oxidation processes of wastewater containing disperse and acid dyes. Compared with other treatment methods the ozone process was the best method regarding the operational costs and remaining color intensity with disperse and acid dyes wastewater.

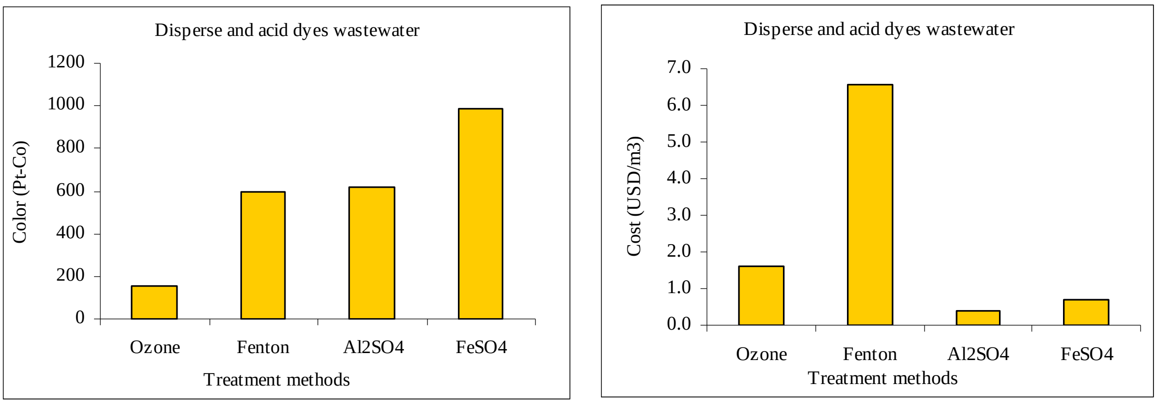


Figure 5.4: Operational costs and remaining color intensity after coagulation process (aluminum and ferric sulfate) and advanced oxidation processes (Fenton' reagent and ozone) of disperse & acid dyes wastewater

The 28 Company-Agtex (2005) produces 700 m^3 of wastewater per day. From this 700m^3 about 200 m^3 of wastewater originates from the batch dyeing process and the remaining 500 m^3 of wastewater is from the continuous dyeing process. According to the collected data and measured flow rates, the volumes of each wastewater stream originating from the batch dyeing process per day consist of:

- 20 m^3 of wastewater that can meet the discharge standards and/or can be reused in another process of the production;
- 20 m^3 of wastewater is characterized as high strength wastewater regarding color intensity and COD, which have to specially treated (after dyeing step),
- 160 m^3 of wastewater consists of highly biodegradable wastewater streams.

In order to assess the feasibility of two options, separated wastewater treatment and treatment of all wastewater, mixed and diluted, the operational costs of both options were estimated and are presented in Table 5.3. According to Table 5.3 the operational costs of separated wastewater treatment are lower than that of treatment of mixed wastewater streams.

Table 5.3: the estimated operational costs for treating separated wastewater streams and mixed wastewater

Volume wastewater	Stream No.1	Stream No.2	Stream No.3
(m^3)	20	20	160
Treatment method	Reuse	Coagulation and ozone	Activated sludge
Operational costs	-	(0.4US$/$m^3$+1.6US$/m^3) 2*20 = 40 US$/day	0.04*160 = 6.4 US$/day
Benefit reuse wastewater	0.24*20=4.8 US$/day		
Total operational costs for three wastewater streams	40 + 6.4 - 4.8 = 41.6 US$/day		
Operation cost for mixed wastewater	200 m^3/day * 0.3 US$/$m^3$ = 63 US$/day		

Note: 0.24 US$/$m^3$ is cost of water supply, 1.6 US$/$m^3$ is cost for treating wastewater with ozone, 0.04 US$/$m^3$ is cost for treating wastewater with activated sludge, 0.3 US$/$m^3$ for treating mixed wastewater (reference chapter 3, section operational costs)

In brief, separating the wastewater streams for individual treatment is economically feasible because the operational costs will decrease. For the dyeing batch process, the cost of separating wastewater can be decreased nearly 46% (approximately 29 US$ per day or 8,700 US$ per year in comparison with costs of mixed wastewater treatment (non-separation wastewater).

Table 5.4: The composition samples of wastewater (see figure 5.3) of the batch dyeing of product G.TW.538 L5

Parameters	Unit	S. 1 After bleaching	S. 2 After neutralizing	S.3 After washing	S. 4 After dyeing	S. 5 After overflow 1	S. 6 After washing 1	S.7.1 After overflow 2	S. 7.2 After overflow 2	S. 8 After washing 2	TCVN 5945:2005 Class B
Water consumption	Liter	6,600	5,500	5,500	5,500	7,000	5,500	5,500	5,500	5,500	
Temperature	^{0}C	52	46	74	76	45	75	74	74	32	40
pH	-	9.3	4.6	5.0	4.6	5.0	5.5	6.5	6.7	6.7	5.5-9
Suspended solid	mg/L	70			40	32	27	14			100
Electrical Conductivity	µS/cm	1,415	935	705	2,100	960	635	565	560	335	
SO_4^{2-}	mg S/L	84	40	39	196	16	92	50	64	52	
PO_4^{3-}	mg P/L	7.3	1.5	0.6	2.1	3.2	2.1	1.2	0.8	0.7	6
$N\text{-}NH_3$	mg N/L				15.1		0.8			-	
N-Org	mg N/L				150		10.6			0.9	
N-total	mg N/L				165		11.6			0.9	30
COD_{total}	mg O_2/L	1800	2080	390	6,400	1,520	1,320	240	96	88	80
$COD_{coll\ \&\ dissolved}$	mg O_2/L				6,270		1,195			76	
$COD_{dissolved}$	mg O_2/L				5,610						
Color apparent	Pt-Co	730	117	27	3,950	825	1,020	614	234	62	
Color centrifuged	Pt-Co	250	75	17	3,360	405	620	337	201	45	50
Color filtered 1.6µm	Pt-Co				3,400		440			24	
Color filtered 0.45 µm	Pt-Co				2,140						
Turbidity	FAU	90	10	3	405	70	105	65	25	8	

Note: TCVN 5945:2005: Industrial wastewater-discharge standards, class B is water quality standards for industrial effluents discharged into water resources which are not used for potable water production

Continuous dyeing process

The continuous dyeing process consists of 5 main stages: singeing & pad batch, bleaching, dyeing, pad-steam, and sizing & finishing stages. The material flow for a typical continuous dyeing process of blended fabric coded G.TC.219, which is a mix of 35% cotton and 65% polyester dyed with vat dyes, is described in Table 5.5. The quantity of blended fabrics dyed per continuous dyeing process is 347 kg/run. The amount of all inputs (water, chemicals and dyestuffs) used during the continuous dyeing process were recorded.

Various wastewater streams generated by different stages were analyzed in terms of flow rate, temperature, pH, color, and COD. Tables 5.6 (a) and (b) show the main composition of wastewaters and flow rates of three main stages of wastewater generation in the continuous dyeing process.

Table 5.5: Material flow chart for a run of a typical continuous dyeing process of blended fabric coded G.TC.219

Stage	Process	Input	Output pH	Output Color (Pt-Co)	Output COD (mgO_2/L)	Output T (^0C)
Stage 1 **Singeing, pad bath**	Turn over fabric	347 kg grey fabric				
	Singeing					
	Chemical immersion 30^oC	1000 L H_2O 6.5 kg Invatex MD 20 kg NaOH 25 kg H_2O_2 9 kg Tinoclarite CBB				
	Pad bath 16 hours					
Stage 2 **Bleaching**	Washing 1 (95^oC)	1500 L H_2O	13	146	1015	82
	Washing 2 (95^oC)	1500 L H_2O	12.5	78	770	86
	Chemical immersion	350 L H_2O 16.41 kg NaOH 3.73 kg Biolit 2090				
	Pad-steam, 20 min (99^oC)					
	Washing 3 (95^oC)	1500 L H_2O	5.0	2015	40	85
	Washing 4 (95^oC)	1500 L H_2O 4.88 kg CH_3COOH	4.7	3025	27	86
	Washing 5 (60^oC)	1500 L H_2O	4.8	2380	5	86
	Drying					
	Chemical immersion	1500 L NaOH	Alkalinity: 40g $CaCO_3$/L			
	Pre setting					
	Washing 6 (60^oC)	3000 L H_2O 1.51 kg Invadine MR	4.5	450	10	70
	Washing 7 (80^oC)	3000 L H_2O 4.92 kg CH_3COOH	4.2	780	15	70
	Washing 8 (70^oC)	3000 L H_2O	4.8	470	10	60

Stage	Process	Input	Output pH	Output Color (Pt-Co)	Output COD (mgO_2/L)	Output T (^0C)
	Drying					
Stage 3 **Dyeing**	Dyestuffs immersion	250 L H_2O 0.92 kg Cibanon Green BF MD 2 kg Cibanon Golden Yellow RK MD 3.55 kg Cibanon Olive S-01 MD 0.49 kg Cibaflow PAD 3.67 kg Irgapadol PT				
	Drying by UV					
	Drying 1 (95^oC)					
	Drying 2 (120^oC)					
	Drying 3 (120^oC)					
Stage 4 **Pad-steam**	Chemical immersion	390 L H_2O 5.89 kg $Na_2S_2O_4$ 4.19 kg NaOH 0.26 kg Vitex DN				
	Pad steam (104^oC)					
	Washing 9 (35^oC)	3360 L H_2O	10.4	420	60	40
	Washing 10 (50^oC)	505 L H_2O 1.045 kg H_2O_2 2.09 kg Vitex SP 59	10.9	320	1345	40
	Washing 11 (50^oC)	505 L H_2O 1.045 kg H_2O_2	10.5	165	490	40
	Washing 12 (95^oC)	505 L H_2O	10.5	137	255	95
	Washing 13 (95^oC)	505 L H_2O	9.9	92	135	95
	Washing 14 (95^oC)	1260 L H_2O	9.7	75	50	80
Stage 5 **Sizing and finishing**	Drying					
	Chemical immerse sizing	340 L H_2O 0.068 kg CH_3COOH 13.53 kg Vitex SN	8.3	30,860		30
	2x drying (130^oC)					
	4x drying (130^oC)		End product 350 kg fabric			

The total water used in the continuous dyeing process of blended fabric G.TC 219 was about 27.9 m^3/shift (this volume does not include the 3.49 m^3 water used for chemical dissolution). Out of the 27.9 m^3 water 24.4 m^3 was used for the washing steps which accounts for 87% of the total water consumption. In total 25.218 m^3 wastewater (90% of the water supply) was produced from one shift of the continuous dyeing process. Wastewater was generated from the bleaching stage (18 m^3, 64% of total wastewater volume), the pad-steam stage (7.2 m^3, 28.5% of total wastewater volume) and the sizing & finishing stage (18 L). However, some of these wastewater streams exceeded the discharge standards, but some washing steps did meet discharge standards. In the continuous dyeing process, the bleaching stage consumed much more water than the pad-steam stage and sizing & finishing stage. The results from the flow chart showed that the organic matter pollution, expressed as COD, mainly came from the bleaching stage. The composition of bleaching stage washing wastewater (washing samples 1-8) had a high COD in the range of 420-3,025 mg O_2/L, and the pH was very high or low (4.7-13.0). However, these samples had low color intensity (10-145 Pt-Co). With these characteristics of a high biodegradability and low color intensity biological treatment can be applied to treat this wastewater at low operational costs. Also energy can be recovered from the biological treatment by using anaerobic treatment. In addition, the volume of wastewater of the mercerizing unit of the bleaching stage generated about 500 L/batch, and the only pollutant in this wastewater was sodium hydroxide solution resulting in a high alkalinity of the sample. This solution can be collected for reuse in other manufacturing processes or for pH adjustment purposes in the wastewater treatment system or for treating waste air from the boiler.

The results of the pad-steam stage wastewater showed that the total volume of wastewater generated in this stage was about 8 m^3 of which only 2.0 m^3 (washing 10, 11, 12 and 13) had a color intensity of 250-1,350 Pt-Co, thereby exceeding the discharge standards TCVN 5945:2005, in average 5-50 times. In these streams, the wastewater from washing 10 produced the highest color (1,350 Pt-Co). In contrast with the wastewater from the bleaching stage, the pad-steam wastewater had high color intensity and low COD. Therefore, for these streams the color needs to be treated. For the remaining 6 m^3 wastewater of the pad-steam stage (washing 9, 14, and 15) all parameters met the discharge standards. The pH values of all washing wastewaters from the pad-steam stage were over 8.8. These wastewater streams can be directly reused for other units within production process.

The sizing & finishing stage wastewater had the highest COD concentration with a COD of 30,800 mg O_2/L. However, the volume of wastewater was very low (18 L/batch).

The feasibility of separated treatment of wastewater streams was assessed by estimation of the operational costs. The estimated cost for separation of wastewater streams is shown in Table 5.7. The results indicated that separating wastewater streams of the continuous dyeing process reduces the volume of wastewater, saves chemicals and water, and results in a decrease of operational costs. For the continuous dyeing process the benefit is about 122 US$ per day or 36,600 US$ per year.

5.6 Conclusion

In the manufacturing process of textile companies large volumes of water and chemicals are consumed, resulting in generation of large volumes of wastewater with high pollution concentrations. In general, three quarters of the total water consumption is for the washing processes. Difficulties in treatment of the wastewater mostly arise from mixing wastewaters from different process steps that have a variety of concentrations of chemicals and dyestuffs. The treatment of the mixed wastewater cannot meet the discharge standards although the operation costs of the treatment are as high as 15% to 30% of the production costs. From the results obtained, some conclusions can be drawn regarding the separation of wastewater streams. The separation of wastewater streams in textile companies seems a suitable measure for it facilitates treatment of each wastewater stream separately in an optimal way. The separation of wastewater streams allows not only the reuse of water and chemicals, but also for the effluent to meet the discharge standards. The reuse of water and chemicals will save water, chemicals and energy use, and reduces the quantity of the discharged harmful compounds as well as exploitation of natural resources. Even when the operational costs are not reduced by separating the waste streams, it can still be an attractive option. Undesirable influences can be avoided in specific treatment processes compared to treating the mixed wastewater. The similar results are found in literature. Mattioli et al. (2002) reported on water reuse without treatment of water used in rinsing steps. Research on multiple use of water in textile industry, Rott (2003) presented advantages of the split flow treatment compared to mixed wastewater treatment; they were material recovery, higher recycling rate and higher process water qualities at decreased costs.

In the case of the 28 Company-Agtex, an average of 700 m^3 wastewater/day was generated from which 130 m^3 water and 10 m^3 of NaOH solution can be saved. About 350 m^3 of wastewater has good biodegradability. Only 40 m^3 of wastewater had a high color intensity and COD which needs special treatment. The 28 Company-Agtex can save 43,020 US$ per year by separating waste streams. The disadvantages of the separation of wastewater streams are space for wastewater storage and an increase in complexity of the system for split flows.

Table 5.6 (a) Composition of wastewater of the bleaching stage from the continuous dyeing process of blended fabric of the 28 Company-Agtex

Parameters	Unit	TCVN 5945:2005		Bleaching stage								
		Class A	Class B	Washing 1	Washing 2	Washing 3	Washing 4	Washing 5	Mercerizing	Washing 6	Washing 7	Washing 8
				[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Temperature	^0C	40	40	82	86	85	85	86	74	70	70	60
pH	-	6 – 9	5.5 – 9.0	13.0	12.5	5.0	5.0	4.7	14.0	4.5	4.3	4.5
Turbidity	FAU			16	9	4	4	3	3	4	3	3
Color	Pt - Co	20	50	145	75	40	40	30	30	10	15	10
COD	mg O_2/L	50	80	770	1015	2015	2015	3025	420	450	780	470
Alkalinity	mg$CaCO_3$/L			665	2200	-	-	-	40,000	-	-	-
Water supply	Liter							20,000				
Wastewater	Liter							18,000				

Note: Industrial wastewater – discharge standards (TCVN 5945:2005), class A is water quality regulations for discharged into water resources which are used for potable water production and class B is water quality regulations for discharged into water resources which are not used for potable water production.

Table 5.6 (b) Composition of pad–steam and sizing& finishing stages wastewater from the continuous dyeing process of the 28 Company-Agtex

Parameters	Unit	TCVN 5945:2005		Pad – steam stage							Sizing & finishing stage
		Class A	Class B	Washing 9	Washing 10	Washing 11	Washing 12	Washing 13	Washing 14	Washing 15	
				[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]
Temperature	^0C	40	40	40	75	95	95	95	80	60	30
pH	-	6.0 - 9	5.5 - 9	10.4	10.9	10.5	10.5	9.9	9.7	8.8	8.3
Turbidity	FAU			8	179	64	34	33	17	5	-
Color	Pt - Co	20	50	50	1,350	490	250	135	50	8	-
COD	mg O_2/L	50	80	420	320	165	137	92	73	68	30,860
Alkalinity	mg$CaCO_3$/L			100	420	225	125	75	70	70	-
Water supply	Liter					8,000					18
Wastewater	Liter					7,200					

Note: Industrial wastewater – discharge standards (TCVN 5945:2005), class A is water quality regulations for discharged into water resources which are used for potable water production and class B is water quality regulations for discharged into water resources which are not used for potable water production.

Table 5.7: Estimated operational costs of wastewater treatment for separated streams and mixed wastewater

	Bleaching stream (1)		Pad -steam stream (2)		Sizing & finishing stream (3)
Total wastewater: 500 m^3/day:	Washing	Mercerizing	Dyeing	Washing	360 kg/day
	340	10	40	110	
Treatment method	Activated sludge	Reuse NaOH	Oxidation with Fenton's reagent	Water reuse	Burningcycling
Operational costs	0.04US$*340= 13.3 US$/day	-	0.7 US$*40= 28 US$/day	-	0.35US$*360 kg = 127 US$/day
Benefit of reuse chemical and wastewater	-	26.5US$*10 = 265 US$/day	-	0.24US$*110 = 26.4 US$/day	
Total benefit	265+26 = 291 US$/day				
Total operation cost	13.3 + 28 +127 = 168 US$/day				
Benefit of separation of wastewater streams	291-168 =122 US$/day				
Operational costs for mixed wastewater	500m^3/day * 0.3 US$/$m^3$ =150 US$/day				

Note: cost of wastewater treatment 0.24 US$/$m^3$; cost of NaOH solution 26.5 US$/$m^3$; cost of sizing waste incineration 0.3 US$/kg; cost of wastewater ozone treatment 1.6 US$/$m^3$; cost of wastewater activated sludge treatment 0.04 US$/$m^3$; cost of mixed wastewater treatment 0.3 US$/$m^3$(chapter 3 and 4, section operational costs)

Chapter 6

Greening production in the textile industry: The case of Thanh Cong Company

6.1 Introduction

This chapter investigates the greening of textile production by developing a model for Thanh Cong Joint-stock Company, herein after called Thanh Cong Company (TMC). This company is a typical large, state-owned Vietnamese textile and garment industry, regarding both the scale of production and the high level of environmental pollution. The chapter starts with a general introduction of the current situation with respect to manufacturing and environmental protection of Thanh Cong Company (sections 1 and 2). Section 3 provides an extensive analysis of options for cleaner production and pollution prevention in this company, applying experimental results from chapter 3, 4 and 5. Subsequently, using the various options a model for greening production is proposed for the Thanh Cong Company, based on ideas of cleaner production and industrial ecology. The last part of this chapter focuses on the actual and potential roles of actor networks in supporting the actual implementation of the designed greening production model in the Thanh Cong Company.

6.2 General description of the company

In the middle of 1960s, the Thanh Cong Company was established and located in Hochiminh city, Tan Phu District, Vietnam. This location is not situated in an industrial zone; it is in a semi-rural area and not far away from residential areas, so its manufacturing process influences these areas. Presently, Thanh Cong Company has 21 departments and 5 plants with a total labor force of 4,200 people. It operates under the Vietnam Textile and Garment Group (VINATEX), of the Ministry of Industry and Trade.

The products made at Thanh Cong Company include a wide range of yarns, woven and knitted fabrics, knitted wears and sport wears. These products supply both domestic and foreign markets, as products are being exporting to American, European and Japanese markets. Table 6.1 gives the company's average monthly production output.

Table 6.1: Monthly average company production

Products	Unit	Quantity
Yarn (cotton, polyester, cotton/polyesters)	ton	500
Dyed yarn	ton	50
Woven fabric	m	1,235,000
Knitted fabric	m	1,850,000
Garment products	pieces	585,000

Source: TCM (2005)

In recent years, the company's yearly turnover has been more than 1,000 billion VND (approximately 62,500,000 US$), from which the export turnover was 65% of the total turnover; the remaining 35% comes from the domestic market. A scheme of the company organization is depicted in Figure 6.1. This scheme shows that, although the Thanh Cong Company is a large textile company, it does not have a specialized department for environmental management.

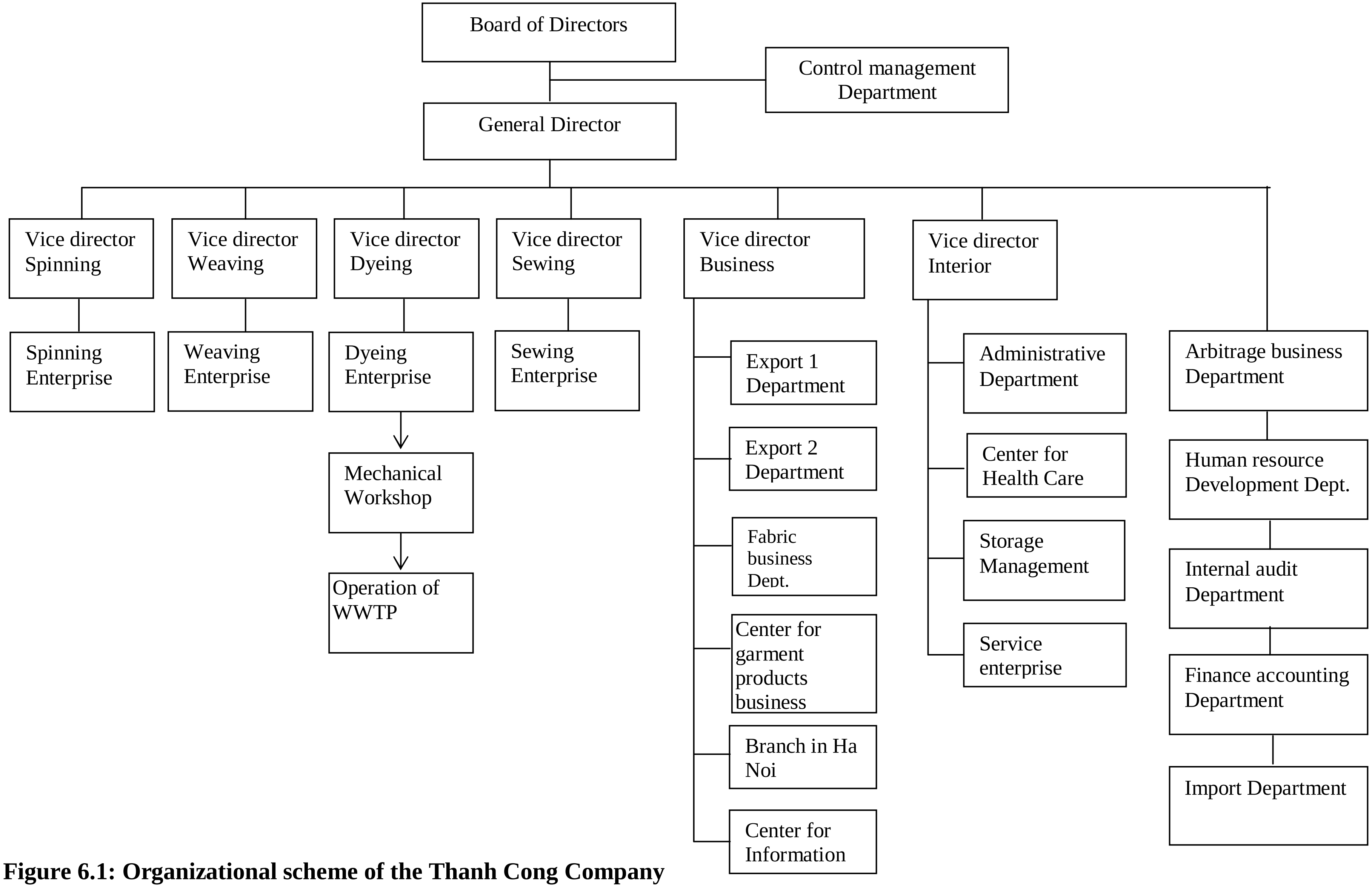


Figure 6.1: Organizational scheme of the Thanh Cong Company

Demand of raw material, water and energy

Raw materials

The raw materials used in the Thanh Cong Company are cotton fiber, dyestuffs, auxiliary and basic chemicals. Presently, nearly 100% of the raw materials for production inputs are imported from foreign countries, mainly from Japan, the United States, Switzerland, the EU, Taiwan and China. The annual demand for cotton fiber is about 7,000 tons; for chemicals and dyestuffs it is in the range of 4,000-5,000 tons (TCM 2005).

Water

According to our survey results of the production processes at the Thanh Cong Company, the water demand is estimated at 8,000-9,000 m^3 per day (Loan 2005), mainly coming from groundwater sources.

Energy

Thanh Cong uses two sources of energy: fuel and electricity. Fuel is consumed in considerable amounts, mainly for the boiler and oil heater. Besides that, the company also has a demand for gasoline for transportation means. The amount of fuel used per year is given in Table 6.2.

Table 6.2: Amount of fuel used per year in Thanh Cong Company

Fuel	Unit	Quantity
Diesel oil (DO), sulphur content 0.25%	Liter	290,000
Fuel oil (FO) sulphur content 0.5%	Liter	790,000

Source: TCM (2005)

Electricity is used for lighting and electric equipment. According to company information, Thanh Cong's electricity consumption is about 3,000,000 kWh per month (TCM 2005).

6.3 Current environmental situation

In recent years, the Thanh Cong Company has started to focus on environmental protection performance. It invested in a wastewater treatment facility in the year 2005 and joined the energy efficiency program of Energy Conservation Center in Hochiminh City. The current situation of the company's environmental performance follows below.

6.3.1 Air emissions

Like all textile and garment companies, the dyeing plant is the major contributor to air pollution of the Thanh Cong Company. Pollutants generally come from operation of boilers and oil heaters. The composition of air pollution is shown in Table 6.3. The concentration of particulates at all sampling points exceeds the permissible values for air quality – industrial emission standards (TCVN: 5939-2005, class B). The SO_2 concentration in the smokestacks of boiler No.1, of oil heater No.3 and of boiler No.2 exceeds many times the standards. For the other boilers and oil heaters, SO_2 concentrations fall within the permissible values of the standard. The results indicate that the source of air pollution is not treated adequately. The air quality of the working environment at some plants and workshops of the Thanh Cong Company is presented in Table 6.4. Almost all parameters, such as particulates, SO_2, NO_2 and CO, meet the working environment standards of the Ministry of Health TCVSLD: 3733-2002.

Table 6.3: Composition of polluted air from smokestacks of boilers and oil heaters

Sampling points	Temperature (^0C)	Dusts (mg/m^3)	NO_2 (mg/m^3)	SO_2 (mg/m^3)	CO (mg/m^3)
Oil heaters					
No.1 - After treatment	115	255	235	660	175
No.2 - After treatment	115	215	125	410	140
No.3 - After treatment	175	430	820	1,420	610
Boilers					
No.1 - After treatment	90	400	395	680	333
No.2 - After treatment	90	215	145	380	120
No.3 - After treatment	90	303	630	330	285
TCVN5939:2005, class A	**-**	**400**	**1,000**	**1,500**	**1,000**

Source: Loan (2005); TCVN 5939:2005, class A: Air quality: maximum allowable concentration of inorganic substances and dusts for air pollution for enterprises in operation.

Table 6.4: Composition of polluted air in some plants of the Thanh Cong Company

Sampling points	Particulates (mg/m^3)	SO_2 (mg/m^3)	NO_2 (mg/m^3)	CO (mg/m^3)
Sewing enterprise No.6	0.20	0.18	0.10	0.55
Spinning enterprise No.6	0.30	0.25	0.18	1.10
Weaving enterprise	0.20	0.30	0.15	1.20
Dyeing enterprise	0.10	0.15	0.08	0.25
Boiler area	0.45	1.10	0.95	5.70
TCVSLD 3733-2002	1.0	10	10	40

Source: Centema (2008); TCVSLD 3733-2002: Air quality – maximum allowable concentration standards at the working place (regulation of Ministry of Health)

6.3.2 Noise pollution

Noise is a main pollution source for the weaving process of the Thanh Cong Company. Noise generally comes from weaving equipment; the noise levels inside weaving plants are about 85-90 dB, with the highest value at 95 dB. The noise level at the weaving enterprise usually exceeds the permissible value of 85 dB for the working environment quality (Standards of the Ministry of Health). The noise level in the spinning plant is lower than in the weaving plant; it is in the range of 80-87 dB and reaches the highest level at 87 dB. Noise is not a major issue for the dyeing plant, compared to the weaving and spinning plants. The noise level inside the dyeing enterprise is in the range of 80-82 dB and meets the noise level standard. In particular, at areas with high noise levels the workers are equipped with ear protecting devices to minimize the influence of noise on their health.

6.3.3 Thermal pollution

Among the plants of Thanh Cong Company, the dyeing enterprise usually has the highest indoor temperature, especially in dyeing and boiler areas. The temperature ranges from 33-34^{0}C. The dyeing and finishing processes are carried out at high temperature (160-180^{0}C) and the boiler area harbors many thermal machines. For the spinning plant, the average indoor temperature in the workshops is about 32^{0}C, however there are some areas with temperatures of 33^{0}C, which exceed the permissible limit of the standard TCVSLD 3733/2002/QD-BYT (permissible limit is 32^{0}C). The weaving plant has the lowest indoor temperature among all plants; the average temperature is about 31^{0}C. The high temperature at working places affects worker health. Presently, the prevention of thermal pollution at Thanh Cong Company is only managed through airy work areas with fan systems.

Air pollution from Thanh Cong Company is not a major and significant issue. The air quality of the working environment falls within the permissible standards. Only particulates and SO_2 generated from boilers and oil heaters of the dyeing enterprise need suitable treatment to minimize the effects on worker's health and environment.

6.3.4 Wastewater

Industrial wastewater

Among the plants of Thanh Cong Company, dyeing processes use a huge volume of water, up to 70-75% of the total water demand of the entire company. Besides, the dyeing enterprise also consumes a large variety of chemicals and as a result it discharges a large amount of wastewater with high pollution levels. The company built a centralized wastewater treatment facility with a capacity of 5,000 m^3/day and brought it into operation in December 2005. The applied treatment technology was a combination of physical/chemical (coagulation/flocculation), biological (activated sludge) and adsorption processes (with activated carbon). Although the wastewater treatment plant was constructed as a relatively complete system, it has not operated stable and with large efficiency. The reasons are that wastewater contains a complex mixture of various kinds of chemicals and dyestuffs which are difficult to treat. Coagulation/flocculation is the most commonly used process for the removal of color, but it is not effective for the extreme variability in used dyestuffs. Figure 6.2 presents the wastewater treatment system. In Table 6.5 the composition of the wastewater before and after treatment is given. Treated wastewater exceeds the permissible values of the Vietnamese standard (TCVN: 5945-2005, class B): color exceeds the standard value 47 times, COD 1.5 times, Fe_{total} 7.6 times and SS 1.3 times. The other parameters, such as total nitrogen and phosphor, meet the permissible values. Each day, treated and untreated wastewater from the Thanh Cong Company is discharged into Tham Luong canal and contributes to water pollution of this canal, which is seen as one of the most polluted canals of Hochiminh city.

Table 6.5: Composition of wastewater of the Thanh Cong Company before and after treatment

Parameters	Unit	Before treatment	After treatment	TCVN 5945:2005, class B
pH	-	9.6	7.7	5.5 – 9.0
True color, at pH = 7	Pt-Co	530	240	50
Apparent color, at pH = 7	Pt-Co	900	2,360	50
SS	mg/L	40	170	100
COD	mgO_2/L	240	125	80
BOD_5	mgO_2/L	100	25	50
N_{total}	mg/L	7.4	18.8	30
P_{total}	mg/L	2.8	2.8	6
SO_4^{2-}	mg/L	965	1,170	-
Fe_{total}	mg/L	6.5	38.3	5
Cr_{total}	mg/L	0.018	Not detected	1.10
Mineral oil	mg/L	5.2	3.2	5

Source: Centema (2008), TCVN 5945-2005, class B: water quality standards for industrial effluents discharged into surface water resources which are not used for potable water production

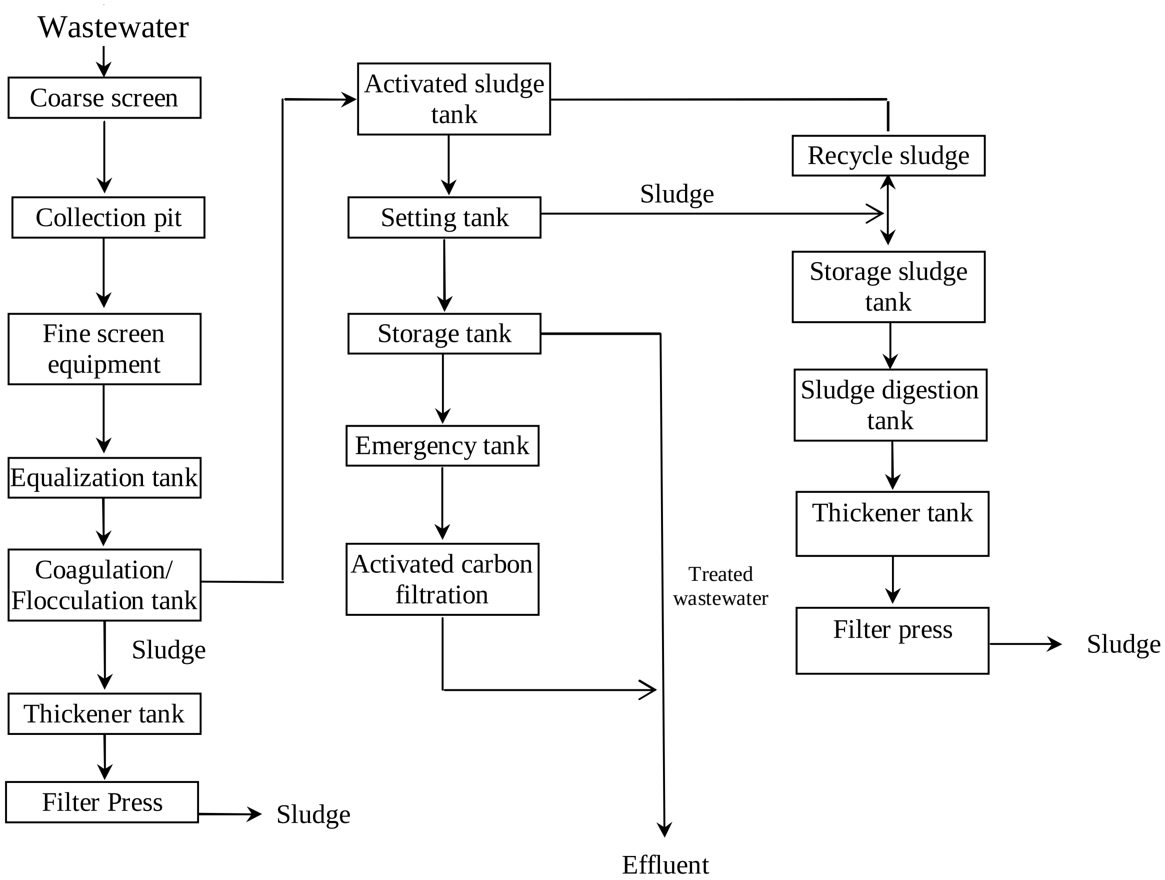


Figure 6.2: Diagram of wastewater treatment technology at Thanh Cong Company

Domestic wastewater

Sources of domestic wastewater are the canteen and toilets. The total flow rate of domestic wastewater is about 150 m^3 per day. Black wastewater is treated by a septic tank and after that directly discharged into Tham Luong canal. Grey wastewater flows directly into Tham Luong canal without treatment.

6.3.5 Solid waste

Solid waste comprises of two types: domestic and industrial waste. Domestic solid waste is generated mainly in canteens and a small quantity in offices. The quantity of generated domestic solid waste is about 3 tons/month and collected by Nhan Huong Ltd., Co. Industrial waste is divided into two types: non-hazardous and hazardous industrial waste. The non-hazardous waste comprises fabric scraps, thread scraps, packaging paper and cardboard and metal scraps. The estimated quantity is about 3 tons/month. All non-hazardous wastes are sold to waste purchasing units for recycling. The hazardous waste includes sludge, waste oil, chemical and oil contaminated cloths and fluorescent lamps. These hazardous wastes are collected and treated by Tho Nam Sang Co., Ltd. The quantity of generated solid waste per month of Thanh Cong Company is presented in Table 6.6.

Table 6.6: Quantity of solid waste generated per month

Items	Quantity (kg)
Hazardous industrial waste	**2,820**
Sludge	2,000
Waste oil	500
Chemical and oil contaminated cloth	100
Packing infected chemical and oil	200
Spoilt fluorescent lamp and electronic waste	100
Non-hazardous industrial waste	**6,000**
Scrap of yarns and fabrics, plastic, carton, paper	3,000
Cinder	3,000
Domestic solid waste	**3,000**

Source: TCM (2008)

Through the survey of the current environmental situation at Thanh Cong Company, it can be concluded that wastewater and air pollution, such as SO_2 and particulates, create the most pollution problems. These pollutions affect directly the health of people working in the factories and those living in residential areas.

6.4 Cleaner production/pollution prevention

The site survey on Thanh Cong Company shows that production processes are generating much more waste than necessary, which has a negative impact on the company but also on the environment. This opens opportunities to implement cleaner production and pollution prevention at Thanh Cong Company. This section first analyzes production processes in more detail to determine mass balances and secondly, assesses cleaner production options for improving the present environmental performance.

6.4.1 Production process and its waste stream

Thanh Cong Company is a leading textile and garment industry, with a closed technological process comprising four main sub-processes: yarn fabrication, fabric production, dyeing & finishing and sewing. Through a survey of the entire production process of Thanh Cong Company, it was found that the dyeing enterprise is generating significantly more waste than the other ones. Therefore, this enterprise was selected for implementing cleaner production options. A mass balance of material, energy and emissions within the dyeing process should be made before identifying options to reduce waste discharge. In order to give data on water, chemical and energy use, a general scheme of the dyeing process together with generated wastewater streams is presented in Figure 6.3.

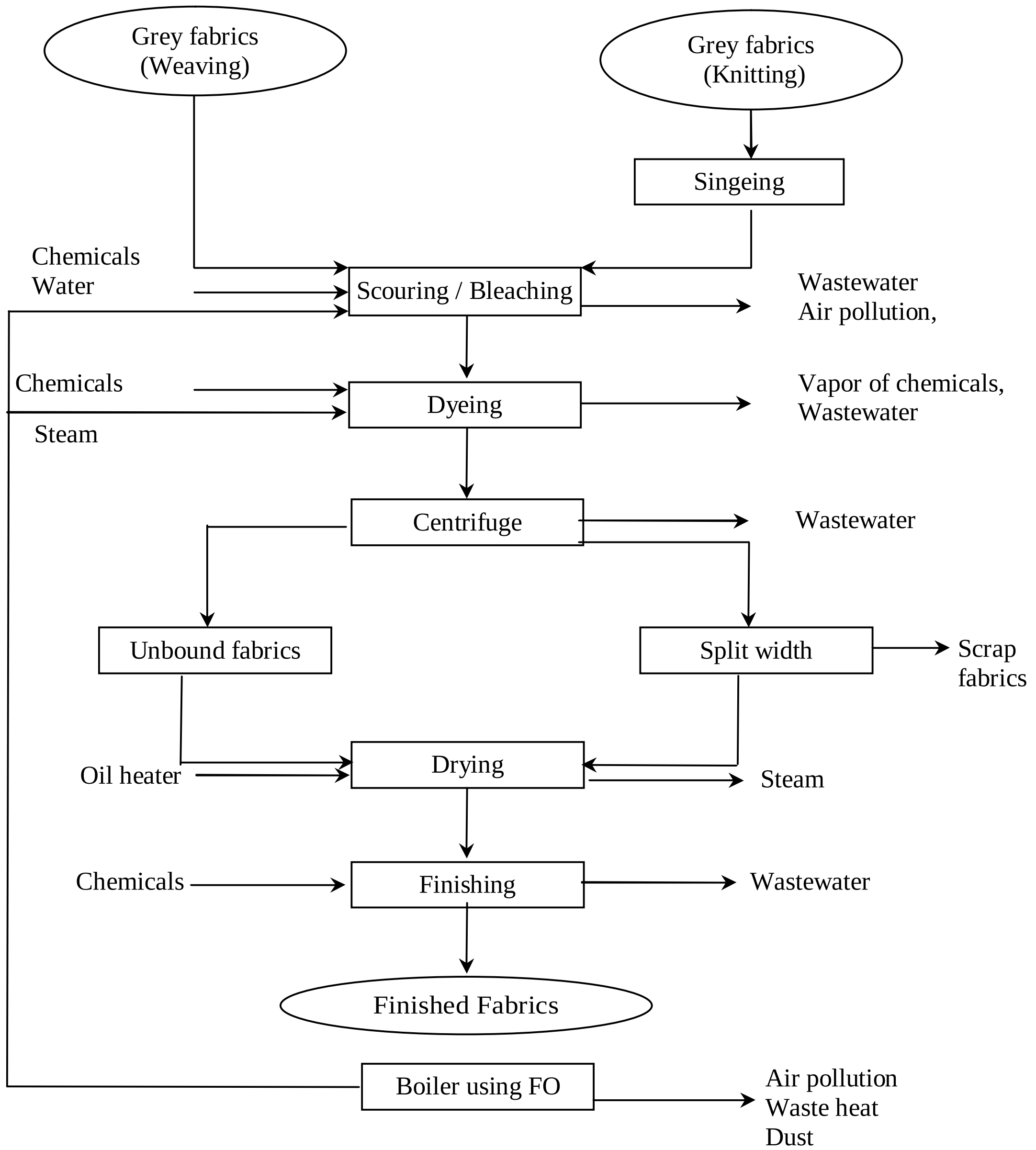


Figure 6.3: Flow diagram of dyeing process and waste streams

6.4.2 Methods for determining water, chemical and energy consumption

Indicator factors

A number of indicators can be used to determine material consumption and loss in each step of the production process. If the indicator concentration in the outflow is large, it points at inefficiencies in the production process. If the concentration remains low, the process performs better. Specific indicators in consumption of water, auxiliary chemicals and dyestuffs are:

- Alkalinity for the scouring step;
- COD_{total} for the neutralization step using acetate acid and COD_{coll} for dyeing step with auxiliary chemicals and not-dissolved dyestuffs;
- Color for the dyeing step with dissolved dyestuffs;
- Total dissolved solids, suspended solids (SS), volatile suspended solids (VSS) for the dyeing step with not-dissolved dyestuffs;
- H_2O_2 for the bleaching step;
- SO_3^{2-}, SO_4^{2-} for dyeing steps.

Analytical methods

The analyses followed the Standard Methods for the Examination of Water and Wastewater (APHA 1995), as described in chapter 3.

Method of determination of used dyestuffs

In order to carry out a mass balance in the dyeing process, the calibration method was applied for determining consumed and remaining dyestuffs after the dyeing step. This method is based on measuring the strength of color with known dyestuff concentrations. The strength of the color is measured by UV/VIS spectrophotometer with optimal wave length, which was obtained from detecting the absorbance maximum in the range of 200-900 nm for each dyestuff. The six calibration equations for the used six dyestuffs in the two dyeing processes are enclosed in Appendix 1. According to the determined calibration equations, the concentration of dyestuffs before and after the dyeing process can be calculated. From the consumption of dyestuffs the efficiency of the dyeing processes is calculated.

6.4.3 Mass balance of water, chemicals and energy

Mass balances are necessary for identifying waste minimization options. The first task in a mass balances is to make a flow diagram of the dyeing process. In the mass balance, the inputs and outputs of each manufacturing process step are determined. In addition, tests are carried out to estimate efficiency and loss of materials that occur during the production process. As the dyeing technology is very complicated, it is difficult to provide exact losses of material. However, estimation of consumption of raw materials and loss of materials can be made through the different indicators (see next section). The dyeing plant of Thanh Cong Company applies a dyeing batch method (exhaust method), in which several steps are made on a dyeing machine. Through observation and collected data, the mass balance focuses on two main dyeing processes, which include the largest quantity of dyes in Thanh Cong Company:

- Dyeing process of blended cotton/polyester (T/C) fabrics with red color: a dye batch is for 227 kg fabrics with two stages in the dyeing process: first the dyeing of polyester with dispersed dyes and then the dying of cotton with reactive dyes.
- Dyeing process of cotton with blue color: a dye batch is for 678 kg fabrics using reactive dyes.

Dyeing process of blended cotton and polyester fabrics

Inputs and outputs of various stages in the dyeing process of blended cotton/polyester fabrics are described in Table 6.7. It shows that the textile production process is very complicated, especially when customers put higher requirements on the finished products.

Table 6.7: Listing of inputs and outputs of the T/C dyeing and finishing process

Input	Characteristics input	Process	Output	Characteristics output
227 kg grey fabric				
2,300 L H_2O 460 g VITEX SL 11,500 g NaOH 32%	pH: 6.2 COD_{total}: 488 mg O_2/L Alkalinity: 4.6 g $CaCO_3$/L	Scouring/ bleaching	1,300 L H_2O at 68°C	pH: 12.4 COD_{total}: 1317 mg O_2/L Alkalinity: 1.89 g $CaCO_3$/L
2,300 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Hot washing 1	2,300 L H_2O at 41°C	pH: 11.6 TDS: 828 mg/L COD_{total}: 385 mg O_2/L Turbidity: 38 FAU
1,300 L H_2O 1,380 g CH_3COOH	pH: 3.5 COD_{total}: 640 mg O_2/L	Neutralization 1	1,300 L H_2O at 44°C	pH: 6.9 COD_{total}: 115 mg O_2/L
3,920 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Washing 1	3,920 L H_2O at 37°C	pH: 6.5 TDS: 175 mg/L Turbidity: 1 FAU
1,300 L H_2O 1.15 kg Sunholt RM 340 805 g Sandasid PBN Liq	pH: 6.2 TDS: 219 mg/L TSS: 768 mg/L VSS: 310 mg/L COD_{total}: 675 mg O_2/L	Dyeing with POLY	1,300 L H_2O at 75°C	pH: 3.7 TDS: 452 mg/L TSS: 2,507 mg/L VSS: 1,868 mg/L COD_{total}: 3,740 mg O_2/L COD_{SS}: 31 mg O_2/L $COD_{col\&diss}$: 3,710 mg O_2/L COD_{col}: 312 mg O_2/L COD_{disl}: 3,395 mg O_2/L
4.767 g Serilen Red HWF 104.4 g Serilen Yellow 93008 (CH) 828.6 g Terasil Red R	pH: 3.5 TDS: 450 mg/L TSS: 3,705 mg/L VSS: 1,910 mg/L COD_{total}: 3,950 mg O_2/L COD_{SS}: 54 mg O_2/L $COD_{col\&diss}$: 3,895 mg O_2/L COD_{col}: 625 mg O_2/L COD_{disl}: 3,275 mg O_2/L			
1,300 L H_2O 2,300 g Bioterge ST 9,200 g NaOH 32 % 4,600 g $NaHSO_3$	pH: 10.9 COD_{total}: 810 mg O_2/L Alkalinity: 690 mg $CaCO_3$/L SO_3^{2-}: 697.4 mg/L	Color stabilization	1,300 L H_2O at 74°C	pH: 11.5 COD_{total}: 880 mg O_2/L Alkalinity: 165 mg $CaCO_3$/L SO_3^{2-}: 549.9 mg/L

Input	Characteristics input	Process	Output	Characteristics output
1,300 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Hot washing 2	1,300 L H_2O at 76°C	pH: 9.4 TDS: 700 mg/L Turbidity: 28 FAU COD_{total}: 395 mg O_2/L
1,300 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Washing 2	1,300 L H_2O at 38°C	pH: 6.5 TDS: 155 mg/L Turbidity: 3 FAU COD_{total}: 42 mg O_2/L
1,300 L H_2O 184,000 g Na_2SO_4	pH: 7.67 TDS: 37,120 mg/L SO_4^{2-}: 32,845 mg/L	Dyeing cotton	1,300 L H_2O at 54°C	pH: 12.25 TDS: 35,720 mg/L COD_{total}: 390 mg O_2/L SO_4^{2-}: 30,605 mg/L Reactive dye: 763 g
3,087 g Cibacron Red FN3G	pH: 7.58 TDS: 34,360 mg/L COD_{total}: 1,090 mg O_2/L Reactive dye: 3053 g			
8,625 g Bioflow PE	pH: 12.28 TDS: 33,440 mg/L COD_{total}: 405 mg O_2/L			
1,300 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Hot washing 3	1,300 L H_2O at 47°C	pH: 11.10 TDS: 10,750 mg/L COD_{total}: 157 mg O_2/L Abs (λ 490 nm): 0.34
1,300 L H_2O 3,450 g CH_3COOH	pH: 3.4 TDS: 4020 mg/L COD_{total}: 2650 mg O_2/L	Neutralization 2	1,300 L H_2O at 45°C	pH: 3.6 TDS: 3,770 mg/L Turbidity: 4 FAU COD_{total}: 159 mg O_2/L Abs (λ 490 nm): 1.25
1,300 L H_2O	pH: 6.41 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Hot washing 4	1,300 L H_2O at 78°C	pH: 4.9 TDS: 1,582 mg/L Turbidity: 2 FAU COD_{total}: 61 mg O_2/L Abs (λ 490 nm): 0.520
1,300 L H_2O 2,300 g Vetanol NF	pH: 6.1 TDS: 588 mg/L COD_{total}: 106 mg O_2/L	Washing 3	1,300 L H_2O	pH: 6.4 TDS: 525 mg/L Turbidity: 1 FAU COD_{total}: 120 mg O_2/L Abs (λ 490 nm): 0.524
1,300 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Hot washing 5	1,300 L H_2O at 76°C	pH: 6.7 TDS: 256 mg/L Turbidity: 6 FAU COD_{total}: 13 mg O_2/L Abs (λ 490 nm): 0.153
1,300 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Hot washing 6	1,300 L H_2O at 69°C	pH: 6.8 TDS: 188 mg/L Turbidity: 1 FAU COD_{total}: 11 mg O_2/L Abs (λ 490 nm): 0.057
3,920 L H_2O	pH: 6.41 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Washing 4	3,920 L H_2O at 40°C	pH: 6.5 TDS: 273 mg/L Turbidity: 0 FAU COD_{total}: 8 mg O_2/L Abs (λ 490 nm): 0.007
Product			225 kg finished fabric	

Source: Loan (2005; 2008)

Scouring and bleaching stages

In the preparation stage, different steps such as scouring, washing and neutralization are required. A combined scouring and bleaching step is applied to remove impure substances in grey fabrics including fats, waxes and pectin. This step is traditionally done by immersing grey fabrics in sodium hydroxide solution of 32% at elevated temperature, together with chelating agents and emulsifiers. Selected parameters such as alkalinity, pH and COD show that near half of the alkalinity remains in the output of the scouring step. Alkalinity in the output was around 1,900 mg $CaCO_3$/L. Hence sodium hydroxide is heavily wasted in the scouring step; this opens up possibilities for recycling sodium hydroxide or decreasing consumption with cleaner production options. The COD of the input is caused by chelating agents (Vitex SL) and the increased COD in the output is generated mainly from impurities originating from the grey fabric and a small amount of remaining Vitex SL. The wastewater of the scouring and bleaching step has a high COD concentration compared with other wastewater streams. After this step, the fabric material is rinsed several times with water and then neutralized with acetic acid.

Hot and cold washing

Hot washing: after each stage in the production process (such as scouring, neutralization and dyeing processes), hot washing is the first washing step. With high temperature and pressure, hot washing can efficiently remove dirt and remaining chemicals from fabrics. Effluents of these steps often have a high temperature. However, total dissolved solids (TDS), color and COD are not problematic, except in the step "hot washing 3" (see Table 6.7), which has a high TDS and color. The reason is that a large amount of salt and dyestuffs remains in the output. On the other hand, the output of some washing steps has a similar water quality as the input water, such as hot washing 5 and 6.

Cold washing: this step often takes place after the hot washing step. Effluent from cold washing steps is low in COD and TDS, comparable to industrial effluent standards (class B), except for cold washing 3. The output of washing 1, 2 and 4 has a low TDS and turbidity and this output can directly be reused in any step of the production process.

The water consumption of hot washing and cold washing steps makes up 70 % of the total water supply for dyeing and finishing processes. Therefore cleaner production options will concentrate on the decrease of water use or the further reuse of washing wastewater.

Neutralization steps 1 & 2

The output of the neutralization steps has a low COD: a little higher than the industrial effluent standard (class B). It shows that process control is optimal. The output from neutralization steps only needs to be pre-treated before being reused in the next batch.

Dyeing step

The dyeing step includes two parts. In the first part the polyester part is dyed, in the second the cotton is treated.

Dyeing polyester: as mentioned in chapter 2, the dispersed dyes are mostly insoluble in water and are really practical for coloring polyester fabrics. Therefore, calibration methods cannot be used to determine the consumption of dispersed dyes; the COD of the colloidal fraction (COD_{coll}) indicator is used in this case. Nearly half of the COD_{coll} remains in the output; the fixation degree of dispersed dyes is thus about 50%.

Dyeing cotton: the calibration method is suitable to determine the consumption of reactive dyes in this dyeing process, because reactive dyes are mostly soluble in water. It is calculated that about 60% of the reactive dyes goes into fabrics and 40% remains in the wastewater. In addition, during dyeing with reactive dyes, a large amount of salt (Na_2SO_4) is used for electrolytic dissociation, which helps to increase dye efficiency. Measurements of SO_4^{2-} concentrations show that almost all salts enter into the wastewater.

Dyeing and finishing process of cotton fabrics

Dyeing and finishing processes for cotton fabric are similar to dyeing for blended T/C; it only slightly differs in terms of used raw material (only cotton fabric), dyestuffs and auxiliary chemicals. A flow diagram of inputs and outputs of the dyeing process with cotton fabric is shown in Table 6.8. The following sections give more details about the input and output characteristics for each step.

Table 6.8: Listing of inputs and outputs of dyeing and finishing cotton fabrics

Input	Characteristics input	Process	Output	Characteristics output
678 kg grey fabric				
10,200 L H_2O 2,040 g Biavin TCC 2,040 g Cibaflow Jet 51,000 g NaOH 32% 7,140 g Tannex Geo 24,888g H_2O_2 50 %	pH: 12.0 TDS: 3,790 mg/L TSS: 3,883 mg/L VSS: 1,563 mg/L COD_{total}: 1,574 mg O_2/L Alkalinity: 4.08 g $CaCO_3$/L H_2O_2: 0.1217 %	Scouring/ bleaching	7,070 L H_2O at 74°C	pH: 11.6 TDS: 2,550 mg/L TSS: 4,780 mg/L VSS: 2,480 mg/L COD_{total}: 3,115 mg O_2/L Alkalinity: 1.57 g $CaCO_3$/L H_2O_2: 0.032 %
7,070 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Washing 1	7,070 L H_2O at 41°C	pH: 10.4 TDS: 575 mg/L TSS: 515 mg/L VSS: 273 mg/L COD_{total}: 604 mg O_2/L Turbidity: 38 FAU Abs (λ 455 nm): 0.086
7,070 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Hot washing 1	7,070 L H_2O at 75°C	pH: 6.6 TDS: 653 mg/L TSS: 1063 mg/L VSS: 408 mg/L COD_{total}: 222 mg O_2/L Turbidity: 25 FAU Abs (λ 455 nm): 0.055

Input	Characteristics input	Process	Output	Characteristics output
7,070 L H_2O 10,200 g CH_3COOH	pH: 3.2 COD_{total}: 1,067 mg O_2/L	Neutralization 1	7,070 L H_2O at 44°C	pH: 3.4 COD_{total}: 136 mg O_2/L
14,140 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Washing 2	14,140 L H_2O at 37°C	pH: 6.0 TDS: 314 mg/L Turbidity: 3 FAU COD_{total}: 9 mg O_2/L
7,070 L H_2O 10,200 g Cibacell DBC	pH: 6.0 TDS: 402 mg/L COD_{total}: 184 mg O_2/L	Dyeing cotton	7,070 L H_2O at 47°C	pH: 12.0 TDS: 40,960 mg/L SO_4^{2-}: 30,652 COD_{total}: 668 mg O_2/L Abs (λ 420 nm): 6.875 Abs (λ 540 nm): 12.375 Abs (λ 620 nm): 15.000
21,967.2 g Navy Blue BF 6,102 g Rubine Exf 6,915 g Yellow Exf	pH: 5.8 COD_{total}: 2,298 mg O_2/L Abs (λ 420 nm): 20.25 Abs (λ 540 nm): 35.25 Abs (λ 620 nm): 39.25			
815,900 g Na_2SO_4	pH: 6.7 TDS: 41,040 mg/L SO_4^{2-}: 32,714 mg/L			
38,250 g Bioflow PE	pH: 12.0 TDS: 41,280 mg/L COD_{total}: 954 mg O_2/L			
7,070 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Hot washing 2	7,070 L H_2O at 49°C	pH: 10.7 TDS: 15,440 mg/L SS: 10 mg/L Turbidity: 5 FAU COD_{total}: 339 mg O_2/L SO_4^{2-} :15,026 mg/L
7,070 L H_2O 15,300 g CH_3COOH	pH: 3.6 TDS: 4570 mg/L COD_{total}: 1,235 mg O_2/L	Neutralization 2	7,070 L H_2O at 49°C	pH: 3.9 TDS: 4,290 mg/L Turbidity: 5 FAU COD_{total}: 288 mg O_2/L
7,070 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Hot washing 3	7,070 L H_2O at 79°C	pH: 6.0 TDS: 1,590 mg/L Turbidity: 7 FAU COD_{total}: 189 mg O_2/L
12,100 L H_2O 10,200 g Vetanol NF	pH: 6.6 TDS: 1,389 mg/L COD_{total}: 164 mg O_2/L	Washing 3	12,100 L H_2O at 81°C	pH: 7.0 TDS: 604 mg/L Turbidity: 22 FAU COD_{total}: 150 mg O_2/L
7,070 L H_2O	pH: 6.41 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Hot washing 4	7,070 L H_2O at 77°C	pH: 7.5 TDS: 269 mg/L Turbidity: 13 FAU COD_{total}: 80 mg O_2/L
7,070 L H_2O	pH: 6.41 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Hot washing 5	7,070 L H_2O at 77°C	pH: 7.3 TDS: 244 mg/L Turbidity: 10 FAU COD_{total}: 49 mg O_2/L
7,070 L H_2O	pH: 6.4 TDS: 102 mg/L Turbidity: 1 FAU Fe_{total}: 0.08 mg/L	Washing 4	7,070 L H_2O at 40°C	pH: 7.2 TDS: 314 mg/L Turbidity: 1 FAU COD_{total}: 15 mg O_2/L
7,070 L H_2O 6,780 g Alcofix R	pH: 7.0 TDS: 331 mg/L COD_{total}: 111 mg O_2/L	Mordal	7,070 L H_2O at 28°C	pH: 6.85 TDS: 247 mg/L COD_{total}: 49 mg O_2/L
Product				675 kg finished fabric

Source: Loan (2005; 2008)

Scouring/bleaching step

The output of the scouring/bleaching step has a high concentration of alkalinity, revealing that sodium hydroxide is only partly consumed and significant amounts of sodium hydroxide are found in the wastewater.

Scouring chemicals used for this step are organic compounds, which cause the COD load in the output. In addition, singeing chemicals on the fabrics are dissolved in the solution during the scouring/bleaching step and add COD to the output. Hence, COD cannot accurately indicate if the scouring chemicals are used in an effective way. Clear is that the scouring chemicals give a high COD concentration in the input.

Concentration of total suspended solids (TSS) in the output is higher than in the input, because the purpose of the scouring/bleaching step is to remove impurities from fabrics. It is also noted that a high concentration of TSS in the input expresses that the preparation of chemicals by workers was not performed well, leading to a waste of chemicals added. The volatile suspended solid (VSS) is an indication of the organic matter content in the solution. The ratio of VSS/TSS in the output (52%) is higher than in the input (40%) as a result of the removal of organic impurities from fabrics.

The TSD concentration decreases in the output because a part of the sodium hydroxide is consumed during the bleaching step.

According to our analyses, the amount of consumed H_2O_2 is about 70% and the remaining 30% enters into the output.

The data of input and output of the scouring/bleaching step shows that sodium hydroxide is ineffectively used and wasted and optimizing production should be considered. A high COD in the output opens possibilities for cleaner production options.

Neutralization 1 & 2 steps

Wastewater generated from neutralization steps gives a low COD which means that wastewater can be reused in the next batch to prepare the neutralization solution.

Hot washing and cold washing steps

Hot washing steps: there are five hot washing steps in the dyeing process of cotton fabrics. Outputs of hot washing steps usually have a high temperature (70-80^{0}C). Hot washing steps gave the following results:

Hot washing 1: effluent contains a high TDS and COD concentration because of the scouring step wastes that are washed out in hot washing 1.

Hot washing 2: effluent COD, TDS and color in the output have the highest value among the hot washing steps; after the dyeing process, the remaining auxiliary chemicals and dyestuffs on fabrics are washed out completely into the output of this washing step.

Hot washing 3: effluent COD and color only just exceed the industrial effluent standards; output of hot washing 3 could be treated together with output of the dyeing unit.

Hot washing 4 and 5: effluent COD and TDS are lower than the industrial effluent standards (class B). Thus wastewater can be reused in other units or for other purposes.

Cold washing steps: output TDS and COD concentrations of cold washing 1 are high due to remaining chemicals and impurities of fabrics which are washed out. During the next cold washes (washing 2, 3 and 4) the TDS and COD of the output increases insignificantly compared with the input. TDS in output is about 314–600 mg/L COD, which is in the range of 9–15 mg O_2/L, where the lowest COD is 9 mg O_2/L (for washing 2) and 15 mg O_2/L (for washing 4). Therefore, outputs from washing steps 2 and 4 can directly be reused in washing 1 during the next batch.

Dyeing step with cotton
Two indicators (color and sulfate) are used in analyzing inputs and outputs of the dyeing step of cotton. According to the calibrated equation of color (as established above) the amount of reactive dyes in input and output are 34.7 g and 15.1 g. The consumption of dyestuffs can then be quantified as about 60%. This result corresponds with the fixation ratio of dispersed dyes, which is in range of 60-90%. The quantity of Na_2SO_4 consumed in the dyeing step is almost insignificant; the sulfate concentration hardly differs between input and output. The COD in input is mainly caused by reactive dyes and from auxiliary chemicals (Bioflow PE). After the dyeing step, remaining COD in the output is about 20% compared to the input COD.

Mordal step
This step is performed in order to achieve a stable color of the finished product. Compared with the input, the composition of the output of the mordal step shows a low TDS and COD concentration. Thus the output can be reused in the next batch to prepare the mordal solution.

Mass balance of water, chemicals and energy of the two dyeing processes

Mass balance of water
The dyeing batch is characterized by the ratio of volume of the dye solution (water) and the mass of fabrics, herein after called liquor ratio. Thanh Cong Company is equipped with high- pressure dyers (jet machine). For the operation of these jet machines, water is added through the semi-automatic distribution system. The volume of water depends on the liquor ratio; once the required water level is achieved, water supply to the dyeing machine stops. After that, fabrics are brought in contact with the solution and the fabrics increase the water level inside the dyer; this level is calculated and marked for the next adding of water. After the first step in the dyeing process, the discharged volume (output) is lower than the input because an amount of water is kept in the fabrics. During the following steps, the volume of water input is equal to the water output. In order to calculate the volume of each unit, the amount of water kept in the fabrics is determined as follows:

- First the mass of dry grey fabric is determined (before dyeing process);
- Second, the water mass kept in the fabric is determined: the grey fabric is put into the beaker containing water. The beaker with water and fabric is weighed. After the (soaked) fabric is removed from the beaker, the beaker with the remaining water is weighed.

The total water holding of the fabrics blended T/C and cotton can then be calculated:

- 227 kg of T/C fabrics holds 995 liters of water;
- 678 kg of cotton fabrics holds 3,130 liters of water.

The mass balance of water and the generated wastewater are calculated based on inputs and outputs of the two flow diagrams of dyeing T/C and cotton processes (Tables 6.7 and 6.8). The results are presented in Table 6.9 and 6.10.

Table 6.9: The mass balance of water and wastewater for the dyeing process with T/C fabrics

Process steps	Water use (L)	Cooling water (L)	Recycled water (L)	Total consumed water (L)	Wastewater (L)
Scouring	2,300	1,080	0	3,380	2,380 #
Hot washing	1,300	-	-	1,300	1,300
Neutralization	1,300	-	-	1,300	1,300
Wash	3,920	-	-	3,920	3,920
Dyeing polyester	1,300	3,000	0	4,300	4,300
Stable color	1,300	-	-	1,300	1,300
Hot washing	1,300	-	-	1,300	1,300
Wash	3,920	-	-	3,920	3,920
Dyeing cotton	1,300	-	-	1,300	1,300
Hot washing	1,300	-	-	1,300	1,300
Neutralization	1,300	-	-	1,300	1,300
Hot washing	1,300	-	-	1,300	1,300
Wash	1,300	1,080	0	2,380	2,380
Hot washing	1,300	-	-	1,300	1,300
Hot washing	1,300	-	-	1,300	1,300
Wash	3,920	-	-	3,920	3,920
Total	29,600	5,160	0	34,820	33,820 30,505 *

Remark: # About 1,000 L water is held by the fabric
Remark: * 10% of the water exits as water vapor during the production process
Note: Consumed water = used water + cooling water
Source: (TCM 2005) and (VINATEX 2003); Loan (2004; 2005)

Table 6.10: The mass balance of water and wastewater for the dyeing process with cotton fabrics

Process steps	Water use (L)	Cooling water (L)	Recycled water (L)	Total consumed water (L)	Wastewater (L)
Scouring	10,200	5,040	0	15,240	12,110 #
Wash	7,070	-	-	7,070	7,070
Hot washing	7,070	-	-	7,070	7,070
Neutralization	7,070	-	-	7,070	7,070
Wash	14,140	-	-	14,140	14,140
Dyeing cotton	7,070	-	-	7,070	7,070
Hot washing	7,070	-	-	7,070	7,070
Neutralization	7,070	-	-	7,070	7,070
Hot washing	7,070	-	-	7,070	7,070
Wash	7,070	5,040	0	12,110	12,110
Hot washing	7,070	-	-	7,070	7,070
Hot washing	7,070	-	-	7,070	7,070
Wash	14,140	-	-	14,140	14,140
Mordal	7,070	-	-	7,070	7,070
Total	116,250	10,080	0	126,330	123,200 110,880 *

Remark: # About 3,130 L water is held by the fabric
Remark: * 10% of the water exits as water vapor during the production process
Note: Consumed water = use water + cooling water
Source: (VINATEX 2003); Loan (2004; 2005) and (TCM 2005)

Specific water consumption and wastewater generation for dyeing and finishing T/C fabrics and cotton process can now be calculated:

Specific water consumption of T/C fabric: 34,820 L for 227 kg fabric = 157 L/kg
Specific water consumption of cotton fabric: 126,330 L for 678 kg fabric = 86 L/kg
Specific wastewater generation of T/C fabric: 30,505 L per 227 kg fabric = 134 L/kg
Specific wastewater generation of cotton fabric: 110,880 L for 678 kg fabric = 163 L/kg

According to Thanh Cong Company, daily production capacity of the enterprise is about 55 tons of finished fabrics, of which the capacity of knitted fabrics is about two times higher than of woven fabrics. Therefore, production capacity of woven fabric (cotton) is 18,200 kg and knitted fabric (blended T/C fabric) is 36,800 kg. The total water consumption of and wastewater generation can be calculated:

Total water consumption for one day per fabric type is:

- For woven fabrics:
  18,200 kg / 678 kg / batch $\times$ 126 m^3 water / batch = 3,382 m^3/day
- For knitted fabrics:
  36,800 kg / 227 kg / batch $\times$ 34.8 m^3 / batch = 5,640 m^3/day

Total water consumption for one day:

3,382 m^3 / day + 5,640 m^3 / day = 9,022 m^3/day

Total generation of wastewater for one day per fabric type:

- For woven fabrics:
  18,200 kg / 678 kg $\times$ 110 m^3 / batch = 2,952 m^3/day
- For knitted fabrics:
  36,800 kg / 678 $\times$ 30.5 m^3 / batch = 4,945 m^3/day

Total generation of wastewater for one day:

2,952 m^3 / day + 4,945 m^3 / day = 7,897 m^3/day

Hence, water consumption for cotton fabrics is higher than for T/C fabrics. Because the raw cotton material contains a larger amount of impurities than polyester material, the dyeing process with cotton fabrics consumes more water than T/C fabrics and thus it discharges a larger volume of wastewater with higher levels of pollutants. The specific water consumption and wastewater generation of some large textile companies in Vietnam and in the world is presented in Table 6.11. As shown, only small differences exist between the specific water consumption of the Thanh Cong Company and other large textile companies in Vietnam. The Agtex Company uses a continuous dyeing process with a pad-steam dyer. The Dong A and Phuoc Long Company use the same dyeing batch process as the Thanh Cong Company. The Thanh Cong Company consumes less water than the maximum use of the UK Textile Industry and the maximum standard of USA/US EPA; but it uses more water than the maximum use of the India Textile industry. But the minimum specific water consumption for these three countries is significantly lower than for the Thanh Cong Company and other Vietnamese textile companies.

Table 6.11: Specific water consumption and wastewater generation of some large textile companies in Vietnam and in the world

Company	Specific water consumption (L/kg)		Specific wastewater generation (L/kg)	Wastewater standard (L/kg)
Vietnam	Minimum	Maximum		
- Thanh Cong Company		157-186	134-164	
- Agtex Company		115	104	
- Thang Loi Textile & Garment Joint stock Company		179	160	
- Dong A Textile & Garment Joint stock Company		236	212	
- Phuoc Long investment Joint stock Company *		240	210	
World	Minimum	Maximum		
- India Textile Industry [(a)] for knitted fabric	25	60		
- UK Textile Industry[(a)] for knitted fabric	52	200	108-183	
- USA/US EPA[(a)] for knitted fabric	8.3	392.8		
- WHO (1993)				265
- World bank (1997)				100-150

Source: * VINATEX (2003), Viet (2003), TCM (2005), [(a)] Visvanathan. et al. (2000)

Given the close relationship between specific water consumption and specific wastewater generation, it is no surprise that the company with the highest specific water consumption also has the highest specific wastewater generation. Wastewater generation of the Thanh Cong Company is lower than the WHO (1993) standard, but 1.5 times higher than the minimum level of the World Bank (1997) standards. Thanh Cong's specific wastewater generation is equal with the UK Textile Industry.

Mass balances of chemicals

According to indicators as described in section 6.3.2, inputs and outputs of chemicals in each unit of the two dyeing processes are used to calculate mass balances of chemicals. Calculated results are presented in Table 6.12 and 6.13.

Table 6.12: Mass balance for chemicals of the dyeing process of T/C fabrics

Production processes	Items	Input (g)	Output (g)	Consumed (%)
Scouring	NaOH 32% solution	11,500	4600	60
Neutralization 1	CH_3COOH	1,380	250	82
Dyeing polyester	Disperse dyes	5,700	2,855	50
	Sunsolt RM 340 + sand acid PBN	1,955	1,850	5
Stable color	NaOH 32%	9,200	950	90
	$NaHSO_3$	4,600	1,645	64
Dye Cotton	Na_2SO_4	184,000	104,115	43
	Reactive dyes	3,087	735	76
	Bioflow PE	8,625	ND *	-
Neutralization 2	CH_3COOH	3,450	343	90
Washing	Vetanol washing chemical	2300	2100	10

Consumed % = [(input – output)/input x 100] and ND*: not determined
Source: Loan (2004; 2005)

Table 6.13: Mass balance for chemicals of dyeing process of cotton fabrics

Production processes	Items	Input (g)	Output (g)	Consumed (%)
Scoring	NaOH 32%	51,000	19,600	61
	H_2O_2 50%	24,890	1,475	94
Neutralization	CH_3COOH	10,200	0.13	100
Dyeing Cotton	Dyestuffs	34,985	15,085	57
	Cibacell DBC	10,200	3,223	68
	Na_2SO_4	815,900	613,350	25
Neutralization	CH_3COOH	15,300	0.27	100
Washing	Vetanol NF (washing chemical)	10,200	8,700	15
Mordal	Alcofix Rl	6,780	2,995	56

Consumed % = [(input – output)/input x100]
Source: Loan (2004; 2005)

Obtained results for the mass balance per dyeing batch show that auxiliary chemicals (salts) and washing chemicals are hardly consumed, in the range of 5-15%; this is representative for all textile processes. Sodium hydroxide used in the scouring step is consumed at a medium level of 60% and the remaining 40% is discharged through the wastewater. For the neutralization step, 90% of the acetic acid is consumed; this means that there is good process control. To estimate the amount of dyestuff used in both processes, the fixation of dyestuffs can be used. For instance, reactive dyes have an average fixation of 60 to 76% and dispersed dyes give an average fixation level of 50%. The possibilities to carry out cleaner production options are thus significant, especially for reducing sodium hydroxide (dyeing process with T/C fabrics) and dyestuff discharges.

Energy and mass balances of boiler

Energy is used extensively in the dyeing plant; this plant consumes about 85-87% of the total energy consumption of the Thanh Cong Company. Therefore, the dyeing plant is selected to carry out cleaner production options. It is necessary to determine energy efficiency through gaseous emission and fuel use. According to supplied data from the Thanh Cong Company and the composition of air pollution of the boilers of the company (Table 6.14), the loss of energy during operation processes of boilers and the efficiency of the boilers can be determined by two methods.

Table 6.14: Composition of air pollution from boilers the Thanh Cong Company

Parameters	Unit	Boiler IHI (8 ton/hour#)		Boiler BIB (10 ton/hour#)	
		Sample 1	Sample 2	Sample 1	Sample 2
Ambient temperature	^oC	30.4	29.4	28.1	29.3
Temperature inside stack	^oC	255	405	260	269
O_2	%	13.8	8.6	10.7	10.0
CO_2	%	9.3	9.6	7.7	8.2
SO_2	ppm	577	816	708	805
NO_x	ppm	92	154	149	161

Fuel consumption
Source: (TCM 2005)

Method 1:

The efficiency is determined based on the composition of waste air. From the CO_2% in the smoke stack the wasting of oil (oil burning that does not contribute to heating water) can be calculated as follows:

Loss of oil (based on % CO_2) = $\frac{0.63\times(t_F - t)}{\%CO_2}$ (%) (TCM 2005)

In which: t_F (^0C) : temperature inside smokestack;
t (^0C) : temperature ambient air
% CO_2: percent of CO_2 in smokestack.

Table 6.15 summarizes the efficiency, energy consumption and loss of oil from operation of the four boilers. The efficiency of most boilers is about 82-87%, so these efficiencies are high.

Table 6.15: Monthly average loss of oil for four boilers

Boiler	Oil Consumption of L/month	Loss of oil L/month	Efficiency (%)
IHI	152,870	22,930	85
BIB	45,830	8,249	82
OMICAL I	167,670	21,797	87
OMICAL II	167,000	25,150	85
Total	534,040	78,127	

Loss of oil = (100% - efficiency %) x Consumption of oil
Source: TCM (2005)

Method 2:

The efficiency is determined based on consumption of fuel and water according to the following equation:

Efficiency of boiler = (water consumption/oil consumption) x E x 1,000/calorie of oil

In which:

E is the enthalpy factor (kJ/kg);
The unit of water consumption is m^3/month;
The unit of oil consumption is L/month (TCM 2005).

Table 6.16 shows average oil consumption, average water consumptiom per month, enthalpy factor and the efficiency of BIB and OMICAL I boilers at Thanh Cong Company.

Table 6.16: Efficiency of the BIB and OMICAL I boilers

Boiler	Average oil consumption (L/month)	Average water consumption (m^3/month)	Enthalpy factor (kJ/kg)		Consumption water/oil (m^3/liter oil/month)	Efficiency (%)
			Calorie	Enthalpy		
BIB	45,830	615	42,756	2672	0.013	83.7
OMNICAL I	167,670	2330	42,756	2672	0.014	86.8

Source: TCM (2005)

6.4.4 Analyzing waste generation

In order to assess options for cleaner production at the Thanh Cong Company, the causes for waste generation in each step of dyeing are analyzed in detail. Based on the results gathered from the survey, observation and mass balance calculations, the causes for waste generation in each step of dyeing processes are presented in Table 6.17.

Table 6.17: Cause for waste generation in each step of dyeing processes

Process unit	Cause
Scouring/bleaching	- High percentage of impurities in grey fabrics, especially in cotton fiber causes a high COD, BOD, suspended solids (SS) concentration. - High liquor ratio leads to a huge amount of wastewater and chemicals discharged. - After the scouring process 40% of the added sodium hydroxide is discharged. Wastewater is characterized by a high pH, because of this sub-optimal scouring step. - Wastewater in this unit contains about 50% of the total COD, BOD load of the whole dying process
Hot washing	- High liquor ratio results in a large amount of wastewater. - The several hot washing steps applied in this process lead to a great volume of wastewater with high temperature. Due to high temperature, loss of fuel can be expected in these steps, causing air pollution.
Neutralization	- High liquor ratio leads to high consumption of chemicals and remaining chemicals will go into wastewater. - Acetic acid used in neutralization step adds to the COD load in the wastewater.
Washing	- The several washing steps need a large water volume, creating huge flow rate of wastewater. The wastewater of this step has a COD concentration that is not problematic.
Dyeing	- Dyeing methods carried out by a discontinuous process (exhaust batch) consume more water, auxiliary chemicals and dyestuffs. - High liquor ratio, hence more wastewater, auxiliary chemicals and dyestuffs discharged. - Spilled dyestuffs and chemicals at chemical preparation areas; after cleaning workshop these chemicals increase COD load and color causing complex wastewater and wastage of materials. - Dyer does not function well causing high consumption of materials, water and energy. - Finished fabrics cannot meet quality requirement; re-dyeing leads to more consumption of chemicals, water, energy and generation of more wastes. - The cooling water is discharged without recycling, which increases the wastewater volume and increases the dimensions of the WWTP. - Fixation of dyestuffs is not high leading to high color and COD in effluent, difficult treatment and high treatment cost. - After dyeing step, almost all auxiliary chemicals go into wastewater; only a small part is consumed in the dyeing step. This will cause a high TDS, which affects biological treatment methods.
Stabilization of color	- High liquor ratio in dyeing process generates huge amount of wastewater. - The consumption of stabilizing chemicals is relatively low. It results in a high COD load and high pH in effluent.
Mordal color	- High liquor ratio in dyeing process causes a huge amount of wastewater - Mordal chemicals are not much consumed in finishing process, leading to high residual concentration in effluent.

6.4.5 Cleaner production options

The obtained results listed above are used as a basis to identify cleaner production options for environmental improvements at the Thanh Cong Company. Cleaner production options can be carried out in many different ways, but have to be feasible in practice. For this reason, proposed options have to be selected on the condition of feasibility for the Thanh Cong Company. In practice, not all proposed options can be implemented at the same time because they require large financial and human investments that the company cannot afford at once. So priorities have to be set. In the short term, improvement of good housekeeping, reuse of water, chemicals and replacement of dyestuffs are the most feasible measures to be carried out to reduce pollution. In the long term, the company will have to be equipped with advanced technologies and modern machines. Implementing cleaner production options will significantly reduce waste streams and production cost and increase competitiveness by a more environmental sound Thanh Cong Company. The priority order of proposed cleaner production options for each unit of the dyeing process are described in Table 6.18. This table also shows the kind of (financial) benefits to be gained from these options.

Table 6.18: Cleaner production options and benefits for each unit

No.	Cleaner production options	Benefits
	Scouring/bleaching	
1	Process control optimizes conditions of scouring/bleaching. These conditions are established from laboratory studies of the company.	- To decrease sodium hydroxide use (20-30%) - To decrease pollutant load for WWTP
2	Selection of raw cotton fiber with less impurities (1-2%; the presently raw material contains over 2-3% impurities)	- To decrease organic load for WWTP, water and chemicals
3	Reuse scouring solution to treat air pollution from boiler or adjustment pH of wastewater	- To decrease air pollution treatment costs (about 10% of chemicals)
4	Automatic process for chemical dosage	- To reduce spills of chemicals - To decrease pollution load - To decrease chemical losses
	Cooling water	
5	Reuse of cooling water for hot washing step, about 5 m^3 for T/C and 10 m^3 for cotton per one batch	- To decrease use of water - To decrease use of fuel - To reduce flow rate of wastewater leading to reduced wastewater treatment plant (WWTP)
	Neutralization	
6	- Process control optimizes conditions of neutralization process. These conditions are established from laboratory studies of the company - Using a pH sensor to control pH values	- To minimize chemical use - To decrease pollutant load for WWTP

No.	Cleaner production options	Benefits
7	Replace acetic aicd with inorganic acid	- To reduce production costs (inorganic acid is cheaper than acetic acid) - To decrease COD load rate for WWTP
8	Automatic process for chemical dosage	- To reduce spills of chemicals - To decrease pollution load - To decrease chemical loss
	Dyeing	
9	To make a detailed production schedule for dyeing plant	- To increase productivity - To decrease consumption of water, energy and materials
10	Installation of water meter for each dyeing machine	- To control consumption of water
11	- Optimization of dyeing process by carrying out experimental tests in laboratory - Priority in design of light products instead of dark products	- To decrease use of chemicals, water and energy - To decrease COD load and color for WWTP - To reduce labor costs due to reduced re-dyeing
12	Computerized dye handling devices to control weighing and mixing of dyestuffs	- To decrease pollutant load for WWTP - To decrease chemical loss
13	Installing an external light switch of dyer to easy manipulate dyeing machine if needed	- To decrease consumption of fuel, and re-dyeing
14	To install an automatic water pump system	- To reduce water overflows; to save water and energy
15	To substitute acetic acid with formic acid	- To decrease COD load for WWTP
16	- Substitution of dyestuffs with a low fixation and high toxicity with dyes with a higher fixation and lower toxicity. For example, reactive dyes with a fixation degree 100% with liquor ratio 1:5 and 90% with LR of 1:10 such as Cibacron LS, Procion XL, ect. (Phong, 2003). - Dispersed dyes: high degree of fixation from 90-100% of well known dye manufactures	- Such reactive dyes can save 50% energy, 40% water and reduce 10-33% salts - Dispersed dyes in wastewater have a low concentration in the range of 0-10% - To decrease COD load, color and salts for WWTP - To achieve high quality products
17	Advanced technologies and machines for dyeing process, such as: - Short liquor ratio (LR) (1:5 to 1:10) with modern dyer machine, for example Thies - ecosoft, Air jet, Air flow jet - Semi continuous process- cold pad batch - Continuous process	- To decrease consumption of dyestuffs (25-30% of hydrolyzed reactive dyes), salts (56-68%), energy and water (for dyeing process and for washing process) - To reduce pollution load and wastewater volume - To achieve higher product quality

No.	Cleaner production options	Benefits
	Washing and hot washing units	
18	Process control optimizes conditions regarding water amount and temperature to be applied in each washing step and time	- To decrease flow rate of water, wastewater and energy
19	Change overflow washing to normal washing	- To decrease wastewater flow rate and energy consumption
20	- Reuse of washing water (hot washing and cool washing water). After second wash, this wastewater is used for first wash in next batch. - If washing wastewater meets standards of water supply, it can be used directly in any process step	- To decrease flow rate of water, wastewater and energy - To reuse water directly for other units - To reduce exploitation of water resource
21	Reduction of hot washing times	- To decrease flow rate of wastewater, energy and air pollution
	Boiler	
22	Installation of heat meter for boiler	- To control consumption of fuel, efficiency of boiler and decrease loss of steam
23	Investment in modern boiler	- To increase the efficiency of boiler and reduce fuel and water use as well as air pollution.
24	- Optimum burning process by control of proper air inlet, oil regime - Reduction of CO concentration and residual air	- To reduce consumption of fuel - To reduce loss of fuel - To reduce air pollution
25	Recovery of heat from smoke-stack	- To reduce consumption of fuel and heat to environment
26	Recovery of condensate water to supply hot water for boiler	- To reduce consumption of fuel
	Other options	
27	Production schedule is carried out carefully by supervisors to avoid change of products with different color	- To increase productivity - To decrease discharge of wastewater streams with high pollutants - To decrease consumption of water, energy and materials
28	- To improve the drainage system at dyeing plant - Separation of wastewater streams for reuse or recycling water.	- To decrease water overflow on floor - To protect health of workers and to restrict equipment laying on floors - To decrease wastewater flow rate, chemicals, energy, treatment costs - To reuse wastewater and chemicals - To reduce difficulties for treatment of mixed wastewater

No.	Cleaner production options	Benefits
29	- Awareness enhancement for toxic chemicals, environment and safety at work - Training courses for workers	- To reduce chemical spills on floor - To reduce re-dyeing batch
30	Return storage drums of sodium hydroxide, hydrogen peroxide and acetate acid to suppliers or changing to bulk storage tanks for these chemicals	- To decrease solid waste, water and wastewater

6.4.6 Environmental benefits

Although Thanh Cong Company invested in upgrading its production technology, the significant waste production is a sign of inefficiency. The company has a large potential for cleaner production, which can save costs and reduce environmental impacts. The largest environmental benefits are the improvement of water quality of Tham Luong canal and the reduction of air pollution.

The implementation of the proposed options reduces water use with 4,000 m^3/day by the reuse of all cooling water and a part of washing and hot washing water. The cooling water volume per batch is 5 m^3 for blended fabrics and 10 m^3 for cotton fabrics. About 11.8 m^3 of the cold and hot washing water meets water supply quality and can be reused directly. The investment of a modern dyer with a low liquor ratio (1:6) will decrease the amount of consumed water and energy compared with the old dyer (with liquor ratio 1:8-1:12). For instance, water use decreases from 0.161 to 0.108 m^3/kg fabric, electricity consumption from 0.603 to 0.418 kWh/kg fabric and fuel cost reduces from 1,824 to 1,192 VND/kg fabric (TCM 2008). Improvements of process control and materials substitution result also in environmental benefits. According to this study, the amount of sodium hydroxide can be reduced by 30% by optimal process control. As noted in chapter 3, with mixed dyestuffs in the wastewater, decolorization is a difficult and costly task. By substitution of old for new dyestuffs, the consumption of dyestuffs, salts and auxiliary chemicals can be reduced, resulting in reduced loads of color, total dissolved solids and organic compounds into environment. For example, the used dispersed dyes can be replaced by new dyes with a high degree of fixation (90%), which reduces the dyestuff load in the wastewater to 2,257 g per batch for blended fabrics. Replacing the present low degree of fixation dyes (57%) dyes with high fixation reactive dyes for cotton (85-95%), a significant amount of reactive dyes can be saved. This reduces the release of toxic absorbable organic halogens (AOX) components from reactive dyes. In addition, colored wastewater reduces the light transmission in water streams and thereby disturbs photosynthesis. High salt concentrations significantly affect the operation of biological wastewater treatment systems and an amount of 2 g sodium chloride per liter can be toxic to fish. In addition, sewer systems erode at high sulfate concentration.

In the short-term, the proposed cleaner production options are often improving procedures and ways of operation rather than technology. With that Thanh Cong's production process cannot avoid waste generation, especially wastewater. Although wastewater streams are reduced in volume and load, they still have to be treated in order to recycle wastewater and reduce water use.

6.4.7 Economic benefits

Economic benefits from the proposed cleaner production options can be estimated. Each option can be calculated in terms of investment costs, cost of operation, savings and payback period. The payback period is commonly used because it is easy and fast to calculate. In Table 6.19 the benefits of the proposed cleaner production are presented and Table 6.20 the estimated investment costs and payback period for the proposed cleaner production options are given.

Water and wastewater

Water

Among the proposed cleaner production options, water reuse has the lowest economic benefit. This is not surprising as ground water exploitation is free of charge for the company. Presently, treatment fee of groundwater is about 750 VND/m^3 (approx. 0.043 US$ /m^3 water), which consists of electricity and labor costs. Water costs are insignificant in the total production costs. Hence, Thanh Cong Company does not pay attention to saving water. With a reuse volume of 4,000 m^3 water per day, the economic benefits are 3,000,000 VND/day (approx. 172 US$/day). However, benefits are about 6 times higher if the water was purchased from a water company (4,200 VND or approx. 0.25 US$/$m^3$). Since May 2010 groundwater use is banned or a natural resource exploitation water fee is due. In addition, the volume of water for treating air pollution every day is approximately 3,400 m^3/day and the company can save from this additionally 150 US$/day.

Wastewater

Significant economic benefits relate to reducing wastewater treatment costs and decrease of environmental protection charges. By implementing reuse of wastewater, the flow of wastewater decreases from 8,000m^3/day down to 3,100m^3/day. The estimated costs of treating one cubic meter of textile wastewater to meet the industrial effluent standards are about 8,000 VND/m^3 (in 2006). Once pollution loads decrease with 30% for main materials such as dyestuffs and sodium hydroxide, the treatment costs also reduce with 30% and the cost are then estimated at 5,600 VND/m^3. With a decrease of waste water flow of 4,000 m^3/day, savings on treatment costs are 9,600,000 VND/day (approx. 565 US$/day). Other benefits can be obtained from the reduction of environmental protection charges. According to the Joint Circular for environmental protection charges No. 125/2003/TTLT-BTC-BTNMT of December 12, 2003 of the Ministry of Finance and Ministry of Natural Resources and Environment, the environmental protection charges are accounted based on flow rate and specific pollutant concentrations in wastewaters. With a decrease of 4,000 m^3 of wastewater per day, the economic benefits are only 800,000 VND (50 US$).

Energy

The implementation of an automated water pump system results in saving 40 kWh/day or 3.2 US$/day (average electricity cost is 0.054 US$/kWh). Reuse of cooling water, hot washing and washing wastewater saves 1-2% in fuel use, an approximate benefit of 65 US$/day. Changing the old boilers for modern boilers and oil heaters, with a high energy efficiency (80-90%), saves 225 US$/day in energy use.

Chemicals

About 168 kg of sodium hydroxide can be reused per day from the scouring wastewater, to treat SO_2, saving about 1,500,000 VND/day or 93 US$/day. In addition, the amount of sulphuric acid for neutralization of alkaline wastewater, can be reduced with 224 kg, a cost reduction of 1,200,000 VND (approx. 74 US$/day). Each day, the Thanh Cong Company can reduce chemical costs for the operation of the wastewater treatment system by 2,700,000 VND (or 167 US$/day).

Table 6.19 summarizes the total economic benefits when saving water, materials and energy of the Thanh Cong Company through cleaner production options. The company works 30 days per month, which results in a total benefit of VND 425 million or 35,280 US$ per month. This economic benefit equals the monthly salary of 260 workers (average salary 2,2 million VND/month, approximately 137.50 US$). It shows that a large company like Thanh Cong, with a high production capacity, greatly benefits from the implementation of cleaner production instead of paying for treatment.

Table 6.19: Total benefits (excluding investment costs) following cleaner production options, in savings per day

Items	Saving on materials	Benefits (VND *1000)	Benefits US$
Reuse of water	4000 m^3/day	2,900	183
Wastewater			
- Treatment cost	4000 m^3/day	9,600	565
- Discharge charge fee		800	50
Reuse of scouring wastewater	168 kg NaOH 224 kg H_2SO_4	2,700	167
Reuse of treated wastewater	3,400 m^3/day	2,500	150
Energy			
- Install automatic water pump system	40 kWh	57	3.2
- Reuse of cooling water and hot washing wastewater	96 L FO	1,152	64
- Use of modern boiler and heater	307 L FO	3,684	206
Total		23,393	1,388

Table 6.20: Estimated investment costs and payback time of proposed cleaner production options

CP option	Cleaner production options	Items	Capital costs (US$)	Payback (months)
No. 3	Reuse scouring solution to treat air pollution from boiler or adjustment pH of wastewater	- Filter system: 50-70 m^3/h - Container with volume of 1,000 m^3 - Pump: 30-50 m^3/h	11,235 54,215 1,125	15
No. 4	Automatic chemical dosage process	- Pump (20 pieces) - Stirrer system (20 systems) - Balance - Containers (20 tanks)	7,865 11,235 2,247 5,617	27
No. 5	Reuse of cooling water, condensate water and hot washing wastewater	- Two tank each 1,000 m^3 - Two pumps Q= 30 m^3/h	109,550 1,125	5
No. 10	Installation of water meter for each dyeing machine	- Water meters	10,115	
No. 12	Computerized dyes handling devices to control weigh and mixing of dyestuffs	- Computerized dyes handling devices: 2 pieces	2,810	
No. 13	Installation of a light lamp inside dyeing machine to be able to observe needed actions of dyeing processes	- An external light switch	845	
No. 14	To install an automated water pump system	- An automated water pump system	3,370	61
No. 17	Advanced technologies and machines for dyeing process: low liquor ratio (LR) (1:5 to 1:10) with modern dyer	- Dyer with low liquor ratio (1:6): 7 machines (e.g. Thies, Tungshin)	726,000	33
No. 22	Installation of heat meter for boiler	- Heat meter	3,400	18
No. 23	Investment of modern boiler and heater	- Equipment of modern boiler (fluidized bed boiler, e.g. Shengchan, Martech)	717,000	43
	Other options			
No. 29	To improve the drainage system at dyeing enterprise; Separation of wastewater streams to reuse or recycle water and treatment	- Improve the drainage system at dyeing enterprise - Reuse neutralization wastewater: tank 550 m^3 - Reuse of mordal wastewater: tank 180 m^3 - Pumps: 2 pieces	43,820 30,620 19,660	 9 18

6.4.8 Wastewater treatment

Thanh Cong built a wastewater treatment system with a capacity of 5,000 m^3/day with a combination of physical/chemical, biological and adsorption methods. However, the effluent usually does not meet the discharge standards for the recipient surface water (TCVN 5945:1995, class B). The treatment system consumes a large amount of coagulant and activated carbon, leading to high operation costs. The proposed cleaner production options for the Thanh Cong Company help to reduce the flow rate of wastewater. However, the textile production processes will still generate wastewater. According to the results presented in chapter 4 and 5, together with the implementation of a closed water loop, the wastewater treatment system can be improved. This process comprises two stages. First, the wastewater streams should be separated, the next stage is to treat each stream with a suitable technology.

Separation of wastewater streams for dyeing processes of blended fabrics is listed below.

- Stream No.1 comprises wastewater of the scouring and hot washing 1 step. This stream, which has high alkalinity concentration, is used to treat air pollution from boilers or it is used to optimize pH (5.0-5.5) for the coagulation process of the wastewater treatment from the dyeing process of polyester fabrics (chapter 3).
- Stream No.2 is the wastewater of neutralization steps 1 & 2. This wastewater is reused to prepare the neutralization solution for the next batch.
- Stream No.3 includes wastewater from the dyeing process of polyester (dispersed dyes), stabilisation step and hot washing 2. In order to treat this stream, the first treatment step is a coagulation process; the next step applies aerobic activated sludge process.
- Stream No.4 consists of collected wastewater from the dyeing processes of cotton (reactive dyes), hot washing 3 and 4 and washing 3 steps. The treatment technology encompasses two steps. In the first step, ozone is used to remove color and the second step is aerobic treatment to remove organic matter.
- Stream No.5 concentrates all wastewater of washing 1, 2, 4 and hot washing 5, 6, together with cooling water. This wastewater has a good quality and can directly be reused for other processes.

Separation of wastewater streams for dyeing processes of cotton fabrics:

- Wastewater of scouring, washing 1 and hot washing 1 are joined with stream No.1 (see above).
- The wastewater of neutralization 1 with low pollution is gathered into stream No.2.
- Dyeing (reactive dyes), hot washing 2 and 3, neutralization 2 and washing 3 wastewaters are collected into stream No.4.
- Wastewater from washing 4, hot washing 4 and 5 wastewaters and cooling water are collected into stream No.5.
- Stream No.6 directly receives wastewater from the mordal unit. The generated wastewater is less polluted so it can be reused in preparing the mordal solution for the next batch.

The results in saving water and separation of wastewater streams are given in Table 6.21. Figure 6.8 shows six wastewater streams of Thanh Cong Company after separation process and improved wastewater treatment technology at Thanh Cong Company.

Table 6.21: Volume of each wastewater stream per day after implementation of wastewater separation

Product	Water consumption (m^3)	Generated wastewater (m^3)	Stream No. 1 (m^3) #	Stream No. 2 (m^3)	Stream No. 3 & 4 (m^3) #	Stream No. 5 (m^3)	Stream No. 6 (m^3)
Woven	3,428	3,009	518	172	571	1,282	172
Knitting	5,655	4,945	381	381	1,625	2,848	-
Total	9,083	7,954	899	553	2,196	4,130	172

to be treated

According to Table 6.21 the flow rate of wastewater that should be treated decreases from 7,954 m^3/day down to 3,100 m^3/day, coming from wastewater of stream No.1 (after treating air pollution 899 m^3) and wastewater of stream No. 3 & 4 (with 2,196 m^3). Hence, the improved wastewater treatment system can operate at a capacity of 3,500 m^3/day. However, a small increase of pollutant concentration can be identified:

- As mentioned in section 6.2, the average flow rate is about 8,000m^3/day with the COD fluctuating between 183-300 mg O_2/L.

- After recycling and reuse of the wastewater from hot washing and washing steps, the flow rate of wastewater decreases in the range of 43-57%, depending on the type of fabric.

- After introduction of cleaner production options, the amount of sodium hydroxide decreases ± 30%, CH_3COOH 10-20% and dyestuffs between 30-40%. However, the flow rate decreases significantly (43-57%), hence the COD and color load increases with 10-20% per liter of wastewater.

With these results, an improved WWTP is proposed that operates more efficiently at lower costs. In addition, the company will have the opportunity of expanding the production process without expanding the WWTP. The flow diagram of the improved wastewater treatment technology at Thanh Cong Company is presented in Figure 6.4.

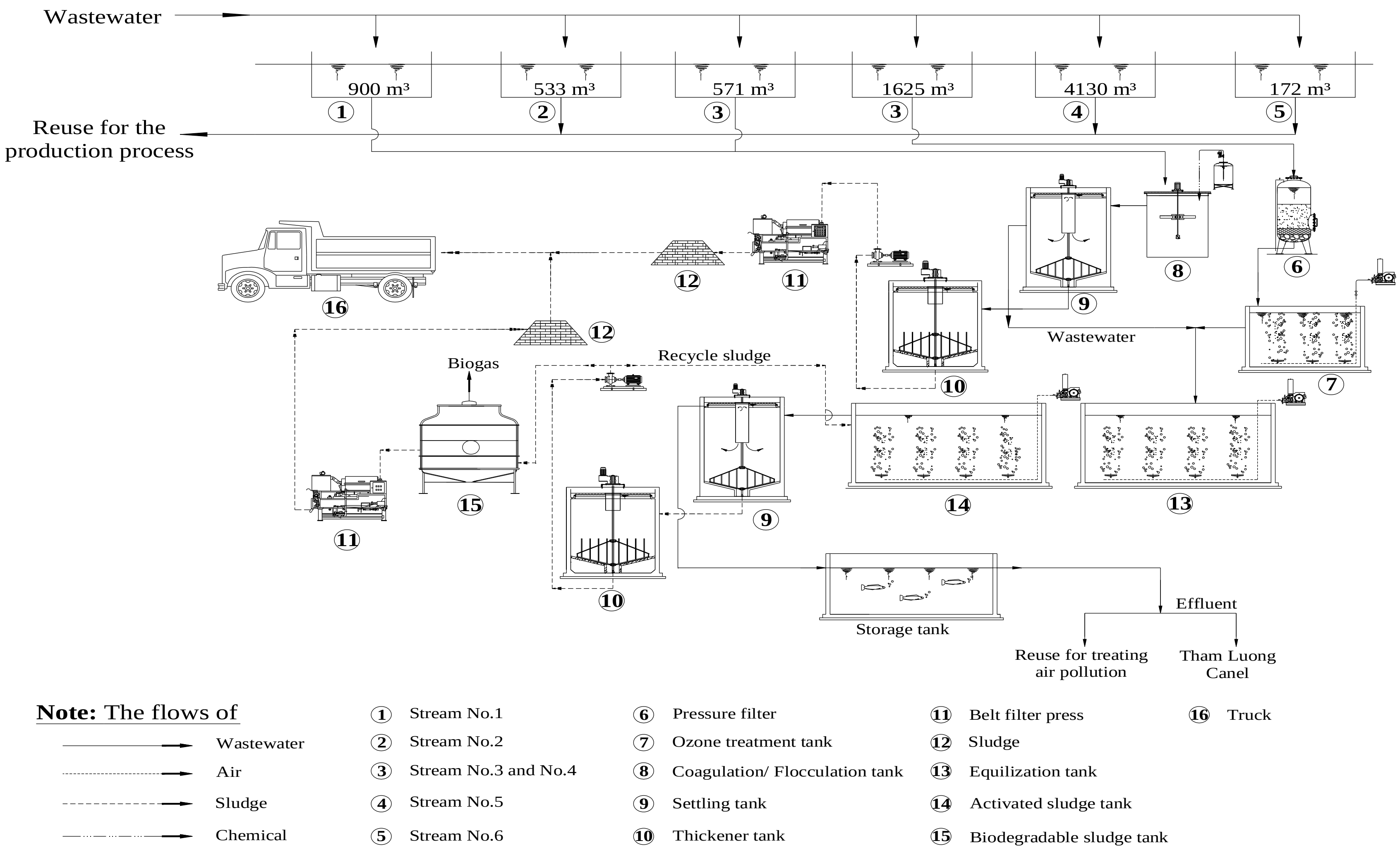


Figure 6.4: Flow diagram of improved wastewater treatment technology at Thanh Cong Company

In this treatment system a combination of physical/chemical, biological and AOPs methods can produce an effluent that meets the Vietnamese standards (TCVN 5945: 2005, class B). Treated wastewater can contribute to the improvement of the water quality of the Tham Luong canal. It can also be used for irrigation on surrounding agricultural areas in Binh Tan and Go Vap districts.

6.4.9 Treatment of air pollution

Although the Thanh Cong Company achieves a high-energy efficiency, the air pollution from boiler operation exceeds the permissible values. Presently, the air treatment system cannot meet air quality allowable concentrations of dust and inorganic substances and the operation costs are high. Total loading rate of air pollution and flow rate of waste air is calculated by modeling air emission inventories and control for commercial boilers, using different fuels (WHO 1993). Table 6.22 presents the results of the calculation of remaining pollutants and flow rates in generated exhaust gasses after implementation of cleaner production options. The results show that only two parameters, dust and SO_2, exceed the permissible values, so that they have to be treated. A treatment system is designed reusing scouring wastewater to treat the air pollution from boiler. The scheme of the air pollution treatment set-up is illustrated in Figure 6.5. The scouring wastewater, some sources of hot washing and washing wastewater usually have a high alkalinity; values of pH are higher than 11. For the wastewater treatment system, a large amount of sulphuric acid is used to neutralize the alkaline wastewater. The scouring wastewater can be reused for treating SO_2. With applying the double alkali method (Stanley 2005), not only SO_2 is removed, but also expensive sodium hydroxide solution is regenerated with inexpensive lime (lime is 6 times cheaper than sodium hydroxide) and forms the valuable product gypsum. The reaction of treating SO_2 and regenerating sodium hydroxide is illustrated in equations (1) and (2).

$$2NaOH + SO_2 \rightarrow Na_2SO_3(s) + H_2O \quad (1)$$
$$Ca(OH)_2 + Na_2SO_3 \rightarrow CaSO_3(s) + 2NaOH \quad (2)$$

In the equation (3) gypsum ($CaSO_4.2H_2O$) is formed, which has commercial values in the manufacturing of plasterboard. The neutralization reaction is expressed in equation (4).

$$CaSO_3(s) + 1/2O_2 + 2H_2O \rightarrow CaSO_4.2H_2O\ (s) \quad (3)$$
$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O \quad (4)$$

Table 6.22: Calculated pollutant concentrations in exhaust gas from boilers

Commercial boilers	Unit	CO	NO_x	SO_2	Dusts	Flow rate m^3/day
Fuel oil (FO): 570 ton/day						
Loading rate	kg/day	21	270	1,904	139	796,500
Air emission	mg/m^3	23	315	2,222	161	
Coal: 367 ton/day						
Loading rate	kg/day	4	110	191	1,530	225,000
Air emission	mg/m^3	14	446	771	6,181	
Total loading rate	kg/day	39	760	2,990	6,343	1,020,000
*TCVN (5939:2005)						
class A		1,000	1,000	1,500	400	
class B		1,000	850	500	200	

Flow rate of FO: 24.3m^3/kg; and coal: 18.2m^3/kg (WHO 1993)
* TCVN (5939-2005): Air quality allowable concentration of dusts and inorganic substances for industrial waste air; with class A is applied for operating enterprise and class B is applied for new enterprise

As can be seen in Table 6.22, the concentration of SO_2 in exhaust gas was about 2,990 mg/m^3 and needs to be reduced to 500 mg/m^3. Thus 2,490 mg SO_2/m^3 needs to be treated. The total SO_2 loading rate that has to be treated is about 2,545 kg/day (2,490 mg/m^{3}x 1,020,500m^3/day). Amount of chemicals needed and formed products from reactions (1), (2) and (3) include:

- Needed sodium hydroxide to treat SO_2: 4,500 kg/day following equation (1)
- Needed $Ca(OH)_2$ to regenerate sodium hydroxide solution: 4,330 kg/day following equation (2)
- Regenerated sodium hydroxide: 7,550 kg/day following equation (2)
- Formed gypsum ($CaSO_4.2H_2O$): 7,550 kg/day following equation (3)

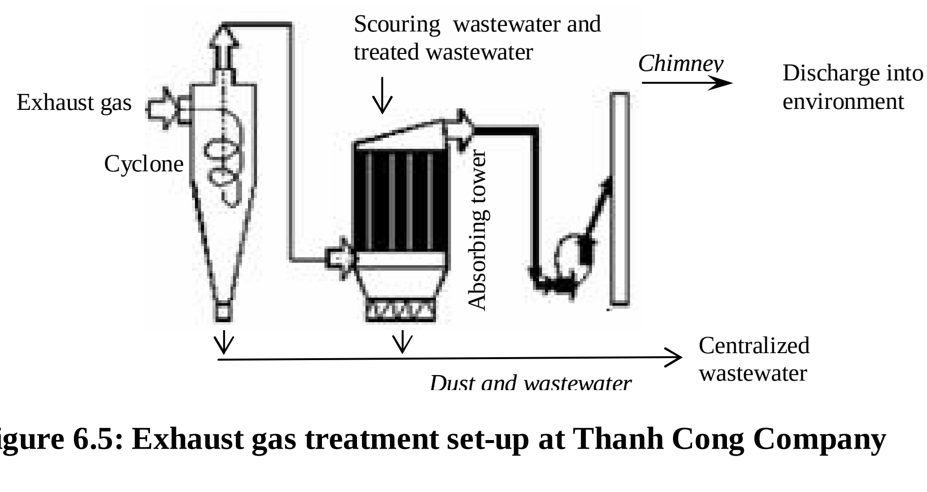


Figure 6.5: Exhaust gas treatment set-up at Thanh Cong Company

Table 6.23 presents the results for 28 Company-Agtex for the reuse of scouring wastewater to treat air pollution of a boiler with an average consumption of 50,000 L FO per month. According to Table 6.23 the volume of wastewater required to treat

1,020,500 m^3 exhaust gas every day is approximately 3,000 m^3/day (3 boilers with an average air pollution of 10,000 m^3/hour, which need 30 m^3 scouring wastewater/hour in total. Wastewater, generated from the scrubber system, is continuously treated before discharge. Strict inspection of environmental management agencies will promote investment and frequent operation of waste treatment facilities at the company and will enhance compliance of environmental protection performance.

Table 6.23: Specification in using scouring wastewater to remove SO_2 from air pollution

Exhaust gas flow rate (m^3/hour)	SO_2 loading rate (kg/hour)	Demand scouring wastewater flow rate (m^3/hour)	Treated SO_2 (mg/m^3)
2000	4.8	11	420
2300	5.5	13	450
3000	7.2	15	480
4000	6.9	16	480
5000	12.0	17	440
6000	14.4	19	490
7000	16.8	22	430
8000	19.2	24	450
9000	21.6	28	420
10000	24.0	30	430
		TCVN 5937: 2005,	
		Class B	500
		Class A	1,500

Source: Vietnam environmental protection agency 12/1999(VEPA 1999)

6.4.10 Treatment of solid waste

The load of hazardous waste decreases hardly after implementation of the proposed CP options. By sending empty containers back to the supplier, a reduction of approximately 50 kg (50%) per month of chemical packaging waste can be reached. The waste oil can be separated at the source, after which a part of the waste oil can be reused to maintain sewing machines; this reduces 10% or 50 kg of the generated waste oil per month. The amount of waste sludge is also decreased by reduction of pollutant concentration and volume of wastewater.

However, some types of industrial waste remain after application of pollution prevention measures. Therefore, they have to be treated outside the company. Following the objectives of industrial ecology, recycling of hazardous and domestic waste is needed. There is a significant market for recycled waste oil in Hochiminh city. The Thanh Cong Company can earn money from selling waste oil to recycling companies. These are located in the Thu Duc district, Hochiminh city (17 km from the Thanh Cong). Other hazardous waste is treated (on contractual basis) by a specialized company with an incinerator and air pollution treatment system; this company is located in Binh Chanh district, which borders on the Tan Phu district. Valuable non-hazardous solid waste is sold for different reclamation purposes. Large fabric scraps are used to manufacture cloths. Small fabric scraps are used as toys stuffing or as a raw material for paper towel production. Scraps of soft yarns and yarns with poor quality are used as material for making mops. Cardboard, plastics and paper are also sorted at the source and are sold to scrap buying companies who sell these to specific recycling companies. Almost all recycling activities are carried out in the districts of Go Vap and Tan Binh in Hochiminh city, at about 10 km from Thanh Cong Company.

Organic matter usually makes up 80-90% of the domestic solid waste in Vietnam, perhaps a little lower at industrial enterprises. Still, sorting at the source is very important for a successful composting process. Thanh Cong generates monthly about 3 tons of domestic solid waste. With implementation of separating at source, 2.4-2.7 tons of organic matter can become raw material for composting plants, which are located in the same area as the sanitary landfill (Cu Chi district, Hochiminh city). Composting products can be used in the surrounding countryside of Tan Phu district, or at rubber tree and cotton farms in Dong Nai and Tay Ninh provinces. The remaining non-organic matter (10-15%), can be sold together with non hazardous industrial waste.

6.5 Greening production model for textile industry

Through the results presented above, it can be seen that dyestuffs, auxiliary chemicals, water and energy consumption in Thanh Cong Company will be reduced when the proposed cleaner production options are implemented. However, an amount of waste is still generated from the production process. This shows cleaner production can help environmental improvement in industry, but is not sufficient to deal with all waste streams. It needs to be combined with a waste exchange network, both on-site and off-site. Figure 6.6 shows the proposed greening production model of Thanh Cong Company.

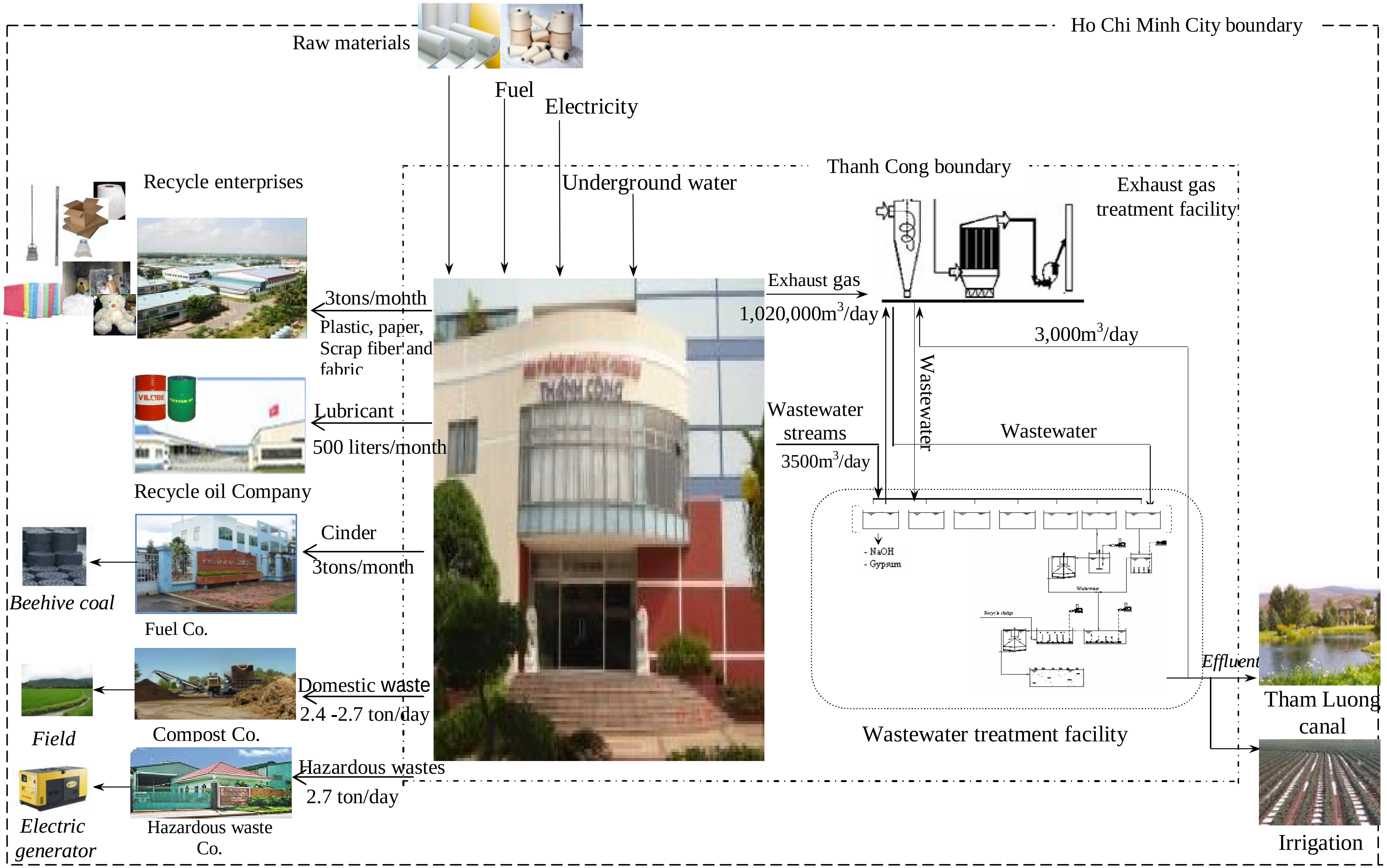


Figure 6.6: Model of greening production at Thanh Cong Company

The greening production approach is not much applied in Vietnam, because it is not widely disseminated, policies and measures to promote implementation of greening production are not readily available. The next section will analyze the role of actor networks as promoters in the development of the greening production model in Vietnam.

6.6 Actor networks in support of greening production in Thanh Cong Company

The introduction of cleaner production options at Thanh Cong Company does not only or even mainly depend on company internal relations, but is significantly motivated or hindered by the functioning of external actor networks. An analysis of these networks helps to understand possibilities for the implementation of the greening production model for the textile industry. Three actor networks are involved and are analyzed, being the economic, policy and societal networks.

6.6.1 Economic network

An analysis of the economic network in which Thanh Cong Company is embedded, focuses on three dimensions. First is the economic interactions between the company and its suppliers and customers; the second dimension encompasses the interaction between the company with other textile companies producing similar products, directly or via branch associations; the last dimension relates to the interaction between the company with other economic agents such as banks, research institutes and waste treatment companies.

Supply chain actors

Raw material suppliers

Thanh Cong's production input requires about 7,000 tons raw cotton per year. Vietnamese cotton fiber companies are not able to meet this material requirement. According to An (2007), the Vietnamese fiber companies only satisfied about 10-15% of the national raw cotton demand in 2007, making overseas imports necessary. The Thanh Cong Company imports about 90% of natural raw cotton from foreign companies, especially from China, Pakistan and the United States. The raw cotton quality is one of the important factors affecting production technology and wastewater treatment costs. Low quality raw cotton contains a high amount of impurities such as fat, wax and pectin. This leads to the use of large amounts of chemicals, water and energy in the preparing step of dyeing and finishing processes. Subsequently these impurities are discharged into wastewater, causing a high COD load and a difficult and costly treatment process. Thanh Cong Company can control the quality of imported raw material by making contracts with suppliers, involving cotton quality (less than 2% impurities) and price. High quality raw material thus reduces production expenses because of decreasing consumption of chemicals, water and energy as well as minimized organic loads into the wastewater treatment system. The preparation step (scouring/bleaching step) makes up about 50-70% of the COD load in the effluent and consumes a large amount of chemicals in the treatment process.

Like any textile company, Thanh Cong Company consumses a large amount of chemicals, especially in the dyeing and finishing process. However, the chemical industry of Vietnam is not able to produce these chemicals for the textile industry. Most chemicals and dyes used at Thanh Cong Company are imported, mainly from Switzerland, the EU, US, Japan, Taiwan and China. Chemicals from Taiwan and China are usually cheap, but of low quality resulting in a high concentration of chemicals in the wastewater. This can be found in the chemical mass balance of dyeing and finishing processes for blended and cotton fabrics of Thanh Cong Company. The high residual dyestuffs and auxiliary chemicals after dyeing leads to intense color and a high total dissolved solids concentration in wastewater streams, and needs difficult and costly treatment.

Hence, all relevant raw input materials for Thanh Cong depend largely on imports. Selecting co-operation with foreign suppliers for buying high quality materials can have a significant effect on environmental performance. But these foreign suppliers have little influence of the material sourcing and selecting behavior of Thanh Cong Company.

Water supplier

Thanh Cong Company consumes 8,000-9,000 m^3 water per day from self-managed groundwater sources. This reduces production costs as groundwater is free of charge, while water utility supply costs (0.25 US$/$m^3$) would contribute 10-15% to the production costs (VINATEX 2003). Resolution No.17/2006/QD-UBND of February 2, 2006 of the Hochiminh People's committee for management of water resource indicates that in areas with a water utility supply network, groundwater exploitation is forbidden. However, the Thanh Cong Company still exploits groundwater sources. According to Thanh Cong, they built the groundwater exploitation and treatment system before the resolution passed. They spent a large amount of money in building this system and have to use groundwater until the payback period (estimated at 5-6 years) has passed. In addition, the water supply company is not good enough to provide the quality of water the company demands. According to article 28 of the LEP (2005), Thanh Cong Company must pay an environmental tax for their groundwater exploitation and an environmental protection charge for discharged wastewater. Until now the company has not paid taxes for groundwater use. In 2004 and 2005, Thanh Cong did not have a wastewater treatment plant (WWTP) and they paid 447,214,560 VND (29,950 US$) per year for environmental protection charges. After building a WWTP in December 2005, they only paid 9,360 US$ per year, because the pollution load decreased significantly. With no charges for groundwater use and low payments of environmental protection charges, the company pays little attention to water saving in their production process. In addition, diluted wastewater can be treated more easily and less costly. Proper enforcement of environmental taxes for groundwater exploitation or enforcement of using groundwater instead of tap water will put pressure on Thanh Cong Company to implement cleaner production options to minimize water use and generation of wastewater. These then not only bring economic benefits for the company but also increase environmental performance.

Fuel supplier

Fuel costs contribute significantly to production costs, in the range of 10-15% (VINATEX 2003). FO is usually used in boilers and oil heaters. However, as the fuel price increase continuously, Thanh Cong has studied to substitute a part of the FO by coal and cashew skins, as these materials are cheaper than FO; but these fuels generate more air pollution. The quality of fuel influences the operation of the boiler. High quality fuel will decrease the amount of fuel consumption, the maintenance fee and the operational costs of the treatment system. A contract for fuel supply has been signed between the Petrolimex Company and Thanh Cong Company, in which the supplier is bound to a fixed price and quality. The business department of Thanh Cong Company discusses with the supplier the quality of fuel and Thanh Cong requires fuels with low sulphur concentration resulting in less SO_2 generation and reduced treatment cost. At present, Thanh Cong Company pays more attention to fuel saving, due to the high fuel price. Therefore the company joined the energy efficiency program introduced by the Energy Conservation Center of Hochiminh (ECC-HCMC). Through this program, the consumption of fuel and related air pollution has been reduced somewhat.

Electricity supplier

Electricity is required for some equipment and for lighting. In fact, electricity consumption is insignificant compared to the amount of fuel used in boiler operations. Tan Phu Electricity Company supplies the electricity for Thanh Cong Company regulated by contract. Price depends on service hours during the day (low, normal and peak times). The current power price does not encourage electricity saving for Thanh Cong Company. In addition, the electricity price has hardly increased between 2005 and 2008. According to the Ministry of Industry and Trade (2008), the electricity price increases at least 20% in 2009; this is probably not enough to stimulate Thanh Cong Company to consider electricity saving through cleaner production.

Consumer/customer

Thanh Cong‘s products are not only for domestic customers, but also for the more strict importers of their products. Main source of company profits come from exports (65% of turnover) (TCM 2009). Thanh Cong Company focuses on the foreign markets, with American, Japanese and European customers. Importers or foreign retailers not only require high product quality and competitive prices, but they also ask exporting companies for environmental performance and social standards (ISO 14000; SA 8000). In order to fulfill these customer requirements, Thanh Cong Company built wastewater and waste air treatment systems, introduced registration systems of hazardous waste management, as well as improved the working environment at the company.

With a total population of over 80 million in 2005, Vietnam really is a large domestic market for the Thanh Cong Company. Local consumers highly appraise Thanh Cong’s products; Thanh Cong Company was chosen as Vietnam’s High-Quality Goods producer for many years. However, with more than seventy percent of the Vietnamese population being low-income and young customers, price and fashion are more likely to be sensitive issues than environmental performance. Hence, environmental criteria are not mentioned as characteristics of high quality goods by domestic consumers.

The role of importers in improving environmental performance at Thanh Cong Company is significant, while local consumers have no influence on environmental performance improvement at Thanh Cong Company. For exported products, especially to large markets such as US, Japan and EU, an ISO 14000 certification will help companies in penetrating these markets. In order to compete with other large exporters in the world, Thanh Cong Company plans to apply for ISO 14000 in their development strategies.

Horizontal interactions between Thanh Cong and competitors

At present, there are more than two thousands textile enterprises in Vietnam, of which 47 can be considered large textile companies An (2009). In terms of scale, the Thanh Cong Company is classified as a large company and belongs to the state-owned sector. In general, the production technology of local large textile companies is the same, with four stages, but they differ in products. Few competitors produce the same products as Thanh Cong Company. The competitors of Thanh Cong are large joint ventures and foreign-owned textile companies. These textile joint ventures and foreign companies have the advantage of more capital and better technologies and machines, so that their products have a higher quality and lower price. In addition, inflexibility in the production process is seen as one of the main competitive disadvantages of state-owned companies in comparison with private companies, joint ventures and foreign companies.

In order to improve competitiveness, Thanh Cong Company has carried out several projects to improve technology, machines and change of materials. This resulted in some reduction of specific material consumption, waste generation and energy use in comparison with other large textile companies.

In recent years, Thanh Cong Company built a waste treatment facility with high investment and operational costs, contributing with 10-15% to the production cost. This can cause a reduction in competitiveness of the company, compared to other companies that discharge untreated wastewater or only dilute wastewater before discharging.

Vietnam National Textile & Garment Group

Vietnam National Textile & Garment Group (herein after called Vinatex) was established by the Prime Minister, based on resolution No 253/TTg on April 29, 1995, and is directly controlled by the Ministry of Industry. The group has 66 members including institutes of economic and technology research, fashion design, schools for training workers and technicians, trading departments, service companies and nearly 100 sub-companies An (2009). The main targets of Vinatex are: investment, production, supply, distribution, import and export in the field of textile and garment; upgrade technological applications, conduct research, application of latest developed technologies and renovate equipment; provide training and refresher courses for managers, technicians and skillful workers.

Nowadays, Vinatex has a significant influence on the textile and garment industry in Vietnam. In the development strategy of the Vietnamese textile and garment industry until 2010, with an outlook towards 2020, Vinatex is given the role of engine and core position in the development of the textile and garment industry. With great concentration in business activities, Vinatex realizes also that manufacturing production pertains to environmental protection. To support environmental protection performance for members within the group, Vinatex has established cooperation with the Vietnam Cleaner Production Centre **(**VNCPC) to provide training courses in cleaner production for their members. In addition, Vinatex acts as a guarantee for bank loans in cleaner production application or waste treatment projects for group members. For instance, Vinatex guaranteed a bank loan for the Thanh Cong Company to invest in a wastewater treatment facility with total costs of 28 billion VND. Vinatex has also cooperated with universities such as the Polytechnic University and Education and Technology University, to perform studies on the modernization of textile equipment with low cost; this helps companies with capital limitations to invest in new technology. In order to improve the environmental performance of the textile industry, Vinatex can lead in cleaner production and industrial ecology development strategies or action programs for the group, as well as for individual textile and garment industries. Moreover, the group could play a central role in exchanging information on environmental issues between their members, for instance by disseminating experiences of Thanh Cong in implementing the greening production model to their members. The group can help raise environmental awareness among their members via training courses and show the benefits of ISO 14,000 for exported companies.

Vietnam Textile and Apparel Association

Vietnam Textile and Apparel Association (Vitas) is a unique organization representing all economic sectors in the field of textile and garment production. This association is a social-economic, voluntary organization, established in 1997. Vitas' main activities are to advise entrepreneurs in terms of production management, trade promotion, technical skills, financial services and quality management in conformity with social standards, international standards (ISO), technological renovation, investment and staff training. Although this association does not directly engage in environmental reform for the textile industry, it does play a role as facilitator of cooperation and coordination in all activities of its members and with governmental and scientific-technological organizations. The current role of Vitas in supporting environmental reform in textile industry is limited. However, as a representative of its members Vitas could help to propose relevant solutions to the government to support the implementation of greening production, industrial ecology and waste treatment among its members.

Interaction with other economic agencies

Banks

The more than 40 state, private and foreign banks that operate in Vietnam are in strong competition nowadays, resulting in low interest rates for lending, which is beneficial for businesses. Thanh Cong Company receives support from many large banks, because they are a large, prestigious and important client for banks. The company can easily lend money to invest in technological upgrading and innovation, resulting in better environmental performance with less material consumption and decreased pollution. Hence, capital availability is not a major constraint for greening Thanh Cong Company.

Research institutes

Textile industry is one of the key industries in Vietnam for research and training institutes. There are a few universities and specialized institutes for educating textile industry specialists, mostly located in major centers, such as Ha Noi, Dong Nai and Hochiminh city. Besides, many training programs focus on management cadres of various levels, designers, skilled worker and technicians for spinning-weaving-dyeing technologies. These training programs increase the labor productivity of the textile industry and sometimes also improve environmental performance. For instance, the Vietnam Cleaner Production Centre and Vinatex provide introductions and training courses for cleaner production for their member companies, through a program “Production cost reduction through cleaner production in Textile and Garment Industry” which started in 2002. Thanh Cong Company offered to join a demonstration project in this program. The Energy Conservation Center of Ho Chi Minh City works directly under the Department of Science and Technology of Ho Chi Minh City (DOST) since May 2002. Its aim is to gather dedicated scientists, technologists and managers from various industries in making policies, offering resolutions and training on efficient energy use and energy conservation for all socio-economic sectors. Thanh Cong's programs for saving energy usually run via Energy Conservation Center of Hochiminh (ECC-HCMC) for assistance.

Environmental (treatment) companies

Regarding waste treatment technologies the company prefers to collaborate with environmental consulting companies and environmental firms, rather than universities and research centers as the latter are too research oriented for such standard solutions. Obviously, these universities should focus more on closed loop systems and industrial ecology solutions, which require still more in-depth research.

According to supervision and inspection data of the Vietnam Environment Administration (VEA 2008) over the years 2006-2008, 74.7% of the industrial enterprises had installed wastewater treatment systems by 2008. Although the percentage of companies with wastewater treatment systems has increased recently, the status of industrial environmental pollution has not improved (VEA 2008). Many pollution treatment systems (85-90%) could not meet industrial effluent standards due to unsuitable technology, high operational costs and poor operation. In order to improve the industrial environmental performance, waste treatment companies will need to promote new advanced technologies. But the quantity and quality of local waste treatment companies is still limited. For instance, almost all wastewater treatment systems in Hochiminh city are designed by 10 consulting, designing and contracting companies, with limited competition on prices and technological innovation. To improve services of waste treatment, the government can encourage investment of international environmental companies through support of tax reductions and copyright/patent laws. It can support local environmental companies by tax reduction on imports (machine and accessories) and capital support in terms of low interest rates.

6.6.2 Policy network

In the policy network, the interaction between Thanh Cong Company and state environmental management organizations is analyzed. As can be seen in the scheme of Vietnam's environmental management organization (chapter 1), the highest environmental authority is the Ministry of Natural Resources and Environment, followed by provincial Departments of Natural Resources and Environment and then the district offices of Natural Resources and Environment.

As a large company, MONRE is responsible for supervision and inspection of environmental protection at the Thanh Cong Company. As Thanh Cong is located in Hochiminh city, DONRE of Hochiminh city can also conduct inspections and request environmental protection measures when it notices signs of violation in environmental laws/decrees or receives complaints from the public. Thanh Cong Company was brought in to operation before the launch of the Law on Environmental Protection (2005) and therefore it did not have to carry out an environmental impact assessment.

Over a period of 12 years (1993-2005), the company discharged wastewater and air pollution to environment without any treatment and did not carry out any periodical monitoring of environmental quality. Consequently, Thanh Cong was on the “black list” (list of heavily polluting enterprises), although it did not encounter any problems having that black list status. Only one time DONRE of Hochiminh city fined Thanh Cong for 17 million VND (1,062 US$), as air pollution exceeded industrial effluent standards. In order to reduce the serious pollution in industrial production, the Prime Minister promulgated Decree No. 64/2003/QD-TTg of 24th April, 2003, “Plan of strict treatment for serious polluted enterprises”. As written in this decree, during the first stage from 2003-2007, companies such as Thanh Cong Company had to build waste treatment systems and after that, all seriously polluting enterprises (such as the dyeing enterprises belonging to Thanh Cong Company) will be relocated to a specific industrial zone. To implement this decree, Thanh Cong built a wastewater treatment plant (WWTP) with a capacity of 5,000 m^3/day and has also a plan to relocate its dyeing enterprises in 2012.
According to Thoa (2006) and Loan (2004), to meet strict Vietnamese standards treatment costs of one cubic meter of textile wastewater is estimated at 8,000 VND (0.45 US$), excluding environmental protection charges. Since the Thanh Cong Company discharges about 8,000 m^3/day, 30 days per month, the treatment costs would be 1,920 million VND per month (approx. 180,000 US$). Thus it is no surprise that Thanh Cong did not treat wastewater over a long period of time and this still happened even when the company installed the WWTP. The director of Dong Nai DONRE, Le Viet Hung, stated that although they know companies pollute the environment and these firms have been fined, they can not shut down the company, because of the employment effects for instance over 4,200 workers within Thanh Cong Company. In addition, Thanh Cong is a state-owned company, so they are less afraid for competent environmental management agencies because Thanh Cong knows that these organizations can not close the company. This shows that poor enforcement of environmental regulations includes many causes. Firstly, making environmental policy in Vietnam is still in its infancy, with an incomplete legal framework, inappropriate for the current socio-economic development and environmental protection needs. Secondly, there is limited supervision and inspection, especially of industrial

companies, together with low penalties for environmental violations and low environmental charges. Thirdly, government's appeasement in solving infringements in environmental protection regulations is dominant. Finally, especially state-owned companies have little to fear from stringent enforcement, as they are well-protected by their parent ministries.

To improve the situation MONRE has to improve the national laws, regulations and complete the legal framework. MONRE also need to further develop and introduce environmental taxes for exploitation of natural resources, develop industrial effluent standards for textile industry, increase environmental protection charges and enforce heavy fines for environmental violations. At present, existing policies on encouraging cleaner production remain insufficient and MONRE should provide more details in the legal frameworks to encourage and direct cleaner production as well as the development of environmental management systems (ISO 14,000).

In order to improve monitoring and enforcement, it is better that DONRE of Hochiminh takes on responsibilities of MONRE. The local environmental management agency (DONRE) can strengthen the frequency of supervision, inspection activities and a coherent monitoring system aimed at Thanh Cong Company. This will motivate Thanh Cong Company to carry out environmental protection measures. Once waste treatment costs become a financial burden, Thanh Cong will consider greening its production approach. Besides, supervision will provide feedback on the effectiveness of existing strategies, policies, laws and regulations. It will not be easy to change the relation between the parent ministries and the state-owned companies, but this seems essential for setting the right incentives for greening the production of Thanh Cong.

The Vietnamese Government can provide financial assistance for technological innovation and the application of clean technologies through environmental protection funds. These funds support environmental protection activities, which include cleaner production, waste treatment, prevention of environmental incidents and pollution control. The interest rate of these funds is very low (from 1to 2%/year, or even 0% depending on the type of industries). At present, environmental protection funds are established at the central and local levels and some funds related to environmental protection are listed below:

- The Revolving Fund for Industrial Pollution Control in Businesses in Ho Chi Minh City (established in 2001 with a capital of 2.5 million US$);
- The Industrial Pollution Minimization Fund in Ho Chi Minh City (IPMF, established in 1999 with a capital of 1 million US$);
- Vietnam Environmental Protection Fund (established in 2002 with an initial capital of 12.7 million US$);

Up to April 2009, Vietnam Environmental Protection Fund had 85 projects with a total capital of 10.3 billion VND (562 million US$). The interest rate at commercial banks is higher than that at the Vietnam Environmental Protection Fund (7.5 to 12 times as high). However, companies have difficulties to receive capital support from the Vietnam Environmental Protection Fund for environmental protection projects due to complicated administrative procedures. This is similar for the Revolving Fund for

Industrial Pollution Control and the Industrial Pollution Minimization Fund in Hochiminh City.

According to Decree No. 64/2003/QD-TTg of 24th April, 2003 issued by the Prime Minister, Thanh Cong Company appeared in the lists of 4295 highly polluting industrial enterprises. This company was asked to perform wastewater treatment in order to minimize environmental pollution. Because the company is in the list of high polluters Thanh Cong Company can receive capital support from Vietnam Environmental Protection Fund (VEPF) to implement environmental protection measures. Thang Cong Company is also a state-owned company, which is an advantage compared with private companies for receiving a loan from VEPF. However, the administrative procedures for the loan are very difficulty. The government has recognized the institutional weaknesses of these funds and is making greater efforts to accelerate administrative reform.

In Vietnam, regulations on taxes regarding import-export and environment change continuously. Currently, companies should pay two main taxes: value-added tax with a tax rate of 10% for domestic goods and a 25% gross enterprise tax with a rate. Moreover, exporting companies have to comply with the law on import-export taxes. The government has recently promulgated tax policies to stimulate the development of export companies like the Thanh Cong Company. The textile and garment industry, as an important economic sector in Vietnam, are provided with preferential loans with interest rates 25% less than on normal loans (depending on current commercial rates). The loan duration is 12 years with a three-year grace period. In Hochiminh city, the local government provides incentives for textile companies to improve their production: textile companies receive loans from the city budget with low interest rates (6%/year) to upgrade their technology. This relates to preferential tax policies to support clean technology in domestic investment in Vietnam as presented in Government Decree 55/2001/QD-TTg dated April 23, 2001. These include:

- Exemption of the gross enterprise tax in the first 3-4 years and reduction of 50% of regulated taxes in the next five years for hi-tech investment projects. Through the new products companies should be able to compete effectively with similar foreign products.
- Appling 0% value-added tax rates on sales of domestically made fabrics to local enterprises that make garments for export.
- Exemption of import tax for equipment, machines and materials related to technology innovation (the common import tax is around 10-20%).

6.6.3 Societal network

Societal networks focus on interactions between industry and society. In the absence of non-governmental civil society organizations in Vietnam, this network comprises especially neighbors, mass organizations and mass media.

Neighbors

Most of the 60 textile (including Thanh Cong), paper, soy and instant noodles factories at both sides of Tham Luong canal discharge highly polluted wastewater into the canal without proper treatment. This canal is one of the most polluted canals in Hochiminh city and its problems have existed for over 15 years. Monitoring results of the Environmental Protection Agency of Hochiminh city during recent years (2002–2008) show suspended solids (SS), BOD and coli form indicators increasing in consecutive years, all exceeding permissible values many times. Especially the BOD concentration exceeded the standards of surface water quality (TCVN 5942:1995, class C) 4 to 22 times at Tham Luong Bridge. Odor from Tham Luong canal can be noticed at 1–2 km from the canal, negatively affecting the quality of life of people living at both sides of the canal. Mrs. Dao Thi Bich Dau, a resident in an affected neighborhood, mentioned she constantly suffers from bad smell and locals call it the "stinking canal". Many households had to change the hour of having dinner to the late evening, to avoid pungent fishy smell from canal during diner. Mr. Nguyen Van Si, representing a households group at ward 13, Go Vap district, complained about the serious pollution through wastewater discharges, leading to degradation of fish culture and of vegetable cultivation areas surrounding the Tham Luong canal. Moreover, after heavy rain, wastewater from the polluted canal floods into residents' homes.

Following pressure and complaints of local citizens living around Tham Luong canal, the local district government required that industrial sites should treat wastewater before discharging it into the canal. These complaints had an effect on DONRE, as it frequently inspects and tries to take action against companies that fail to treat their wastewater properly. As results of these complaints, the government has considered the problem in their master plan for pollution reduction in the Tham Luong canal. Though the case study reveals the role of communities in environmental reform, as others have done (Phuong and Mol 2004), their role remains limited. Via citizen‘s complaints, the local government has made additional efforts to solve this problem by relocating residents along the canal to a different area and by intensifying inspections. However, environmental pollution has increased year after year during the last decade.

Mass organizations

Mass organizations, such as the Women union, Youth union and Veteran’s union (part of the Fatherland Front), work closely with the government at provincial, district and commune levels. Such organizations could help to file complaints of residents at competent authorities. In the case of the Thanh Cong Company, local residents do not complain directly about the discharge of wastewater from Thanh Cong, because communities lack knowledge to relate the water pollution to the source. There are over 60 companies on both sides of the canal discharging wastewater into Tham Luong canal. In 2007, the Fatherland Front of Tay Thanh ward submitted complaints on air pollution (dust and odor) from Thanh Cong to the Tan Phu district office of Natural Resources and Environment. As a result of these complaints, DONRE of Hochiminh city inspected Thanh Cong, fined the company and required the building of waste air treatment systems. After that, the air pollution situation remained the same. This shows that the complain system does have a voice, but its effects are limited.

In preventing complaints, Thanh Cong Company keeps a close relationship with the People's Committee of Tan Phu district. When the Vietnamese Fatherland Front of Tan Phu District launched a program to support poor people, the company contributed 500 million VND from its business profits. They also built a medical clinic to serve workers and poor local residents. This all has most likely contributed to reduce complaints from the community and mass organizations.

Mass media

The media (radio, television and newspapers being the most relevant for Vietnam) are increasingly paying attention to the environment. Violations of environmental protection laws by enterprises, incidents and accidents, pollution situation of water, air and solid waste at provinces/cities and the handling of violations by state management agencies are frequently reported. Newspapers and magazines regularly covering environmental issues are for example Liberated Sai Gon, Youth newspaper, Laborer newspaper, Vietnam News, and People newspaper; for Hochiminh city are relevant Youth, Liberated Sai Gon and Laborer.

These newspapers also take up and articulate complaints. In addition, newspapers help raising environmental awareness among the public. Newspapers reporting on serious pollution at the Tham Luong canal by industrial activity included Thanh Cong in the general list of polluters. Thanh Cong, as a major company in Vietnam, is sensitive for such newspaper reporting, as negative publicity can affect its image in the eyes of domestic consumers and exporters.

6.7 Conclusions

Thanh Cong is known as a large textile company that gains foreign currency and contributes to employment. However, its environmental performance is poor and high waste treatment costs are an important cause for that. The results of our case study of Thanh Cong Company demonstrate that the economy and environment benefits from pollution prevention and industrial ecology in large textile industries in Vietnam. A greening production model, combining cleaner production and external waste exchange, is feasible and attractive for such a textile industry. The largest benefit is that the application of cleaner production options, separation of waste streams and advanced waste treatment technology decreases significantly the volume of wastewater and chemical loads going into wastewater. In addition, an external waste exchange network helps to recycle most remaining waste materials, by reusing it as raw material in other companies. All this contributes to a sustainable development of Thanh Cong Company.

The case study shows that various actors can be involved in the implementation of the greening production model. In the economic network, the roles of customers (especially importers) and Vinatex are important and a further pricing of natural resources (especially groundwater) will also be vital in improving the company's environemntal performance. The policy network analysis revealed that the role of state authorities can be influential in improving environmental performance, but is still limited in the current setting due to a number of flaws at the national and local level. In recent years, concerns and complaints of citizens and reporting in newspapers on pollution threaten to affect the image of companies like Thanh Cong; this can contribute to behavioral change. It is at these points in the actor networks that pushes towards the implementation of the green production model can be expected in the future.

Chapter 7

An industrial ecology model for Nhon Trach 2 Industrial Zone, Vietnam

7.1 Introduction

In the previous chapter, the greening production model for the Thanh Cong Textile and Garment Company provided a feasible and attractive new approach to sustainable development of individual large textile companies. In previous studies Côté and Smolenaars (1997), Chertow (2000), Zhu et al.(2007), Jin (2008), Graedel and Allenby (2003), Erkman (1997), Ayres & Simonis (1994) and Lowe (1997), it was shown that industry ecology can also reduce environmental impacts and use resources in an efficient way for groups of industrial companies.

To investigate the relevance of such an industrial ecology approach for Vietnam, an integrated textile and garment industrial ecology model for Nhon Trach 2 industrial zone (Nhon Trach 2 IZ) will be developed in this chapter. This model is based on a mutually beneficial relationship of the geographical proximity of seven textile companies in the Nhon Trach 2 IZ and an external waste exchange network. These two components enable the minimization of impacts of the industrial system on the environment by optimizing the material and energy flows going into and out of the industrial system.

This chapter is divided into five parts. In the first section, the situation of the development and current environmental performance of the Nhon Trach 2 IZ is shown. The second section presents more details of the material inputs and outputs of the seven textile companies. Subsequently, the development of a textile and garment industrial ecology model based on the gathered data is discussed. The fourth section provides an analysis of actors' roles in implementing the model. The final section concludes the analysis of an industrial ecology model at the Nhon Trach 2 IZ.

7.2 General description and environmental performance of the Nhon Trach 2 IZ

The Nhon Trach suburb is located in the southwest of Dong Nai Province and is one of the agricultural suburbs of Dong Nai province. The Nhon Trach suburb was established in 1994 after splitting from the former Long Thanh suburb. The Nhon Trach suburb has an advantageous position on the regional waterways and will become a future entrance to Hochiminh City, which will facilitate its industrial development. Being aware of the economic benefits provided by industrial development, the Government approved the establishment of the Nhon Trach 2 IZ, which was established in 1997 under the Corporation for urban industrial development No.2 (Company D2D). The communes of Hiep Phuoc, Phuoc Thien and Phu Hoi are also located there. The location of Nhon Trach 2 IZ in Dong Nai province and the location of the seven operating textile companies in Nhon Trach 2 IZ are shown in Figure 7.1 and 7.2. This industrial zone has a total area of 347 ha, in which the land area used for the industrial plants occupies 80.4% (279 ha) and the remaining area 68 ha is used for roads, public utilities and vegetation watering. The industries that have invested into this industrial zone include:

- Textile and garment;
- Footwear and leather products;
- Electronic & electrical products;
- Mechanical engineering;
- Building materials;
- Wood processing;
- Foodstuffs;
- Chemicals;
- Cosmetics;
- Pharmaceutical products;
- Services.

In 2007, the Nhon Trach 2 IZ had attracted 52 projects with an area coverage percentage of 100%. By then only 24 companies had been brought into operation; the remaining 28 projects were still under construction.

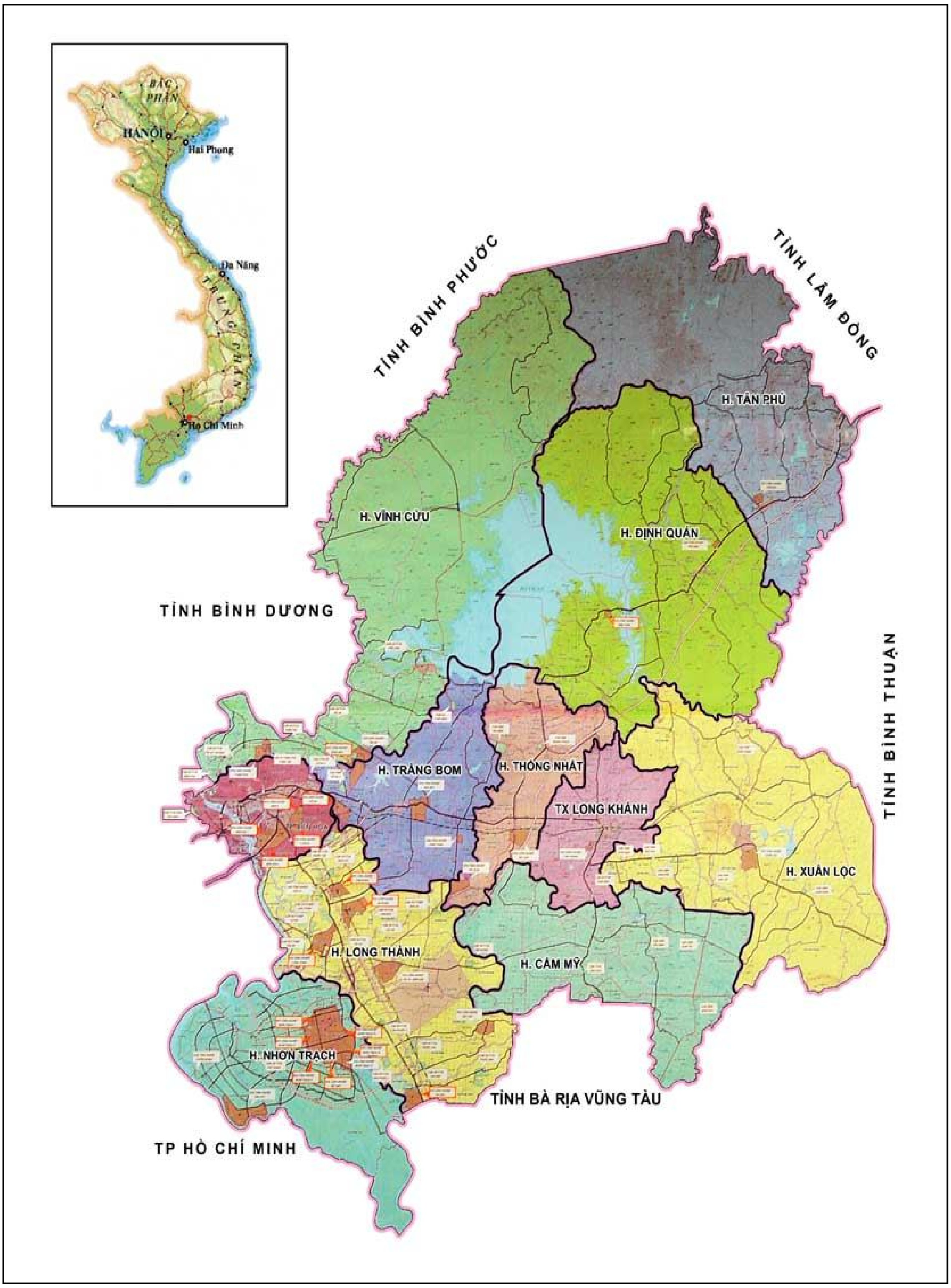


Figure 7.1: Location of Nhon Trach 2 IZ in Dong Nai province

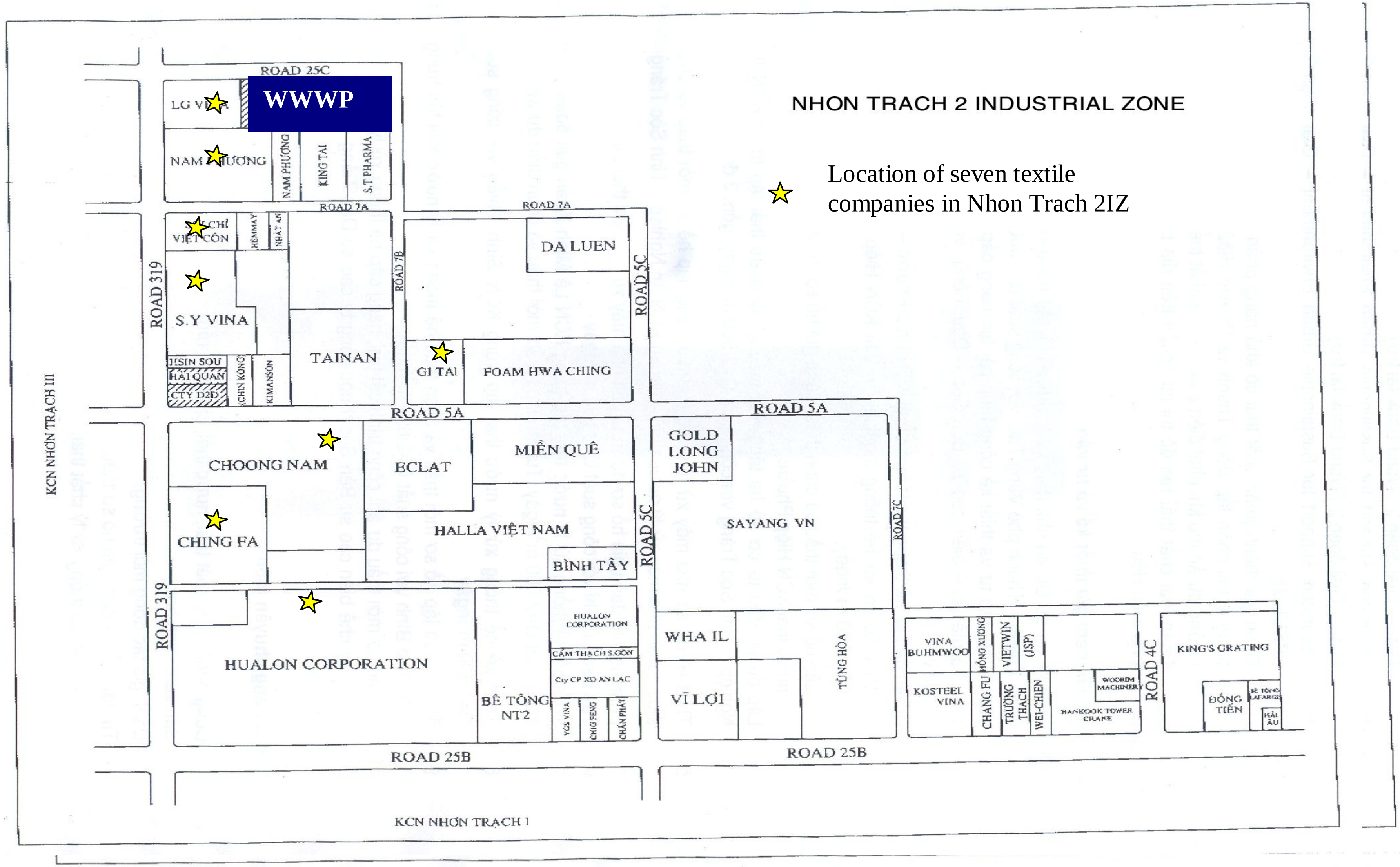


Figure 7.2: Location of seven textile companies in Nhon Trach 2 IZ

7.2.1 Wastewater

According to measurements of the wastewater flow rate of the 24 operating enterprises in the Nhon Trach 2 IZ, the total wastewater volume generated varies from 13,000-15,000 m^3/day. The seven textile and garment companies have an aggregate metered quantity of 13,900 m^3/day of wastewater, comprising 96% of the total current volume of wastewater of the entire industrial zone. The remaining companies produce the remaining quantity of wastewater about 525m^3/day, amounting to 4% of the total wastewater flow. Although the coverage percentage has reached 100%, the industrial zone has not yet completed the infrastructure, such as the drainage network and the central wastewater treatment plant. Therefore, the operating enterprises in this industrial zone have to treat their wastewater to meet the standards of TCVN 5945-2005, recipient source class B, before discharging into the drainage system of the industrial zone. Among the 24 operating factories, there are 21 companies generating industrial wastewater and three companies releasing only domestic wastewater. Currently, 10 companies have built industrial wastewater treatment systems and the remaining 11 companies have not yet installed wastewater treatment systems. Domestic wastewater is treated by a septic tank. Most treated wastewater at each company is drained into the sewer system of the industrial zone before being discharged into the Rach Dua Canal. To assess the impact of wastewater on the environment, effluent samples were collected and analyzed. The results show that the textile companies are the main source of wastewater at the Nhon Trach 2 IZ. For instance, the color fluctuates between 350-615 Pt-Co, the COD fluctuates around 140-450 mg O_2/L, the BOD_5 is in range of 35-110 mg O_2/L and the mineral oil concentration fluctuates from 2.9-15.2 mg/L. These figures exceed the permissible values of industrial effluent standards (TCVN 5945-2005, class B). Among the analyzed parameters, color is exceeded by 7-12 times, COD by 1.8-2.5 times and BOD_5 by 2.5 times compared to the standards. On the other hand, the heavy metal and surfactant concentration is very low and meets the standards for concentration. This is also the case for the pH, which fluctuates between 7.0-7.4. Based on the analysis results, the suspended solid (SS) concentration fluctuates from 20-114 mg/L. However, after 18:00h on the 13th, 14th and 15th of July 2006, the wastewater samples had particularly high SS concentrations, up to 334 mg/L; in addition, the COD concentrations were as high as 450 mg O_2/L and the color was as high as 1,800 Pt-Co, with a signature specific to textile wastewater. Some samples also indicate that certain textile enterprises execute wastewater treatment in a rather obscure way. These enterprises wait until after regular working hours to discharge untreated wastewater into the canal because they are afraid that during administrative working hours (from 07:30 to 17:30h), environmental agencies might inspect their discharges.

The large flow rate of wastewater causes erosion on the sides of the Rach Dua canal. Most wastewater comes from textile companies and therefore has high color intensity and a foul smell. When the water in the canal level is high the wastewater is diluted with the canal water and overflows into the surrounding residential areas, also affecting the cultivation of agricultural of the inhabitants in the region. In addition, the Thi Vai River is the final recipient of the wastewater from various industrial zones in the Nhon Trach suburb, among Nhon Trach 2 IZ. According to recent monitoring results of the Dong Nai Department of Natural Resources and Environment, the BOD_5 concentration in this river exceeds the permissible level for Vietnamese standards for surface water quality by 110 times (Dong Nai DONRE 2006).

7.2.2 Air pollution

The results of monitoring air quality within and around the Nhon Trach 2 IZ, 2x times/year point measurement by the D2D company (2006), are presented in Table 7.1. These results, together with results of an investigation on environmental pollution caused by activities of industrial zones during the first 5 years of the new Millennium in Hochiminh City (Tuan 2007) show that for nearly all indicators the quality of the air meet the Vietnamese standard (5937, 5938-2005, average 1 hour). Only the particulate concentration exceeds the permissible value, due to truck traffic in the industrial zone. The particulate concentration at some industrial zones is shown in Figure 7.3.

Table 7.1: Monitoring ambient air quality at Nhon Trach 2 IZ

Parameters	Unit	Results						TCVN 5937-2005
		S1	S2	S3	S4	S5	S6	
Temperature	^0C	30	31.1	31	32.7	31.5	32.5	-
Humidity	%	67.3	66.9	66	57.6	61.6	59.1	-
Noise	dB	69-74	65-72	66-73	52-60	54-59	63-70	-
Particulate	mg/m^3	0.56	0.22	0.22	0.28	0.14	0.2	0.3
SO_2	mg/m^3	0.02	0.14	0.02	0.01	0.02	<0,01	0.35
NO_2	mg/m^3	<0,004	<0,004	0.029	0.03	0.024	0.007	0.20
CO	mg/m^3	2	2	3	4	1	1	30

Source: D2D company (2006)
Note: S1 to S6: sampling points including inside and outside industrial zone
TCVN 5937-2005: ambient air quality standards.

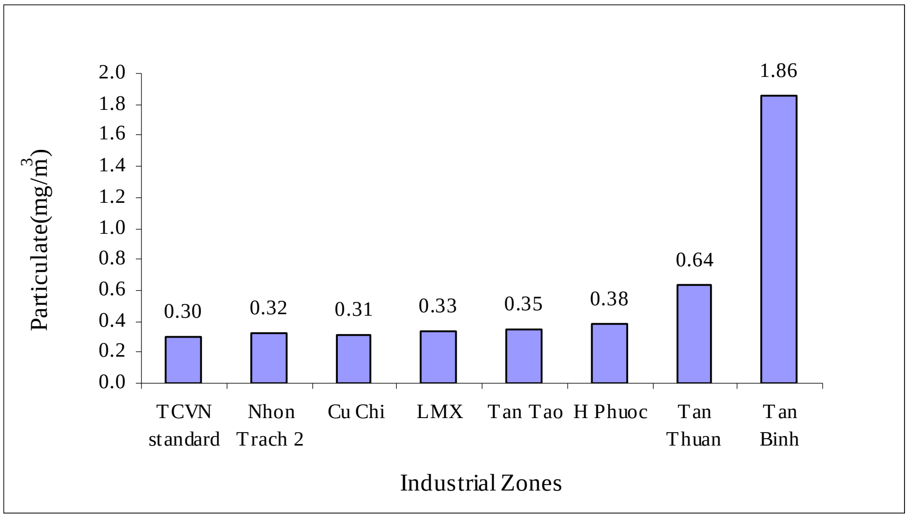


Figure 7.3: Particulate concentrations in air at industrial zones in Hochiminh City, including Nhon Trach 2 IZ

7.2.3 Solid waste

Until recently, the industrial zone did not have a sorting station and adequate equipment for the collection and storage of industrial waste as mentioned in the Law on Environmental Protection (2005). Currently, domestic solid waste generated by the companies located in the industrial zone is collected and transported to a temporary dump site in the Nhon Trach suburb by an environmental service company. Alternately, some companies sign contracts with private companies to collect domestic solid waste locally. Most of the hazardous waste is jointly collected with the domestic solid waste and is buried either permanently or at the temporary dumping site. Moreover, a portion of the hazardous waste is collected by scrap-purchasing units. They then separate the waste; one part of waste is reused and the remaining hazardous waste is dumped on unoccupied land or in canals, endangering the terrestrial and aquatic environment. One of the hazardous solid wastes that is associated with textile companies is sludge, which is generated from the wastewater treatment systems and left-over chemicals. According to the report on monitoring environmental quality at the Nhon Trach 2 IZ of Company D2D in 2006, the total generated domestic solid waste was estimated to be about 1.5-2.0 tons per day and the industrial waste was about 32-35 tons per day. The collected data show that the amount of solid waste generated by textile companies is larger than any other industry in this industrial zone.

In brief, the wastewater, air pollution and solid waste generated in the Nhon Trach 2 IZ is primarily due to the textile industry. Hence, the textile industry has to concentrate on solving their pollution problems to ensure a balance between the economy and environmental protection. For this purpose, we will develop a textile and garment ecological industrial zone for the Nhon Trach 2 IZ, based on the existing industrial zone. To realize an industrial ecology model, the identification of raw materials, energy flow and the composition of waste of all companies in the industrial zone has to be conducted. This information forms the basis for the selection of technologies for the minimization, reutilization and circulation of the textile industry’s waste and for designing a waste exchange network.

7.3 Current environmental performance of textile companies in Nhon Trach 2 IZ

7.3.1 General description of textile and garment companies

Twelve textile and garment companies have invested in the Nhon Trach 2 IZ representing the highest percentage (27%) among invested industrial companies in the industrial zone. In 2007, at the time this research was executed, seven of the textile and garment companies had already begun operation and the remaining five companies are under construction. A list of the textile and garment companies in the IZ is presented in Table 7.2.

Table 7.2: List of the textile and garment companies in the Nhon Trach 2 IZ

Company	Est. year	Investor	Area (ha)	employees (persons)	Note
Hualon Corporation Vietnam	1993	Malaysia	31.5	2800	Operating
Ching Fa Fishing Implements Manufacturing Co., Ltd	1994	Taiwan	7.5	1100	Operating
Choongnam Vietnam Co., Ltd	1995	Korea	15	1300	Operating
S.Y. Vina Co., Ltd	1997	Korea	6.55	700	Operating
Yue Kun Co., Ltd	2002	Taiwan	3.1	150	Operating
Namtex Co., Ltd	2003	Taiwan	6.35	460	Operating
Gi Tal Sewing Thread Co., Ltd	2004	Taiwan	3.0	100	Operating
Da Luen (Vietnam) Co., Ltd	2006	Brunei Darussalam	3.0	-	Under construction
Eclat Textile Co., Ltd (Vietnam)	2006	Taiwan	2.5	-	Under construction
Wha Il Vina Co., Ltd	2007	Korea	3.0	-	Under construction
Hemmay Co., Ltd	2007	Taiwan	2.5	-	Under construction
Vietnam Dona Gold Long John International Co., Ltd	2007	Taiwan	3.0	-	Under construction

Source: www.diza.vn and monitoring environmental quality report of seven textile companies in Nhon Trach 2IZ, 2006 (D2D company 2006)

All of the seven textile and garment companies in the Nhon Trach 2 IZ were built completely with foreign capital. The average monthly production capacity of each company is listed in Table 7.3. These companies occupy 50% of the land area, generate 96% of the total wastewater, generate 90% of the solid waste and are the only significant source of air pollution at the Nhon Trach 2 IZ, which is why only the textile and garment companies are included in this study.

In general, the textile and garment technology is composed of four basic processes: spinning, weaving, dyeing & finishing and sewing (see Chapter 6). However, not all textile and garment companies in the Nhon Trach 2 IZ have all four stages. While the S.Y. Vina Co. Ltd has four processes, the remaining companies perform only two or three of the four work stages of the textile industry (weaving and dyeing & finishing stages, or spinning, weaving and dyeing & finishing stages). Most textile companies in the Nhon Trach 2 IZ are equipped with modern machines and advanced technology. Although the technology of these companies is modern, each company still generates a large amount of waste and consumes a large amount of materials.

Table 7.3: Monthly average production capacity of each company

Companies	Production capacity					
	Yarn (ton)	Synthetic Yarn (ton)	Grey Fabric (m)	Knitted Fabric (ton)	Finished Fabric (m)	Towel (pieces)
Choong nam Vietnam Co., Ltd	350		1,006,926		1,153,570	
Hualon Corporation Vietnam	2,500		10,000,00		1,500,000	
Namtex Co., Ltd				360		
Gi Tal Sewing Tread Co., Ltd		62.8				
S.Y. Vina Co., Ltd					1,822,800	500,000
Ching Fa Fishing implements Manufacturing Co., Ltd		200				
Yue Kun Co., Ltd		12				

Source: D2D company (2006)

Demand for chemicals and raw materials

The principal raw materials used in the production of textile companies are raw cotton and polyester fiber. The total raw material use per month of the seven operating companies is about 6,200 tons. Similar to other textile enterprises, the textile companies in the Nhon Trach 2 IZ use a large quantity and a wide variety of chemicals during their production processes. The total amount of chemicals used per month by the seven companies totals over 8,000 tons. Of this amount, the amount of dyestuffs used is 385 tons and other chemicals (such as auxiliary chemicals, bleaching agents, finishing chemicals) account for about 7,780 tons.

Demand for water, electricity and fuel

At present, some textile companies in the Nhon Trach 2 IZ are using water from both self-exploited groundwater and water from the Nhon Trach groundwater plant, which has a capacity of 10,000 m^3 per day. The electricity is supplied by the national grid through sub-station 103 MVA of the industrial zone. A large amount of fuel is also used in the production facilities. The fuel used for boilers and oil heaters is Fuel Oil (FO), Diesel Oil (DO) and coal, but FO is increasingly being replaced by coal because coal is cheaper than FO. Table 7.4 presents the monthly demand for water, electricity and fuel of the seven textile companies in the Nhon Trach 2 IZ.

Table 7.4: Water, electricity and fuel demand of seven textile companies in Nhon Trach 2 IZ for one month

Companies	Water consumption (m^3/day)			Electricity consumption (kWh/month)	Fuel (ton)		
	Water supply	Groundwater	Total		FO	DO	Coal
Choong nam Vietnam Co., Ltd	2,500	0	2,500	164,342	650		
Hualon Corporation Vietnam	2,500	2,500	5,000	18,557,280	5	9	1,500
Namtex Co., Ltd	1,200	3,300	4,500	1,228,137	25		
Gi Tal Sewing Tread Co., Ltd	100	300	400	14,366	5.5		1,000
S.Y. Vina Co., Ltd	3,000	0	3,000	2,137,947	370	4	
Ching Fa Fishing implements Manufacturing Co., Ltd	450	0	450	267,252		30	
Yue Kun Co., Ltd	115	0	55	760,239	-		
Total	9,865	6,100	15, 905	23,129,563	1057.5	40.7	2,500

Source: D2D company (2006)

Demand for labor

The textile and garment companies in the Nhon Trach 2 IZ have made remarkable contributions to provide jobs for poor people in the Nhon Trach suburb, with nearly 7,000 people involved. Among the seven companies, the Houlon Corporation Vietnam employs the largest workforce with 2,800 people; the next largest is Choong Nam Vietnam Co., Ltd with 1,300 people, followed by Ching Fa Fishing implements Manufacturing Co., Ltd with 1,100 people and S.Y Vina Co., Ltd and Namtex Co., Ltd, which employ about 700 and 460 people, respectively. The remaining companies, including Gital Sewing Tread and Yue Kun Co., Ltd, have about 100-150 employees.

7.3.2 Present environmental performance of the seven textile companies in Nhon Trach 2 IZ

Wastewater

Through the collected and analyzed data on the present environmental situation in the Nhon Trach 2 IZ, it is clear that the textile industry is a polluting industry because their wastes are heavily contaminated and they generate the largest volume of wastewater produced among all the industrial sectors. The most significant pollution source of the textile companies is wastewater. Table 7.5 presents the generated daily wastewater volume and the capacity of the treatment systems of the seven textile companies in the Nhon Trach 2 IZ.

Table 7.5: Wastewater volume and the capacity of treatment system of seven textile companies

Companies	Volume of wastewater (m^3/day)	Capacity of treatment system (m^3/day)
Choong nam Vietnam Co., Ltd	2,400	2,400
Hualon Corporation Vietnam	4,400	6,600
Namtex Co., Ltd	4,000	3,000
Gi Tal Sewing Tread Co., Ltd	350	80
S.Y. Vina Co., Ltd	2,250	3,000
Ching Fa Fishing implements Manufacturing Co., Ltd	300	300
Yue Kun Co., Ltd	50	80
Total	13,600	

Source: Viet (2006)

As noted in the previous chapters, textile wastewater is generated mainly during the dyeing and finishing processes, which produce a large volume of wastewater with a high concentration of pollutants. This is also similar for textile companies in the Nhon Trach 2 IZ. At present, all textile companies in the Nhon Trach 2 IZ have to treat their wastewater to meet the industrial effluent standard of TCVN 5945:2005, recipient source class B. Currently, all textile companies in the industrial zone have installed wastewater treatment systems. The current wastewater treatment technologies applied in these companies are described in Figure 7.4.

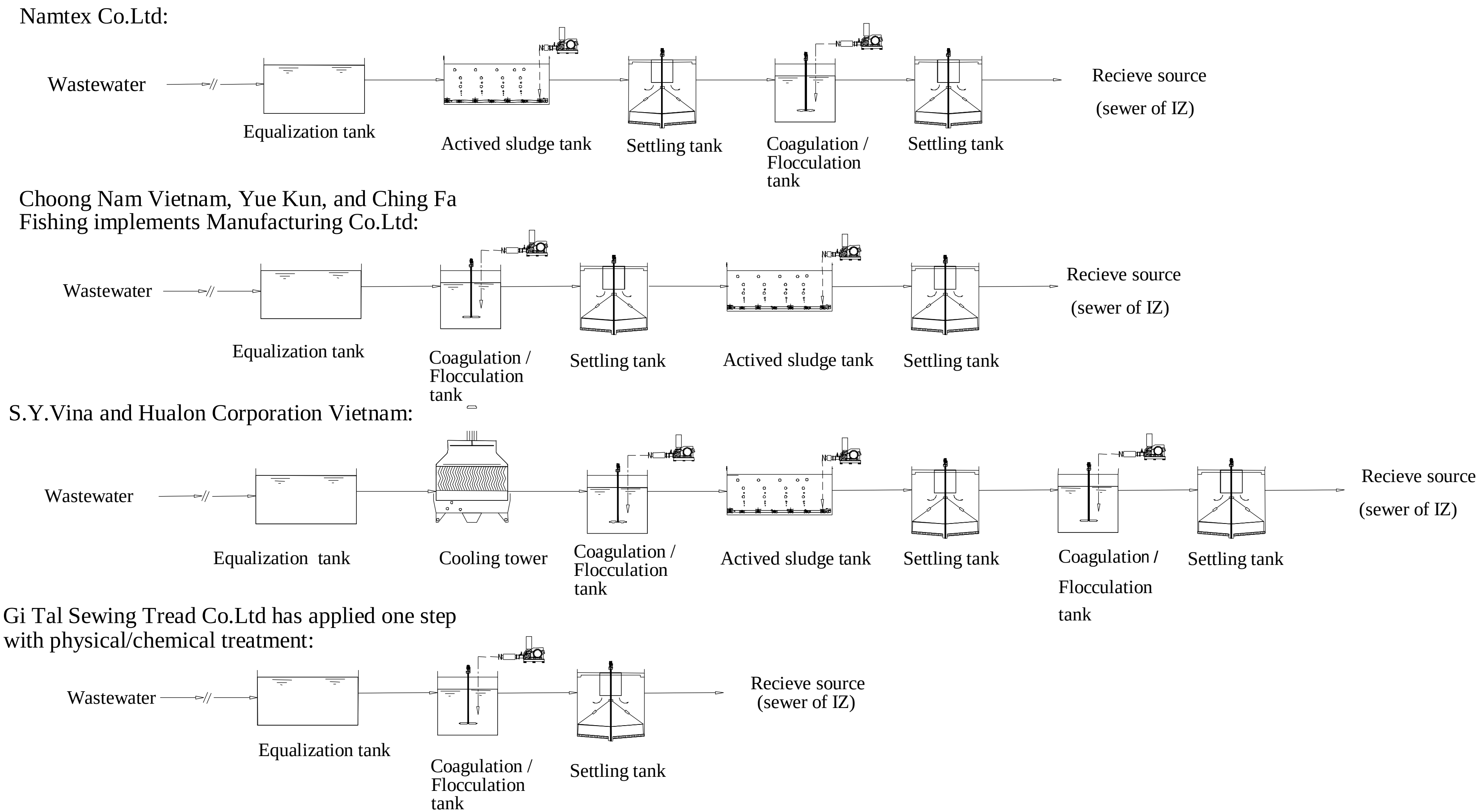


Figure 7.4: Scheme of wastewater treatment technologies of the seven textile companies in Nhon Trach 2 IZ

Table 7.6 presents the composition of treated wastewater of the seven textile companies in the Nhon Trach 2 IZ. The results show that the effluents of these treatment systems cannot meet the discharge standards of TCVN 5945:2005, class B, especially with respect to color and COD. A survey of the present efficiency of the seven wastewater treatment systems shows that, among the seven textile companies, the Yue Kun and Ching Fa companies have regular and well operated wastewater treatment systems and the remaining five companies do not regularly operate their systems or the treatment systems are overloaded. This makes it difficult to assess the real efficiency of the treatment systems. The Yue Kun and Ching Fa companies apply a technology appropriate for wastewater generated during dyeing of synthetic yarn (using dispersed dyes). For this technology, non-dissolved dyes are removed through a coagulation process. Next, an activated sludge process removes the organic material. Although this process achieves a high efficiency, it is very hard to meet strict standards on color (50 Pt-Co) with only two treatment steps. Comparing the applied treatment technologies of the Gi Tal and Ching Fa Companies (which have the same production process, raw material input and use the same dispersed dyes), it is clear that Ching Fa Company has a better working treatment technology than the Gi Tal Company. Using dispersed dyes with one-step coagulation/flocculation, it is impossible to meet the standard as in case of the Gi Tal Company. According to theory dispersed dyes can be removed with a coagulation/flocculation process. In reality auxiliary chemicals (organic matter) are used during the dyeing process; thus, the coagulation process only can remove color and only a part of the COD. Therefore, the standard for COD (100 mg O_2/L) cannot be reached using the current treatment technology of the Gi Ta Company.

As stated in Chapter 2, wastewater treatment significantly raises the production costs, which is why most companies are not willing to treat wastewater. To save money, wastewater is diluted by cooling water, condenser water and/or groundwater before being discharged into the receiving water body, due to the low taxes for the exploitation of groundwater and the fact that water supply costs are lower than wastewater treatment costs. In addition, some companies are discharging wastewater into the environment without treatment at night (from 7-12 pm) or during heavy rains to reduce the operational costs of the wastewater treatment system. These violating strategies are difficult to discover by environmental inspectors.

Table 7.6: Effluents of wastewater from seven textile companies in Nhon Trach 2 IZ

Parameters	Unit	Namtex Co., Ltd	SY. Vina Co., Ltd	Hualon Corporation Vietnam	Ching Fa Co., Ltd	Choong Nam Vietnam Co., Ltd	Gitai Sewing Tread Co., Ltd	Yue Kun Co., Ltd	TCVN 5945-2005, class B
pH	-	7.7 - 8.0	7.3 - 7.7	6.8 - 6.8	4 .9	8.0 - 8.1	7.2	7.8 - 8.1	5 - 9
SS	mg/L	11 - 32	33 - 134	47 - 2,465	5	26 - 46	21	9 - 17	100
Color	Pt-Co	613 - 1,240	658 - 903	42 - 62	122	259 - 466	323	85 - 117	50
COD	mg O_2/L	76 - 189	252 - 446	225 - 4,470	61	75 - 105	240	22 - 32	80
BOD_5	mg O_2/L	13 - 66	60 - 94	57 - 1,500	15	15 - 26	57	6 - 15	50
Total nitrogen	mg/L	3.7 - 7.3	4.6 - 19.7	3.3 - 4.3	15	3.3 - 3.6	5.3	1.3 - 1.8	30
Total phosphorus	mg/L	17.7 - 23.4	0.2 - 2.4	0.6 - 10.4	0,3	0.9 - 1.2	0.1	0.1 - 0.2	6
Mineral oils	mg/L	0.1-2.3	4.1- 23.3	8.0 - 9.5	0.3	4.8 - 5.0	4.5	2.5 - 2.7	10
Surface active agents	mg/L	0.020 - 0.055	0.006 - 0.015	0.045 - 0.135	0.084	0.015 - 0.022	0.223	0.127 - 0.130	10

Source: Viet (2006)

Air emission

Almost none of the textile companies in the Nhon Trach 2 IZ are equipped with waste air treatment systems. Air pollution treatment consists of simply diffusion into the surrounding zone through the installation of chimneys. Among the seven companies, only the Hoalon Corporation Vietnam is equipped with an air treatment system, which utilizes the wet absorption method. Table 7.7 shows the composition of the polluted effluent air emitted from of some textile companies. These data show that in the three companies without treatment systems, the SO_2 concentration exceeds the industrial emission standards TCVN 5939-2005. In the case of the Hualon Company, the concentration of all pollutants discharged after treating meets the standards. Based on annual environmental quality monitoring reports, all analyzed parameters of ambient air, such as temperature, humidity, dust, noise, SO_2, NO_2 and CO, meet the working environment sanitation standards of TCVSLD 3733/2002/QD-BYT of the Ministry of Health and the ambient air quality standards (TCVN5937:2005) of the Ministry of Natural Resources and Environment.

Table 7.7: Composition of air pollution from smokestack of some textile companies

Companies	Temperature (^oC)	Concentration (mg/m^3)			
		Dust	SO_2	NO_2	CO
Hualon Corporation Vietnam (after air treatment system)	52	60	820	420	23
Ching Fa Fishing Implements Manufacturing Co., Ltd	276	65	3,044	504	13
S.Y. Vina Co., Ltd	182	108	1,765	356	21
Namtex Co., Ltd	162	372	1,242	646	355
TCVN 5939: 2005, class A	-	400	1,500	1,000	1,000

Source: Hualon Corporation Vietnam (2006), Ching-Fa (2006), S.Y Vina (2006), Namtex (2006); TCVN 5939: 2005, class A: air quality-industrial emission standards-inorganic substances and dust, where class A is applied for operating enterprises.

Solid waste

The industrial solid waste generated during production includes two types: non-hazardous solid waste and hazardous waste. Non-hazardous waste is divided into five groups: scraps of yarns and fabrics; cardboard and paper; metals; plastics; and cinder (ash after burning coal). The hazardous waste comprises six groups: sludge generated from the wastewater treatment system; packaging material contaminated with chemicals and oil; used fluorescent lamps; waste oil; cloths contaminated with chemicals and oil; and left-over chemicals and dyestuffs. The monthly average mass of the industrial solid waste from the seven textile companies is presented in Table 7.8.

Table 7.8: Monthly average mass of industrial waste generated from seven textile companies

Companies	Quantity (kg/month)	
	Non- hazardous	Hazardous waste
Choong nam Vietnam Co., Ltd	4,910	9,121
Hualon Corporation Vietnam	523,000	88,005
Namtex Co., Ltd	278,000	4,856
Gi Tal Sewing Tread Co., Ltd	1,800	143
S.Y. Vina Co., Ltd	4,350	5,223
Ching Fa Fishing implements Manufacturing Co., Ltd	26,200	2,403
Yue Kun Co., Ltd	1,630	131
Total	**839,890**	**109,882**

Source: Hualon Corporation Vietnam (2006), Ching-Fa (2006), S.Y Vina (2006), Namtex (2006), Choongnam Vietnam (2006), Yue Kun (2006), Gi Tal Sewing Tread (2006)

In general, the industrial solid waste treatment of the seven textile companies can not meet regulations of Vietnamese industrial waste management. At present, each company has arranged a separate area for solid waste storage. However, hazardous waste is not classified based on the regulations for industrial waste management. Regarding non-hazardous solid waste, the companies have entered into a waste sale contract with waste-purchasing private enterprises or scrap-buying companies. For hazardous waste, some companies have signed contracts with professional companies, such as the Tan Phat Tai Private Enterprise (Dong Nai), to collect, transport and treat the hazardous waste. Other companies use local environmental service enterprises to treat their hazardous waste, but these enterprises are unable to differentiate between non-hazardous and hazardous wastes. Therefore, some types of hazardous waste are sold to scrap-buying premises and the remaining hazardous waste is burnt or buried together with the domestic solid waste. Only the S.Y Vina Co. Ltd carries out onsite (and offsite) reuse. For example, the company reuses residual oil to lubricate the cogwheels of the power-loom and for the sewing machine maintenance, additionally the company exchanges packaging containers and chemical containers with suppliers.

As noted in the general introduction, the textile industry attracts a large amount of workers; the seven textile companies employ nearly 7,000 people. Thus, a significant amount of domestic solid waste is generated daily from the activities of canteens and offices. The average mass of domestic solid waste generated over one month for each of the seven textile companies is listed in Table 7.9. The domestic solid waste is not yet separated into recyclable components at each textile company. The companies entered into a contract with an environmental service company for the daily collection of trash. The waste is then buried at open landfills. In fact, the open landfills in the Nhon Trach suburb are overloaded, creating pollution to air and water in the area.

Table 7.9: Mass of domestic solid waste from seven textile companies in Nhon Trach 2 IZ

Company	Quantity (kg/month)
Choong Nam Vietnam Co., Ltd	3,000
Hualon Corporation Vietnam	25,000
Namtex Co., Ltd	2,000
Gi Tal Sewing Tread Co., Ltd	200
S.Y. Vina Co., Ltd	4,000
Ching Fa Fishing implements Manufacturing Co., Ltd	1,500
Yue Kun Co., Ltd	100
Total	**35,800**

Source: Hualon Corporation Vietnam (2006), Ching-Fa (2006), S.Y Vina (2006), Namtex (2006), Choongnam Vietnam (2006), Yue Kun (2006), Gi Tal Sewing Tread (2006)

Monitoring environmental quality

In accordance with the approved environmental impact assessment, twice a year the textile companies should implement the environmental quality monitoring report. Each textile company usually has a contract with a consulting company tasked with assembling this report. The annual environmental quality monitoring reports of the seven textile companies show that effluents from wastewater treatment facilities meet the discharge standards (TCVN 5945:2005, class B) and the ambient air quality standards (TCVN 5937:2005) as well as meets the working sanitation standards of TCVSLD 3733/2002/QD-BYT of the Ministry of Health. However, actual surveys of the seven treatment systems revealed that five wastewater treatment systems either were not operating or were overloaded and wastewater was diluted or discharged directly into the receiving water source. Hence, the completed reports do not reflect the real environmental situation at these companies. This disqualifies the purpose of monitoring reports, which can be a useful tool for competent authorities to direct environmental control and can also be useful to help companies to improve their existing environmental performance. The reason for the inaccurate reports is that the textile companies specifically prepared their treatment systems to satisfy the monitoring requirements, but after that reverted to their previous practices.

In brief, the collected data and a practical investigation of the seven textile companies in the Nhon Trach 2 IZ show that understanding environmental performance is still very limited for these textile companies. Despite that, the companies have complied with the regulations of the Environmental Protection Law by constructing wastewater treatment systems and providing annual environmental quality reports; however, these steps are taken only to satisfy the authorities. The wastewater treatment systems do not operate adequately and the environmental quality monitoring does not reflect the real environmental performance. All restrictions are related to an economic problem: the costs for waste treatment are very high. To be competitive by reducing production costs, the companies refrain from treating waste. Minimizing waste at source does not receive due concern of the businesses because the law on the exploitation of natural resources (groundwater) is weak and the inspection of the competent authorities (Department of Natural Resources and Environment) is still limited. Moreover, with the strict discharge standards implemented currently, it is very difficult for wastewater treatment system to meet the standards for textile and garment industry and it requires very high costs for both investment and operation. Therefore, textile companies have to find solutions that reduce production costs and at the same time protect the environment. That is exactly the aim of the industrial ecology concept.

7.4 Textile industrial ecology model

According to experiments in the industrial ecology parks of Kalundborg in Denmark, Brunnside in Canada, Riverside in United States, Fujisawa in Japan, Map Ta Phut in Thailand and the Guitang Group in China, three main factors are facilitating the development of an industrial ecology park: (1) one main industrial sector in the estate, (2) a network of companies inside and outside the estate for exchanging waste, (3) voluntary coordination of companies.

To develop an industrial ecology model for the textile industry at the Nhon Trach 2 IZ, the start should be in identifying and quantifying the material and energy flows through the entire industry. After that follows the first step, cleaner production, which focuses on one of industrial ecology's main objectives and entails a radical approach to improve the efficiency of using material and energy resources. The second step, to form a waste exchange network, this encourages the reuse and recycling of almost all waste products of the Nhon Trach 2 IZ. Finally, cooperation among companies in the industry will promote the implementation of the industrial ecology idea or model on a voluntary basis.

7.4.1 Cleaner production

As mentioned by Karamanos (1995), the industrial ecology concept is closely linked to that of cleaner production. Both concepts focus on the general purpose of preventing pollution and increasing the economic and environmental efficiency of materials and energy. However, the difference between cleaner production and industrial ecology is that cleaner production is conducted at the company level and industrial ecology can be applied at the industrial sector level (Erkman and Ramaswamy 2001). As can been seen in the case study of the Thanh Cong Company (chapter 6), cleaner production has brought not only environmental benefits but also economic benefits. Many potential savings are gained from relatively simple housekeeping, better process control and material substitution options. Thanks to the implementation of the proposed production options, the Thanh Cong Company can save 20%-45% in the flow rate of wastewater, 10%-30% for basic chemicals, 30%-40% of the amount of dyestuffs used and 10% energy. These results are in line with VNCPC and VEA (2006), who mention the following results from demonstration projects of cleaner production in the Vietnamese textile industry. Fuel use decreases from 6%-57%, the amount of chemicals used is reduced by 2%-33%, the electricity used is reduced by 3%-57%, wastewater decreased from 5%-32% and the COD loading rate reduced by 10%-32%.

During a visit to the seven textile companies in the Nhon Trach 2 IZ, it has been observed that there was bad housekeeping and no formally arranged schedules; as a result, raw materials were being wasted at these companies. These features show that the textile companies in the Nhon Trach 2 IZ have much room to improve efficiencies through cleaner production. The cleaner production practices of the case study at the Thanh Cong Company can provide a practical guide for the seven textile companies in Nhon Trach 2 IZ to decrease material and energy consumption. To identify cleaner production options, data and surveys were collected and a calculation of the material and energy consumption for the seven textile companies in the Nhon Trach 2 IZ was completed. The rough calculations are based on the assessment of efficiency in production processes by comparing the specific material consumptions of the seven textile companies in the Nhon Trach 2 IZ with benchmarks of the textile industry in other parts of the world and Vietnam. In this study, three indicators were selected: specific water, fuel and electricity consumption. Each indicator is presented in more detail below.

Specific water consumption

A comparison of the water consumption of textile companies in the Nhon Trach 2 IZ, with benchmarks for water consumption established by the US EPA and with the textile industry in India, is presented in Table 7.10. As reported in this table, the textile companies in Vietnam consume less water than the standards of the US EPA, the textile industry in India and finishing textile companies in Finland. The minimum specific water consumption is 8.3 m^3/ton for the US EPA, 25m^3/ton for India and the maximum is 392.8 m^3/ton for US EPA and 60 m^3/ton for India. In contrast, the consumption of water per product unit of Vietnam's textile companies varies widely, ranging from 10-415 m^3/ton (Loan (2004)). The input and output of water data from textile companies in the Nhon Trach 2 IZ show that textile companies with synthetic yarn products have a range of specific water consumption between 6.0-6.4 m^3/ton. Blended yarn and fabric products consume between 8.3-20.5 m^3 per ton of raw material. It is obvious that companies producing blended yarn and fabric may potentially incorporate cleaner production options to decrease water consumption to the minimum specific water consumption. The cleaner production options can be applied to the reuse of cooling water, condenser water and washing water. The estimated amount of water that can be saved is 36,650m^3/month or 1,220m^3/day. This translates into approximate annual savings of 110,000 US$ (the price of water is 0.25US$/$m^3$). As noted by VINATEX (2003), water supply costs account for 15% of the production costs, so reducing water consumption is synonymous with reducing production costs.

Table 7.10: Specific water consumption of textile companies in Nhon Trach 2 IZ and benchmarks of water for US EPA, Finland and India textile industry

Company	Water supply (m^3/day)	Specific water consumption (L/kg)	Benchmarks of water (L/kg)	
			Minimum	Maximum
In Vietnam				
Synthetic yarn products				
Ching Fa Fishing implements Manufacturing Co., Ltd	450	6.0		
Gi Tal Sewing Tread Co., Ltd	400	6.4		
Yue Kun Co., Ltd	55	6.7		
Blended yarn, fabric products				
Hualon Corporation Vietnam	5000	20.5		
Namtex Co., Ltd	4500	12.5		
S.Y. Vina Co., Ltd	3000	12.5		
Choong nam Vietnam Co., Ltd	2500	11.1		
In the world				
US EPA (for knitted fabric)			8.3	392.8
India			25	60
Finishing textile companies in Finland			50	500

Source: Hualon Corporation Vietnam (2006), Ching-Fa (2006), S.Y Vina (2006), Namtex (2006), Choongnam Vietnam (2006), Yue Kun (2006), Gi Tal Sewing Tread (2006)

Specific fuel consumption

The textile companies in the Nhon Trach 2 IZ use three types of fuel to operate boilers: FO, DO and coal. The specific fuel consumption is dependent on the characteristics of the boiler and usually varies between companies. The specific fuel consumptions of the seven textile companies in the Nhon Trach 2 IZ and some textile companies around the world are given in Table 7.11. Compared with the data of (Visvanathan and Kumar 1999), the specific coal consumption of the Hualon Corporation Vietnam and the Namtex Company are higher than that of Thailand's textile industry. The remaining companies use FO/DO for boiler operation. When comparing the specific FO/DO consumption for companies making blended yarn and fabric products in the Nhon Trach 2 IZ with Enviro Tex GmnH Company in Germany and finishing textile companies (using wet processing) in Finland, the Nhon Trach textile companies consume more fuel than Enviro Tex GmnH Comapny, but an amount similar to the finishing textile companies in Finland. Three textile companies producing synthetic yarns in Nhon Trach 2 IZ consume less fuel than finishing textile companies in Finland with the same raw material, but in comparison with Enviro Tex GmnH Company in Germany, these companies consume slightly more fuel. Through the collected data, it can be seen that the boilers of the seven Nhon Trach textile companies are citied to have new boilers with low fuel consumption. However, there is no proper method for boiler operation and employee management. This causes air pollution and human health concerns. Therefore, it hinders the development of cleaner production options such as good housekeeping, better process control and recycling. For instance, the reuse of hot washing water and the recovery of condensate water to supply hot water for the boiler; the installation of a heat and water meters for boilers; adjusting air inlets and oil regime to achieve optimum burning processes; and recovering heat from the boiler and stack emissions. The estimated benefit of these options is about 2-3 tons FO and 5-6 tons coal per day. The economic benefit could be up to 2,000-3000 US$ per day.

Table 7.11: The consumption of fuel and specific fuel consumption of textile companies in Nhon Trach 2 IZ, Germany, Thailand and Finland

Company	Fuel consumption (ton/month)			Specific fuel consumption (kg/kg)	
	FO	DO	Coal	DO+FO	Coal
Vietnam					
Synthetic yarn products					
Ching Fa Fishing implements Manufacturing Co., Ltd	30	-	-	0.40	-
Gi Tal Sewing Tread Co., Ltd	-	25	-	0.40	-
Yue Kun Co., Ltd				-	-
Blended yarn and fabric products					
Hualon Corporation Vietnam	5	9	1500	0.06	6.14
Namtex Co., Ltd	3	3	1000	0.02	2.80
S.Y. Vina Co., Ltd	370	4	-	0.80	-
Choong nam Vietnam Co., Ltd	650	-	-	-	-
In the world					
Visvannathan (2000) using coal in boiler operation in Thailand					2.2
Enviro Tex GmnH Company, Germany				0.24-0.32	
Finishing textile companies in Findland				0.86-2.39	

Source: Source: Hualon Corporation Vietnam (2006), Ching-Fa (2006), S.Y Vina (2006), Namtex (2006), Choongnam Vietnam (2006), Yue Kun (2006), Gi Tal Sewing Tread (2006), Visvannathan (1999), Enviro Tex GmnH, applying air blower dyer with ratio 1:1 (VNCPC 2004), Kalliala and Talvenmaa (2000)

Specific electricity consumption

The specific electricity consumption is in the range of 0.2-1.3 kWh/kg for the production of synthetic yarn and 0.5-4.9 kWh/kg for the production of blended fabrics. The data in Table 7.12 show that the specific electricity consumption of the textile companies making blended fabric products is higher than electricity consumption in the Enviro Tex GmnH Company-Germany, but synthetic yarn companies consume less electricity than the German ones. The electricity consumption of five finishing textile companies in Finland was 1.4-7.5 kWh/kg. The wide range in electricity consumption was due to differences in type product being produced. In general, the electricity consumption of finishing textile companies in Finland is less than similar textile companies in the Nhon Thach 2 IZ. The Choong Nam Company uses both electricity supplied by the Nhon Trach 2 IZ and electricity supplied by its own generators, so its electricity consumption can not be compared with that of other textile companies.

From data regarding the consumption of electricity for textile companies in the Nhon Thach 2 IZ, it can be concluded that these companies can reduce electricity consumption through some simple options such as rearranging the light system in company workshops, replacing 40 W light bulbs with energy-saving light bulbs. These companies can install capacitors to improve the power factor from 0.8 to 0.9 and boost transformer loads to 80%. These options would result in saving 37,000 kWh of electricity per day with an economic benefit of 2,300 US$.

The dyeing method applied at some textile companies in the Nhon Trach 2 IZ is similar to that employed by the Thanh Cong Company, which employs the exhaust method using a jet machine. It should be possible for these companies to apply the same cleaner production options developed for the Thanh Cong Company. These options should be tailor-made according to the present situation of each company. The improvement of housekeeping, better control process and the reuse of water and chemicals are the most feasible measures to reduce pollution. Furthermore, the presently used chemicals and dyestuffs can be replaced by alternatives that are better for the environment. In the long term, new technologies with (semi-)continuous processes could be applied at most companies. Among the four companies producing blended yarn and fabric products, only Choong Nam Company uses a continuous dyeing process and its water consumption is the lowest. Therefore, Choong Nam Company could achieve maximally efficient production with relatively simple options, such as good housekeeping, better process control, the reuse of water and chemicals and the substitution of dyes.

Table 7.12: Consumption of electricity of textile companies in Nhon Trach 2 IZ, Germany and Finland

Company	Electricity (kWh/month)	Specific electricity consumption (kWh/kg)
Vietnam		
Synthetic yarn products		
Ching Fa Fishing implements Manufacturing Co., Ltd	267,252	1.3
Gi Tal Sewing Tread Co., Ltd	14,366	0.2
Yue Kun Co., Ltd	117,165	-
Blended yarn and fabric products		
Hualon Corporation Vietnam	18,557,280	4.5
Namtex Co., Ltd	1,228,137	3.4
S.Y. Vina Co., Ltd	2,137,947	4.9
Choong nam Vietnam Co., Ltd	164,342	-
In the world		
Enviro Tex GmnH Company, Germany *		2.4-3.5
Finishing textile companies in Findland		1.4-7.5

Source: Source: Hualon Corporation Vietnam (2006), Ching-Fa (2006), S.Y Vina (2006), Namtex (2006), Choongnam Vietnam (2006), Yue Kun (2006), Gi Tal Sewing Tread (2006)
* Enviro Tex GmnH, applying air blower dyer with ratio 1:1 (VNCPC 2004), Kalliala and Talvenmaa (2000)

7.4.2 Waste exchange network

The next step of the industrial ecology model is to develop a waste exchange network in the Nhon Trach suburb, which is also one of the pollution abatement and prevention options. In the waste exchange network, a coalition is formed with various waste-processing sectors that use by-product materials, upgrade them and feed them back in the system. To develop the textile industrial ecology model at the Nhon Trach 2 IZ, the waste exchange network should focus on four broad areas:

- The transfer of raw materials from one process to other processes; a substance that is a waste product from one process may serve as a raw material for another, sometimes in an entirely different industry.
- The direct recycling of raw materials not completely consumed in the production process.
- The utilization of exhaust gas generated from the operation of boiler to neutralize alkaline wastewater.
- The recovery of energy through burning solid waste by an incinerator.

Solid waste

After the implementation of cleaner production options mentioned above, the amount of solid waste decreases insignificantly, with the exception of sludge generated from the wastewater treatment system. Currently, the amount of solid waste produced by textile companies at the Nhon Trach 2 IZ is about 970 tons/month (reports on monitoring environmental quality of seven textile companies from 2005-2007); and about 200 tons per month of sludge from the centralized wastewater treatment plant (with a capacity of 5,000 m^3/day) will be generated in 2010.

These solid wastes can be divided into two categories. The first category is non-hazardous waste, which is composed of five main groups: scrap of yarns and fabrics, paper, plastics, scrap of metals and cinder. The second category ranks as hazardous wastes, which include sludge from wastewater treatment plants, left-over chemicals, fluorescent lamps, cloth contaminated with chemicals, waste packaging materials contaminated with chemicals or oil and waste oil. According to the quantity and type of wastes, two main waste processors have to be established inside the Nhon Trach 2 IZ. The first involves a by-product enterprise and the second is a waste treatment enterprise, in association with outside companies to form a waste exchange network in the Nhon Trach suburb.

Non-hazardous waste: industrial

The amount of non-hazardous industrial waste generated at the Nhon Trach 2 IZ is about 840 tons/month. The largest amount of the waste, about 750 tons, is cinder. After implementing cleaner production options, the cinder is only decreased by a small amount. The remaining wastes are not reduced. The amount of non-hazardous industrial waste generated before and after the implementation of cleaner production at the Nhon Trach 2 IZ is shown in Table 7.13. For non-hazardous wastes, a by-product enterprise will have to be established inside the Nhon Trach 2 IZ; the technologies for reusing and recycling non-hazardous waste are described below.

Scrap of yarns and fabrics: All textile companies generate scraps of yarn and fabrics in their manufacturing production. There are about 32.8 tons of yarn and fabric scraps created each month; therefore, the capacity of the by-product enterprise should be about 1-2 tons/day. Recycling scrap yarns and fabrics could be applied as follows:

- When scrap fabric dimensions are larger than 1 yard, they are used to manufacture cloths. Then the products are sold to consumers in the Nhon Trach suburb.
- When the scrap of fabric has dimensions from 0.15 up to 1 yard, they are broken into dust, which is used as stuffing in new toys or as a raw material source of paper towels.
- Soft scrap yarns and scrap yarns with poor quality are used as material for making mops.

Recycling cardboard, paper and plastics The total generated waste cardboard and paper is about 23 tons/month. The large cardboard pieces could be used to produce paper boxes at the by-product enterprise in the Nhon Trach 2 IZ. Cardboard leftovers (generated from the by-product enterprise), paper tubes, newspapers and office paper could sorted at the station then sold for recycling purposes. In Dong Nai province, there are four paper recycling companies.
The waste plastics are composed of plastic bags, plastic cones and other plastic waste. After collecting waste plastics, they are first classified based on their chemical characteristics, such as PVC, PP, PE and HDPE. Then they are sold for reuse or to be recycled into valuable products, such as plastic pipes, broomsticks, etc.
Pure metals are easily recycled; the recycling process commonly involves the reduction of metal oxides to metal. As with plastics, metals will be classified at a sorting station before they are returned to industrial consumers.

All recycling activities (plastics, paper and metal) take place outside of the industrial zone.

Cinder The cinder generated after burning coal amounts to 75-80% of the total solid waste generated at the Nhon Trach 2 IZ. The cinder is given back to the supplier or to enterprises that produce combustibles.

In 2007, the Dong Nai province had 27 industrial zones with different industries and 50 scrap business enterprises, meaning that a local market has actually developed for reuse and recycling potential waste materials. All wastes, such as cardboard, plastics and metals are sold to companies in the local market. For instance, waste papers are sold to the Dong Nai Paper Joint Stock Company, the plastic waste is sold to the Dong Nai Plastic Company and metals (iron) are sold to the Bien Hoa Steel Joint Stock Company. In this way, waste materials do not need to be shipped long distances, which results in decreased production costs for the recycling company and increase of benefits for the textile company.

Table 7.13: Quantity of non-hazardous waste generate per month in Nhon Trach 2 IZ

Items	Before cleaner production (kg)	After cleaner production (kg)
Cardboard, paper	35,630	35,630
Metals	4,400	4,400
Plastics	16,610	16,610
Scrap of yarns and fabrics	32,800	32,800
Cinder	750,450	705,000
Total	**839,890**	**794,440**

Source: D2D company (2007)

Non-hazardous waste: domestic

Organic materials comprise 85%-90% of the domestic solid waste in Vietnam (Centema 2007), therefore, sorting at source is very important for successful composting processes. Table 7.14 presents the quantity of domestic solid waste in the Nhon Trach 2 IZ. These organic materials have become a major material for composting plants in the Dong Nai province; the composting product can be applied to soil in rubber tree or cotton farms in Dong Nai province, which is one of three cotton cultivation development projects of the Vietnam Textile Industry Group. Switching from chemical to organic fertilizer (from composting products) in cotton cultivation is the most environmentally friendly solution, because of reduced pollution and environmental treatment costs. The remaining non-organic matter (10%-15%) can be classified and sold together with non-hazardous industrial waste.

Table 7.14: Quantity of domestic solid waste from textile companies in Nhon Trach 2 IZ

Company	Quantity (kg)
Choongnam Vietnam Co., Ltd	3,000
Hualon Corporation Vietnam	25,000
Namtex Co., Ltd	2,000
Gi Tal Sewing Tread Co., Ltd	200
S.Y. Vina Co., Ltd	4,000
Ching Fa Fishing implements Manufacturing Co., Ltd	1,500
Yue Kun Co., Ltd	100
Total	**35,800**

Source: Source: Hualon Corporation Vietnam (2006), Ching-Fa (2006), S.Y Vina (2006), Namtex (2006), Choongnam Vietnam (2006), Yue Kun (2006), Gi Tal Sewing Tread (2006)

Hazardous waste

The hazardous wastes generated from textile companies are composed of sludge (generated from textile wastewater treatment systems), cloths contaminated with chemicals and oil, packaging materials contaminated with chemicals and oil and left-over oil and chemicals. Table 7.15 lists the quantity of hazardous waste generated at the Nhon Trach 2 IZ before and after the application of cleaner production options. The total hazardous waste remains about 300 tons/month in which sludge gives the highest amount (290 tons/month); the next is waste oil with 3,0 tons/month; then contaminated packing material with 2,75 tons/month; and last, contaminated cloths with 2,72 tons/month. However, the Nhon Trach suburb does not have a hazardous waste treatment plant. All waste must be treated off-location about 40-60 km away. According to the Law on Environmental Protection (2005), each industrial zone has to install an intermediate transmission station for normal and hazardous industrial solid waste. Building a common waste treatment enterprise inside the Nhon Trach 2 IZ will suit the development of industrial ecology. The capacity of the enterprise design should be about 300 tons/month or 10 tons/day. This enterprise would not only help the industrial zone comply with the environmental protection laws but also reduce the hazardous waste treatment costs for each company in the Nhon Trach 2 IZ, because transport charges account for about 3%-5% of the waste treatment cost (VUC 2008) and heat can be recovered. This enterprise will include three workshops: one for classification, one for incineration and one for reclaiming sodium hydroxide. The wastes will be collected from all companies in the Nhon Trach 2 IZ and the surrounding industrial zones; they will then be transported to the waste treatment enterprise. The waste is sorted at a classification area and then the valuable hazardous wastes can be sold to recycling enterprises. The remaining hazardous waste is stored in a separate area to await treatment.

Incinerating hazardous waste at Nhon Trach 2 IZ.
Incinerators can be installed to recover energy and remove air pollutants. They have a capacity of 10 tons/day (about 300 tons/month), in which the following amounts of material can be treated:

- Amount of sludge: 9.7 tons/day;
- Amount cloths contaminated with chemicals and oil waste: 0.1 ton/day;
- Amount of packaging (most mixed plastics) contaminated with chemicals and oil: 0.1 ton/day.

The recovered heat is converted into steam and the steam can be used to generate electrical power using a steam turbine. Likewise, the generated heat from the boilers of textile companies in Nhon Trach 2 IZ can be recovered, or sludge can be dried from a humidity of 85%-90% down to 15%-20%: optimal conditions for burning (humidity of 10%-15%). The recovered heat of the wastes can be calculated. According to Metcalf and Eddy (2003), typical heating values of sludge are:

- Activated sludge : 21,000 kJ/kg total solids;
- Raw chemically precipitated primary sludge : 16,000 kJ/kg total solids.

The reference of composition of dewatered sludge from a centralized WWPT of Loteco industrial zone –Vietnam, which has similar characteristics as Nhon Trach 2 IZ (Centema 2006) is presented below:

- Humidity : 85%-88%
- Volatile suspended solid (VSS) : 53%
- Ash : 47%
- Dry matter : 10%-15%

According to Tchobanoglous (1993), Robinson (1986) and Mortensen and Kiely (1997), typical energy content of textile and mixed plastic waste are:

- Textiles : 18,300 kJ/kg
- Plastics mixed : 32,700 kJ/kg

The total heating value generated in one day of combustion of 10 tons of waste may be calculated by:

- Q_{sludge} = 21,000 kJ/kg x 100 kg/day
  (10 tons sludge with 10% dry matter contents 100 kg total solids)
  = 2,100,000 kJ = 2,100 MJ/day
- $Q_{textile}$ = 18,300 kJ/kg x 100 kg/day = 1,830 MJ/day
- $Q_{plastics\ mixed}$ = 32,700 kJ/kg x 100 kg/day = 3,270 MJ/day
- Q_{total} = 2,100 MJ/day + 1,830 MJ/day + 3,270 MJ/day = 7,200 MJ/day

The formation of electrical power is estimated to be about 2,000kWh/day by using the conversion factor of heat into electrical power: 1055.06 J is approximately $2.931*10^{-4}$ kWh. The schematic process of burning hazardous waste is depicted in Figure 7.5.

Table 7.15: Quantity of hazardous waste generate in Nhon Trach 2 IZ every month

Items	Before cleaner production (kg)	After cleaner production (kg)
Packing contaminated with chemicals and oil	3,922	2,750
Broken lamps	16	16
Sludge	299,830	290,000
Waste oil	3,342	3,008
Cloth contaminated with chemicals and oil	2,715	2,715
Left-over/outdated chemicals and dyes	7	7
Total	**309,800**	**298,500**

Source: Source: Hualon Corporation Vietnam (2006), Ching-Fa (2006), S.Y Vina (2006), Namtex (2006), Choongnam Vietnam (2006), Yue Kun (2006), Gi Tal Sewing Tread (2006)

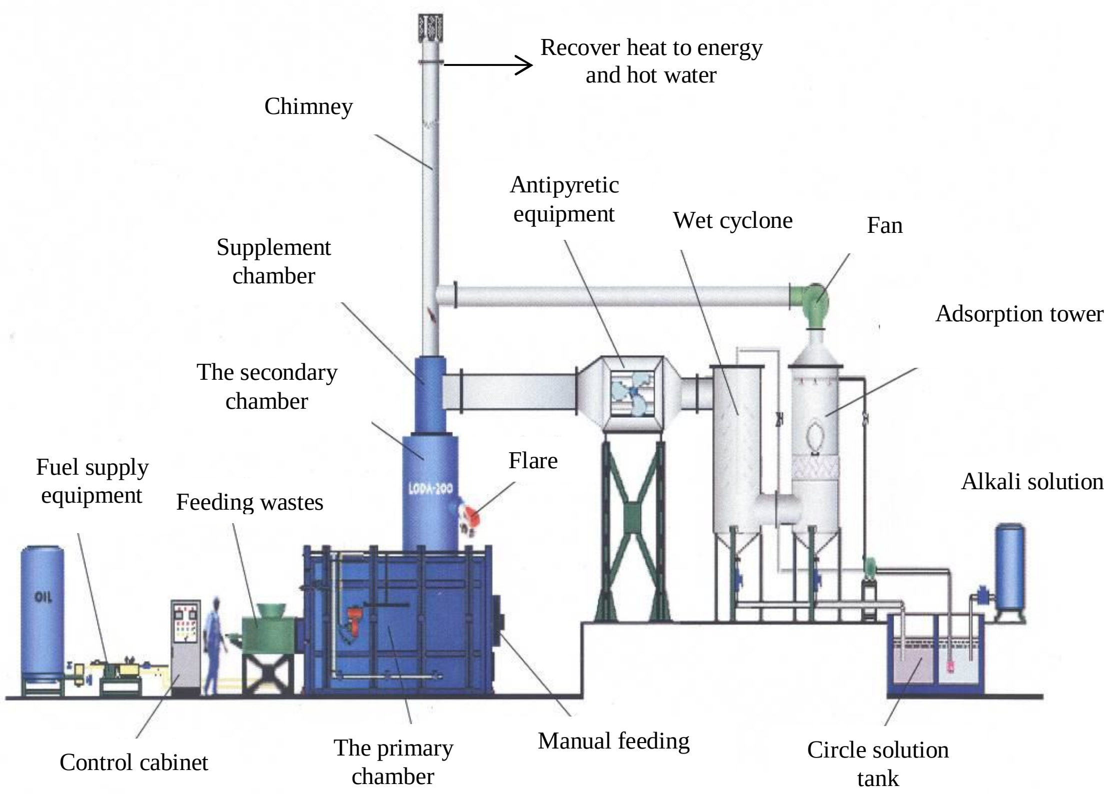


Figure 7.5: Schematic process of burning hazardous waste with recovery of steam and hot water

Reclaiming sodium hydroxide and starch inside the Nhon Trach 2 IZ

As mentioned in Chapter 6, wastewater from the scouring and sizing step of the dyeing and finishing process usually contains a high sodium hydroxide and starch concentration. Textile companies do not like to recycle these onsite because of high expenses and facilities needed. With separation of these wastewater streams and if the recycling of these chemicals could be conducted centralized, it could be cheaper than recycling at each company separately. The method of recycling sodium hydroxide solution is a vacuum system (evaporation of sodium hydroxide) and starch can be condensed to a sizing solution that can be used as by-product. In addition, the scouring wastewater can be used directly as an absorber for the treatment of fuel waste gas from the incinerator and boiler.

Reclaiming waste oil outside the Nhon Trach 2 IZ

Waste oil is produced at a volume of 3.0 tons/month; this amount is not enough to be recycled efficiently onsite; it is more efficient to reclaim it outside of the Nhon Trach 2 IZ. Two kinds of waste oil are produced: waste oil generated from lubricants in production processes and waste oil from boiler fuel. The waste oil is sold to the Toan Thang Reclamation Company, which is located outside the industrial zone. The process of recycling waste oil is shown in Figure 7.6. This technology combines vacuum distillation and adsorption processes using clay as an adsorbent. This company is at some distance from the Nhon Trach 2 IZ at a distance of 30 km. Its products are sold to a brick production company as fuel.

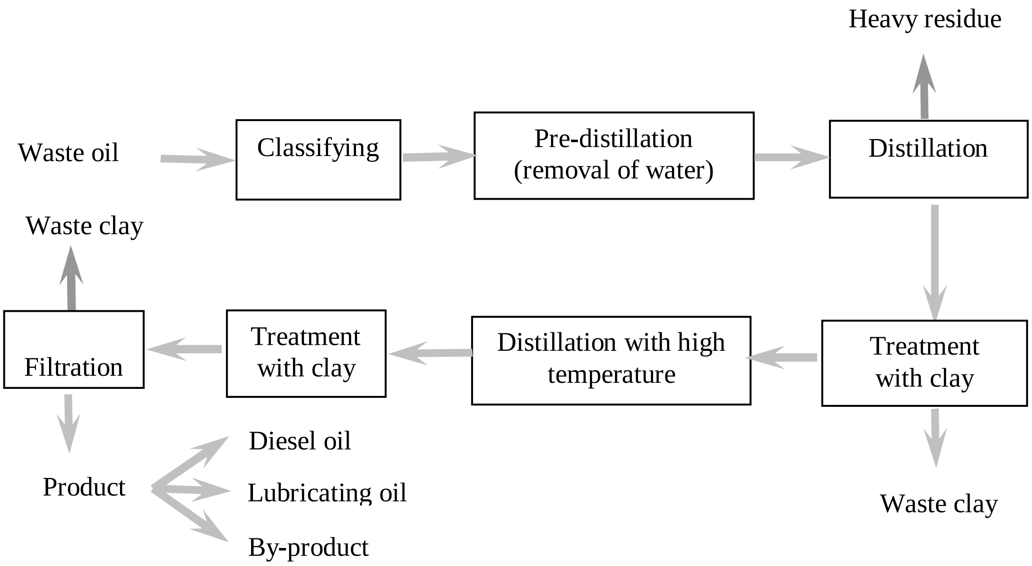


Figure 7.6: Schematic process of reclamation waste oil of Toan Thang Company

Wastewater

In the entire Nhon Trach 2 IZ, 24 companies have started operation by 2007. However, a centralized wastewater treatment plant (WWTP) has not yet been built according to the approved environmental impact assessment by MONRE. A WWTP with a capacity of 5,000m^3/day is under construction. Although the seven textile companies have already built wastewater treatment systems, there is no company whose effluents meet the discharge standards (TCVN 5945:2005, class B). According to the measured results of the composition of effluent from this industrial zone, parameters such as color, suspended solids, COD and BOD all exceed the permissible values of the standard. The wastewater of the industrial zone is typical of textile wastewater; therefore, it is difficult and costly to treat. The treatment technology has to have specific characteristics and has to be adapted to the flow rate of textile wastewater. To overcome these problems, a cleaner production approach would help to reduce the pollutant load and the flow rate of wastewater at each company. Applying cleaner production, the wastewater flow rate can be reduced between 20% to 45% (Loan 2004; VNCPC and VEPA 2006). Consequently the total volume of wastewater from the industrial zone would decrease from 14,000 m^3/day down to 9,000-11,000m^3/day. As noted in the case study of the Thanh Cong Company in chapter 6, the concentration of pollutants could increase with 5% to 10% in the effluent if the flow rate reduction does not correspond to a reduction of pollutant concentration. However, a small increase in pollutant concentration does not affect the selected technology. Following the wastewater composition, the objective of water reuse and the results presented in the chapters 3, 4 and 5, the centralized wastewater treatment plant of the Nhon Trach 2 IZ is designed for a capacity of 10,000m^3/day with a combination of conventional biological, physical/chemical and advanced oxidation processes. The scheme of the treatment technology is depicted in Figure 7.7.

With the application of this technology, the effluent can meet the water quality standards for reuse. Table 7.16 gives the standards for irrigation reuse water quality. The treated wastewater can be used to water the plants in the industrial zone and around surrounding companies (500 m^3/day for 100 ha at 0.5 L/m^2) and to water the transport roads inside the industrial zone (20 m^3/day).

In addition, the textile industry attracts a large number of people and, due to the high housing necessity for workers; the textile companies often build dormitories nearby the industrial zone. The treated wastewater can be also used for the sanitary system of these dormitories and in the industrial zone (8,000 workers use about 240m^3/day assuming 30L per person per day).

The treated wastewater can be used as an absorbent for the removal of dust and fuel waste gas of a boiler. The demand for water use is about 7,500m^3/day for a waste air treatment system as mentioned in the section above.
In addition, the Nhon Trach 2 IZ is located in an agriculture area; thus, treated wastewater that meets the water quality for irrigation can be used for irrigation purposes in the surrounding area.

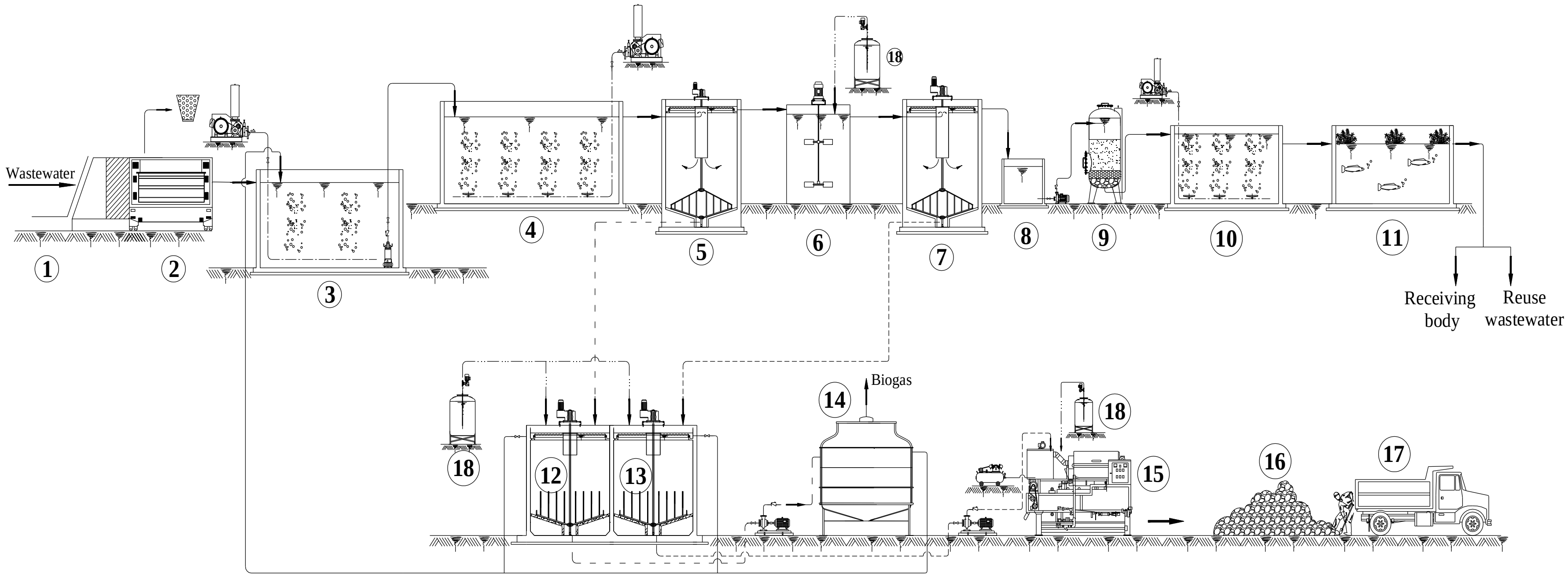
Finally, the remaining wastewater, which amounts to 1,700m^3/day, can be discharged into the Rach dua Canal flowing into the Thi Vai River.

Regarding the management of industrial waste, the generated sludge from the WWTP has to be treated with a suitable technology because it can contain potentially hazardous components. The estimation of sludge generated from a centralized wastewater treatment plant with a capacity of 10,000m^3/day is about 5-6 tons waste sludge/day. Cost of sludge treatment in Vietnam is about 330-.440 US$/ton (MOF 2008; VUC 2008). Total cost for treatment is approx. 1,998-2,664 US$/day. If sludge is combusted in the incinerator with energy recovery and air pollution treatment, the cost will decrease from 1,998-2,664 US$/day to 736 US$/day with an energy recovery of about 584 kWh/10 tons per day as presented in section 7.3.2. In addition, sludge can be used as raw material for compost production, if in the cleaner production the toxic materials were replaced by non-toxic ones. In this case, sale of the produced compost is about 55 US$/ton (Dung 2008).

Table 7.16: Some parameters of water quality standards for irrigation

Parameter		Units	Degree of restriction on use		
			None	Slight to moderate	Severe
Salinity EC_w[a]		dS/m	< 0.7	0.7 - 3.0	> 3.0
Total dissolve solid		mg/L	< 450	450 - 2000	> 2000
Total suspended solid		mg/L	< 50	50 - 100	> 100
Iron (Fe)	Drip irrigation	mg/L	< 0.1	0.1 - 1.5	> 1.5
Total nitrogen (TN)		mg/L	<5	5 - 30	> 30
pH		-	Normal range 6.5 - 8		
Fecal coliform	*	MNP/100cm^3	1,000 as WHO, 1989		
Helminths	*	Eggs/100cm^3	1 as WHO, 1989		

Sources: Ayers and Westcott (1985), WHO (1989), Pescod (1992), Asano Takashi and Levine Audrey (1996), * Criteria (maximum limits) for the irrigation of crops consumed by human with reused wastewater by WHO (1989).



Note: The flows of

- Wastewater
- Air
- Chemical Sludge
- Biological Sludge
- Chemical

(1) Coarse screening bar	(6) Coagulation tank	(11) Storage tank	(16) Sludge
(2) Fine Screen	(7) Settling tank No 2	(12) Sludge thickener	(17) Truck
(3) Equalization tank	(8) Storage tank 1	(13) Sludge thickener	(18) Chemical
(4) Activated sludge tank	(9) Pressure filter	(14) Sludge digestion tank	
(5) Settling tank No 1	(10) Ozone treatment tank	(15) Belt - filter press	

Figure 7.7: Scheme of improved centralized wastewater treatment plant at Nhon Trach 2 IZ

Air pollution

Gaseous emissions have been identified as the second largest pollution problem for the textile industry. The textile companies use FO, DO and coal as fuels for the operation of boilers; therefore, the composition of air pollution mainly consists of SO_2, NO_x, CO and dust. However, even these waste products can be used more economically by using them for certain chemical synthesis processes. Table 7.17 shows the total loading rate and flow rate of fuel waste gas for one month at the Nhon Trach 2 IZ.

Table 7.17: Total loading rate and flow rate of fuel gas with the use of 40 tons of DO, 1060 tons of FO and 2,500 tons of coal for one month at Nhon Trach 2 IZ

Commercial boilers	Unit	CO	NO_x	SO_2	Dusts	Flow rate m^3/day
Use diesel oil (DO)						22,400
Loading rate	kg/day	0.24	0.96	6.8	0.10	
Air emission	mg/m^3	11	43	303	4	
Use fuel oil (FO)						856,780
Loading rate	kg/day	23	300	2,116	154	
Air emission	mg/m^3	26	350	2,469	179	
Use coal						1,516,670
Loading rate	kg/day	25	750	1,300	10,417	
Air emission	mg/m^3	16	495	857	6,868	
Total loading rate	**kg/day**	**48**	**1,051**	**3,422**	**10,570**	**2,395,850**
Total air emission	**(mg/m^3)**	**54**	**887**	**3,629**	**7,052**	
TCVN (5939:2005), class A	mg/m^3	**1,000**	**1,000**	**1,500**	**400**	

Flow rate of DO: 16.49 m^3/kg; FO: 24.3 m^3/kg; and coal: 18.2 m^3/kg (WHO 1993)
TCVN (5939-2005) class A: Air quality: maximum allowable industrial emission standard concentrations of dusts and inorganic substances and class A requirements are the allowable concentration of waste air for operating enterprises.

According to the Law on Environmental Protection (2005), if companies are located in an industrial zone they have to install treatment systems for gaseous emissions. Among the seven textile companies allocated in the Nhon Trach 2 IZ, there are only two companies equipped with a treatment system because the investment and operation of treatment systems are costly, especially the chemicals. The treatment systems of these companies use wet absorption (scrubber) with sodium hydroxide solution as the absorbent. Through the survey results of the composition of wastewater from the textile and garment industry with cotton, polyester and blended (polyester/cotton and polyester/vinyl) products, one can see that wastewater effluents usually have a high alkalinity. For instance, the alkalinity of scouring wastewater of Agtex Company was 19,000 mg $CaCO_3$/L. The wastewater from the scouring and mercerizing steps usually has a high pH (> 11). For textile wastewater a large amount of sulphuric acid is used to neutralize the alkalinity of the wastewater as a first step in the water treatment process. However, the alkaline wastewater can be reused as an absorbent for treating air pollutants of the boilers of the textile companies and treating flue gas (SO_2, HCl and HF) from the incinerator of hazardous waste treatment enterprise (the double alkali method (Stanley, 2005). When applying this method not only SO_2 is removed but also the expensive sodium hydroxide solution is regenerated with inexpensive lime (Stanley, 2005). The reaction of treating SO_2 and the regeneration of sodium hydroxide is given in equations (7.1) to (7.3).

$2NaOH + SO_2$	→	$Na_2SO_3(s) + H_2O$	(7.1)
$Ca(OH)_2 + Na_2SO_3$	→	$CaSO_3(s) + 2NaOH$	(7.2)
$CaSO_3(s) + 1/2O_2 + 2H_2O$	→	$CaSO_4.2H_2O\ (s)$	(7.3)
$H_2SO_4 + 2NaOH$	→	$Na_2SO_4 + 2H_2O$	(7.4)

In the equation (3) gypsum ($CaSO_4.2H_2O$) is formed, which has commercial value in the manufacturing of plasterboard. The neutralization reaction is expressed in equation (7.4).

The total loading rate of air pollution and the flow rate of waste air have calculated by a model for air emission inventories and control for commercial boilers using different fuels (WHO 1993). Table 7.17 shows the total loading rate and flow rate of waste air of the seven textile companies in the Nhon Trach 2 IZ. The results show pollution levels of dust and SO_2 that exceed the permissible values many times for the industrial effluent standards. According to Table 7.17, the emission of SO_2 is about 3,422 kg/day or 3,629 mg/m^3 (detailed calculation in appendix 2). The allowable concentration of SO_2 discharge is 1,500 mg/m^3. The efficiency of gas treatment system using a scrubber can range from 60-80% (Nevers 1995). At a treatment efficiency of 80% the SO_2 concentration goes from 3,629mg/m^3(table 7.17) to 2,903 mg/m^3 and the remaining SO_2 would then be 726 mg/m^3 and thus meting the standard. The consumed and formed products include:

- The amount of sodium hydroxide needed to treat 2738 kg SO_2/day (3,422 kg/day x 0.8): 3,422 kg/day following equation 7.1;
- The amount of $Ca(OH)_2$ needed to regenerate the sodium hydroxide solution: 3,165 kg/day following equation 7.2;
- The quantity of formed gypsum ($CaSO_4.2H_2O$): 7,357 kg/day following equation 7.3;
- The quantity of regenerated sodium hydroxide: 3,422 kg/day following equation 7.2.

Table 7.18 lists the quantity of used scouring chemical (sodium hydroxide) at textile companies. The amount of sodium hydroxide that can be reused from scouring wastewater is 37,700 kg/month or 1,257 kg/day. Reusing the sodium hydroxide in the treatment of SO_2 saves about 188,500 US$/year (the price of sodium hydroxide in Vietnam (2007) 0.5 US$/kg). In addition, the amount of sulphuric acid used to neutralize the alkaline wastewater can be reduced to 1,539 kg; therefore, the sulphuric acid costs are decreased by about 153,900 US$/year (sulphuric acid costs about 0.33 US$/kg in Vietnam, 2007). Each year, the seven textile companies will save 342,400 US$ operational costs of their wastewater treatment systems. However, to avoid the production of large quantities of calcium sulfite, which poses a major solid waste disposal problem and to reduce expenses, the double alkali method should be applied. This method allows the regeneration of expensive sodium hydroxide solutions with inexpensive lime and forms valuable products like gypsum. As calculated above, the amount of sodium hydroxide that needs to be regenerated is of about 3,422 kg/day. This corresponds to 3,165 kg/day calcium hydroxide. The price of lime is about six times lower than the price of sodium hydroxide.

Table 7.18: Quantity of used scouring chemical (sodium hydroxide) at textile companies

Company	Quantity (kg/month)
Ching Fa Fishing implements Manufacturing Co., Ltd	1,500
Choong nam Vietnam Co., Ltd	16,500
Gi Tal Sewing Tread Co., Ltd	500
Hualon Corporation Vietnam	15,000
Namtex Co., Ltd	55,000
S.Y. Vina Co., Ltd	100,000
Total use	**188,500**
Total reuse (20% in wastewater)	**37,700**

The system set-up for treating the exhaust gas generated from boilers of textile companies in Nhon Trach 2 IZ is same as the technology presented in the case study of Thanh Cong Company (Figure 6.5). This treatment system includes a cyclone unit and scrubber. The cyclone is used to remove particulates and is widely used as the first stage of dust removal. The scrubber is very efficient and can trap gaseous pollutants as well as very fine particulate matter. The more efficient scrubbers use alkali solutions. In this case, the source of alkali for the scrubber is the scouring wastewater and treated wastewater.

Table 7.19 presents study results from the textile and garment Agtex Company for the reuse of wastewater to treat air pollution from boilers with a cycle of 11.5 hours/day and average consumption of 50,000 L of FO per month. According to Table 7.16, the total volume of wastewater required to treat 2,395,845m^3 waste gas/day is approximately 7,200 m^3/day. If the textile companies in the Nhon Trach 2 IZ have to pay the 0.25 US$/m^3 for the water supply, they would save 587,000 US$/year by reusing wastewater. The wastewater generated from the scrubber unit only needs to be filtered and adjusted in pH before being discharged. When environmental performance is no longer a burden for enterprises, the investment in pollution treatment facilities can be promoted more easily to textile companies.

Table 7.19: Specification of reuse of scouring wastewater to remove sulphur dioxide

Waste air flow rate (m^3/hour)	SO_2 loading rate (kg/hour)	Demand scouring wastewater flow rate (m^3/hour)	Treated SO_2 concentration (mg/m^3)
2,000	4.8	11	420
2,300	5.5	13	450
3,000	7.2	15	480
4,000	6.9	16	480
5,000	12.0	17	440
6,000	14.4	19	490
7,000	16.8	22	430
8,000	19.2	24	450
9,000	21.6	28	420
10,000	24.0	30	430
		TCVN 5939: 2005, class A	1,500

Source: Vietnam environmental protection agency 12/1999(VEPA 1999)

7.4.3. An industrial ecology model for Nhon Trach 2 IZ

By applying the cleaner production approach and waste exchange network for textile and garment companies in the Nhon Trach 2 IZ, a textile and garment industrial ecology model can be designed, which is illustrated in Figure 7.8. As the figure shows, this model can satisfy the requirements of the industrial ecology idea with the maximum recycling of materials, the reuse of wastewater, treatment of waste air and renewable resources. Applying industrial ecology to the textile and garment industry would minimize the pollution of textile industry activities for the environment, which would help Vietnam's textile and garment industry to achieve sustainable development.

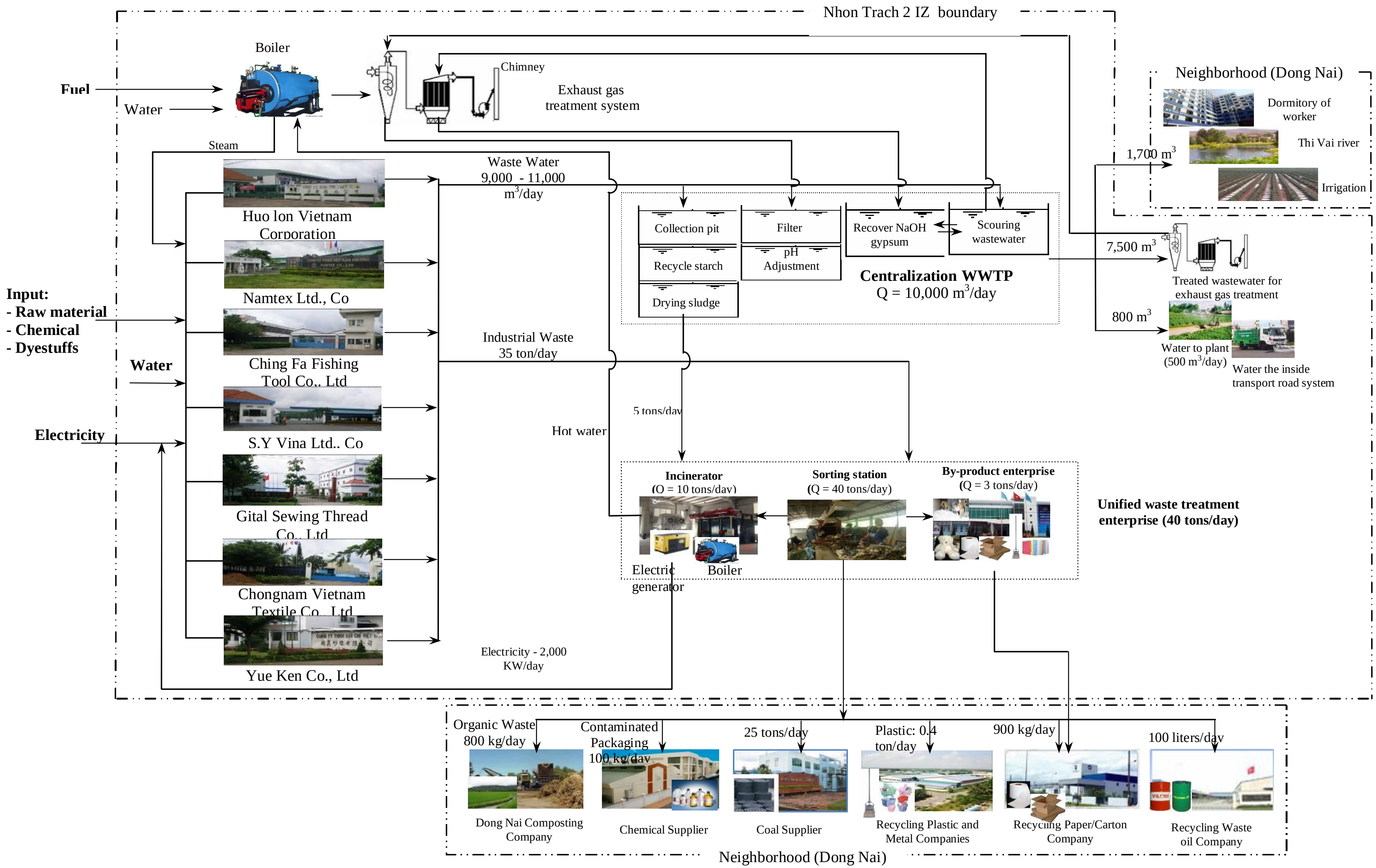


Figure 7.8.: Textile and garment industrial ecology model at Nhon Trach 2 IZ

7.5 Actors supporting a textile and garment industrial ecology model

According to Van Koppen and Mol (2002) to move industrial ecology ideas from the drawing table into practice, a better understanding is needed of the actors and institutions in which the network of companies is embedded. In this section, the implementation of the textile and garment industrial ecology model in the Nhon Trach 2 IZ is studied through a triad network analysis of the role of actors and institutions.

7.5.1 Economic network

In the economic network, the economic relationships of textile companies in the Nhon Trach 2 IZ with external economic entities and institutions are analyzed. The analysis concentrates on three main interactions: the first is the interaction between textile companies, suppliers and customers, along the supply chain; the second encompasses interactions between these textile companies and other textile companies via branch organizations; the last is the interaction of these textile companies with credit institutions and research institutes.

Supply chain actors

Raw material suppliers

In the manufacturing process of textile companies in the Nhon Trach 2 IZ, diverse materials are used, including raw cotton, synthetic yarn, blended fabric and chemicals, such as basic and auxiliary chemicals and dyestuffs. According to the Vice President of the Association for Garment, Textile - Embroidery and Knitting An (2007), Vietnamese cotton fiber companies only satisfy 30% of the raw materials requirement. In addition, the quantity of Vietnamese cotton fiber has proved not to be stable and is low in quality, so textile companies usually avoid buying Vietnam's cotton fiber. As stated above, the seven textile companies in the Nhon Trach 2 IZ are 100% foreign direct investments. The raw materials and chemicals required to assure production inputs for these textile companies are almost completely provided through their mother companies. Textile companies in the Nhon Trach 2 IZ have to respond to their mother company's set targets related to production quality and capacity. Hence, raw material suppliers have little influence on the environmental performance of these textile companies.

Water supplier

The seven textile companies in the Nhon Trach 2 IZ have a water consumption volume of about 14,000 m^3 /day and are supplied from two sources: from private wells owned by each company and from the Nhon Trach groundwater plant with a capacity of 10,000m^3/day. Although Dong Nai DONRE forbids industrial companies to exploit groundwater in the Dong Nai area, some textile companies still use groundwater. Because these textile companies use a huge amount of water, they can significantly reduce production costs by using groundwater for free. As the infrastructure developer charges 4,590 VND/m^3 water (approx. 0.25 US$ /m^3) the textile companies use, to a limited extent, water from the water supply network of the industrial zone. Because groundwater is free of charge, textile companies seem not to know the quantity of water used in their production processes and do not pay attention to water saving in their production process. In addition, these textile companies use groundwater, cooling water and excess water from the production process to dilute the wastewater before discharging it into the receiving body. As mentioned above, to achieve Vietnamese discharge standards, wastewater treatment costs are estimated to be 8,000-9,000VND/m^3 (approx. 0.50-0.56 US$/$m^3$), so diluting and discharging wastewater is cheaper than treating it. The infrastructure developer only controls the water quantity supplied to companies in the Nhon Trach 2 IZ through the water meter, but they cannot supervise the flow rate of wastewater at each company. For example, one textile company in the Nhon Trach 2 IZ uses 4,500 m^3 of water per day. With a water price of 0.25US$/$m^3$, they will pay 1,125 US$/day, which is a considerable amount of money for the company. However, if the company uses groundwater, the water cost is considerably lower (200 US$ per day, as treatment costs of ground water is 0.044US$/$m^3$). Only when inspection and control on illegal groundwater use improves, companies will be motivated to become more (ecologically) rational in water use.

Fuel supplier

Fuel in the form of FO is a necessary input for production activities of all textile companies and is usually used to operate boilers. Fuel costs significantly affect production costs (15%-20%, VINATEX 2003). At present, the textile companies pay more attention to saving fuel than to saving water, because the costs for fuel are higher. To cut fuel costs some textile companies in the Nhon Trach 2 IZ replaced FO for coal. However, coal produces more air pollution. The textile companies also negotiate the quality of fuel with their suppliers to obtain coal with less sulphur concentration and impurities, which increases the efficiency of boilers while reducing air pollution (SO_2), resulting in decreased pollution treatment costs. Facing high and rising fuel prices, the textile companies will have to consider every angle to increase the efficiency of their boilers. By increasing energy efficiency or using a cleaner production approach, air pollution, especially gaseous emissions, will be reduced along with reduced fuel consumption. But these kinds of improvements are not triggered by fuel supplying actors.

Electricity supplier

Electricity is supplied to textile companies from the national grid via the 103 MVA transformer station of the industrial zone. The distribution of electricity to each company is determined by a contract between the infrastructure developer and the company. Currently, the power price depends on the service time during the day; at the peak time from 16.00 – 22.00 h electricity has a stipulated price of 0.11 US$/kWh, at norm time from 06.00-16.00 h the price is 0.05 US$/kWh and at low time from 22.00-05.00 h the price is 0.02 US$/kWh. The Vietnamese government has not increased the electricity price for production in the past three years and has at the moment the cheapest electricity in Asia (Thanh nien Newspaper 2007). With the current power price, foreign textile companies in Nhon Trach 2 IZ ignore saving electricity. According to the Ministry of Industry and Trade, the power price will increase. Once the price of electricity rises, the textile companies might be encouraged to use power in a more efficient way. However, this is in the hands of governmental agencies rather than the electricity supplier.

Customers/consumers

The textile products of the textile companies in the Nhon Trach 2 IZ are sold on the domestic and international markets. All textile companies are 100% foreign equity, including investors from Taiwan (four companies), Korea (two companies) and Malaysia (one company). A portion of the products of these companies is returned to the mother companies and these products are then exported to other countries or consumed in their domestic markets. Because of the low labor price and lax environmental regimes, the production costs in Vietnam are lower than in the original countries. The majority of consumers in Asia (both in these countries as well as in Vietnam) prefer products with high quality at a reasonable price and they are less concerned about production related environmental pollution. This means that both domestic and foreign Asian customers hardly influence the environmental performance of these textile companies. Only customers from the OECD countries might include environmental performance criteria into their preferences for products, but a very limited percentage of products of the seven textile companies currently find its way to these markets.

Horizontal interactions between the producers and other companies

There are more than 2,500 textile and garment companies in Vietnam, of which joint stock and limited companies (state-owned capital <50%) and private companies occupy a large percentage of 76 %, the foreign direct investment companies (FDI) account for 18.5% (VITAS 2009). Dong Nai province, as one of three major centers of textile production in Vietnam, houses 61 operating textile companies. The Hualon Corporation Vietnam, Choongnam Vietnam, S.Y. Vina, Namtex, Ching Fa, Co., Ltd. are classified as large-scale companies, whereas Gi Tal Sewing Thread Co., Ltd, Yue Kun Co., Ltd are classified as small-scale companies. Most textile companies experience fierce competition among existing companies, not only in the domestic market, but also in the export market. Competition mainly relates to production costs, and that influences the environmental performance. Among the seven textile companies in the Nhon Trach 2 IZ, Choongnam Vietnam Co., Ltd is equipped with the most modern dyeing technology (a continuous dyeing method with a cold pad batch method), using technology imported from Japan. Only a few textile companies in Vietnam are equipped with such technology. The remaining textile companies use dyeing batch technology with an exhaust method using a jet dyer machine. The quantity of wastewater and the production costs depend greatly on the technologies used. As shown above, the specific water consumption among textile companies in the Nhon Trach 2 IZ is not so different. The Choong Nam Company has the lowest specific water consumption, giving it a competitive advantage over other foreign companies in the Vietnamese market. In addition, some textile companies in the Nhon Trach 2 IZ comply with the regulation forbidding the exploitation of groundwater; other companies still use groundwater sources. As a result, the production costs of these companies that comply with this regulation are higher. As mentioned above, all textile companies in Nhon Trach 2 IZ built wastewater treatment facilities using similar treatment technologies. However, these treatment systems are not operated in an optimal manner because the treatment costs are high and the enforcement and sanctions are lax when discharging exceeds standards. To lower production costs, the dilution of wastewater by fresh water is applied at almost all textile companies in the Nhon Trach 2 IZ as a solution for wastewater.

Regarding information exchange the following communication pathways are used: There are some Taiwanese, Korean and Japanese business associations established in Vietnam. It is also through these associations that contacts between textile companies in the Nhon Trach 2 IZ and other textile companies in Vietnam are facilitated. Foreign companies do exchange experiences with each other over issues of common concern such as how to reduce waste emissions in processing production, improvements in production technologies, good service of suppliers of waste treatment and environmental regulations in Vietnam by regular meetings of these associations. These contacts are thus more or less within nationality and rarely cross the boundary to another nationality.

The textile companies in the Nhon Trach 2 IZ do contact each other regarding Vietnamese regulations, but exchanges of information regarding production technology and waste treatment technology is rare compared to textile companies with same nationality. Technological secrets and competition may play are role in the relation of different countries and companies.

Interactions with credit institutions and research institutes

Improvement in wastewater treatment facilities of textile companies often includes capital investment. Capital limitation is one the most difficult problems of both domestic and foreign textile companies. It is often extremely difficult for textile companies to borrow money from banks, especially for investments in waste treatment systems. The various local and national environmental protection funds (see chapter 6) are too small and bureaucratic to relieve textile companies from their capital shortage for environmental investments, both in treatment systems and cleaner production methods. To improve the situation, the national banks must guarantee loans for the pollution prevention projects of textile companies and the national or local environmental protection funds should find additional sources of capital and improve the administrative procedures for loans.

The textile industry is seen as one of the most polluting industries. Therefore, Vietnamese research centers, universities and environmental companies have been involved in research on and development of environmental improvements for this industry. For example, research was conducted on the removal of color and COD of textile wastewater, the recovery of wastewater to treat air pollution and demonstration projects for cleaner production. However, as analyzed in the case study of the Thanh Cong Company (chapter 6), the role of special institutes, universities and environmental companies in the improvement of environmental performance of the textile industry is very limited. The textile companies in the Nhon Trach 2 IZ are no exception. They receive almost no technology, equipment, information, training and services from these institutes, universities and companies.

Through an analysis of the economic network around the industrial zone, it is clear that the role of the relevant economic network actors in implementing an industrial ecology model is limited. Only foreign customers and branch associations such as Vitas can be expected to support the implementation of the developed model. Phuong (2002), Dieu (2003) and Nhat (2007) came to the same conclusion in their industrial ecology informed research on industrial sectors in Vietnam.

7.5.2 Policy network

Policy efforts to reduce industrial pollution in Vietnam have focused on developing environmental laws, regulations and recently economic instruments. Formal regulation by itself has not proven very effective in reducing industrial pollution in the country. While there is no substitute for an environmental regulatory regime, there is a need to assess what makes industry take environmental action. Hence, the role of the different actors in the policy network around Nhon Trach 2 IZ is analyzed below (see Figure 7.9), with special emphasis on the authorities related to industrial zones (VEA 2009).

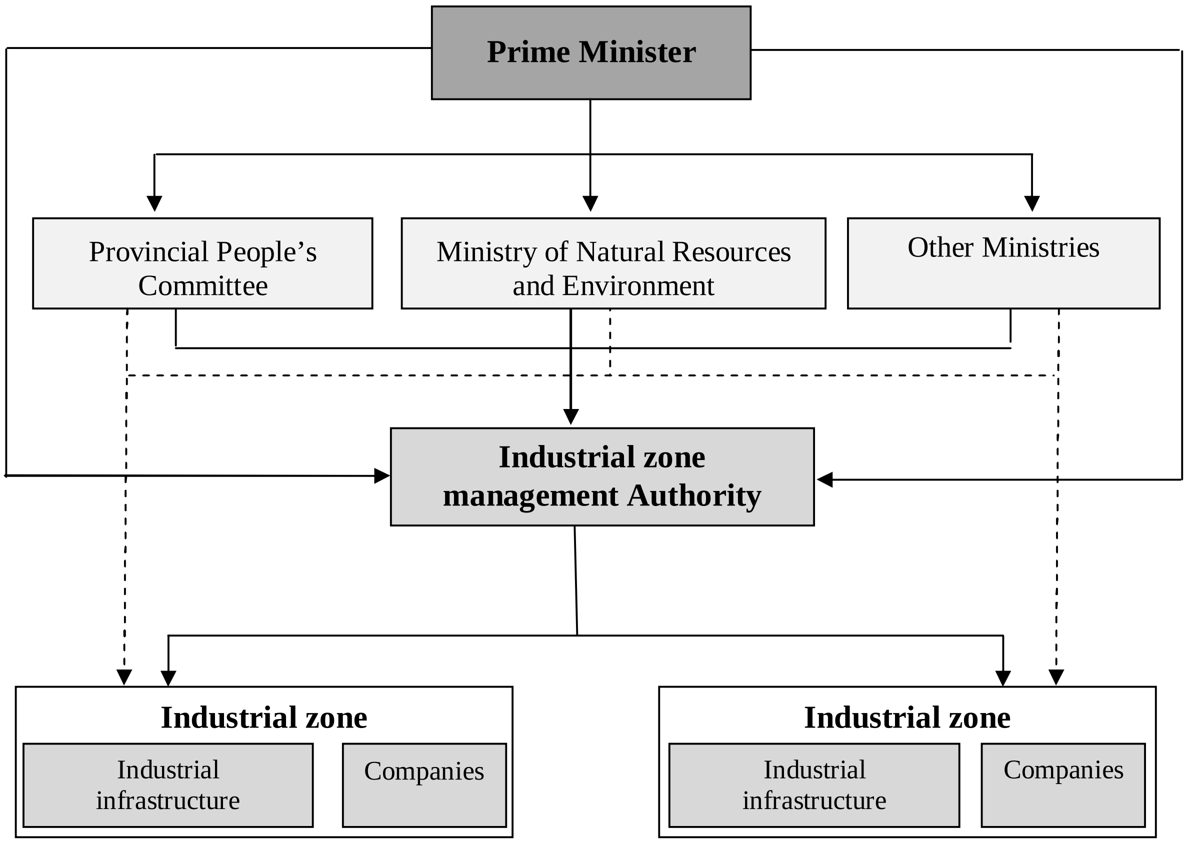


Figure 7.9: State environmental management organizations related to industrial zone

In Vietnam, the Ministry of Natural Resources and Environment (MONRE) is the top state management agency for national natural resource management and environmental protection. MONRE is responsible to the Government for environmental protection through the highest legal document, the 2005 Law on Environmental Protection (LEP). In case of Nhon Trach 2 IZ, MONRE has effect on the environmental protection of the Nhon Trach 2 IZ via an appraised environmental impact assessment (EIA) report and the supervision and inspection of environmental performance after approval of the EIA. The Nhon Trach 2 IZ elaborated and approved the EIA report in 1997. The contents of the approved EIA focused on environmental performance, building a concentrated sewage system for the collection and treatment of all wastewater of the industrial zone and monitoring (and reporting) environmental quality twice per year. September 30, 2008, the birth of Vietnam Environment Administration (VEA) based on Decision No. 132/2008/QD-TTg of the Prime Minister is the first specialized agency of environmental functions to assist the MONRE unified management of environmental protection activities throughout the country. VEA's pollution control division is responsible for supervising and inspecting the environmental protection performance of industrial zones with EIA reports approved by MONRE. However, the 13 persons employed in the pollution control division cannot carry out all the necessary tasks in the entire country. Hence, while the Nhon Trach 2 IZ did not perform according to the approved EIA or even comply with the LEP, they did not encounter problems from MONRE.

At the provincial level, the Department of Natural Resources and Environment of Dong Nai (DONRE) is the main body responsible to the People’s Committees (PCs) for exercising environmental protection regulations and requirements at Dong Nai. Presently, DONRE is responsible for appraising EIA reports, supervising and inspecting individual companies with respect to environmental performance. In the entire Nhon Trach 2 IZ, there are 24 enterprises, all of which have to make EIA reports or negotiate environmental protection commitments (depending on capacity of each company and type of industry as regulated in Decree No. 80/2006/ND-CP by the Government on detailed regulations and guidelines for implementation of some articles of the Law on Environmental Protection), which are then approved by the Dong Nai PC or MONRE. Of the seven textile companies in Nhon Trach 2 IZ the EIA of two large companies (Houlong and Chong Nam Co. Ltd,) were approved by MONRE and the EIAs of the remaining companies were approved by Dong Nai People’s Committees. The approved EIAs of the seven textile companies in Nhon Trach 2 IZ prescribe that high concentrations of wastewater or air pollution must be treated to meet the environmental standard, before discharging effluents into the environment. Until now, all companies had their own wastewater treatment system, but discharged wastewater almost never met Vietnamese standards. Only two out of the seven textile companies have an air pollution treatment system, but both systems are unstable. All companies carry out environmental quality monitoring and reporting, but these are not in accordance with the frequency (two times per year) and contents of the approved EIA. DONRE is responsible for providing guidelines and enforcing environmental protection regulations to enterprises. It should be noted that DONRE pays attention to environmental performance (including checking effluents from waste treatment systems, monitoring environmental quality standards and solid waste management at all companies located within industrial zones). However, they typically do not consider the production technology. It is difficult for DONRE to verify the accuracy of the environmental monitoring reports of these companies, especially as the number of companies and industrial zones increases every year. According to the Dong Nai Industrial Zone Authority, in 2007 the Dong Nai PC approved 34 industrial zone investment projects, while 21 IZs with more than 671 enterprises have already been brought into operation by 2007. If violations of the regulations are noted, environmental protection inspectors administratively sanction those companies. According to governmental Decree No. 81/2006/ND-CP, sanction levels range for 500,000-70,000,000 VND/incident (approximately 30 to 4,000 US$) depending on the nature and severity of the enterprise's violation. These low levels discourage enterprises from implementing appropriate and effective cleaner production or waste treatment; they find it more cost effective to take the risk and eventually pay the fine. In the case of textile companies in the Nhon Trach 2 IZ, a lack of human resources and professional knowledge, as well as inadequate inspection plans (in which companies are alerted before they are inspected) means that DONRE falls short in adequate inspection. As a result, none of these companies encounters problems with DONRE, but environmental pollution is continuously increasing (Dong Nai DONRE 2006).

The Dong Nai Industrial Zone Authority (DIZA) was established by the Prime Minister and is responsible for the management of industrial estates and all enterprises located within the industrial estates. DIZA belongs to the People's Committee of Dong Nai and has limited tasks with respect to environmental management within industrial estates. At present, the division of environment management tasks between DONRE and DIZA is still not clear. When a problem arises, enterprises need to find out which agency is entitled to give an opinion in advance and which agency is entitled to decide. DIZA needs to coordinate with DONREs to resolve environmental disputes and problems caused by environmental accidents in the industrial zones.

The Company D2D is the industrial infrastructure developer of the Nhon Trach 2 IZ. The formal environmental management responsibilities of the infrastructure developer, as mentioned in the LEP (2005), are:

- To supervise and inspect compliance with environmental protection requirements by establishing investment projects within industrial zones;
- To manage the domestic waste and hazardous waste collection system; sewage collection and treatment system; and gas emission treatment system;
- To organize environmental quality monitoring and assessment and elaborate periodical environment reports to province-level specialized environmental protection agencies;
- To advise the management boards of the industrial zone on the settlement of environmental related disputes between companies located in the industrial zone.

In order to do this, industrial infrastructure developers need to establish a major environmental division within their organization, with sufficient human and financial resources. However, the current practice is different. According to the industrial zone environmental protection regulation No. 62/2002/QD-BKCNMT issued by the Ministry of Natural Resources and Environment, the industrial infrastructure developer should have completed (environmental) infrastructures including the installation of a centralized wastewater treatment plant, when 70% of the industrial zone area is given out for investment. However, the centralized wastewater treatment plant in the Nhon Trach 2 IZ is not yet completed, even though 100% of the area of the industrial zone is handed out. Furthermore, the industrial zone developer was lax in implementing the monitoring environmental quality regime, as mentioned in the approved EIA. The monitoring environmental quality regime in the Nhon Trach 2 IZ started only in 2006 and it is still not functioning properly. This non-compliance of EIA requirements had no consequences for the industrial developer. In addition, the company investment in infrastructure of the Nhon Trach 2 IZ still does not provide for an environmental division; one mechanical engineer manages all issues related to the environment at industrial zone.

The policy network analysis shows that the government's appeasement in processing infringements, the limitations in supervision, inspection and the perfunctory handling of violations of environmental management agencies has lead to the poor enforcement of environmental regulations. Improvements need to be made on many fronts. In the case of the textile industry, regulatory adjustments need to be considered at various places. For instance, the strict regulations on color and COD of effluents are 50 Pt-Co and 50 mg O_2/L for discharge into water bodies that are used for potable water and 150 Pt-Co and 150 mg O_2/L or 50Pt-Co and 80mg O_2/L for discharge into rivers that are not used for potable water. It is difficult for the textile industry to comply with these regulations with the current levels of treatment technology and hence it is not surprising that textile enterprises dilute or neglect to treat wastewater. Proper textile wastewater discharge regulations might help to prevent this. In addition, the tasks, responsibilities and power of the Industrial Zone Authority with respect to environmental protection in the industrial zone have to be clearly regulated, in relation to those of DONRE and the Industrial Estate Developing Company. A better division of tasks, where the Industrial Zone Authority is given larger tasks, coordination and responsibilities for the environmental performance of (groups of) companies within the zone. For instance cleaner production and waste treatment may help DONRE organizations to prioritize on inspecting environmental violations outside industry zone borders, developing environmental protection strategies, developing regulations and monitoring environmental quality in local areas. The industrial zone authority together with the infrastructure developer will have to play important roles in developing and implementing industrial ecology models. This should be facilitated by stringent application of environmental protection charges, fines and stringent supervision by DONRE. When infrastructure developers will have to pay larges fines for wastewater discharges, air pollution, water consumption, they will have to strictly meter the influent and effluent of all companies and charge them. This will function as a foundation for ‘voluntary’ cooperation among companies in establishing an industrial ecology model.

7.5.3 Societal network

The textile companies in the Nhon Trach 2 IZ are located in the industrial zone and the surrounding agricultural area. Therefore, the actors that form a societal network interacting with the textile companies in the Nhon Trach 2 IZ include traditional social organizations like the Women’s Union, Veteran’s Union, Farm’s Union, Fatherland Front’s Union, Young’s Union and Party’s Union.

All wastewater from the Nhon Trach 2 IZ is discharged into the Rach Dua canal, which flows into the Thi Vai River. With a high flow rate and high pollution of the textile wastewater, the water of the Rach Dua canal has become seriously polluted, leading to a degradation of fish culture areas along Rach Dua canal. At present, local residents claim that Thi Vai has become a dead river due to the wastewater it is receiving from 10 industrial zones within the Nhon Trach suburb. The surrounding residents are affected by bad smell and the low quality of ground and surface water. The representatives of The Veteran's Union, Women's Union and Fatherland Front's Union received many complaints from residents and farmers on pollution from Nhon Trach 2 IZ, among others on fish mortality in ponds and on the color and smell of wastewater coming from the Nhon Trach 2 IZ. These organizations deliver the complaints to competent state agencies such as Commune People's Committees, District People's Committees, Dong Nai DONRE and Province People's Committees at their monthly and quarterly meetings. However, complaining residents have not received much feedback from these state agencies. This reveals that the role of traditional social organizations is limited in industrial environmental reform, especially in rural areas.

Hence, we can see more often that households and citizens directly complain with state agencies. Before 2003, a group consisting of 22 households submitted a complaint on wastewater discharges to the Commune People's Committee, District People's Committee, Province People's Committee, the Dong Nai DONRE and MONRE. Mr Le Van Dung at Hamlet 3 Long Tho village, recorded that after six months these households received an answer from MONRE, stating that all companies in the Nhon Trach 2 IZ are required to treat their wastewater to meet the discharge standards. They did not hear back from the local or provincial agencies. In 2003, households submitted another complaint about the building of a drainage system for the industrial zone through their land. Their complaints resulted in inspectors of the Department of Natural Resources and Environment Dong Nai asking the infrastructure developer of the Nhon Trach 2 IZ to compensate these households and to have a completely centralized wastewater treatment plant ready for operation in 2009. Research by Phuong (2002), Phuong and Mol (2004), Dieu (2003) and Nhat (2007) report similar cases of more or less successful of citizens complaints, although the number of such cases remains quite limited.

In article 54 of the LEP (2005), the State encourages communities to found self-management organizations to protect the environment within their localities and assigns the commune-level. People's Committees are responsible for issuing regulations for self-management organizations in environmental protection and to facilitate their effective operation. Self-management organizations operate on principles of voluntary service, joint responsibility and observance of the law. Based on this article of the LEP (2005), the Vietnam Fatherland Front has gained more power and a larger role in environmental protection activities. They are responsible for training and mobilizing their members and other citizens to participate in the monitoring of Environmental Protection Law implementation (as defined in Article 124 of the LEP (2005).

The role of the conventional and new media in triggering environmental reform along the lines of the industrial ecology model are not fundamentally different from their role as outlined in Chapter 6.

7.6 Conclusion

In the strategies for the development of the textile and garment industry until 2025, the Vietnam National Textile Garment Group will invest in building many centralized textile and garment industrial zones. The industrial ecology model approach can become one of the key projects of the textile and garment industry. Obviously, textile industrial ecology brings benefits in terms of quality, price and environmental protection. By putting the industrial ecology model into practice, the Vietnamese textile and garment industry can continue to compete with many countries in the future.

Our case study of a textile industrial ecology model carried out at the Nhon Trach 2 IZ shows that industrial ecology can make a valuable contribution to achieving sustainable development. This model was planned in three steps. The first step, cleaner production, applies to all enterprises in an industrial system. The second step is to form a waste exchange network, in which a by-product enterprise, a waste treatment enterprise and an outside wastes exchange network will have to be established. The last step is to reuse treated wastewater for treatment of gaseous wastes, irrigation in agriculture (cotton cultivation), sanitary systems and for watering plants and roads. In addition, some outside waste exchange will have to be maintained, such as the reuse of plastics, paper and waste oil.

A successful industrial ecology practice not only depends on the effects of the interaction between enterprises inside the industry but also the interaction with actors outside the system. Among the triad network actors, the policy network actors play the most important role in the implementation of industrial ecology. With respect to the economic network, the pricing of natural resources, the role of foreign customers and the Vietnam Textile & Apparel Association, Vitas, are important actors and institutions for improving environmental performance. The role of actors in social networks seems to be limited with respect to implementing an industrial ecology model in Nhon Trach 2 IZ.

Chapter 8

Discussion and conclusions

8.1 Introduction

The textile and garment industry has made a remarkable contribution to the economic development of Vietnam (accounting now for 9% of the total Vietnamese industrial value) and employs a large labor force of 2.5 million people. However, Vietnam's textile industry uses excessive amounts of material and energy and releases large amounts of emissions into the environment. The results of our survey of Vietnamese textile companies and of our literature review show that wastewater emission is the most polluting part of the textile industry, as it contains high concentrations of pollutants (especially color intensity) and is discharged at large volumes. Some remediation strategies have been developed and implemented in the Vietnamese textile industry in order to protect the physical environment. The main remediation approach concentrates on the application of end-of-pipe or add-on technology, which costs large amounts of energy and chemicals. The result of this approach is often a steady increase in production costs, which often makes these types of treatment unpopular in Vietnam. To overcome the disadvantages (and also poor implementation) of end-of-pipe treatment approaches, experiments have been launched in the Vietnamese textile industry with the application of other measures and strategies, such as cleaner production (CP) and certified environmental management systems (e.g. ISO 14000). However, after experimenting with these solutions for many years the number of enterprises that have implemented cleaner production measures and have obtained ISO 14000 certification is still very limited. Although Vietnam has set up an environmental administration and developed laws, policies and instruments to combat and prevent industrial discharges and to protect the environment against industrial pollution, the policy system seems unable to keep pace with the rapid development of the industry, resulting in the continuing poor environmental performance of Vietnamese industries in general and textile companies in particular. As a consequence the natural environment has been and continues to be seriously destroyed in many geographical areas. The textile industry is seen as one of the most polluting and unsustainable industries in contemporary Vietnam

In highly industrialized countries several pollution prevention approaches have been developed and put into practice, among which a variety of end-of-pipe approaches, cleaner production measures, waste exchange strategies and industrial ecology models. These approaches are applied in order to treat existing waste streams, to prevent waste and maximize pollution reduction at location (cleaner production), to optimize the material and energy flows going through the industrial system (industrial ecology), and to exchange by-products amongst companies on and off site. However, different circumstances require different (combinations of) approaches to effectively protect the environment and the approaches and technologies developed for developed countries are not automatically suited or the best for the conditions of industrializing Vietnam. This thesis assessed existing approaches known from developed countries and evaluated whether and how these approaches can and should be adapted in order to make them relevant for the current conditions of the Vietnamese textile industry. In the end the thesis developed a model for greening production of individual textile companies and a cluster of textile companies, by combining end-of-pipe, cleaner production, waste exchange and reuse/recycling. Moreover the thesis has looked not only into the technological and environmental science dimensions of such improvements, but also into the actor networks that might, can or should play a role in governing the implementation of these various approaches in Vietnam's textile sector.

This chapter first discusses the findings from the various chapters in the next section. Subsequently it draws the main conclusions from the study. In the final section recommendations are formulated for the practice of greening textile production in contemporary Vietnam, as well as for future research into the technological and management aspects of the environmental performance of textile production in Vietnam.

8.2 Discussion

In order to move to a more sustainable textile industry in Vietnam the textile sector and the Vietnamese government need to seek new approaches to improve its environmental performance and safeguard its future market and license to produce. This thesis has investigated options for creating a more sustainable textile sector along two major lines: improvement of end-of-pipe treatment and of pollution prevention strategies. Both are discussed and evaluated below.

8.2.1 End of pipe

At present, the majority of local authorities in Vietnam refuses new investments of textile companies in their local area because this industry sector is seen as a major pollution source. Textile wastewater is characterized by a complex composition containing various organic compounds. The composition of the wastewater of 29 investigated textile enterprises in Vietnam was found to be more or less similar as the composition reported in the international literature. The COD shows a wide range: from 250 to over 11,000mg O_2/L, depending on the type of products and quality of chemicals and dyestuffs. The ratio of BOD_5/COD is often around 0.2-0.5. One of the important characteristics of dyeing wastewater is the fact that it contains a high color intensity: 500-3,700 Pt-Co. Thus, wastewater treatment is an indispensable part of measures to reduce environmental pollution. To design a complete treatment system – with effluent meeting discharge regulations, reuse/recycling and low costs – this thesis looked into separating wastewater streams and treating these with single treatment processes and with combinations of physical, chemical and biological processes.

Separation of wastewater streams

In wet processes, 75% of the total water consumption is used for washing/rinsing processes. Most rinsing steps are characterized by high water consumption and a low effluent pollution concentration. The separation of wastewater streams enables optimal treatment of each waste stream, the reuse of water and chemicals and it especially reduces the operational costs. Similar results are also found in reports of Mattioli et al. (2002) and Rott (2003).

In the case of the 28 Company-Agtex (Chapter 5), an average of 700 m^3/day of wastewater was generated of which 130 m^3 water and 10 m^3 of 45% NaOH solution can be saved. About 350 m^3 of wastewater shows good biodegradability. Only 40 m^3 of wastewater has a high color intensity and high COD which needs special treatment. Separation of wastewater streams saves 122 US$/day or 0.244 US$/m^3.

However, for existing textile companies in Vietnam the separation of wastewater streams is often not suitable because adaptation of the drainage system is expensive. This approach is more suited for new companies and for those located in an industrial zone. In an industrial zone, with application of separating wastewater streams, the individual textile companies do not need to construct pre-treatment systems at their own company. This brings financial benefits through lower operational costs and saves land area.

Individual processes (physical/chemical processes)

Physical/chemical treatment processes for four types of wastewater were experimentally tested. The Fenton's reagent and the coagulation process are the most effective methods for removal of color (81-98%) and COD (53-80%) for the four types of textile wastewater, while the ozone process is significantly affected by particles (colloidal) in textile wastewater.

- Fenton's reagent

The Fenton's reagent process is the most effective method for color and COD removal in comparison with the coagulation and ozone process. Decolorization with Fenton's reagent occurs through two mechanisms: oxidation by hydroxyl radicals and co-precipitation through the coagulation with $Fe(OH)_3$. This process can be applied to treat both soluble and insoluble dyestuffs. These results are in agreement with research of Kuo (1992) and Bharat and Sanjeev (2007). Fenton's reagent is an effective and economic method for decolorization and COD removal of several dye wastewaters. Comparing treatment costs of Fenton's reagent with the costs of coagulation with aluminum sulfate for disperse & reactive dyes and vat dyes wastewater, Fenton's reagent proves cheaper than coagulation. However, for wastewater with a high COD concentration, like disperse & acid dyes wastewater, a high concentration of oxidant is needed. Because the H_2O_2 oxidant in Fenton's reagent is more expensive than the aluminum sulfate in the coagulation process, the treatment of high COD loaded wastewaters with Fenton's reagent is economically less favorable.

- Ozone process

The results from our research into ozone treatment processes are in agreement with the international literature that concludes that the ozonation process is very effective for treatment of direct, acid and reactive dyes (soluble dyes) while disperse and vat dyes (insoluble dyes) are more resistant (Marmagn and Coste. 1996; Oliver et al. 2000).

In this thesis, the effect of (colloidal) particles in the ozone process was studied for artificial wastewater of the Aalten Textile Company in the Netherlands and real wastewater streams from 28 Company-Agtex. It was found that particles significantly affect the ozone process in a negative way, with consequences for the dosage of ozone needed to reach a certain removal efficiency. The presence of colloidal particles alone caused a 12 fold increase in ozone needed for the same removal efficiency. This effect of particles has not yet been reported in the literature.

There are some differences between the international literature and the findings in this study regarding the results of ozone treatment. In a low pH environment, the direct oxidation by molecular ozone is the prevalent process of oxidation; at higher pH this would be by hydroxyl radicals. In this study we found with ozone treatment at low pH that molecular ozone is much more selective than hydroxyl radicals in the decolorization of dyes. The oxidation process did not improve the BOD_5/COD ratio. The azo-linkage is the easiest to break by oxidation, leading to decolorization. However, the cleaved products of oxidation are apparently not more easily biodegradable. In general it can be stated that Advanced Oxidation Processes are not economically effective for treating highly COD loaded wastewater streams.

- Coagulation process

The high removal efficiencies of the coagulation process in this research are similar to results found in the literature. The removal efficiency depends on the type of used dyestuffs. In several reported researches (Tünay et al. 1996; Vandevivere et al. 1998; Oliver et al. 2000; Kao et al. 2001) the coagulation process is found effective in color removal of insoluble dyestuffs such as disperse, azoic, vat and sulphur dyes, but low in efficiency for soluble dyes. In this study the coagulation process achieved the highest color removal efficiency (98%) with the insoluble vat dyes wastewater compared with other wastewater streams (disperse & reactive dyes, disperse & acid dyes wastewater). For wastewater containing soluble acid dye the coagulation process shows a much lower color removal efficiency of 12-55%. This is agreement with the results of Tünay et al. (1996). With a mix of insoluble dyes and soluble dyes (the disperse & reactive dyes and the disperse & acid dyes wastewater) the removal efficiency depends on the ratio of types of dyes (maximum removal efficiency 78-80%). The pH was found to affect the coagulation process significantly. Among three coagulants, aluminum sulfate is relatively the most effective (and cheapest) coagulant in color removal (78-98%). These advantages are confirmed by the research of Thakur et al. (1994) and Turan-Ertas (2001).

Combination of several processes

Although a single treatment process like the coagulation process or Fenton’s reagent yields high color removal efficiencies, the color of the effluent does not meet the strict discharge regulations and standards of Vietnam (50 and 80 Pt-Co). Therefore, a combination of physical, chemical and biological treatment processes was investigated.

The combination of activated sludge, coagulation and ozone processes yielded the best color (45 Pt-Co) and COD (30 mg O_3/L) removal efficiency at the lowest costs compared to all other tested combinations. With the proposed technology, the operational costs are reduced 2.3 times in comparison with average operational costs in Vietnam at present. The operational costs of this combination are estimated at about 0.3 US$/m^3. In this system the biological process, as the first step, was designed to remove biodegradable compounds. With a removal efficiency of 70%, this step reduces the chemical consumption in the next physical/chemical processes. The coagulation process was the next step, eliminating the remaining COD and a part of the color, as well as the effect of colloidal particles on the subsequent ozone process. The coagulation step produces an effluent with pH 5. With the subsequent ozonation at pH 5 the decolorization occurs with molecular ozone which is much more favorable than the oxidation by hydroxyl radicals. The resulting effluent meets the standards for irrigation and reuse.

Kao et al. (2001) reported in a survey for 75 textile wastewater treatment systems in Taiwan that an aerobic treatment followed by a coagulation process (and vice versa) did not achieve effluents that meet the discharge standards for color. Loan (2007) reported a survey of 50 Vietnamese textile companies and concluded that a combination of aerobic treatment followed by coagulation (and vice versa) produced effluents that also did not meet the discharge standards regarding color. Also the operational costs were high. In the here tested combination of an activated sludge, coagulation and ozone processes these adversities were overcome.

8.2.2 Industrial ecology models

Two case studies have been performed for this thesis on the greening of textile production using more preventive and reuse/recycling approaches: one with respect to Thanh Cong Company and one on a textile industrial cluster at Nhon Trach 2 industrial zone. For both an industrial ecology inspired model was formulated.

The design of the greening of production model for the Thanh Cong Company (Chapter 6) was achieved via two stages.

Cleaner production was applied as a first stage. In this stage the application of a variety of cleaner production measures reduces the use of dyestuffs, auxiliary chemicals, water and energy. These measures range from good housekeeping, water reuse, to better process control, equipment modification and new technology. The total benefits following from these cleaner production options in savings per day for the Thanh Cong Company is 1,388 US$. This monetary saving is comparable to savings found in cleaner production application in Western European, Australian, Indian and Chinese textile companies (Sakura 1995; Petek and Glavic 1996; Xie 1996; Fresner 1998). Demonstration projects of Cleaner Production in Vietnam (VNCPC 2005) show that 30-50% of all current wastes and emissions from the textile industry can be prevented at source by a cleaner production approach.

Although a cleaner production approach can help significantly in the environmental improvement of textile industry, it is not sufficient to deal with all waste streams according to the Vietnamese requirements for pollution discharges and environmental quality. So the second stage in greening the textile production focuses on dealing with remaining wastes. These remaining waste streams can be remediated through a waste exchange network, both on-site and off-site, and through a treatment system of wastewater and polluted air. In on-site waste exchange, the scouring wastewater and treated wastewater from the wastewater treatment plant can be used to treat polluted air in a system with wet scrubbers. The off-side waste exchange includes recycling companies of fabrics, cardboard, plastic, etc. The currently existing water treatment system at textile companies is further improved by a combination of activated sludge, coagulation and ozone processes, which can achieve effluents that meet the discharge regulations and requirements for irrigation water at relatively low cost. In addition, such a system of treating the remaining wastes provides textile companies with the opportunity of expanding their production processes without having to expand their wastewater treatment plants.

In analyzing the role of actor networks in the greening of textile production at Thanh Cong Company it was concluded that actors from the economic network were of key importance in pushing towards the implementation of (elements of) the designed green production model. Vietnam is still favoring economic development and social stability, which means that also for actors in the economic network greening issues will only be incorporated when economic benefits are linked to it. This is especially the case for the textile and garment industry, with its major contribution to Vietnam’s domestic and export economy. Hence, the strategy focuses on the implementation of cleaner production, environmental management systems (ISO 14000), market specialization and modernization. In contrast, the role of actors and institutions from the policy and social networks remained limited in the current situation of Vietnam. The main challenge for furthering the implementation of industrial ecology models at the company level is strengthening the development and especially the implementation of support policies and of environmental compliance. In recent years many environmental policies and regulations have been developed in Vietnam, such as strict regulations for discharging wastewater and waste air (2005, 2008 and 2009), taxes on natural resources (2008) and cleaner production strategy up to 2025 (2009). If these policies are to be implemented strictly and come together with a reform in the environmental policy administration, the policy network will be able to significantly contribute to the implementation of our model of greening textile production.

The design of the industrial ecology zone model for Nhon Trach 2 IZ was executed in three steps. In the first step, the greening production model was applied to all textile enterprises in the industrial zone. During this step the wastewater flow rate could be reduced from 14,000m^3/day to 9,000-11,000 m^3/day, comparable to a daily economic saving of 750-1250 US$. According to the development strategy of the textile and garment industry, 2015-2025, new enterprises will anyhow prioritize investments for new process technology with less water use. The second step consisted of the formation of a waste exchange network, in which a by-product enterprise, a waste treatment enterprise and an outside wastes exchange network is to be established. The outside waste exchange network includes the reuse of plastics, paper and waste oil at recycling companies in the neighborhood. Vietnam has a large number of small scale scrap businesses and a local flexible market for reuse and recycling has already developed, especially in larger cities and industrial provinces such as Hochiminh city and Dong Nai province. This opens favorable conditions for a waste exchange network outside the industrial zone related to textile companies and clusters. Hence, Vietnam has clear advantages in implementing an industrial ecology model for industrial zones, compared to Western countries (see also Van Koppen and Mol, 2002). The last step consists of the design of a complete treatment and reuse system of wastewater. Wastewater effluents can be used in sanitary systems and to water plants and roads inside the industrial zone (with an economic benefit of about 190 US$/day) and for irrigation (for instance in cotton cultivation). The treatment of polluted air, which includes a cyclone and a wet scrubber system, reuses treated wastewater and scouring wastewater, which saves 7,500 m^3 fresh water per day and 1875 US$/day. Hence, the entire operational cost of wastewater and polluted air treatment systems when reusing textile wastewater can save

342,400 US$/year. Such economic benefits are also demonstrated in industrial ecology projects such as those in Kalundborg industrial park in Denmark and in the Rotterdam harbor area, the Netherlands (Gertler and Ehrenfeld 1996); in Guangxi city, China (Zhu, Lowe et al. 2007); and in industrial ecology case studies of agro and food processing industries in Vietnam (Phuong 2002; Dieu 2003; Khoa 2006; Nhat 2007).

The analysis of actor networks around Nhon Trach 2 IZ proved that implementation of such industrial ecology models are far from easy. State and policy making actors in the policy network should play a major role in the implementation of the industrial ecology model, but showed similar shortcoming as concluded in the case study of Thanh Cong Company. With respect to the economic network only foreign customers and branch associations, like the Vietnam Textile & Apparel Association, can be expected currently to support the implementation of the developed model. Phuong (2002), Dieu (2003) and Nhat (2007) came to similar conclusions in their industrial ecology informed research on other industrial sectors in Vietnam. The role of citizens, non-governmental organizations and the media (all part of the so-called social networks) was marginal in pushing the greening of Nhon Trach 2 IZ along lines of industrial ecology. Phuong (2002), Phuong and Mol (2004), Dieu (2003) and Nhat (2007) reported cases of more or less successful citizen complaints that resulted in environmental improvements, although the number of such cases remains quite limited, not unlike what was found in this study.

8.3 Conclusions

The study reported here aimed to develop a greening production and industrial ecology model to achieve sustainable development for the textile and garment industry. These models have not only to consider the pollution prevention approach but also to improve existing end-of-pipe technologies towards lower costs and higher efficiencies and towards reuse/recycling of wastewater. The following conclusions are drawn from this study.

8.3.1 Industrial ecology model for textile industrial zones

The development strategy of the Vietnamese textile and garment industry till 2025 mentions the construction of concentrated textile and garment industrial zones as a measure to execute environmental protection programs. This development strategy is most favorable for developing and implementing a textile industrial ecology zone model in Vietnam. Such a textile industrial ecology zone model has been developed and tested for an existing industrial zone, Nhon Trach 2 IZ, in Chapter 7. The model provides a feasible and attractive new approach to sustainable development of the textile industry, with an efficient use of resources and an efficient elimination of waste. Based on the case study of Nhon Trach 2 IZ, a generalized industrial ecology model for textile industrial zones is proposed in Figure 8.1. This abstract model involves five components: textile companies, a by-production company, a unified waste treatment enterprise, onsite and offsite waste exchange networks, and a centralized wastewater treatment plant. Operation of this model is based on the beneficial geographical proximity of spinning, weaving, dyeing & finishing and sewing plants of several textile companies. Between these companies by-products can be efficiently exchanged. The treatment system for such a group of companies can be more economically realized regarding infrastructure and land use. This will reduce transportation costs and air pollution from transportation, allow optimization of scales in infrastructure and valorize waste and by-products through on-site and off-site waste exchange networks. In on-site waste exchange, the scouring wastewater generated from dyeing & finishing companies and the treated wastewater from the centralized wastewater treatment plant are used for air pollution treatment systems. Organic solid waste, chemical storage drums, cinder of coal, plastics, metal waste, paper/cardboard and waste oil generated from production processes are reused/recycled by actors and companies outside the industrial zone: composting business, recycling business for containers (drums, tins and bins), coal supplier, plastic recycling companies, metal companies, paper/cardboard recycling companies and waste oil recycling company. The remaining part of the industrial zone's solid waste stream is treated at a unified waste treatment enterprise within the industrial zone, which includes a sorting station, and an incinerator with heat recovery to produce hot water and electricity. The centralized wastewater treatment plant treats the final flow of wastewater that cannot be reused.

To move this model from the design table into practice a proactive and well-resourced policy actor network is essential, something which is lacking at the moment in Vietnam. Foreign customers that articulate environmental demands, an active Vietnam Textile & Apparel Association that supports its members and disseminates information on environmental measures, strategies and approaches, and an active civil society that is given more opportunities to complain and motivate companies and industrial zones into cleaning up their business are important potential supporters to activate such a policy actor network.

8.3.2 Greening production of individual textile companies

Greening the production of individual textile companies – inside or outside industrial zones - includes a combination of cleaner production, external waste exchange and end-of-pipe technology. Demonstration projects on cleaner production in Vietnam and in other developing and developed countries show that cleaner production options can bring both economic and environmental benefits. This proves also valid for Vietnamese textile companies as demonstrated in our case study of greening production in the large scale Thanh Cong Company (Chapter 6). This case study showed that such cleaner production options need to be complemented by end-of-pipe measures and waste exchange in order to maximize the textile company's environmental performance. Of the 2,500 Vietnamese textile companies more than 50 are large scale textile companies, which have many similarities with our case study company. Hence, the results of our case study have wider relevance.

The stagnating implementation of cleaner production projects in Vietnamese industries during the past 10 years illustrates that the greening of industries does not unfold automatically. The current (policy, economic and social) actor networks do not yet trigger textile companies into ecologizing their production processes. In the case of Thanh Cong, a large exporting company, the economic network (and especially foreign customers) can be of major relevance to motivate the textile companies into better environmental performance. More active and more stringent enforcement of environmental authorities and wider opportunities for the countervailing powers of civil society seem relevant for the greening of all textile companies.

8.3.3 End of pipe

Although a large amount of waste pollution can be reduced with the prevention and reuse/recycling measures of the proposed greening production model or industrial ecology model, a substantial amount of wastewater and polluted air is still generated from the production process of each textile company due to the complex characteristics of the production processes (Chapter 2). The consequence is that end-of-pipe treatment is indispensable to implement the industrial ecology model. Several treatment options were investigated for different types of textile wastewaters. Investigating the various physical/chemical processes for their potential of color and COD removal from several types of textile wastewater showed limited success when applied as individual treatment processes. Each of these processes could only remove one or a few types of pollutants from the wastewater with the consequence that the effluents could not meet all the discharge regulations (Chapter 3). Treatment combinations are investigated in Chapter 4: combinations of coagulation, AOPs and specifically Fenton' reagent, ozonation and aerobic biological processes are tested for treatment efficiency of mixed textile wastewater. The combination of an activated sludge, coagulation and ozone process yielded the best color and COD removal efficiency at the lowest costs compared to all other tested combinations. For textile wastewater, difficulties in treatment and high cost mostly arise from mixing wastewaters from different process steps that have a variety of concentrations and types of chemicals and dyestuffs. The separation of wastewater streams at each textile company seems a suitable measure for it facilitates treatment of each wastewater stream separately in an optimal way, as reflected in results of Chapter 5. The separation of wastewater streams allows not only reuse of water and chemicals resulting in saving of water, chemicals and energy use but also reduces the quantity of the discharged harmful compounds. Even when the operational costs are not reduced by separating the waste streams, it can still be an attractive option. In this way, undesirable by-products (toxic compounds) that emerge in case of treating mixed wastewater can be avoided. The source separated wastewater streams for textile industrial zones are divided into four types, according to their characteristics. The experimental research as discussed in Chapter 3 and 4 can be used for efficient treatment of each stream (see Figure 8.2):

- Wastewater that is low in pollutant concentration does not need treatment;
- Wastewater that can be reused for scouring, and wastewater with high pH that can be used in the air treatment system;
- Wastewater containing biodegradable pollutants, which can be treated by an aerobic process;
- Wastewater with high color intensity and high COD, to be treated with a combination of biological treatment, coagulation and ozone as post-treatment at low pH

The proposed treatment technologies are low in energy and chemical consumption resulting in low operational costs. In order to maintain a stable operation of the treatment systems, pH and temperature control equipment have to be installed to guarantee favorable pHs and temperature for the aerobic and coagulation/flocculation processes, because the composition of wastewater can change considerably within a day, or even an hour.

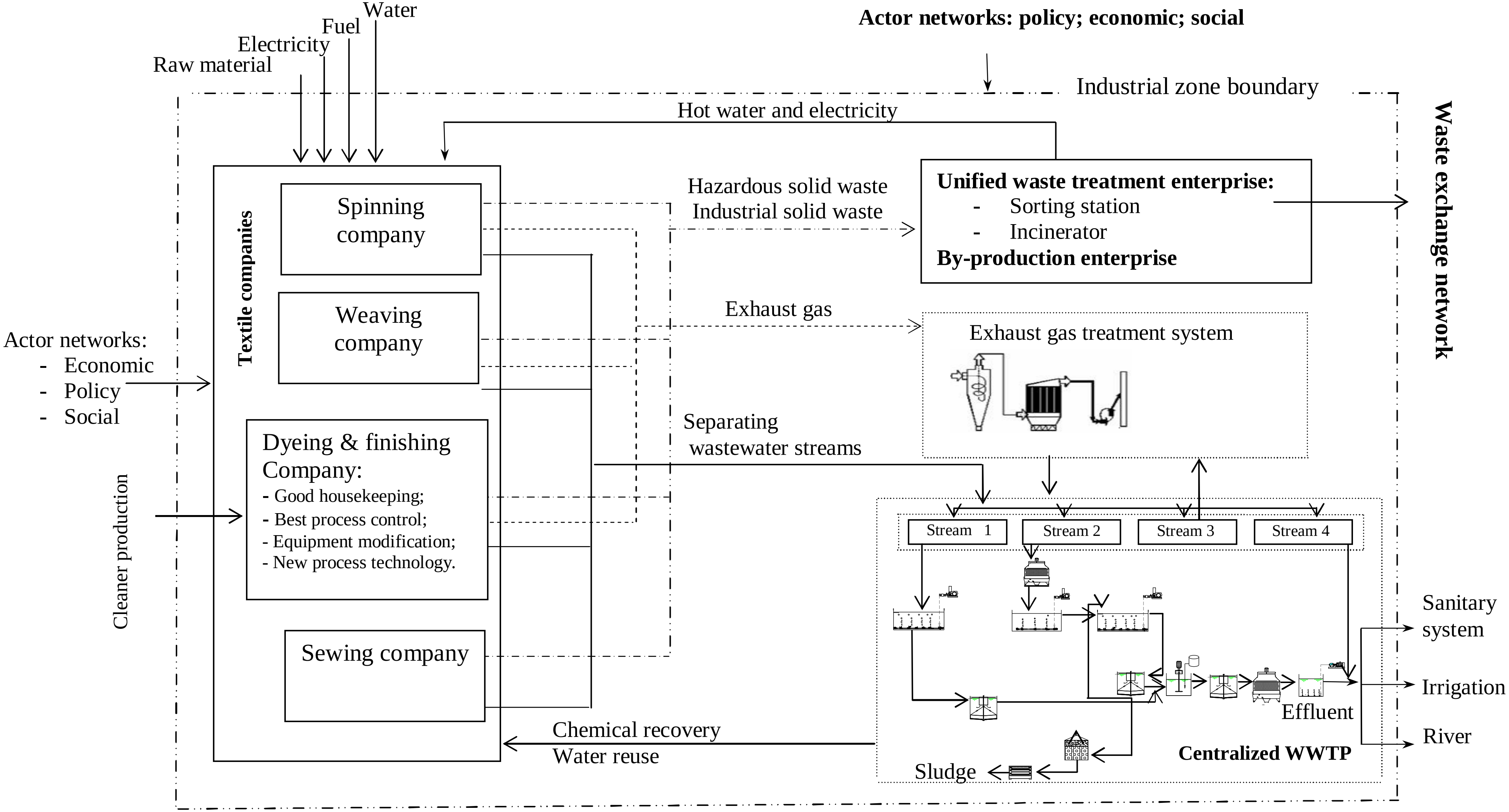


Figure 8.1: Textile Industrial ecology zone model

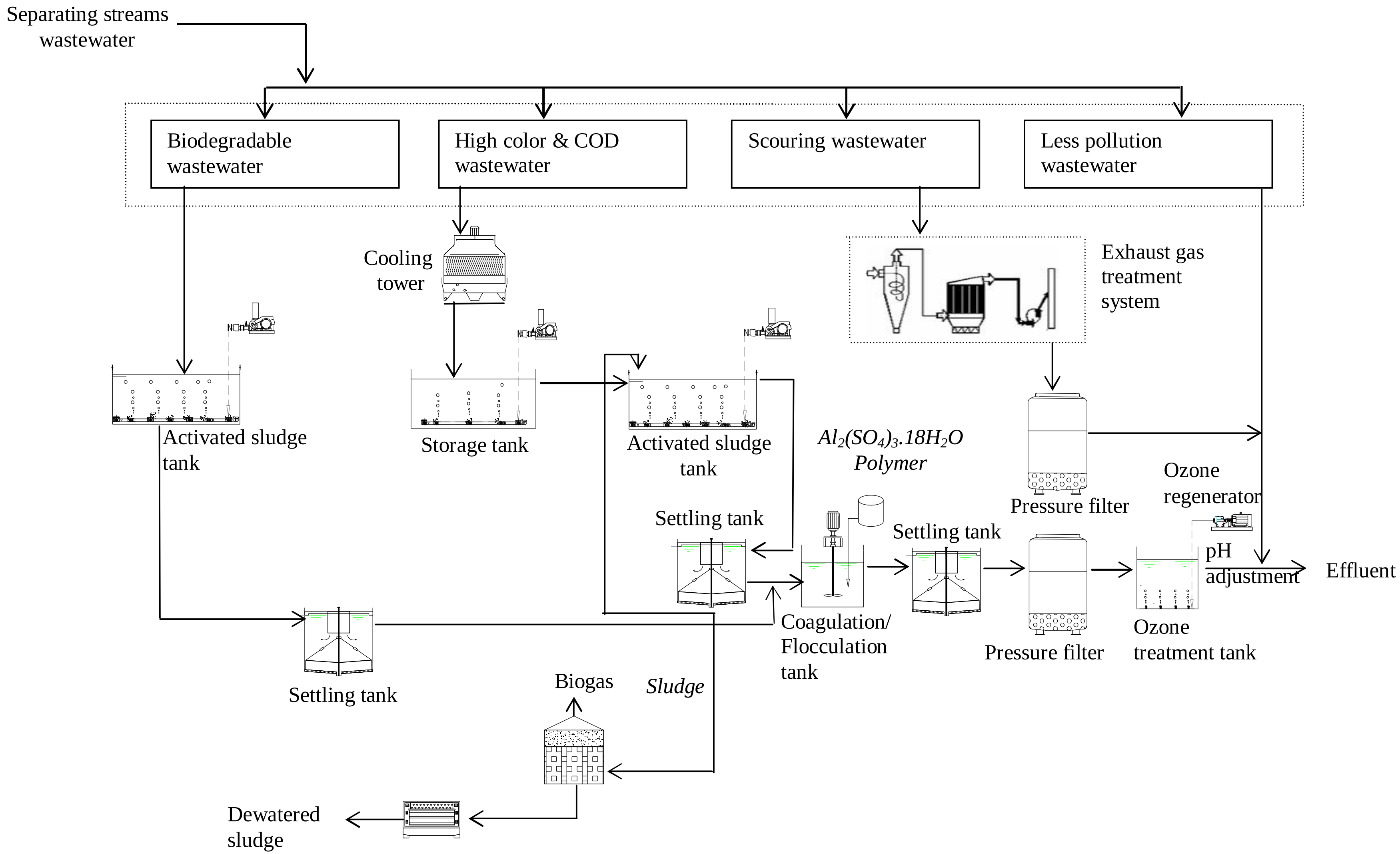


Figure 8.2: Scheme of centralized wastewater treatment plant

8.4 Recommendations

From the obtained results in this study implementation and research recommendations are presented below, in relation with end-of-pipe technology, for achieving reuse/recycling of wastewater, and for a textile industrial ecology model.

8.4.1 Recommendations for improving environmental performance

Although a number of textile companies have built wastewater treatment plants, the pollution situation has not markedly improved. This is mainly due to a lack of knowledge on appropriate treatment technology, a lack skilled of operators and high operational costs. The Vietnam Environment Administration (VEA) should assess textile wastewater treatment technologies and provide a list of appropriate textile wastewater treatment technologies (including the proposed end-of-pipe treatment systems discussed in this thesis). Such a list will help to provide adequate information to textile companies for wastewater treatment approach. Besides filling this knowledge gap, the limitations in supervision and inspection and the perfunctory handling of violations of environmental management agencies have contributed to the violations of environmental regulations. MONRE, DONREs and the industrial zone authorities should thus strengthen the inspection and control efforts on industrial enterprises in their locality. Such measures motivate force and guide the textile industry to implement appropriate treatment technologies approach.

Vietnam's environmental policy-making started later than that in many other countries, and is still in its infancy and incomplete. The policies of Vietnam are not (yet) able to ensure an effective combination of three elements: economic development, social development **and** environmental protection. In recent years many policies and regulations in relation to environmental protection in Vietnam were issued, such as strict regulations for wastewater and waste air discharges (2005, 2008 and 2009). For example, to produce effluent that meets color (20, 50Pt-Co) and COD regulations (COD 50, 80 mgO_2/L) requires modern treatment technologies, which are currently not available. Assessing the both the currently available technologies and the implementation of these regulations will help environmental management agencies (MONRE, VEA) to judge the feasibility of national regulations for effluents of the textile industry and to make it suitable for the conditions of contemporary Vietnam.

In Vietnam, the awareness of enterprises on environmental protection is not very high and one cannot expect that an industrial ecology model will be implemented 'automatically'. In order to improve the environmental performance through an industrial ecology model, textile companies should be brought together (as a sector or with companies from other industrial sectors) in industrial zones and should be guided by environmental authorities and industrial zone authorities on the advantages and implementation trajectories of such models.

There are many advantages to apply the idea of an "industrial ecology zone" in Vietnam, especially when considering the targets and development viewpoints of the textile and garment industry strategy until 2015 towards 2025, as proposed by the government. In advancing an industrial ecology model, there is a need for coordination between ministries (Ministry of Industry and Trade, Ministry of Natural Resources and

Environment, Ministry of Finance) and provincial People's Committees, as shown in Figure 7.9. Establishment of a recycling association outside – but in close relation to – the industrial zone can be expected to support the implementation of the industrial ecology zone.

Policies in relation to support cleaner production are currently rather weak, while policies in relation to industrial ecology zones, reuse/recycling and waste exchanges are almost none-existent. The government should promulgate such policies supporting cleaner production, industrial ecology, waste exchange and waste recycling.

To enhance the environmental awareness and role of communities, environmental management agencies (MONRE and DONRE) can cooperate with the media to disseminate environmental information more widely to people and increase the public's environmental awareness, also with respect to industrial pollution. Once environmental awareness of citizens has increased, they will pay more attention to the negative impacts caused by industrial wastes. As such the social network can not only become a useful information source but can also help environmental agencies to detect environmental pollution and enforce improvements. For that to materialize, however, structures for complaints and participation for civil society need to be enhanced.

In the future, many concentrated textile industrial zones and cotton planting areas will be established (Vinatex, 2009) and one of the solutions for environmental protection is to transfer existing industrial zones into environment friendly zones through implementation of an industrial ecology model (VEA, 2009). In that respect it would be interesting to implement the demonstration project for textile industrial ecology as proposed in this research.

8.4.2 Some recommendations for future research

From the results obtained from this research some future research ideas are suggested.

A disadvantage of the aerobic process is the amount of consumed energy for aeration. Therefore, the treatment efficiency for decolorization of source separated wastewater streams (with high color and COD) with anaerobic UASB or EGSB processes should be investigated. With these processes recovery of energy (biogas) and/or decrease of energy consumption are possible. In addition, textile wastewater often has a high temperature (50-60^{0}C), which is advantageous for mesophilic or even thermophilic anaerobic processes. If treatment at high temperatures is not effective, it is necessary to install a cooling tower as part of a proposed end-of-pipe technology. This may result in a decrease of the operational costs and may recover energy.

In our research and in the international literature it is found that the color can decrease through an activated sludge process. Therefore, future study may consider the absorption capacity of color on activated sludge, the hydraulic retention time and the cycle of sludge.

This study has mainly focused on large textile companies, both stand alone and in industrial zones. Future research is needed on smaller textile companies and the extent to which the approaches and measures developed in this thesis are relevant for these smaller textile companies, in terms of the technologies applied; the cost structure; the cooperation with similar and different industries in industrial networks, zones or clusters; and the supporting networks to trigger the implementation of such strategies.

SUMMARY

The textile and garment industry has made a remarkable contribution to the economic development of Vietnam (9% of the total Vietnamese industrial value) and employs a large labor force of 2.5 million people. Additionally, Vietnam's textile industry is in the top ten garment exporting countries and territories of the world. However, this industry uses excessive amounts of material and is responsible for emission of a large amount of pollutants. Some remediation measures have been implemented in the textile industry for environmental protection. The main remediation approach was focused on end-of-pipe technology, which requires a lot of energy and chemicals, resulting in high costs. The consequence is that the waste is often discharged into the environment without any treatment. Due to these discharges the natural environment has been seriously destroyed in many areas. The textile industry is seen as the most polluting and unsustainable industry in Vietnam. To overcome disadvantages of the application of end-of-pipe technologies, other measures can be applied in the textile industry in Vietnam, like cleaner production (CP) and ISO 14000. However, the number of CP and ISO 14000 implementing enterprises is limited. The poor environmental performance in the textile industry is related to the role of the actors in the industrial system, like the governmental organizations, economic and social organizations.

In the highly industrialized countries several pollution prevention approaches such as greening production, industrial ecology and waste exchange have been developed and practiced. These approaches are applied in order to prevent waste production and to maximize pollution reduction at location (cleaner production), to optimize the material and energy flows going through the industrial system (industrial ecology) and to exchange by-products amongst companies on and off site. However, different circumstances require different (combinations of) approaches to effectively protect the environment. To suit the nature and the conditions in the Vietnamese textile industry practice experiences from developed countries are selected to develop a greening production model for individual textile companies and a textile industrial ecology model combining end-of-pipe technology with reuse/recycling requirements. The approach with these models can improve stability, sustainably and effectiveness of the textile industry in Vietnam. In order to promote the proposed models in practice, the theory and practice of a triad-network model developed by Mol (1995) is introduced and analyzed in greening production, industrial ecology and end-of-pipe models.

Two case studies, executed as desk studies, include greening production in an individual company, and in an industrial ecology zone, demonstrate the economical and environmental benefits of pollution prevention methodologies and models. The greening production model is developed and assessed for a large-scale textile company in Hochiminh city, the Thanh Cong Company. The model includes combining Cleaner Production and external waste exchange. The benefits of the application of the proposed model are the significantly decreased volume of wastewater and the reduced chemical loads going into the wastewater. Furthermore, an external waste exchange network can help to recycle most remaining waste materials, by reusing it as raw material in other companies. The greening production model provided a feasible and attractive new approach to sustainable development of an individual large textile company.

To investigate the relevance of an industrial ecology approach for Vietnam, an integrated model for an industrial zone, the Nhon Trach 2 IZ, is tested. This model is

based on a mutually beneficial relationship of the geographical proximity of seven textile companies in the industrial zone and an external waste exchange network. The proposed industrial ecology model can make a valuable contribution to achieving sustainable development. This model was elaborated in three steps. The first step is to learn from the experiences with the model for the individual Thanh Cong Company, and apply these to all enterprises in an industrial zone. The second step is to form a waste exchange network, in which a by-product using enterprise, a waste treatment enterprise and an outside wastes exchange network have to be established. The last step is to treat waste, polluted air and to treat and reuse wastewater (using the results from Chapters 3, 4 and 5) for irrigation (cotton cultivation), for use in sanitary systems and to water plants and roads in the industrial zone. In addition, some outside waste exchange has to be set-up for the reuse of waste plastics, waste paper and waste oil.

Cleaner production and industrial ecology approaches can help environmental improvement in industry, but is not sufficient to deal with all waste streams. The results of the survey and of the literature review show that the wastewater, containing high concentrations of pollutants (especially color intensity) and characterized by a large volume, is the most polluting part of the textile industry.

Color intensity is considered as one of the key parameters in the treatment of textile wastewater. Removal of color from textile wastewater was studied. This part of the research was focused on the reduction of color by varying the pH, by application of coagulation/flocculation and advanced oxidation processes (O_3, O_3/H_2O_2, Fenton's reagent). The experimental tests were performed with real wastewater streams (disperse & reactive dyes, vat dyes, disperse & acid dyes, mixed wastewater and acid dyes wastewater) from a textile company in Vietnam (28 Company-Agtex), from Belgium (UCO textile factory, Gent) and with an artificial wastewater prepared according to a recipe of the GVA Textile Company in Aalten, the Netherlands. Fenton's reagent is the most effective method for color removal of the four types of wastewater. The coagulation process is a very effective means for color removal of four types of wastewater, but this process is not suited for wastewater containing only soluble dyestuffs. For the decolorization of wastewater with the ozone process at low pH value (pH 5) the direct oxidation by molecular ozone was found to be much more selective than the oxidation by hydroxyl radicals. The O_3/H_2O_2 process gave the lowest removal efficiency in comparison with ozone and Fenton's reagent.

Changing the pH gave no decolorization. The effect of different acids (HCl and H_2SO_4) on the change of color was more or less the same.

Temperatures in the range between 30 and 50^0C have a small effect on the coagulation process. For AOPs at high temperature (50^0C) causes decrease efficiency in comparison with 30^0C and 40^0C.

The physical/chemical processes like pH variation, coagulation, and AOPs, for treatment of textile wastewater have limited success as individual treatment processes. Each of these treatment processes could only remove one or a few types of pollutants from the wastewater with the consequence that the effluents could not meet all the discharge regulations. Therefore combinations of several processes were investigated to achieve an effluent that meets the strict discharge regulations for color and COD (50 Pt-Co and 50 mg O_2/L). Combinations of coagulation, AOPs and biological processes (and vice versa) were tested for treatment efficiency of mixed textile wastewater. The combination of an activated sludge, coagulation and ozone process yielded the best color and COD removal efficiency at the lowest costs compared to all other tested combinations.

In the wet processes applied in the textile industry, 75% of the total water consumption is used for washing/rinsing processes. Difficulties in the treatment of textile wastewater and costs mostly arise from mixing wastewaters from different process steps that have a variety of concentrations and types of chemicals and dyestuffs. Additionally, most rinsing steps contain low pollution concentrations and can be reused in other process stages or can be discharged without treatment. The aim of this part of the study was to assess the possibilities for wastewater separation in practice by investigating wastewater source separation at the 28 Company – Agtex. The total wastewater flow of this company averages at 700 m^3/day of which 130 m^3 of water and 10 m^3 of NaOH solution can be saved. About 350 m^3 of wastewater has a good biodegradability. Only 40 m^3 of the wastewater has a high color intensity and COD which needs special treatment. The separation of wastewater streams can save 122 US$/day or 0.244 US$/m^3. The results show that the separation of wastewater streams allows not only the reuse of water and chemicals, but it also increases the efficiency of treatment since each separate wastewater stream can be treated in an optimal way.

Analyzing triad-network in the case study of the greening production, industrial ecology zone model, shows that a successful industrial ecology in practice not only depends on the interaction between enterprises inside the industrial zone but also on the interaction with actors outside the system. Effects of actor networks will depend on the nature of and condition in each company or industry. In the case of Thanh Cong, a large export company, the economic network is of major importance: e.g. the customers. A social network can also affect a commercial company via the use of mass media and change the behavior of the polluters. These networks contribute to implement the model. However, the role of the policy network is still limited in the current settings of Vietnam due to a number of flaws at national and local level. In the case study of an industrial ecology zone, the policy network plays the most important role in the implementation of the industrial ecology model. With respect to the economic network, the role of foreign customers and the Vietnam Textile & Apparel Association are important actors for improving environmental performance. The role of social networks actors seems to be limited at present. This is due to state priorities and the state's environmental policy is based on a top-down model. Besides that the environmetal awarence of citizents is low. The greening production, industrial ecology, waste exchange and end-of-pipe models can only go successfully into practice when having the combination of the two aspects: technology and triad-network.

SAMENVATTING

De kleding- en textielindustrie in Vietnam heeft in aanzienlijke mate bijgedragen aan de economische ontwikkeling van het land. De economische waarde van de kleding- en textielindustrie bedraagt momenteel ongeveer 9 % van de totale waarde van de industriële productie in Vietnam. Het aantal werknemers in deze industrietak bedraagt ongeveer 2,5 miljoen. Vietnam behoort tot de top van de kleding en textiel exporterende landen en regio’s. Echter, deze industrietak gebruikt grote hoeveelheden grondstoffen en is verantwoordelijk voor aanzienlijke emissies van milieuverontreinigende stoffen. Een aantal maatregelen om de milieuverontreiniging terug te dringen is inmiddels genomen. Deze maatregelen betreffen vooral de toepassing van end-of-pipe technologie en worden gekenmerkt door een hoog gebruik van energie en grondstoffen hetgeen weer gepaard gaat met hoge kosten. Het gevolg is dat afval en afvalwater momenteel vaak zonder enige behandeling worden gedumpt in het milieu waardoor veel gebieden onherstelbaar zijn verontreinigd. De textielindustrie in Vietnam wordt dan ook beschouwd als de meest vervuilende en meest onduurzame industrietak in Vietnam. Om de nadelen van het uitsluitend toepassen van end-of-pipe technologie te voorkómen, zijn ook andere maatregelen ingevoerd, zoals schoner produceren en toepassing van milieumanagement systemen, zoals die gecertificeerd zijn door ISO 14000. Het blijkt echter dat ook na het invoeren van deze maatregelen het aantal bedrijven, dat deze maatregelen daadwerkelijk heeft geïmplementeerd, toch zeer beperkt is gebleven. De zwakke prestaties van de textielindustrie op milieugebied worden o.a. toegeschreven aan de rol die de betrokken actoren in Vietnam, zoals overheidsinstanties, economische en sociaal/maatschappelijke organisaties, vervullen in het industriële productiesysteem.

In de hoog geïndustrialiseerde landen zijn verschillende typen preventiemaatregelen geïmplementeerd om milieuverontreiniging te verminderen. Als belangrijkste maatregelen kunnen worden genoemd de vergroening van het productieproces, de toepassing van industriële ecologie, en geïntegreerde afvalverwerking in samenwerking met andere industrietakken, waaronder ook specifieke verwerkers van afval, gericht op nuttig hergebruik van grondstoffen en energie. Deze aanpak wordt toegepast om het ontstaan van afval te voorkómen en de reductie van emissies op de productielocatie te minimaliseren (schone productie), om het gebruik van grondstoffen en energie bij het industriële productieproces te minimaliseren (industriële ecologie) en om het nuttig gebruik van afvalstromen door andere bedrijven binnen of buiten de industriële locatie te bevorderen. Echter, verschillen in omstandigheden en situaties vragen ook om verschillen in aanpak om effectief het milieu te beschermen.

Praktijkervaringen, opgedaan in de geïndustrialiseerde landen zijn geselecteerd om een vergroeningsmodel voor individuele Vietnamese textielbedrijven te ontwerpen alsmede een industrial ecology model te ontwikkelen voor de Vietnamese textielindustrie in het algemeen, waarbij end-of-pipe technologie gecombineerd wordt met schone productie, hergebruik en recycling en waarbij tevens rekening wordt gehouden met de specifieke aard en omstandigheden van de Vietnamese textielindustrie. De aanpak door middel van deze modellen maakt het mogelijk de stabiliteit, milieuhygiënische duurzaamheid en effectiviteit van de textielindustrie in Vietnam verbeteren. Teneinde de toepassing van de voorgestelde modellen in de praktijk te bevorderen wordt de theorie en

praktijktoepassing van een zogenaamd triad-network, ontwikkeld door Mol (1995), gebruikt voor de analyse van de vergroening van het productieproces, de toepassing van industrial ecology en end-of-pipe toepassingen.

De economische en milieuhygiënische verdiensten van de toepassing van preventiemethoden voor milieuvervuiling worden gedemonstreerd door middel van een tweetal casestudies. Een van de casestudies heeft betrekking op de vergroening van het productieproces van een individueel Vietnamees textielbedrijf, de Thanh Cong Company; de andere heeft betrekking op de gezamenlijke textielindustrie in een industriële zone, de Nhon Trach 2 IZ. Het vergroeningsmodel is ontwikkeld, toegepast en geëvalueerd voor de Thanh Cong Company, een groot textielbedrijf in Hochiminh City. Het model combineert in feite schone productie en duurzame externe verwerking van afvalstromen. De verdiensten die het model illustreert, zijn een aanzienlijke vermindering van de hoeveelheid geproduceerd afvalwater alsmede een sterke vermindering van de hoeveelheid vervuilende componenten in dit afvalwater. Het model toont tevens aan dat de toepassing van een extern netwerk voor een duurzame verwerking van afvalstromen resulteert in recycling van de meeste materialen die in deze afvalstromen aanwezig zijn, middels nuttig hergebruik in andere bedrijven. In het algemeen demonstreren de resultaten van deze casestudies de economische en milieuhygiënische verdiensten van de toepassing van preventie van milieuvervuiling en van industriële ecologie in een groot Vietnamees textielbedrijf. Het bestudeerde model voor vergroening van de productie kan worden beschouwd als een haalbare en attractieve methode om individuele textielbedrijven duurzaam te maken.

Om de relevantie van een industrial ecology benadering voor Vietnam te onderzoeken, is een geïntegreerd model van deze benadering voor de industriële zone Nhon Trach 2 IZ geanalyseerd. Dit model is gebaseerd op de gunstige geografische ligging in elkaars nabijheid van een cluster van zeven textielbedrijven in de betreffende industriële zone en de beschikbaarheid van een extern netwerk voor afval-uitwisseling t.b.v. afvalverwerking en afvalhergebruik. Het voorgestelde industrial ecology model kan een waardevolle bijdrage leveren aan het tot stand komen van een duurzame economische ontwikkeling. Het model is uitgewerkt aan de hand van een drietal stappen. De eerste stap is te leren van de ervaring met het vergroeningsmodel dat ontwikkeld en gedemonstreerd is voor Thanh Cong en dit model toe te passen voor alle textielbedrijven in de betreffende industriële zone. De tweede stap is de oprichting van een afvalnetwerk waarin een bedrijf, dat bijproducten kan gebruiken, een bedrijf dat afval verwerkt en ook een extern netwerk dat zich bezig houdt met uitwisseling van afval, vertegenwoordigd zijn. De laatste stap bestaat uit het behandelen van afval, afgassen, afvalwater en hergebruik van het gezuiverde afvalwater als irrigatiewater (op katoenplantages), voor sanitatiesystemen, voor productie als proceswater of drinkwater of voor het schoonspoelen van wegen. Daarnaast moet ook een extern afvalverwerkingcircuit en hergebruikcircuit worden opgezet voor afvalstromen zoals plastic afval, papierafval, en afvalolie.

Het schoner produceren en de aanpak via het industrial ecology model kunnen bijdragen aan een verbetering van de milieuprestaties van een industrie maar zijn alleen niet voldoende om alle afval- en afvalwaterproblemen aan te kunnen pakken. De resultaten van het literatuuroverzicht dat is gemaakt, tonen aan dat het afvalwater van de textielindustrie, dat gekenmerkt wordt door hoge debieten aan afvalwater en hoge concentraties aan vervuilende componenten, het meest vervuilende onderdeel is van de textielindustrie. Met name gaat het daarbij om de aanwezigheid van kleurstoffen in het afvalwater, die dan ook het grootste probleem vormt bij de behandeling van het afvalwater. In het onderzoek is uitgebreid aandacht besteed aan het verwijderen van kleurstoffen. Daarbij is onderzocht wat het effect is van de pH op de zichtbaarheid van de in het afvalwater aanwezige kleurstoffen en hoe deze kleurstoffen kunnen worden verwijderd door toepassing van coagulatie/flocculatieprocessen en geavanceerde oxidatieprocessen (O_3, O_3/H_2O_2, Fenton's reagent). Het experimentele onderzoek is daarbij uitgevoerd met diverse typen praktijkafvalwater (gedispergeerde en reactieve kleustoffen, kuipkleurstoffen, gedispergeerde en zure kleurstoffen, zure kleurstoffen, en gemengd afvalwater vervuild met verschillende typen kleurstoffen). Deze praktijkafvalwaterstromen waren afkomstig van een textielbedrijf in Vietnam, (28 Company-Agtex) en uit Belgie (UCO in Gent). Ook is onderzoek verricht met een kunstmatig bereid afvalwater, bereid volgend een voorschrift van het textielbedrijf GVA te Aalten in Nederland.

Uit het experimentele onderzoek blijkt dat Fenton's reagent de meest effectieve methode is voor het behandelen van de vier genoemde typen afvalwater. Het coagulatie/flocculatieproces is eveneens een zeer efficiënte methode voor het verwijderen van de kleurstof uit de vier typen afvalwaterstromen, maar dit proces heeft als nadeel dat het niet geschikt is voor afvalwater dat uitsluitend oplosbare kleurstoffen bevat. Ontkleuring van het afvalwater met behulp van ozon bij lage pH (pH=5), waarbij een directe oxidatie plaats vindt met moleculaire ozon, blijkt veel effectiever te zijn dan oxidatie via hydroxyl radicalen. Het O_3/H_2O_2 proces heeft de laagste efficiëntie in vergelijking met ozon oxidatie en met Fenton'reagent. Het effect van verschillende typen zuren (HCl and H_2SO_4) op de kleurintensiteit blijkt min of meer identiek te zijn. Temperatuurvariaties in the range tussen 30 and 50^0C hebben slechts een gering effect op het coagulatiepoces. Toepassing van geavanceerde oxidatiepocessen (AOPs) bij hogere temperatuur (50 ^{0}C) resulteert in een daling in de kleurverwijderingsefficiëntie, vergeleken met de verwijderingsefficiëntie die wordt verkregen bij 30^0C and 40^0C. De fysisch/chemische processen zoals coagulatie/flocculatie, pH verandering en AOPs zijn, indien toegepast als enkelvoudige individuele behandeling, slechts in beperkte mate succesvol voor de behandeling van textielafvalwater. Elk van deze processen kan slechts een of twee typen vervuiling elimineren uit het afvalwater met als consequentie dat het effluent niet voldoet aan alle normen voor lozing. Om na te gaan op welke wijze kan worden voldaan aan de lozingstandaards voor kleur en COD (50 Pt-Co en 50 mg O_2/L), zijn daarom ook combinaties van verschillende typen zuiveringsprocessen, in dit geval coagulatie/ flocculatie, AOPs en biologische zuiveringsprocessen, onderzocht voor de behandeling van gemengd textiel afvalwater. Het blijkt dat de combinatie van een actief slibsysteem, coagulatie/flocculatie en ozon oxidatie het meest efficiënt is wat betreft verwijdering van kleurstoffen en COD en tevens ook de laagste kosten heeft, vergeleken met andere onderzochte zuiveringscombinaties.

Bij de natte processen die in de textielindustrie worden toegepast, wordt 75% van de totale waterconsumptie gebruikt voor het wasproces. De problemen bij de behandeling van het afvalwater en de daarmee gepaard gaande kosten worden vooral veroorzaakt door de behandeling van gemengd afvalwater dat gekenmerkt wordt door de gelijktijdige aanwezigheid van verschillende typen kleurstoffen en andere vervuilende componenten alsmede door de grote variatie in het type vervuilende componenten. Het afvalwater van de meeste spoelprocessen bevat slechts lage concentraties aan verontreinigingen en kan worden hergebruikt in andere processtappen of kan zonder behandeling worden geloosd. Het doel van dit deel van het onderzoek was gericht op het evalueren van de mogelijkheden om afvalwaterstromen in het bedrijf, in dit geval de 28 Company – Agtex, te scheiden. De totale afvalwaterstroom van dit bedrijf bedraagt gemiddeld 700 m^3/dag waarvan ca 130 m^3 water per dag kan worden bespaard alsmede 10 m^3 van een NaOH oplossing. Ongeveer 350 m^3 van het afvalwater blijkt biologisch goed afbreekbaar. Slechts 40 m^3 van het afvalwater vertoont een hoge kleurintensiviteit en heeft een hoge COD waarvoor een speciale afvalwaterbehandeling nodig is. Uit het onderzoek blijkt dat scheiding van afvalwaterstromen kan resulteren in een besparing van 122 US$/dag of 0.244 US$/m^3. De resultaten tonen duidelijk aan dat scheiding van afvalwaterstromen niet alleen hergebruik van het gezuiverde afvalwater mogelijk maakt alsmede van teruggewonnen chemicaliën, maar ook de mogelijkheid biedt om de efficiëntie van de verschillende zuiveringsprocessen te vergroten omdat elk zuiveringsproces afzonderlijk kan worden geoptimaliseerd.

Een analyse van het triad-netwerk van de beide casestudies, vergroening van de productie van een individueel bedrijf en toepassing van het industrial ecology zone model, laat zien dat een succesvolle industrial ecology praktijk niet alleen afhangt van de interactie tussen de bedrijven binnen de industriële zone maar ook afhangt van de interactie met de relevante actoren buiten het systeem. Het effect van het actoren netwerk zal ook afhangen van de aard en de condities van elk van de individuele bedrijven afzonderlijk. In het geval van Thanh Cong, een groot exportbedrijf, is het economisch netwerk, wat in feite gevormd wordt door de consumenten, het belangrijkst. Een sociaal/maatschappelijk netwerk kan ook invloed hebben op een commercieel georiënteerd bedrijf via het gebruik van massamedia, waardoor veranderingen in het milieubeleid van het bedrijf kunnen worden afgedwongen. Deze netwerken dragen dus bij aan de implementatie van de modellen. Echter, in de huidige situatie in Vietnam is de rol van het netwerk van de milieubeleidsbepalers nog beperkt, voornamelijk als gevolg van de tekort komende wetgeving op nationaal en lokaal niveau. In het geval van de casestudy betreffende de industrial ecology zone is het netwerk van de beleidsbepalende instanties het belangrijkste bij de implementatie van het industriële ecologische model. Met betrekking tot het economische netwerk zijn de buitenlandse klanten en de Vietnam Textile & Apparel Association de belangrijke actoren die bepalend zijn voor verbetering van de milieuprestaties. In de huidige situatie is de rol van het sociaal/maatschappelijk netwerk beperkt als gevolg van de het feit dat de staatsverantwoordelijkheid voor het milieu is gebaseerd op een top-down benadering en het milieubesef van burgers zich nog vaak op een laag niveau bevindt. De vergroening van de productie, de toepassing van industrial ecology, recycling and hergebruik van afval tussen verschillende typen industrieen, en implementatie van end-of-pipe technologie kan in feite alleen in praktijk worden gebracht wanneer de twee hoofdaspecten, technologie en triad-netwerk, gelijktijdig en gecombineerd worden ingezet.

TÓM TẮT

Ngành công nghiệp Dệt may đã có những đóng góp đáng kể vào sự phát triển kinh tế của Việt Nam (9% tổng giá trị công nghiệp) cũng như góp phần giải quyết việc làm cho khoảng 2.5 triệu lao động trong cả nước. Ngành Dệt may Việt Nam được xếp vào trong danh sách mười nước xuất khẩu hàng dệt may lớn nhất trên thế giới với việc mang lại nguồn ngoại tệ hơn 9 tỷ US$ mỗi năm. Tuy nhiên Ngành Dệt may cũng được xếp vào danh sách những ngành gây ô nhiễm môi trường nghiêm trọng với việc tiêu thụ một lượng rất lớn nguyên, nhiêu liệu cũng như thải vào môi trường một thể tích lớn nước thải với thành phần ô nhiễm cao và rất khó xử lý. Trong những năm gần đây Ngành Dệt may đã chú trọng đến xử lý chất thải, đặc biệt là xử lý nước thải. Mặc dù số lượng các nhà máy xây dựng trạm xử lý nước thải đã tăng lên nhưng hiện trạng ô nhiễm vẫn chưa được cải thiện rõ rệt, nguyên nhân chủ yếu là do chi phí vận hành quá cao hoặc công nghệ xử lý không thích hợp và nhận thức của doanh nghiệp về bảo vệ môi trường chưa cao. Vì thế nước thải thường được thải ra môi trường mà không qua xử lý. Hậu quả của chính sự xả thải này là môi trường tự nhiên bị phá hủy nghiêm trọng tại nhiều khu vực. Khắc phục những nhược điểm của xử lý cuối đường ống một số giải pháp giảm thiểu ô nhiễm khác cũng được áp dụng đối với Ngành Dệt may là Sản Xuất Sạch Hơn (CP) và hệ thống quản lý môi trường theo tiêu chuẩn quốc tế ISO 14001. Tuy nhiên, cho đến nay số lượng các doanh nghiệp áp dụng CP và ISO 14000 vẫn còn rất hạn chế. Việc thực hiện công tác bảo vệ môi trường kém hiệu quả trong Ngành Dệt may liên quan đến vai trò của các tổ chức như tổ chức chính quyền, kinh tế và xã hội.

Hiện nay, tại các nước công nghiệp hóa, nhiều giải pháp tiếp cận phòng ngừa ô nhiễm đã được phát triển và ứng dụng như là sản xuất xanh, sinh thái công nghiệp và trao đổi chất thải. Những giải pháp này được áp dụng để ngăn chặn sự phát sinh chất thải và giảm thiểu ô nhiễm đến mức tối đa tại nguồn (sản xuất sạch hơn), tối ưu hóa những dòng nguyên liệu và năng lượng đi vào trong hệ thống công nghiệp (công nghiệp sinh thái) và trao đổi các sản phẩm phụ giữa các công ty trong và ngoài khu vực. Tuy nhiên, không phải bất cứ giải pháp tiếp cận phòng ngừa ô nhiễm nào cũng có thể ứng dụng, tuỳ thuộc vào điều kiện thực tế của mỗi nước các giải pháp tiếp cận phòng ngừa ô nhiễm sẽ được thay đổi để việc thực hiện bảo vệ môi trường có hiệu quả hơn. Dựa vào những điều kiện thực tế của Ngành Dệt may và chọn lọc những kinh nghiệm của các nước phát triển, mô hình sản xuất xanh và mô hình khu sinh thái công nghiệp với việc kết hợp giải pháp công nghệ xử lý cuối đường ống với mục đích tái sử dụng và tái chế chất thải được phát triển. Với việc ứng dụng các mô hình trên Ngành Dệt may có thể cải thiện sự ổn định, tính bền vững và sản xuất hiệu quả hơn. Thuyết hiện đại hoá sinh nghiệp công nghiệp được phát triển bởi Mol (1995) với áp dụng mô hình triad-network được sử dụng trong nghiên cứu này nhằm mục đích phân tích vai trò của mỗi tổ chức trong thúc đẩy ứng dụng của mô hình sản xuất xanh, công nghiệp sinh thái và xử lý cuối đường ống.

Trong nghiên cứu này hai mô hình được phát triển: mô hình sản xuất xanh đối với một công ty dệt may và mô hình khu công nghiệp sinh thái đối với khu công nghiệp. Kết quả nghiên cứu đã chứng tỏ những lợi ích về kinh tế và môi trường của các giải pháp phòng ngừa ô nhiễm. Mô hình sản xuất xanh được phát triển và đánh giá tại Công ty Thành Công, một công ty dệt may có quy mô lớn tại thành phố Hồ Chí Minh. Mô hình này bao gồm sự kết hợp của các giải pháp sản xuất sạch hơn và mạng lưới trao đổi chất thải bên ngoài. Những lợi ích mang lại từ việc áp dụng mô hình sản xuất xanh là giảm đáng kể lưu lượng và tải lượng chất ô nhiễm. Hơn nữa, mạng lưới trao đổi chất thải bên ngoài

có thể giúp tái chế hầu hết các chất thải còn lại bằng việc tái sử dụng chúng như là nguồn nguyên liệu sản xuất cho các công ty khác. Mô hình sản xuất xanh đã đưa ra một cách tiếp cận mới mang tính khả thi và hấp dẫn đối với sự phát triển bền vững của một công ty dệt may có qui mô lớn.

Nghiên cứu mối liên quan của tiếp cận hệ sinh thái công nghiệp trong trường hợp của Việt Nam, một mô hình tổng hợp khu công nghiệp sinh thái dệt may tại KCN Nhơn Trạch 2 được phát triển. Mô hình này dựa trên mối quan hệ cùng có lợi của bảy doanh nghiệp dệt may có vị trí địa lý gần nhau trong khu công nghiệp Nhơn Trạch 2 và mạng lưới trao đổi chất thải bên ngoài. Mô hình khu công nghiệp sinh thái dệt may mang lại những đóng góp có giá trị để đạt được sự phát triển bền vững.

Mô hình khu công nghiệp sinh thái dệt may được phát triển trong ba bước. Bước đầu tiên những bài học kinh nghiệm từ mô hình của Công ty Thành Công được áp dụng cho bảy công ty dệt may trong khu công nghiệp Nhơn Trạch 2. Bước thứ hai là hình thành một mạng lưới trao đổi chất thải, trong mạng lưới này bao gồm một doanh nghiệp tái chế sản phẩm phụ, một doanh nghiệp xử lý chất thải, và những doanh nghiệp tái chế chất thải bên ngoài. Bước cuối cùng là xử lý chất thải rắn, khí thải và xử lý và tái sử dụng nước thải (sử dụng các kết quả từ chương 3, 4 và 5) cho tưới tiêu (các khu vực trồng bông), sử dụng cho các thiết bị vệ sinh, tưới cây và tưới đường trong khu công nghiệp. Ngoài ra, một vài hoạt động trao đổi chất thải bên ngoài khu công nghiệp cũng phải được thiết lập đối với tái chế nhựa, giấy và dầu thải phát sinh từ khu công nghiệp.

Những giải pháp tiếp cận sản xuất sạch hơn và khu công nghiệp sinh thái có thể giúp cải thiện thực hiện bảo vệ môi trường trong Ngành Dệt may, nhưng việc áp dụng những giải pháp này lại không thể xử lý tất cả các dòng chất thải, đặc biệt là nước thải. Các kết quả từ khảo sát thực tế và tổng quan tài liệu đã chỉ ra rằng đặc tính của nước thải dệt nhuộm có nồng độ ô nhiễm cao (đặc biệt là độ màu) và với lưu lượng lớn, vì thế nước thải được xem là nguồn ô nhiễm lớn nhất của ngành dệt may.

Độ màu được xem như là một trong những thông số quan trọng đối với xử lý nước thải dệt nhuộm. Việc loại bỏ độ màu của nước thải dệt nhuộm đã được nghiên cứu với thay đổi độ pH, áp dụng quá trình keo tụ/tạo bông và các quá trình oxy hóa bậc cao (O_3, O_3/H_2O_2 và hệ tác nhân Fenton). Thí nghiệm được thực hiện với nhiều dòng nước thải khác nhau (dòng nước thải có chứa thuốc nhuộm phân tán và hoạt tính, thuốc nhuộm hoàn nguyên, thuốc nhuộm phân tán và acid, hỗn hợp của nhiều dòng nước thải, và nước thải có chứa thuốc nhuộm acid). Nước thải được lấy tại một công ty dệt may trong Việt Nam (28 Công ty-Agtex), tại Bỉ (nhà máy dệt UCO, Gent) và nước thải tổng hợp được chuẩn bị theo công thức của Công ty Dệt may GVA ở Aalten, Hà Lan. Hệ tác nhân Fenton là phương pháp hiệu quả nhất để loại bỏ độ màu của bốn dòng nước thải. Qúa trình keo tụ/tạo bông cũng là một phương pháp rất hiệu quả đối với loại bỏ độ màu của bốn dòng nước thải trên, nhưng qúa trình này lại không phù hợp với loại nước thải chỉ chứa thuốc nhuộm hòa tan. Đối với khử độ màu của nước thải bằng quá trình ozone ở giá trị pH thấp (pH 5), kết quả cho thấy oxy hóa trực tiếp bởi các phân tử ozon có tính chọn lọc hơn rất nhiều so với quá trình oxy hóa của các gốc hydroxyl. Quá trình oxy hóa Peroxon (O_3/H_2O_2) cho hiệu quả loại bỏ độ màu thấp nhất so với quá trình oxy hóa với ozone và hệ tác nhân Fenton. Thay đổi pH không làm giảm độ màu. Ảnh hưởng của các loại acid khác nhau (HCl và H_2SO_4) trong thí nghiệm thay đổi pH hầu như không đáng kể. Nhiệt độ trong khoảng từ 30 đến 50^oC ít ảnh hưởng đến quá trình keo tụ. Đối với các quá trình oxy hóa bậc cao (AOPs) tại điều kiện nhiệt độ cao (50^oC) hiệu quả xử lý giảm so với ở nhiệt độ 30^oC và 40^oC.

Đối với xử lý nước thải dệt nhuộm những quá trình hoá lý/hoá học như thay đổi pH, keo tụ và oxy hóa bậc cao (AOPs) chỉ đạt được hiệu quả nhất định khi được áp dụng như các quá trình xử lý riêng lẻ. Mỗi quá trình xử lý trên chỉ có thể loại bỏ được một hay vài chất ô nhiễm trong nước thải do đó nước thải sau xử lý thường không đạt được tất cả những chỉ tiêu trong qui định xả thải. Vì thế kết hợp của các qúa trình xử lý được nghiên cứu để xử lý nước thải đạt được những quy định xả thải nghiêm ngặt như độ màu và COD (50 Pt-Co và 50 mgO_2/L). Kết hợp giữa các quá trình keo tụ, oxy hóa bậc cao và sinh học (và ngược lại) được thực hiện đối với dòng nước thải hỗn hợp. Trong đó, sự kết hợp của quá trình bùn hoạt tính, keo tụ và ozon đưa ra kết quả khử độ màu và COD tốt nhất với chi phí thấp nhất so với tất cả các nghiên cứu khác.

Công nghệ nhuộm theo phương pháp ướt đang được áp dụng rộng rãi trong Ngành Dệt may, 75% lượng nước tiêu thụ được sử dụng trong quá trình giặt/xả. Khó khăn trong xử lý nước thải dệt nhuộm và chi phí xử lý sẽ tăng lên là do trộn lẫn của nhiều dòng nước thải phát sinh từ nhiều công đoạn khác nhau trong quá trình nhuộm với sự thay đổi rất lớn về nồng độ và loại hoá chất và thuốc nhuộm sử dụng. Ngoài ra, hầu hết các bước xả có chứa các chất ô nhiễm ở nồng độ thấp và có thể được tái sử dụng lại trong các công đoạn sản xuất khác hoặc có thể được xả thải trực tiếp mà không qua xử lý. Tách dòng chất thải được nghiên cứu tại Công ty 28 - Agtex. Tổng lưu lượng nước thải của công ty 28 - Agtex là 700 m^3/ngày, trong đó 130 m^3 nước và 10 m^3 dung dịch NaOH có thể được thu hồi. Khoảng 350 m^3 nước thải có khả năng phân hủy sinh học. Chỉ có khoảng 40 m^3 nước thải có độ màu và COD cao cần xử lý đặc biệt. Việc tách các dòng chất thải có thể tiết kiệm 122 USD/ngày hay 0,244 USD/m^3. Kết quả cho thấy sự tách dòng nước thải không chỉ cho phép tái sử dụng nước và hóa chất, mà còn làm tăng hiệu quả xử lý vì mỗi dòng nước thải riêng biệt có thể được xử lý theo từng phương pháp tối ưu.

Mô hình triad-network được áp dụng nhằm phân tích vai trò của các tổ chức và mối tương quan giũa chúng với hệ công nghiệp. Nghiên cứu điển hình đối với mô hình sản xuất xanh và khu công nghiệp sinh thái cho thấy sự thành công của khu công nghiệp sinh thái trong thực tế không chỉ phụ thuộc vào sự tương tác giữa các doanh nghiệp trong khu công nghiệp mà còn phụ thuộc vào sự tương tác với các đối tượng bên ngoài hệ thống. Ảnh hưởng của mô hình trial-network phụ thuộc vào đặc tính và điều kiện của mỗi doanh nghiệp hay ngành công nghiệp. Trong trường hợp của Công ty Thành Công, một công ty xuất khẩu hàng dệt may với qui mô lớn, hệ thống kinh tế ảnh hưởng rất lớn đối với cải thiện thực hiện bảo vệ môi trường trong doanh nghiệp: ví dụ vai trò của khách hàng. Hệ thống xã hội ảnh hưởng đến một công ty thương mại thông qua việc sử dụng các phương tiện truyền thông đại chúng và thông qua áp lực của xã hội thay đổi hành vi của người gây ô nhiễm. Những hệ thống này góp phần vào việc thực hiện mô hình. Tuy nhiên, vai trò của hệ thống chính sách còn hạn chế trong điều kiện của Việt Nam. Trong trường hợp khu công nghiệp sinh thái, hệ thống chính sách đóng vai trò quan trọng nhất trong việc thực hiện các mô hình sinh thái công nghiệp. Liên quan đến hệ thống kinh tế, vai trò của các khách hàng nước ngoài và Hiệp hội dệt may Việt Nam là những đối tượng quan trọng trong việc cải thiện thực hiện bảo vệ môi trường. Trong khi đó vai trò của các đối tượng trong hệ thống xã hội thì vẫn còn rất hạn chế trong thời điểm hiện tại, bên cạnh đó ý thức bảo vệ môi trường của người dân còn thấp.

Mô hình sản xuất xanh, sinh thái công nghiệp, trao đổi chất thải và mô hình xử lý cuối đường ống chỉ có thể ứng dụng thành công trong thực tế khi có sự kết hợp của hai khía cạnh: công nghệ và quản lý .

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APPENDIX 1

The six calibration equations for used six dyestuffs in the two dyeing and finshing processes are listed below:

Red HWF : y = 281.78x + 0.246 (R^2 = 9999) with λ =400 nm
Yellow 93008 : y = 47.2x + 0.158 (R^2 = 9993) with λ =490 nm
Red R : y = 98.547x + 0.005 (R^2 = 9998) with λ =480 nm
Yellow EXF : y = 52.145x + 0.717 (R^2 = 9993) with λ =420 nm
Rubine : y = 44.996 x + 0.2649 (R^2 = 9998) with λ =540 nm
Navy Blue : y = 47.836 x + 0.118 (R^2 = 9998) with λ =620 nm

According to these determined calibration equations, results on calculation of concentration of dyestuffs before and after dyeing process was determined.

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