Sustainable Environmental Protection Using Modified Pit-Latrines

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Dit onderzoek is uitgevoerd binnen de onderzoekschool Wimek

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Proefschrift

ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
Prof. Dr. Ir. L. Speelman,
in het openbaar te verdedigen
op dinsdag 23 maart 2003
des namiddags te half twee in de aula

CIP-DATA KONINKLIJKE BIBLIOTHEEK, DEN HAAG.

Chaggu, E. J.

Sustainable Environmental Protection Using Modified Pit-Latrines

ISBN: 90-5808-989-4

Subject headings: excreta disposal/blackwater/nightsoil/anaerobic digestion/improved pit latrines

Abstract - Chaggu, E. J. (2004). Sustainable Environmental Protection Using Modified Pit-Latrines. Ph.D Thesis, Wageningen University, The Netherlands.

Pit-latrines are on-site excreta disposal facilities widely used as anaerobic accumulation system for stabilizing human wastes like excreta, both in rural and urban settlements of developing countries. Flooding of pit-latrines is often a common phenomenon, especially in situations of high water table (HWT) conditions and during the rainy season, causing a health jeopardy to residents. The pits are not water-tight, the (ground)water can freely flow in and out of the pit, especially in HWT areas. This results in groundwater (GW) pollution and even surface water pollution in the neighbourhood and pits that are filling up far too quickly. With a growing concern of public health, GW pollution and the reuse of nutrients from human waste, there is a serious need to study and improve the pit latrines, especially those in HWT areas. Specifically, the scope of this thesis was to study the socio-cultural aspects of excreta disposal in Dar-es-Salaam City, to improve the understanding of the biological stabilization processes in anaerobic accumulation systems and to come up with proper operational guidelines for emptying practices.

A literature research and the results of a survey on excreta handling amongst 207 households in 9 of the 52 wards of Dar es Salaam (Dsm.) presented in this thesis shows that 50% of the filling up of pits in Dsm. city is the result of HWT. Moreover almost 16,131 kgCOD/day from pit-latrines reach GW sources (Haskoning and M-Konsult, 1989). In this study an improvement of the pit-latrine was proposed using a plastic tank as pit. A 3000-liter experimental improved pit-latrine without urine separation (IMPLWUS) was constructed and monitored at a 10-person household in Mlalakuwa settlement in Dsm., Tanzania. The influent to the reactor merely consisted of urine and faeces in the ratio of 1.3:1. The results obtained revealed that, after 380 days of use as a daily pit-latrine, the reactor content was not yet stabilized. 8000 mg/l dissolved COD (but only 100mg COD/l volatile fatty acids) were still present. Part of this dissolved COD was shown to be biodegradable signifying the need for further stabilization of the reactor content. It was hypothesized that the slow conversion of dissolved COD was due to the fact that the reactor was started with sludge that was not adapted to the resulting high ammonia concentration of 3000 mg N/l, i.e. the system in fact was still under start-up, and in subsequent runs of the reactor the conversion of dissolved COD would be much faster.

For further evaluation of the conversion processes proceeding in the improved pit-latrine a simple mathematical model was used. The model results for the course of the concentration of the different COD components in the accumulating sludge in improved pit latrines receiving black water or night soil reactors, revealed that under tropical conditions 97% sludge stabilization is achievable within 1 year of reactor use. If 99% or more stability is desired, an accumulation period of 2.5 years is required or closing the reactor without adding any new materials for at least two weeks before desludging is necessary. When assuming Monod kinetics with k_m = 1 gCOD·gCOD^{-1}·d^{-1} (Batstone *et al,.* 2003) it was calculated that for a latrine receiving black water as influent the specific methanogenic activity of the sludge after reactor closure will be about 0.12 g COD/g VSS/day. At a sludge concentration of 30 g VSS/l the volume to be left in the reactor as seed sludge for the subsequent runs is about 250 litres.

Finally a short survey was done of existing composting latrines of the type of Ecosan toilets installed in Dar-es-Salaam. The survey revealed that high pH values occur (up to 10.4) in Ecosan toilets due to addition of charcoal ashes. High pH assist in the reduction of *E-Coli and Ascaris eggs,* but on the other hand could not allow biological degradation of waste. The separated urine in Ecosan toilets showed on average *E-coli* counts of 1525 no./100 ml. indicating that urine was not adequately separated.

In the light of sustainable development and in view of cost and economy, simple sanitary systems like Ecosan and IMPLWUS is the correct approach in Dar-es-Salaam and other tropical regions of developing countries. Sludge drying beds can be used for further stabilization of emptied sludge since they are cheaper than mechanized ones. Correct separation of urine in Ecosan toilets is necessary with the assistance of user health education. Comparing the Ecosan toilets to the improved pit-latrines it has to be concluded that both systems are promising alternatives to the conventional pit-latrine systems. However, both systems are still at their developing stage and require further work to provide a genuine sustainable solution for the disposal of human excreta in Dar-es-Salaam. The wealthy developed countries need to work with the developing countries in implementation of public sanitation aspects in low cost manner instead of advocating the expensive systems that will fail anyway.

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CHAPTER ONE

INTRODUCTION

Scope of thesis – Decentralized sanitary infrastructure in the form of pit-latrines (PL) have received little enthusiasm from politicians since at the back of decisions there was an anticipation of upgrading them to sewerage system. An option which offers a concept of "flush and forget", very palatable for producers of excreta but a head-ache for wastewater treatment plant workers, quite a waste to nutrients and a jeopardy to end-of-pipe inhabitants and environment in those localities. Since this option is not sustainable, the reality in the ground in Tanzania is the wide spread of pit-latrines of different standards posing potential dangers to the health of the people and environment at large in their present state. With a growing concern of reuse of nutrients from human waste, decentralized sanitation and reuse options are currently under study in different places of the world. Little information is therefore available at the moment, on this current important subject. This is a change of paradigm in sanitation that has been brought about by the economic reality existing locally. The main objectives of this study were to 1) carry out a socio-cultural and economic study of the sanitation conditions with emphasis on pit-latrines in Dar-es-Salaam, Tanzania and their interrelationships with regard to faecal sludge management, urine separation and reuse; 2) improve the understanding of the biological stabilization processes proceeding in the pit-latrines; 3) cite out proper operational guidelines for pit-latrines with respect to emptying practices 4) come up with adapted designs and construction aspects for community on-site latrines which enable biogas collection and 4) suggest the potentials of safe re-use/recycling of sludge from pit-latrines for urban and peri-urban farming after subjecting it to some further (low-cost) treatment.

1.1 Overview

People as an "asset" for development often produce in secret human "waste" which is of public concern. This is specifically the case if the "waste" is kept in the wrong place. Inadequate/lack of sanitation causes the pathogens in human excreta to be transmitted from one person to another through various routes (*Figure 1.1*). The indiscriminate discharge of human waste into the environment with low provision of clean and safe water results in consumption of contaminated water, direct/indirect contact of people with excreta ending up into preventable outbreak of diseases and squanders valuable nutrients that could augment food production and alleviate malnutrition (Edwards, 1992; NEMC, 1995; Division of Environment, 1997). Table 1.1 summarises the excreta-related infections from the environmental point of view with their major control measures.

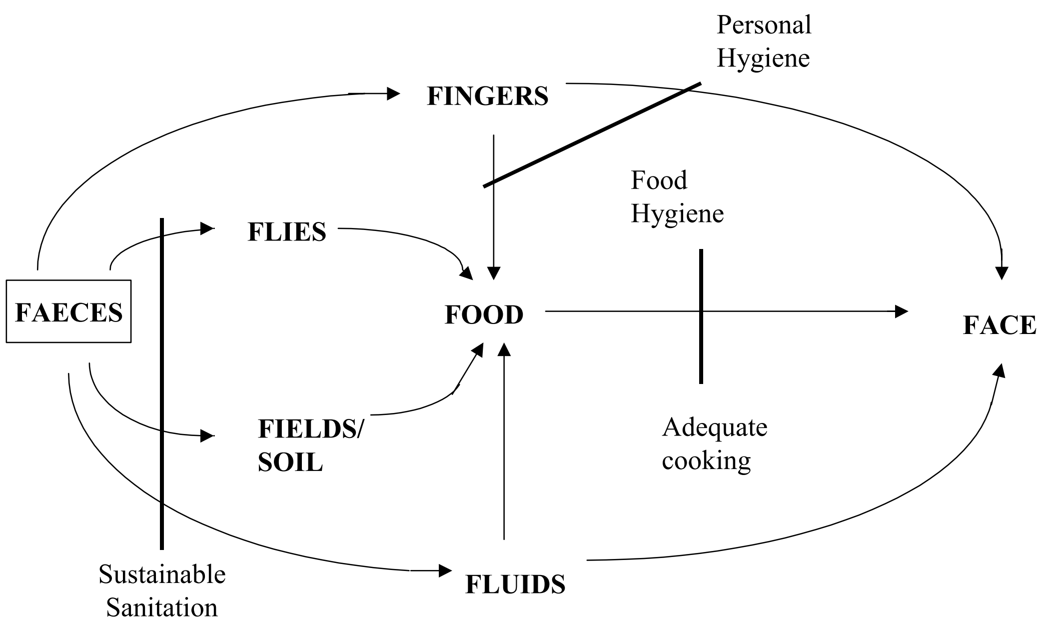

Figure 1.1: The F-Diagram Depicting the Faeces Transmission Routes to a New Host and Possible Sanitation Barriers (adapted from Esrey *et al.*, 1999)

In Tanzania, there has been an outbreak of fatal diseases: cholera, typhus and diarrhoea with no signs of fast departure. Records indicate outbreaks of cholera way back in years 1821, 1936-37, 1958-59 and 1964-71, but the most extensive wave in East and Central Africa started in 1977 in Twasalie, a delta island village on the Tanzania Indian Ocean Coastline in Rufiji District (Pollitzer, 1959; Roberts, 1972; Mandara and Mhalu, 1981). It entered the country from the Middle East and since then, it has spread to different parts of the country (*Table 1.2*) and by 1984 to neighbouring countries: Uganda, Rwanda, Burundi, Zaire, Zambia, Malawi and Mozambique (Mhalu, 1991). The severity of diseases has been growing day by day with maximum occurrence during the rainy season where pathogens spread by water is eminent. Also, malaria which ranks number one killer disease in the country with ~3% deaths, ~15% hospital attendances, and admission ~10% increases with poor sanitation as mosquitoes breed even in wet pits (Kilama and Kihamia, 1991; Chiduo, 1989). It ranks third among major infectious disease in Africa forming 9% of global disease burden. Basically, water supply and sanitation should be handled in an integrated manner. The duty of adequate sanitation is to put excreta in the "right place" using sanitation barriers namely, hygienic toilets, personal and food hygiene and adequate cooking (*Figure 1.1*).

Table 1.1: Environmental Classification of Excreta-related Infections (Faechem, *et al.,* 1983)

Category		Infection	Pathogenic Agent*	Dominant Transmission Mechanism	Major Control measures
E1	Faecal-oral (non-bacterial) Non-latent, low infectious dose	Poliomyelitis Hepatitis A Rotavirus diarrhoea Amoebic dysentery Giardiasis Balantidiasis Enterobiasis Hymenolepsiasis	V V V P P P H H	Person to person contact, Domestic water contamination	Domestic water supply, improved housing, provision of toilets, health education
E-2	Faecal-oral (bacterial) Non-latent, medium or high infectious dose, moderately persistent and able to multiply	Diarrhoeas and dysenteries *Campylobacter* enteritis Cholera *E.coli* diarrhoea Salmonellosis Shigellosis Yersiniosis Enteric fevers Typhoid Paratyphoid	 B B B B B B B B	Person to person contact, domestic contamination, water contamination, crop contamination	Domestic water supply, improved housing, provision of toilets, excreta treatment prior to re-use or discharge, health education
E-3	Soil-transmitted helminths Latent and persistent with no intermediate host	Ascariasis Trichuriasis Hookworm (Anclostomiasis) Strongyloidiasis	H H H H	Yard contamination Ground contamination in communal defaecation area, crop contamination	Provision of toilets with clean floors, excreta treatment prior to land application
E-4	Beef and pork tapeworms Latent and persistent with cow or pig intermediate host	Taeniasis	H	Yard contamination, field contamination, fodder contamination	Provision of toilets, excreta treatment prior to land application, cooking and meat inspection
E-5	Water-based helminths Latent and persistent with aquatic intermediate host(s)	Schistosomiasis Clonorchiasis Diphylobothriasis Fasciolopsiasis paragononimiasis	H H H H H	Water contamination	Provision of toilets, excreta treatment prior to discharge, control of animals harbouring infection, cooking
E-6	Excreta-related insect vectors	Filariasis (transmitted by *Culex pipiens* mosquitoes)	H	Insects breed in various faecally contaminated sites	Identification and elimination of potential breeding sites, use of mosquito netting

* B = Bacterium; H = Helminth; P = Protozoa; V = Virus

Table 1.2: Water Demand and Supply, Cholera and Sanitation in Urban Areas of Mainland Tanzania

Region	Water Source	Daily water demand (m^3)	Daily water supply (m^3)	Installed capacity (m^3)	% Demand Supplied**	Date of cholera entry^	Sanitation# means {sewerage or pit-latrines (PL) and Septic Tanks (ST)}
Arusha	Groundwater	42647	32541	50892	76	2/12/1977	Sewerage (9% of total population) & PL
Dar-es-Salaam*	Rivers Ruvu & Kizinga & Groundwater	409500	191000	273000	47	1978	Sewerage and PL
Dodoma	Groundwater & Dam	55870	36863	43570	68	22/1/1978	Sewerage (20%)
Iringa	River Ruaha, Spring	26251	13127	14772	50	9/11/1978	Sewerage (5% of town population and 18% of targeted population) & PL
Kagera	Lakes, Kanoni River	13007	8380	12975	64	3/8/1981	No Central Sewerage System (a sewerage system study under the financing of AFD will be undertaken) & PL
Kilimanjaro	Ground & small rivers	31240	16033	20722	51	4/1/1978	Sewerage (9% of the total targeted customers) & PL
Kigoma	Lakes	21095	13014	14075	62	13/4/1978	Small Sewerage System
Lindi	Spring, Boreholes	11700	4407	7600	38	3/11/1977	ST and PL (Sewerage System earmarked through ADB financing)
Mara	Lakes and ground	19110	9600	11300	51	11/3/1981	PL
Mbeya	Ground and surface water	39555	25800	31420	65	25/8/1978	Sewerage, PL & ST
Morogoro	Mindu dam and springs	38500	42647	25150	62	25/12/1977	Sewerage (0.87% of targeted people), ST & PL
Mtwara	Boreholes and rivers	13000	7540	n.a.	58	14/11/1977	ST and PL (Sewerage system study is earmarked through ADB financing)

Mwanza	Lake Victoria	50051	43244	61244	74	26/3/1980	Sewerage (9% of the total targeted population), ST & PL
Coast	Rivers	4409	3552	4680	81	2/10/1977	PL & ST
Rukwa	Rivers, Boreholes	6770	4070	4660	60		PL & ST (a sewerage system study earmarked through ADB financing)
Ruvuma	Spring, Boreholes	11070	5633	5833	51	15/11/1978	ST and PL (Sewerage system study earmarked through KfW financing)
Shinyanga	Dams, Boreholes, shallow wells	16751	10995	27260	66	23/4/1980	PL & ST (a sewerage system study is earmarked through ADB financing)
Singida	Boreholes	9041	3925	3000	43	29/2/1980	PL & ST (sewerage study will be carried out through the financing of BADEA)
Tabora	Dams, Boreholes	28222	10379	15417	37	12/10/1978	sewerage (3.9% of the town), PL & ST
Tanga	Sigi river	56792	30525	33672	54	4/1/1978	sewerage (15.5% of the municipality), PL & ST
Total		**915581**	**494629**	**661288**	**54**	**-**	**-**

Source: DAWASA and Regional Water Engineers (1997) in Ngware and Kironde (2000); Msimbira (1999), Annual Report (2002); *Borehole supply is 120 m^3/h (Mato, 2002); **population served urban water – 80% and rural water – 42% (WHO, 2000; WSSCFS, 2003); #sanitation coverage urban – 80% and rural – 86% (WHO, 2000; WSSCFS, 2003); Mhalu, (1991); ADB – African Development Bank; BADEA - Arabic Bank for Economic Development in Africa; AFD – Agence Française de Devellopmėnt; KfW - Kreditanstalt fur Wiederaufbau (Germany Bank for Reconstruction)

1.2 A Short History of Water Supply in Tanzania

The provision of water and sanitation in the country used to be rooted into "received concepts and theories" many of them borrowed from developed countries and characterized by centralization of powers, unrealistic standards, bureaucratic processes and the non-incorporation of popular and community action (Okpala, 1987). Divergent interests and objectives as well as inter-institutional conflicts and rivalries further compound the complexity of the process (Duqqah, 2002; Lettinga *et al.*, 2001). Tanzania is considered to be a well-watered country with good rainfall (between November to May) and many rivers and lakes. However, in some parts of the country, rainfall is seasonal, water is not readily available in the dry season (long dry spell is experienced from late May to October) and drinking water quality is generally a problem (Mato *et al.*, 1997; WSSCFS, 2003).

The demand for water is increasing with increased urbanization and population while the supply has not been expanded to cope up with the growth or is almost stagnant. Aging and poorly maintained plants as well as inadequate and unreliable water sources, unreliable power supply, poor record keeping, low tariffs and illegal connections characterizes the existing supply (Kironde, 2000). The daily water demand for 62 registered urban centres (some shown in *Table 1.2*) in Tanzania is 912,300 m^3 while the average supply is 494,300 m^3, implying 54% average supply, which means inadequate supply (Kironde, 2000; WSSCFS, 2003). Other records indicate that, by December 1998, on average, 68% of the urban population in the country was served by piped water (Msimbira, 1999), the differences between the percentages of water supply as presented by the different authors is a clear indication of inadequate data storage and dissemination. The remaining unserved population use other water sources, including shallow wells, traditional wells, direct drawing from rivers/streams, street vendors, and rainwater. The rural water supply coverage by 1999 was 48% (Rukiko, 1999; Task Team, 2000; Uronu, 1999). Stren *et al.* (1992) noted that the large African cities reflect both dysfunction and inability to cope with rapid changes. In 1999, Tanzania was ranked 156 of 174 countries in the Human Development Index[1] (HDI) due to the widespread level of poverty. More than half of the population (51%) live on less than US$1/day; about half or 42% of these live in absolute poverty (less than US$ 0.75/day); 81% of the people are underemployed and minimally skilled (UNDP, 2000). This means, inadequate availability of funds for infrastructure provision. People are living from "hand to mouth"; what they earn only partially provides a day's meal. In summary, inadequate resources; human, institutional and financial adds to the problems of water supply in Tanzania.

1.3 Sanitation Situation in Tanzania

There is no national sanitation policy at the moment. Sanitation aspects are included in the main health policy which just mention without further details about promotion of the construction of improved pit-latrines and their use in all households, health facilities and public institutions (WSSCFS, 2003). This condition stresses that, research work, data gathering and storage including dissemination on sanitation is important in order to assist the policy makers in making the right decisions at appropriate times. The country's dependence on agriculture and its present agricultural

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[1]Human Development Index (HDI) measures the average achievements in a country measured in three composite variables – life expectancy, educational attainment (adult literacy and combined primary, secondary and tertiary enrolment) and real GDP per capita. For any component of the HDI individual indices can be computed according to the general formula: Index = $\frac{Actual x_i value - \min imum x_i value}{Maximum x_i value - \min imum x_i value}$ (UNDP, 2000).

policy, monetary policies, human resources policy and the ruling party policies are considered as the basis for development (Mwaiselage, 2003). The Arusha Declaration in 1967 and abolition of the local government in 1972 marked a shift towards supporting rural development more and placing powers in the central government, which resulted into neglect and continued deterioration of the few sanitation services in urban areas. However, the current re-institutionalization of local government offers higher prospects of change. Haphazardly disposed wastewater often is mistakenly used by downstream people as perennial natural drainage courses and so the spread of diseases. Almost 90% of the Tanzanians use PLs (*Table 1.3*). A PL is a structure consisting of a pit or vault, a pit cover (or slab) and superstructure fitted in some occasions with other features like ventilation system or a toilet seat. They receive excreta that accumulate in the pit over time. The walls of the pit are not water tight and so, (ground)water can flow freely in and out of the pit. Generally speaking, the government's attitude towards pit-latrines has been lukewarm, and there has been a lingering belief in the superiority of water-borne sanitation systems and the possibility of many of the people getting hooked on these (Kironde, 2000). However, this spirit is slowly changing due to the economic reality of using sewerage that is not sustainable (criteria *Table 1.4*; Humphreys, 1995). PLs in their present state of design and operation are believed to be one of the major groundwater (GW) polluters (*Table 1.5 as example*) in Tanzania. The COD:BOD_5 in Table 1.5 is 1.06 which is lower than the typical range expected for untreated domestic waste which varies from 1.25-2.5 (Metcalf and Eddy, 1991). Since the value is lower than the low limit, it means that the sludge in the sampled latrines are highly degradable.

Table 1.3: National Coverage of Excreta Disposal Facilities (Tanzania)

Type of Facility	**National Coverage (%)***		
	Urban	**Rural**	**Total**
Pit-latrines	92.6	82.3	84.6
Traditional Pit-latrines	89.3	81.9	83.5 (90)**
Ventilated Improved Pit-Latrine (VIP)	3.3	0.4	1.1
Elevated Traditional pit-latrine (ETPL)	NI^	NI	NI
Septic Tanks and Soakage pits	3.6#	0.5#	1.2#
Sewerage	1.4@	0.3@	0.5@
Others (type not indicated)	0.7	0.9	0.8
Without access to any excreta disposal facility	1.7	16	12.8

***Source:** Demographic Health Survey (1992 and 1996); **some literature show that, 90% of the excreta disposal facilities used by 90% of the population is pit-latrines; ^NI = not indicated; #own flush toilet; @shared flush toilet

Haskoning and M-Konsult (1989) estimated that ~50% of the pollution produced, at domestic level ends up in PL and 33% of the original COD remains in water that infiltrates to groundwater. Similarly, 10% of the SS, 90% of dissolved solids, Total-N and Total-P end up in GW. PL has a pollution load to GW and surface water as presented in Table 1.5. This situation if it goes unchecked and uncontrolled, it will continue to be a big health problem in future and the water sources will be completely contaminated.

Table 1.4: Criteria for Sustainable, Robust Sanitation and Prevention of Pollution with Advantages and Disadvantages of Decentralized Sanitation Systems and Pollution Prevention (Douglas, 1998; Haandel and Lettinga, 1994; Lettinga *et al.,* 2001)

Criteria for sustainable sanitation	**Criteria for robust urban sanitation**	**To avoid/prevent pollution**
Little, if any, dilutions of high strength domestic (and industrial) residues with clean water.	Little dependency on complex infra-structural services.	Complete utilization of all possible waste resources.
Maximization of recovery and reuse of treated water and by-products.	High self-sufficiency in construction, operation and maintenance of systems (independent of highly specialized people/companies).	No pollution of water, soil or air.
Application of efficient, robust and reliable wastewater collection and transport systems and treatment technologies, which require few resources and which have a long lifetime.	Low vulnerability to sabotage terrorism, destruction and so on.	High public participation; acceptance to all social actors.
	High public participation and acceptance to all social actors.	Applicable at any site and scale.
	Applicable at any site and scale.	Finding a proper final destination for any type of residue.
Advantages and disadvantages of decentralized sanitation systems pollution prevention		
Advantages	**Disadvantages**	**Prevention of pollution**
It saves money as separate waste(water) streams can be treated on-site.	Difficult to re-use the biogas from a single family as the production is low.	Complete utilization of all possible waste resources
Protect the homeowners investment since it is relatively easy to operate	A risk of coming into contact with wastewater if not well constructed, operated and managed.	No pollution of water, soil or air.
Promote watershed management. It offers the possibilities of reuse of water and nutrients.	Possible heavy metals in agricultural land. A problem only if they pass the set limits or standards.	Applicable at any site and scale.
Offer an appropriate solution for low to high-density communities.	Destruction of aesthetic value of the environment if not well constructed and managed.	Finding a proper final destination for any type of residue.
Provide a sustainable alternative for varying site conditions	If not well-managed wider pollution potential.	High public participation.
Gives effective solutions for ecologically sensitive areas.	Requires change of attitude in some cases.	Acceptance to all social actors.

Table 1.5: Pollution Loads from Pit-latrines and Without Facility to Surface and Groundwater Sources in Dar-es-Salaam City

Type of Pollution Load (kg/d)	Surface Water Sources Pollution	Groundwater Sources Pollution	Without Facility Pollution
BOD_5	15282	15282	1100
COD	16131	16131	1161
Suspended Solids	25470	6116	1833
Dissolved Solids	45280	97857	3258
Total-N	2236	4829	120
Total-P	425	915	23

Source: UNEP (2002); Haskoning and M-Konsult (1989)

1.4 Initiatives to Improve Sanitation

At the back of the mind of many citizens in urban areas lies an idea that one day, they will be connected to a central sewerage system, a "flush and forget" concept. However, the increased demand for water normally causes problems of conflict and unending tensions in society and so, advocating using the sewerage system is a "dream or wishful thinking" that will never be fulfilled in the lifetime of many Tanzanians. In fact, since the developed countries have the experience of sewerage difficulties, it is clear that, they should never wholly be replicated to developing countries. Sewerage choice and development in developing countries is a result of aid projects, grants or loans (Reuterswärd, 1984). This implies little possibility to influence the decision of their inception by the community or beneficiaries and create a "financial dependency syndrome" for the users. Nonetheless, the desire of providing sanitation to majority of the people of developing world through sewerage system has practically failed (Mgana, 2003). Basically, sewerage is unaffordable by the community; its initial costs are extremely high, very expensive maintenance, complex for poor communities, serve a small high class of people and have no reuse possibilities of nutrients (Stoner, 1977; Merinyo, 1989; Esrey *et al.,* 2001; Lettinga, *et al.*, 2001; Zeeman and Lettinga, 2001; Chaggu *et al.*, 2002; El-Gohary, 2002; Otterpohl, 2002; Mgana, 2003). This situation needs other options of sanitation initiative in order to reach the millenium development goals (MDGs), target no. 10 which is to halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation. Practically, decentralized sanitation and reuse options (DESAR-concepts) of "human waste" are the only possible sustainable concepts.

Their main challenges are from the established engineering world, which is reluctant to developments, and new technologies, which are sustainable and robust; prejudices against decentralized options of human waste treatment and specialized groups sticks to their own system(s) for commercial interests and scientific prestige (Lettinga *et al.*, 2001). Often, engineering disagreements take place at the expense of the needy resulting into market and people-based solutions, failures to meet demand, individual developers at own-set standards, crippled minds and dead motivation of users (Lettinga *et al*, 2001; Mwaiselage, 2003). Moreover, the training of engineers in developing countries has been particularly in western technologies. This means, they have little/no exposure to low-cost robust excreta disposal systems, but are required to be flexible in wider range of environmental issues and so, there is a need for additional training (Vesilind, 1993; Mitschke, 1998; Chaggu, 2002). On the other hand, developed countries solutions should be used as guidelines only for developing countries (Lettinga *et al*, 1991). The current wave is increased need of privatization and public participation and partnerships (not well understood by the people) in sanitation provision for sustainability (criteria *Table 1.4*). To meet the challenge proposals are people centred market-based and earth-friendly approaches. Decentralized sanitation options that are mainly accumulation systems with anaerobic digestion requiring technical, legal, cultural and planning aspects of popularization are important (Kironde, 2000; World Bank, 2003).

1.5 Anaerobic Digestion as Central Technology for Decentralized Sanitation and Reuse (DESAR) Concepts

1.5.1 Meaning of Anaerobic Digestion

Anaerobic digestion refers to the treatment of slurries whereas anaerobic treatment is for wastewater (Lettinga, 2003). Palenzuela-Rollon (1999) defines anaerobic digestion as biodegradation in the absence of oxygen (O_2) resulting in formation of CH_4 and CO_2 when ions like NO_3^- and SO_4^{2-} are absent. A number of studies by Lettinga and his colleagues have cleared many of the doubts about this technology and is increasingly recognized as an appropriate and core technology for waste(water) treatment. It is becoming more and more popular and admirable especially in tropical countries, where large-scale installations have been installed and are under construction (Zeeman, *et al.,* 1999). The history of anaerobic treatment is longer than aerobic treatment; it dates back over 100 years and is one of the oldest methods used to treat wastewater (McCarty, 1985; Wang, 1994; Mahmoud, 2002). The oldest and simplest treatment process of domestic sewage is the septic tank (Jewell, 1987). Among the two competitive technologies applied for domestic sewage treatment, aerobic and anaerobic, the latter one offers very promising results. With respect to sustainability, anaerobic digestion by far is favorite because hardly if any energy is needed, the methane produced can be used as a substitute for fossil fuels, lower excess sludge production and possible to recover useful products (Lettinga and Hulshoff-Pol, 1991; Sanders, 2001). Anaerobic digestion may represent the core method for a sustainable environmental protection and resource conservation technology (Lettinga *et al.*, 1997; Gonzalez-Gil, 2000).

Fast promotion or usage of anaerobic waste(water) treatment reactors, started way back in early eighties by applying high-rate anaerobic reactors developed in the seventies (Gonzalez-Gil, 2000). Most parameters of concern for treatment of human waste(water) are suspended solids, organic (biodegradable) material, nutrients (notably nitrogen and phosphorus) and pathogenic organisms (Haandel and Lettinga, 1994). In Tanzania, where access to safe drinking water is not yet guaranteed for considerable fractions of the population, it is of great importance to maintain the hygienic quality of surface water and underground water as high as possible. This means, it is necessary to eliminate as completely as possible the harmful micro-organisms present in sewage or faecal sludge (FS) that may cause proliferation of water-borne diseases (Haandel and Lettinga, 1994) by using a technology which offers sustainable options like anaerobic digestion. The important prerequisites on anaerobic treatment of complex wastes are highlighted in the following sections.

1.5.2 Processes in Anaerobic Digestion of Complex Waste(water)s

Complex wastewater and wastes can both be defined as substrates containing a large fraction of suspended solids; 45-70% of domestic sewage (Zeeman and Sanders, 2001). Their main difference is between the total solids (TS) and the total COD concentration that normally results in different treatment technology. Anaerobic digestion of complex wastes and particulate organic materials comprises a number of sequential and parallel reactions subdivided into four stages. These are mainly (*Figure 1.2*) hydrolysis, acidification, acidogenesis and methanogenesis (Sanders, 2001). Organic polymers cannot be utilized directly by micro-organisms and so, are firstly hydrolyzed into smaller sub-units that can be assimilated by bacterial cells. This process is catalyzed by extracellular enzymes from acidogenic bacteria to form for example, amino acids from proteins by the activity of proteinase or soluble monomers or dimers, single sugars and long chain fatty acids (LCFA) as the main products of lipid hydrolysis by lipase (Schlegel, 1993; Palenzuela-Rollon, 1999; Elmitwalli, 2000; Sanders, 2001). During the acidogenesis, the hydrolysis products are converted into acetic acid and other volatile fatty acids and alcohols (Sanders, 2001). The fatty acids, including LCFAs from lipid hydrolysis, and other products of acidogenesis are further converted into acetate, CO_2 and H_2 as main intermediary products (Palenzuela-Rollon, 1999; Sanders, 2001). These products are the basic substrates for methanogenesis in order to yield methane and carbon dioxide. A number of scientists have concluded in their studies that, hydrolysis is the rate-limiting step in overall anaerobic process (Eastman and Ferguson, 1981; Ghosh, 1987, Sayed *et al.*, 1988; Pavlostathis and Giraldo-Gomez, 1988 & 1991; Miron, *et al.*, 2000). Hydrolysis and acidification are considered as first order (*Equation 1.1*) while, methanogenesis follows Monod kinetics (*Equation 1.2*) (Palenzuela-Rollon, 1999; Sanders, 2001; Batstone *et al.*, 2002).

$$\frac{dX_{\deg r.}}{d_t} = -kh.X_{\deg r.} \qquad \textbf{(1.1)}$$

with: kh = first order hydrolysis constant (day^{-1})
$X_{degr.}$ = biodegradable substrate ($kgCOD.m^{-3}$)
t = time (days)

$$\mu = \frac{\mu_m S}{(Ks + S)} - b\,; \qquad \frac{-dS}{dt} = \frac{X\mu_m}{Y} \qquad \textbf{(1.2)}$$

where: μ = specific growth rate of microorganism, θ^{-1}
μ_m = maximum specific growth rate of microorganisms, θ^{-1}
Ks = half-saturation constant, $M.L^{-3}$
S = substrate concentration, $M.L^{-3}$
X = microorganism concentration, $M.L^{-3}$
Y = growth yield coefficient $M.M^{-1}$
b = specific decay rate of microorganisms, θ^{-1}
θ, M, L^3 ≡ units of time, mass, and volume respectively

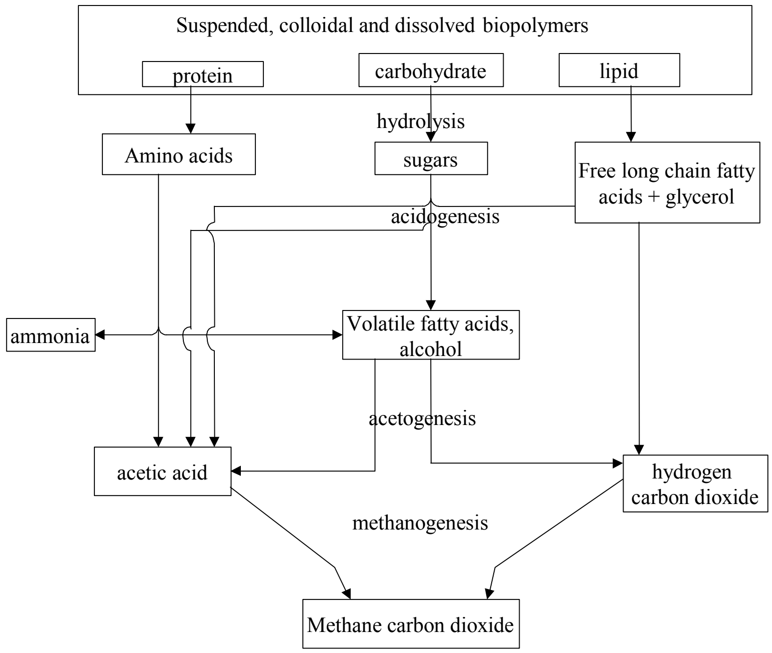

Figure 1.2: Simplified Schematic Representation of the Anaerobic Degradation of Complex Waste(water) after Sanders (2001)

1.5.3 Performance of an Anaerobic Treatment and Digestion Systems

Anaerobic treatment processes are well-established methods for the elimination of easily biodegradable organic matter from waste(water) (Kato, 1994). The performance of an anaerobic system depends strongly on the environmental conditions and the characteristics of the (waste)water (Wang, 1994). These are temperature, pH, nutrients, toxicants (Henze and Harremoes, 1983; Speece, 1983), hydraulic retention time (HRT), influent characteristics (concentration, particle size distribution and charges) and sludge bed characteristics (Mahmoud *et al.*, 2003). However, in developing countries other parameters like good governance, workmanship of structures, availability of adequate building materials and motivation to use anaerobic structures need to be added to the list. Moreover, the main operational parameters should be selected for each different application depending on wastewater characteristics (Guerrero *et al.*, 1999). In systems treating complex waste, the most important anaerobic digestion parameters are biodegradability and hydrolysis rate.

Anaerobic degradation or digestion is a biological process where organic carbon is converted by subsequent oxidations and reductions to its most oxidized state (CO_2), and its most reduced state (CH_4) (Angelidaki and Sanders, submitted). In other words, biodegradation means the biological transformation of an organic chemical to another form (Grady, 1985). Methane production can only represent the hydrolysis rate of particulate organic matter when there is no accumulation of intermediary products (Veeken and Hamelers, 1999). Assuming first order kinetics for the hydrolysis of particulate organic matter, the cumulative methane production according to Veeken and Hamelers (1999) can be described by:

$$CH_4(t) = CH_{4,max}\,[1-\exp(-k_H t)] \qquad \textbf{(1.3)}$$

Where $CH_4(t)$ represents the cumulative methane production at time t (in STP ml. i.e. ml. at standard temperature of 0^0C and standard pressure of 1 atm), $CH_{4,max}$ is the maximum methane yield of the substrate (in STP ml.), k_H the first-order hydrolysis rate constant (in d^{-1}) and t is the time (in d). The net cumulative methane production of the substrate is obtained after correction for endogenous methane production of the inoculum. Parameter values for $CH_{4,max}$ and k_H can be estimated using non-linear least squares curve fitting of the net cumulative methane production (Doucet and Sloep, 1992). The anaerobic biodegradability of the materials can be calculated from the maximum methane yield and the COD of the substrate, according to:

$$BD = \frac{CH_{4,\max}}{W_{sam}}\ \frac{COD_{sam}}{2.85}\ 100 \qquad \textbf{(1.4)}$$

where BD represents the biodegradability (in % of VS), $CH_{4,max}$ the maximum methane yield (in STP ml.), W_{sam} the sample weight (in g-VS), COD_{sam} is the COD of the sample (in $gO_2\ g^{-1}VS$) and the factor 2.85 corresponds to the COD (gO_2) of 1 STP litre of methane.

Veeken and Hamelers, (1999) noted that, the anaerobic degradability test gives a good indication of the rate and extent of degradation of particulate organic substrates. In their study, they digested 6 bio-wastes (whole-wheat bread, leaves, bark, straw, orange peelings, grass and filter paper) at 20^0, 30^0 and 40^0C. The rate of hydrolysis is a function of pH, temperature, concentration of hydrolyzing biomass, and type of particulate organic matter (Pavlostathis and Giraldo-Gomez, 1991). Methanogenic bacteria are very sensitive to a drop in pH that could be caused by accumulation of volatile fatty acids and so, the digestion of complex waste is obviously a delicate balance between the rate of hydrolysis, acidogenesis and methanogenesis (Sanders, 2001). Wang (1994) suggested that, in case the wastewater consists of a more complex substrate, such as lipids, long chain fatty acids and proteins, the rate-limiting step in EGSB-reactors using a high grade granular sludge generally is hydrolysis. This is certainly true for temperatures below 15^0C. Under low temperature conditions, the low degree of hydrolysis may lead to accumulation of suspended solids, resulting in decreased methanogenic capacity and removal efficiencies (Miron, *et al.,* 2000).

1.5.4 The effect of Temperature on Anaerobic Biological Conversion

The temperature is one of the major (key) factors or variables influencing the overall digestion process of waste in anaerobic reactors (Barnett, *et al.,* 1978; Wang, 1994; Sanders, 2001; Rebac, 1998; Sanders, 2001; Mahmoud *et al*., 2003). Micro-organisms are classified into “temperature classes” on the basis of optimum temperature and the temperature span where the species are able to grow and metabolize and it affects the particles removal through influencing the wastewater viscosity and conversion of organic matter (Rebac, 1998; Mahmoud, 2003). When enzyme concentration is not rate-limiting, the rate of hydrolysis as a function of temperature can be described by the Arrhenius equation for enzyme catalysis (Atkins, 1986; Sanders, 2001):

$$k = A.e^{-\Delta G^*/RT} \quad \textbf{(1.5)}$$

where k represents the kinetic rate constant or hydrolysis rate constant (in d^{-1}); A is the Arrhenius constant, G* the standard free energy of activation ($Jmol^{-1}$) with typical values of 15-70 $kJmol^{-1}$ (Chaplin and Bucke, 1990); T the temperature (K) and R the gas constant with 64 (± 14) kJ mol^{-1} as a typical value for enzyme kinetics (Roels, 1983).

From literature it is clearly demonstrated that the anaerobic process offers big prospect for tropical areas (sewage temperature is 20-35^{0}C) (Schellinkhout *et al.*, 1985, 1991; Grin, 1985 and Veira and Souza 1986; Veira, 1988; Haandel and Lettinga, 1994). But also very promising results have been found by different authors for the anaerobic digestion of waste at lower temperatures; Wang (1994) observed that, with a modified version of UASB reactor, that is, the expanded granular sludge bed (EGSB) reactor, anaerobic treatment looks feasible for settled sewage at temperatures below 13^{0}C. Rebac (1998) at psychrophilic (3-20^{0}C) conditions studied treatment of low strength waste waters using single and two stage EGSB system. The study came up with COD removal efficiencies of more than 90% in the single stage at a HRT of 1.6 h at ambient temperature of 10-12^{0}C. Elmitwalli (2000) studied domestic sewage in anaerobic hybrid (AH) and anaerobic filter (AF) reactor at 13^{0}C and short HRT with total and suspended solids removal efficiencies of as high as 55 and 82% in AF and 34 and 53% in AH reactors. Low temperatures in anaerobic treatment have always been associated with low methanogenic activity of sludge (Kato, 1994). Furthermore, at low temperatures, hydrolysis of the entrapped particles becomes limited resulting into a decrease of methanogenic activity. The decreasing hydrolysis rate can be compensated with a long hydraulic retention time (De Man, 1990). Bogte *et al.* (1993) observed that, below 12^{0}C purification was predominantly based on settling while above 12^{0}C microbial degradation of organic matter increased.

1.6 Accumulation Systems

Pit Latrines receive "waste" daily cumulatively as people use them for defecation, urination or bathing. This means, they act as a fed batch system with a slow accumulation of solids in the pit that eventually requires emptying (Mara, 1996). Their design and maintenance are location specific (Waterlines, 1999; Riberio, 1985; Chaggu *et al.*, 2002) but as mentioned before, the walls of the pit are in general not water-tight. Accumulation (AC) systems are reactors that act like a fed batch system and are continuously fed with waste(water) and characterized by an increasing liquid and sludge volume in time. Bath water should however be separated as it adds quite remarkably to the volume and complicates the treatment of wastewater. The settled solids accumulate at the bottom of the reactor in the sludge bed. Frequently, there are scum layers on top of the liquid part of latrine. There is no liquid effluent from these structures during use. The only flow that goes out of the reactor is the produced biogas. The effluents (liquid or sludge) from these facilities are obtained only once during emptying of accumulated stabilized sludge. At the start-up period, in order to fasten the biodegradation the inoculum or seed sludge of 10 - 15% of the reactor volume should be applied as observed by Zeeman (1991) when studying the mesophilic and psychrophilic digestion of liquid manure (pig). A portion of the sludge is left to act as an inoculum for the next cycle of use at emptying. In such systems, storage and digestion are combined together and part of the storage volume is always filled with seed sludge. It is clear from this that, with respect to the solids PLs can conveniently be called AC reactor or system. The use of an accumulation system is as well in principle suitable when long-term storage is compulsory. In the Netherlands where temperatures are moderate, it is not allowed to apply fertilizers on the fields during winter and hence, storage capacity of 5-6 months is necessary and AC-systems are highly attractive under those conditions for anaerobic digestion (Zeeman, 1991). However, in case of manure, when there is no need for longer storage and if manure is processed on a large scale the AC-system is less attractive than the CSTR-system (Zeeman, 1991). In Tanzania, enough storage is necessary for the rainy season of March to late May, as pit emptying during that period is difficult and rather cumbersome.

When applying an AC-system not only the gas production and conversion % at the end of the digestion period is of importance, but also development within time (Zeeman, *et al.*, 1999). Constant gas production facilitates its reuse, and accumulation of VFAs could decrease the pH and consequently inhibit methanogenesis. On the other hand however, a period of accumulation of VFA and low pH could increase the pathogen removal (Zeeman *et al.,* 1999) although observation from AC-systems indicated that, always a part of the latrine contents are relatively fresh and will certainly contain pathogens at the time when it is full and so, further treatment is necessary. The performance of AC systems since the reactors are not completely mixed, during the accumulation period can be evaluated based mainly on analysis of soluble components; $COD_{soluble}$, VFA, ammonium, pH and environmental conditions in the filled reactor volume (Kujawa-Roeleveld *et al.,* 2003). Where biogas is to be collected, an accumulation system should have some improved features, which resemble the UASB system in that, a gas collector has to be fitted and some water used.

One of the main disadvantages of AC systems is that, there is a very poor contact between sludge and incoming slurry, so that too little conversion of dissolved components occurs and likewise, removal of SS is limited to settling (Zeeman *et al.*, 1999). There is a possibility of local pH drops due to accumulation of volatile fatty acids and poor distribution of bicarbonate alkalinity (Kato, 1994). It is very difficult to get an ideal system for gas collection where the structure is of PL type. When the reactors are full, sometime is needed for full stabilization of the contents and *E-coli* and *helminthes* removal. Limited studies on accumulation systems found in literature include the mesophilic and psychrophilic digestion of liquid manure (Zeeman, 1991); Wellinger and Kaufmann (1992) who published successful full-scale applications of an accumulation system at two newly built pig farms; anaerobic digestion of physiological waste and kitchen refuse (Kujawa-Roeleveld *et al.*, 2003); decentralised treatment of concentrated sewage at low temperature (Elmitwalli, *et al.,* 2003); co-digestion of concentrated blackwater and kitchen refuse in an accumulation system (AC) within a DESAR concept (Kujawa-Roeleveld, *et al.*, 2002), anaerobic treatment of wastes for on-site and DESAR applications (Wilderer and Fall, 2003) and others like anaerobic digestion of solid animal waste in an accumulation system at mesophilic and thermophilic conditions, start-up (Elmashad, 2003) and this study.

1.7 Pathogens Removal in Anaerobic Digesters

Anaerobic digesters have a capability of killing pathogens to a certain degree and the digested sludge may be used as soil conditioner. The faecal coliform's average survival time in wet sludge at 20-30^{0}C have been found to be <50 days (Strauss and Blumenthal, 1994). Such temperatures are achievable in tropical climates like that in Tanzania. This means, at the time when the PLs are full or has reached the design capacity, sealing them for 14 days is sufficient for killing *E-Colis* in pit-contents. However, more time is needed for removal of *helminthes* if present. Killing rates of pathogens in accumulation systems are still under study. Anaerobic digesters reduce the number of bacteria, parasite eggs, viruses and other pathogenic organisms in the effluent of UASB reactor by ± 90% (Kijne, 1984). This is not sufficient to meet the WHO (1989) Guidelines for reuse (eg for *E-Coli* 1000 no./100 ml.) and hence, post treatment is necessary. However, to impose stricter pathogen requirements on sludge disposal are not only a waste of resources, but also that such restrictions can actually cause a deterioration of public health due to the reduction in "sufficient challenge" (Vesilind, 2003). Sufficient challenge describes the beneficial effect of low exposure to toxins, which improves health (Ottoboni, 1984) by building up natural resistance to attack pathogens. A low level of pathogens allow us to "prime to pump" against infectious disease (Vesilind, 2003). Nonetheless, different aspects need to be integrated for better output of effluents.

Presence of pathogenic organisms is a health risk in sludges and is a treatment concern, although the collection, haulage and treatment of faecal sludges (FS) in urban areas in developing countries remains as yet unresolved (Lettinga *et al.*, 1998; Strauss, 1998). Upgrading FS management constitutes a great economic, institutional and technical challenge.

1.8 Faeces and Urine Reuse Potential/Aspects

1.8.1 Historical Background

Human excreta (humanure) have traditionally been used for crop fertilization in many countries (Schönning, 2001). In Japan the recycling of urine and faeces was introduced in the 12^{th} Century and in China human and animal excreta have been composted for thousands of years (Winblad and Kilama, 1978). In Bukoba (Tanzania), the tradition of visitors was to urinate in the host's homegarden, which was much appreciated and considered a gesture of respect (Baijukya *et al.*, 1998). This practice has disappeared with adoption of modern hygiene and introduction of PLs. Though plentiful everywhere, there is not much written about this subject of humanure and attempts to address this question in Tanzania has been mainly due to difficulties faced for high water table (Missaar, 1997; Chaggu and John, 2002). The possibilities of treating separate fractions of (human) waste (urine, faeces, black-water or night-soil, greywater and swill) are high due to progressing depletion of crucial resources like water and nutrients (Zeeman *et al.*, 2000; Esrey *et al.*, 2001; Lettinga *et al.,* 2001; Kujawa-Roeleveld *et al.,* 2002).

The studies on nutrient budget and balance in Africa pointed to widespread processes of "nutrient mining" (depletion of nutrients) and soil fertility (Smaling, 1993; Scoones and Toulmin, 1999). Considering the urgent need to increase agricultural production in Africa, Tanzania in particular, these are alarming conclusions, which call for reuse of nutrients from human manure to improve the situation (Scoones and Toulmin, 1999; Chaggu and John, 2002). Smaling (1993) questioned that, the "non-sustainable" agricultural systems in sub-saharan Africa due to nutrient mining makes the long-term outlook for agriculture to be so bleak to an extent that, one wonders whether westerners should be prepared for just another form of colonialism. That is, a developed world, in future, structurally feeding a large part of population in Africa, by virtue of its excess soil nutrients and surplus production.

According to VISION 21 (WSSCC, 2000) new approaches to meet future water and sanitary system demands should be based on the principle that, human faeces and urine cannot be considered as "waste" products, but rather as "resources" to be recycled in safe ways. WSSCC (2000) suggests these products to be treated as close as possible to their sources of production and water should be minimally used to transport waste. The decision to reuse (treated) waste(water) in agriculture should always be the outcome of a thorough process of planning in which many factors are considered. It is basically an interactive process including academic, governmental, private- and public sector confrontation with pressing issues of water scarcity and pollution in the realm of broader processes such as population growth, economic development and urbanization (Martijn *et al.*, 2003). An adequate institutional framework to suit local conditions should be created to control, supervise and advise on any scheme involving faeces and urine reuse in order to ensure that use is safe (Duqqah, 2002).

1.8.2 Faeces Production Rate

The faeces production lies between 70-520 g/c/d (wet weight) (Missar, 1997; Wijst and Groot-Marcus, 1998). Tables 1.6 and 1.7 summarize the quantity, composition and characteristics of human faeces and urine. About 25-50 kg. of wet faeces is produced per person per year, which contains up to 0.55 kg-N, 0.18 kg-P, and 0.37 kg-K (Otterpohl, 2002). Elements that are contained in the diet in relatively large amounts, such as aluminium, tin, zirconium, strontium and vanadium, remain practically unabsorbed and more than 99% are excreted in feaces (Schroeder and Nason, (1971). Taking the per capita production into consideration, Tanzania with ~36 million inhabitants (Census, 2002), per annum produce between $9.0 \times 10^{8} – 1.8 \times 10^{9}$ kg of wet faeces nutrient amount of which are shown in Table 1.8. The possible yield of maize from these figures, considering P input, is about 5.73 million tons per annum; 80% of which could feed ca. 41 million Tanzanians. The estimation of population took into account that, 80% of the maize produced is grown by small holders under a wide range of management practices, climatic conditions, and socio-economic circumstances (Bisanda, *et al.*, 1998) and hence, lower production. The annual per capita consumption of maize in Tanzania is estimated at 112.5 kg and the national maize consumption is estimated to reach three million tons per year (Bisanda *et al.*, 1998). These conditions show that, proper reuse of nutrients in faeces and urine could improve very much the food production in the country.

The fertilizer consumption in Tanzania was 53,883 tons in 1972; 142,676 tons in 1991 and 200,000 tons of which 25% was N, P, K, in 1994 (Isaac, 1994). This increasing trend of fertilizer use has been hampered by the closure of the only fertilizer factory in the country in early 1990s and so, there is a great potential for reuse of human waste for fertilization. In contrast to phosphorus, nitrogenous compounds are not retained/stored in the soil matrix. Therefore, nitrogenous compounds will contaminate groundwater if FS is used in a way, which exceeds the plants' nitrogen requirements. These amount to 100-200 kg-N/ha/year, depending on the kind of crop, and for discharge. FS variables of prime importance are COD or BOD and NH_4 (Strauss, 1998). For reuse of FS hygienic characteristics comprising *helminth eggs* as parasite indicators and faecal coliforms need to be looked at as bacterial indicators. WHO (1989) guidelines for unrestricted reuse of FS in agriculture are 1000 no. *E-coli*/100ml. and $\leq$ 1 no./l of *helminthes eggs*.

Table 1.6: Quantity, Composition and Characteristics of Human Faeces and Urine

Approximate Quantity	Faeces	Urine
Quantity (wet) per person per day (g)	70-520	1000-1500
Quantity (Dry solids) per person per day (g)	30-70	50-70
Approximate Composition (% of dry weight/matter#)	88-97	65-85
Moisture content	66-85	93-99.5
Organic matter	88-97	65-85
Nitrogen (N)	5.0-7.0	15-19
NKj (gN)	1.4-2.46	5.29
Phosphorus (as P_2O_5)	3.0-5.4	2.5-5.0
PO_4-P	-	0.20
Total Phosphorus (gP)	0.69-2.5	1.08-2.2
Potassium (as K_2O)	1.0-2.5	3.0-4.5
Potassium (K)	0.80-2.1	2.5-3.7
Carbon (C)	44-55	11-17
Calcium as (CaO)	4.5	4.5-6.0
Calcium (Ca)	2.9-3.6	3.2-4.3
C/N ratio	5.0-10	0.6-1.1
COD_{total} (g/l)	46.23-78.31	12.79-
$COD_{soluble}$	-	11.33
$COD_{particulate}$	-	1.46
TS (%)	33	-
pH	-	7.08-9
Protein (g)	4-12	0.28
Total lipids (g)	4-6	-
Polysaccharides (g)	4-10	0.68

Sources of data: Gotaas. (1956), Mara (1989); Missar (1997); Barnett (1978); Wijst and Groot-Marcus (1998); EET Kiemproject (2002); Gaillard (2002). #dry matter is 30-60 g/person/day for faeces and 50-70 g/person/day for urine with water % of 77 and 94 for faeces and urine respectively.

Table 1.7: Characteristics for High and Low Strength Faecal Sludges (FS)

General Indication of FS Characteristics (adapted from SANDEC, 1997)		
Item	**High Strength**	**Low Strength**
Example	**Pit-Latrine Sludge**	**Septage**
Characterisation	**High Concentrated, FS**	**FS of Low concentration**
COD (mg/l)	20,000-50,000	<10,000
NH_4-N (mg/l)	2,000-5000	<1,000
TS (g/l)	>35	<32
SS (mg/l)	>30,000	7,000
Ascaris eggs (no./l)	2,000-6,000	4,000
Helminthes egg (no./l)	20,000-60,000	40,000

Table 1.8: Crop nutrient removal (*top*), Nutrient Production in Tanzania per annum (*middle*) and Application of fertilizer for some crops in Tanzania (*bottom*)

Crop nutrient removal					
Crop	**Scientific Name**	**Yield, kg/ha**	**N (kg/ha)**	**P (kg/ha)**	**K (kg/ha)**
Cereals					
Rice, paddy	*Oryza Sativa*	4000	60	13	25
Wheat	*Triticum aestivum*	3000	70	13	50
Maize	Zea mays	4000	200	35	133
Sorghum	*Sorghum bicolor*	4000	120	22	116
Tubers etc.					
Cassava	*Manihot esculentum*	20000	125	13	125
Sweet potatoes	*Ipomea batatus*	10000	90	9	12
Potatoes	*Solanum tuberosum L.*	25000	115	20	166
Others					
Soybean	*Glycine max*	1000	125	13	33
Groundnuts	*Arachis hypogeau*	1000	50	7	12
Sunflower	*Helianthus annuus*	1000	39	3	62
Sesame	*Sesamum indicum L.*	1500	45	20	8
Oil palm		15000	90	9	112
Sugarcane	*Saccharum officinarum*	90000	85	26	125
Sugar beet	-	40000	140	26	166

Nutrient Production in Tanzania per annum (36 million inhabitants)					
N (kg)		**P (kg)**		**K (kg)**	
Faeces ($x10^7$)	**Urine** ($x10^8$)	**Faeces** ($x10^6$)	**Urine** ($x10^7$)	**Faeces** ($x10^7$)	**Urine** ($x10^7$)
3.1391	1.44	9.72	1.44	1.998	3.24

Application of fertilizer for some crops in Tanzania				
Type of Plant	**Fertilizer Rate (kg/ha)**			**Total (N+P+K)**
	N	**P_2O_5**	**K_2O**	
Citrus, coconut (123 plants/ha)	12.3	12.3	61.5	82.1
Sesame (1-1.2 tonne/ha)^	45	40	@	85
Maize (3.5 - 8 tonnes/ha)**	20	20	@	40

Source: EUROCONSULT (1989); Koenders (1992); Chaggu and John (2002); author's calculations (2003) **production per ha. depends on soil type, variety and location. In Southern highlands of Tanzania, in fertile soils, the optimum plant population is ~45,000 plants/ha, whereas, in soils with low fertility the population ranges between 22,000 and 33,000 plants/ha (Bisanda *et al*., 1998); @assumed available in the soil (Mkamilo, 2003); ^Yield potential (Mponda, 1996).

1.8.3 Urine Production Rate

An adult produces ~400-500 litres of urine/year and contains 4.0 kg-N, 0.4 kg-P and 0.9 kg-K (Hungerland in Lentner (ed.), 1981; Johnsson, 2002). This means, Tanzania with the population of 36 million inhabitants, produces $1.44 \times 10^7 - 1.8 \times 10^7$ m^3 of urine per annum with disaggregated nutrient content as indicated in Table 1.8. The daily intake of proteins determines the urea in the urine. Approximately 80% of chloride ingested is excreted in the urine. The phosphorus in urine is 95-100% inorganic being present for the most part as primary phosphate (the proportion of secondary phosphate increasing with rising pH). Most of it comes from food; a smaller amount originates from the endogenous metabolism of organic phosphates. About 50-80% of alimentary phosphates appear in the urine (Werle and Schiievelbein, 1957). A third of dietary magnesium, 3% of the dietary copper, 5% of the dietary zinc are excreted in the urine. Lipids may cloud the urine. Normally, the urine has more or less deep-yellow color due to the presence of substances that have not been precisely identified. The faint, usually aromatic odor is due to unidentified substances. When acetone is present, the urine has a fruity odor; when there is decomposition, it smells of ammonia, putrefaction, or of hydrogen sulfide (Lentner (ed.), 1981). Urine is the fraction that contains the major part of nutrients in domestic waste(water), ~80% of the nitrogen, 55% of phosphorus and 60% of the potassium (Jonsson *et al.*, 2000). Human urine is a quick-acting fertilizer that can replace mineral fertilizer in cereal crop production. WHO guidelines for reuse purposes of urine are expected to come in 2004.

1.8.4 Energy Needs and Gas Production

One of the by-products of anaerobic degradation is biogas, which could be reused if tapped in the adequate amount. One latrine user produces 0.02 – 0.03 m^3/day of biogas from 1 kg. of waste per day (Eggeling *et al., no date*). This means according to Chaggu and John (2002), there is a potential of 80,000 – 120,000 m^3/day of biogas from Dar-es-Salaam city at the moment. With this amount of biogas[2], one could light, with an equivalence of a 60 – 100 watt bulb for 480,000 – 720,000 hours (133-200 days); cook 240,000 – 360,000 meals for a family of 5-6 persons; Drive a 3-tonne lorry for 224,000-136,000 km.; run a 1-hp motor for 160,000 – 240,000 hours (44-67 days) and generate 100,000 – 150,000 kW of electricity. More than 90% of the people in Tanzania do not have electricty and only 1% of the rural communities are connected to electricity, >90% of the energy used in the country and 98% of energy used in the household sector is from biomass fuels (Sawe, 2000). One of the promising options for alleviating the energy problems in the country is to reuse the gas from anaerobic digestion of human "waste".

1.9 Urban Agriculture as an Urban Issue

In Tanzania (nationally), the rate of urbanization rose from 6.0% (1957-1967) to 11.1% (1967-1978) and then declined to 9.6% (1978-1988) according to Ministry of Lands and Human Settlements (2000). Increased population means more mouths to eat and hence, a need for adequate food resources. However, whereas in western countries urban agriculture is mainly realized for recreation, in order to give a space to children, to spend the time in the case of retirement or unemployment, by ecological

[2] The calculated figures were according to van Buren *et al*. (1979) whereby, I m^3 of biogas can light 60-100 watt bulb for 6 hours or cook 3 meals for a family of 5-6 persons; or drive a 3-tonne lorry for 2.8 km., or run a 1-hp motor for 2 hrs; or generate 1.25 kW of electricity.

motives or others, in sub-saharan Africa is mainly realized as an important component of the household income (Streiffeler, 2003). A number of African cities took the chance for foods supply as well as job opportunities by cultivating on idle land and keeping livestock in the city (Smit and Nasr, 1992). During the colonial period agricultural production was said to be only on the periphery of Dsm. but the town Ordinance marked in 1920 that crops like maize, cassava and banana were not to be encouraged to be grown in the city because of possible mosquitoes breeding places (Majani, 1997). For a period of 1967 to 1991 the proportion of families engaged in urban farming increased from 18% to 67% (Kyessi, 1997). The Tanzanian Master Plan of 1979 included for the first time urban agriculture as a land use category, and hazardous land. The first act to promote urban agriculture was during a severe famine in Tanzania in 1974. A decree by the president in order to avert famine and hunger was made and the population started cultivation on all vacant land (Majani, 1997). The legal situation for the farmer is not always clear and the production in the city area and especially in open spaces has no land rights for their production. The motivation of agricultural activities over the last decades on all governmental levels led to a "silent agreement" for the land use activities (Muster, 1997). The open spaces are an inner urban production system, like in Dsm 23% of the land is under agriculture (Jacobi, 1997; Sawio, 1997). The effect of greening the city by agricultural activities supports the micro-climate of cities (Kishimba, 1993). Urban Agriculture in Chinese cities manages to supply the urban food markets up to 90% (Smit and Nasr, 1992). However, in 1990s a cholera outbreak in Santiago (Chile) affected thousands of people. The cause was use of raw sewage in urban agriculture (UNDP, 1996) and applied on vegetables and crops mainly eaten raw (Muster, 1997). This implies that, for the FS to be reused, it should be safe from a hygienic point of view.

1.10 The Need for Post Treatment after Anaerobic Digestion Process

Anaerobic treatment of sewage is regarded as a pre-treatment process since it merely converts organic matter, reduce inorganic compounds (ammonia, sulphide and phosphate) and pathogens are insufficiently removed (Wang, 1994). The excess sludge produced in UASB reactors at temperatures above 20^0C is normally sufficiently stable and may be used as soil conditioner in agriculture (Haandel and Lettinga, 1994), but further treatment for pathogen removal may be necessary depending on the use. The post treatment system to be used strongly depends on the characteristics of anaerobic effluent, the effluent standards for discharge on surface water, availability of funds, space and technological know-how specifically in developing countries. Decision has to be made whether the required effluent quality is for direct agricultural uses (irrigation, fish-culture and so on), or discharge into surface water (with accompanied required standards) or for situations where only organic matter, BOD(COD), SS and pathogens have to be eliminated (Wang, 1994). Sludge drying produces a distinctly superior end product and the prolonged period of sun exposure removes pathogens (Haandel and Lettinga, 1994). This could be applied comfortably in Tanzania since it experiences tropical climate. In such climate, investment and operational costs are generally significantly lower than those necessary for mechanized sludge drying options and sludge drying on a bed is always worth considering if available land is sufficient (Haandel and Lettinga, 1994).

1.11 Conclusion

From the literature review presented in this chapter, it can be concluded that, faeces and urine are a health hazard if they are kept in the wrong place otherwise, they have a big potential of reuse if handled locally in the right way. Moreover, anaerobic digestion of these fractions in accumulation systems like improved pit-latrines at ambient temperature conditions of the tropics renders them safe for reuse. However, institutional framework designed to suit local conditions, being well defined and having a clearly specified distribution of responsibilities is very important in this aspect.

1.12 Outline of the thesis

This thesis presents the results of the research work, done in Dar-es-Salaam, Tanzania on collection and anaerobic digestion of human waste and disposal in the improved pit-latrines at ambient tropical temperatures (26-30^{0}C) and ecological sanitation toilets. It contains seven chapters as briefly outlined below. Chapter 1 and 2 outlines the general introduction especially on the overall country and study place status of sanitation, health, water supply, anaerobic digestion of waste(water), accumulation systems, reuse aspects, socio-cultural and -economic issues. Chapter 3 explains the materials and analytical methods used in the laboratory. Chapter 4 presents the modeling of anaerobic conversion of black water and night soil in accumulation systems. Chapter 5 deals with the anaerobic stabilization of black water in accumulation systems "the demonstration reactor" while Chapter 6 looks at the performance of composting latrines in the form of ecological sanitation toilets. Finally, Chapter 7 summarizes and discusses the results of the investigations as a conclusion to the whole study and offers the recommendations for further work.

CHAPTER TWO

EXCRETA DISPOSAL IN DAR-ES-SALAAM

Abstract[3]

The socio-cultural and socio-economic situation of sanitation in Dar-es-Salaam (Dsm), Tanzania was studied with explicit emphasis on pit – latrines. Without considering the socio-cultural conditions, the so-called best solution might not be the right one. Therefore, in order to achieve the intended goal, literature review, questionnaire survey and personal visit to the chosen study areas were done. In total, two hundred and seven household questionnaires were filled in 16 areas of the city. Interviewers did house-to-house visit and questionnaires were filled on the spot. Results indicate that, the city population was about 3.8 million at the time of survey, with over 80% of the dwellers using pit-latrines, some 3% use septic tanks with soakage pits, about 6% are connected to the sewerage system and 1% has no excreta disposal facility. Difficulties faced include dismal budget allocations, fragmentation of sanitation activities among sub-sectors, lack or poor sanitation record keeping, unsatisfactory machinery for septic tank and pit-latrine emptying, lack of clear policy on pit-latrine handling and, in competition of resources, low priority is accorded to excreta disposal system among the people. City residents will continue to use the pit-latrines for a long time to come. Reusing the faecal sludge is not known by most city dwellers and is influenced by socio-cultural habits. To prevent groundwater pollution and to recover useful products in human excreta and urine, ecological sanitation toilets and anaerobic digesters could be an option.

Key Words: Socio-cultural, Socio-economic, Excreta, Disposal, Reuse

[3] Modification of this chapter has been published as: Chaggu, E., Mashauri, D., van Buuren, J., Sanders, W. and Lettinga, G. (2002), Excreta Disposal in Dar-es-Salaam, Environmental Management **30**(5), pp. 609-620.

2.1 Introduction

Effective human waste handling is the center of development and well-being of the community and sustainability of projects. According to Faechem and Cairncross (1978), sanitary disposal of human wastes is perhaps of greater importance than the provision of a safe water supply. That is, if disposal of human excreta is correctly managed, there will be little risk of human waste contaminating domestic water sources. About 60% of the health complaints in Tanzania, in typical unplanned areas, are related to groundwater contamination from pit latrines (Chaggu *et al.*, 1993). However, excreta disposal has both social and technical considerations. Past experience has proved that, without adequate attention to the social aspects, whatever technology that is developed and instituted in the country may be bound to fail.

It is extremely difficult to achieve changes in excreta disposal practices as they are part of the basic behavioral pattern of a community and are not readily modified (Feachem and Cairncross, 1978). This difficulty causes relaxation in maintenance and guarding of the provided facilities if users are not involved in relevant sections of decision-making and, hence, failure of the envisaged project. Nielson and Clauson-Kaas (1980) stated that, without considering the socio-cultural conditions, the pretended best solution might not be the right one. Based on experience, technical solutions do not have many problems apart from site and weather conditions, relative to the social ones (complex in nature) for project sustainability. It is with these aspects in mind that the study presented in this thesis started off with the social considerations of excreta disposal in Dar-es-Salaam (Dsm.).

Historically, Dsm., ("*harbour of peace*") was established as a mere trading centre by the Arabs about 141 years ago. Later on, its role changed to encompass the administrative functions of the nation. Between year 1891 and 1961, it was a center of the German and British Colonial administration. It was the national capital from 1961 (year of independence) to 1973 when the Government made a decision to shift the capital from Dsm. to Dodoma. Dsm. covers a land area of about 1350 square kilometres including the eight off – shore islands. The city is presently comprised of three municipalities also known as districts (Kinondoni, Ilala, Temeke) with a total of 52 wards. The wards are further sub-divided into branches, and branches into ten-cells/street (in Swahili, *mtaa*). The built up land in 1996 was estimated to be 197.3 sq km (more now) with a spatial expansion rate of 7.2% per annum. It has gone through various periods of relatively rapid population growth followed by periods of consolidation as illustrated by Figure 2.1 with data from Ndunguru, (1996), Mvano, (1994), and authors projections (1999). From 1990 to 2001, the population increase in the city was exponential while infrastructure provision grew arithmetically. This situation added to the sanitation problems faced in the city.

2.2 The objective of the Study

The purpose of this study was to carry out a socio-cultural and socio-economic study of the sanitation conditions with emphasis on pit – latrines in Dsm., their problems and inter-relationships with regard to faecal sludge management, urine separation and reuse.

2.3 Methodology and Materials

A literature review was conducted on the state of sanitation in the country covering the last 20 years. Thereafter questionnaires mainly for households were prepared and pretesting of questionnaires was carried out in Dsm. for one week. Later on, modifications were made for the actual survey questionnaire. Three interviewers visited each household and filled the questionnaire on the spot. Neighborhoods visited (representing 9 wards out of 52 wards in Dsm.) included Buguruni Malapa, Kambangwa, Kilimani, Keko Mwanga, Kigamboni, Mlalakuwa, Magurumbasi A, Magurumbasi B, Mbagala, Kisiwani, Msisiri A, Kopa, Bwawani, Mji mwema and Kichangani. A total of 207 questionnaires were recorded in Dar-es-Salaam. In-depth discussions with key informants (officials) were held. These included some officials in the Ministry of Health, National Bureau of Statistics, Sustainable City Programme, Municipal Authorities, the Dar-es- Salaam Water Supply and Sewerage Authority (DAWASA) and some professionals in training institutions. Physical measurements of the pit-latrines were taken on-site together with video recording and slide photographs. A Statistical Package for Social Science (SPSS) computer programme was used for data analysis. Thereafter, data and information interpretation were carried out.

2.4 Results and Discussion

It was evident from the literature review and questionnaire results that, the rural-to-urban migration accounts for a bigger share of the population increase in urban areas than the natural birth in Tanzania (National Census 1978, 1988). The increase causes pressure on urban infrastructure and services, growth of unplanned settlements, unemployment, poverty (Vice President's Office, 1999), individual small-scale trading activities, and deteriorating urban social services. About 95% of the city parts have loamy soils, 4% sandy and 1% is mainly clay. Flood risk is a permanent problem in some areas of the city, especially in unplanned settlements and restricted building areas such as river valleys. Solid waste collection companies serve 30% of the population, while, 36% dispose in hand-dug pits by burying the waste, and 34% apply haphazard disposal either into valleys, in the road-side channels, the storm water channels or even into the pit latrines.

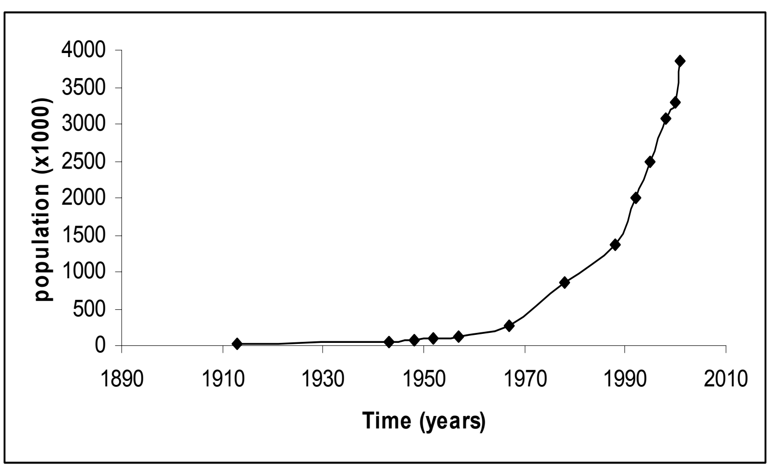

Figure 2.1: Dar-es-Salaam population between 1913 and 2001

Sullage disposal is directly related to the solid waste management. Inhabitants served by the solid waste companies filter the solids from the wastewater contained in the sullage. The solid parts are mixed with the other solid wastes, while wastewater is dumped within the house premises or surroundings in order to stop the dust. A similar practice takes place during the rainy season in order to get rid of the wastewater. This is mainly due to the lack of proper technology and infrastructure in place for the purpose. Those who bury the solid waste in pits pour them together with the sullage. Similarly, those who dispose the solid wastes into the fields, dump sullage into the fields. Other wastes are eaten by the varieties of scavengers (birds and animals), and some people use them to feed their chicken or ducks. The effects or impacts of these practices on human health and the environment at large have not been evaluated.

Sanitation problems in the city arise from various cultures (many residents are migrants from up-country), poor sanitation record keeping and fragmentation of sanitation activities among various sub-sectors. Others are different habits of managing excreta (some people do not want to handle and subsequently termed as faecalphobic society?), inadequate infrastructure facilities to cope with the population growth (7-10%/yr) compared to the national increase (3%/yr) and increased poverty for many city dwellers. Furthermore, people build their houses haphazardly (~ 70% of the residents live in unplanned settlements) and use different excreta disposal facilities of various nature (*Table 2.1*). Additionally, ~45% the city area has a high water table and floods in the rainy season (Mato *et al.*, 1997), it lacks adequate technical advice for assisting the pit-latrine users, and there are not enough resources (human and financial) for faecal sludge management. It has no open spaces close to the residential areas for sludge disposal. The city also lacks a clear policy on pit-latrines and sludge management. The reuse of valuable resources from sludges, know-how and handling technology is very limited.

The majority of the people (~80% of urban population and generally 90% of the people in the country) use on-site disposal (decentralized) systems mostly pit-latrines (*Table 2.1*). In urban areas 10% of middle and upper class populations use septic tanks, 5% of the affluent class are connected to sewerage and 5% of the poorest have no proper sanitation at all (Mwaikyekule, 1999; Rukiko, 1999; Uronu, 1999). This is because sewerage is very expensive and is available to only a small group of the people (*see also Chapter 1*). The first Dsm. sewerage system was constructed in the mid 1940's, and since then no adequate operation and maintenance has been done (Uronu *et al.*, 1997). The city did have public toilets in the 1960s, which fell into disuse by 1990 (Lugalla, 1990). Currently, there are quite a number of privately managed public toilets in different locations of the city.

Questionnaire results revealed that, for water supply, DAWASA serves 12% of the low-income city dwellers, while, about 11% use water from public wells, 5% have in-house connection, 20% utilize yard connection and 44% are supplied through the neighbor's taps. However, those using neighbor's facility, pay from Tsh.500/= to Tsh. 3000/= (US$ 0.62 to US$ 3.74; year 2000 exchange rate) per month per household or from Tsh. 10/= to Tsh. 200/= (US$ 0.012 to US$ 0.249) per 20-liters bucket. Getting water from the neighbour's well (5% of the residents) cost about the same. About 2% of the residents depend on water from vendors. Rainwater collection is minimally practiced (1% of the city dwellers) in Dsm. From such a water supply system, it is obvious that people will opt for an excreta disposal technology, which is within their means and range of knowledge. Mate and Lufeyo (1991) said that users in various forms of construction can afford pit-latrines.

Table 2.1: Compiled estimates on the types of excreta disposal facilities in Dar es Salaam

Type of facility	% of users	Source
Pit-latrines	83	Uronu (1999)
	91	Kirango (1999)
	85	Mvano (1994)
	88	Mbuligwe* (2000)
Traditional pit latrines	81.0	This Study (2001); Waste Consultants, 1989
Ventilated improved pit latrine (VIP)	2.0	This Study; Waste Consultants (1989)
Elevated traditional pit latrine (ETPL)	7.0	This Study (2001)
Septic Tanks & Soakage pits	10	Uronu (1999); Mvano (1994), Mujwahuzi (1994)
	17	Waste Consultants (1989)
	15	Mbuligwe* (2000)
	2.5	This Study (2001)
Sewerage	5	Uronu, 1999
	12	Mbuligwe*, 2000
	6.5	This Study, 2001
Without access to any excreta disposal facility	1	Uronu (1999)
	5	Mvano (1994); Mwaikyelule (1999), Rukiko, 1999)
	1	This Study (2001)

*The compiled data is above 100% which means there was an error but the reason is not known

Storage of human waste and disposal in the city varies from haphazard defecation (by poor people who cannot afford a sanitary facility) in the fields to the use of the neighbor's latrine and the sewerage systems (*Table 2.1*). Since there is no centralized data for sanitation, the table indicates some inconsistency in the obtained data from available sources. Urine separation is minimally practiced in Dsm.

2.4.1 Social Factor

Head of Household/Education Level/Occupation

In the past, households used to be headed mainly by men, although women were as well bread-winners. The trend is changing and women are heading the households more often, as evidenced by the results of this study (*Table 2.2*). The education level of most respondents was very low, and they had an inadequate capacity of understanding a number of issues of concern for many cases. This emphasizes the need for educational campaigns for any project's sustainability. Low education is the reason for low-paying jobs performed by householders (*Table 2.2*) with an implication of inadequate financial resources for daily subsistence and investment into good excreta disposal facilities.

Households Monthly Income/Expenditure

Monthly household expenditures (*Table 2.3*) as evidenced by the questionnaire results ranged from an average minimum of Tsh. 22,900/= (~29 USD; 2001 exchange rates) to a maximum of Tsh. 472,000/= (USD 590) (0.5% of the people, *not shown*). More than 53% of the people use less than Tsh. 100,000/= (USD 125) per month. Surprisingly, out of these mentioned figures, 75% of the money is spent on food while, 25% was used for clothing, house rent, electricity, water, health, school fees, transport, recreation, and other spending. Inadequate money is available for sanitation. The priority of people is not in good excreta disposal facility, especially, when there is competition of resources. This is the reason why a number of latrines observed are half constructed and do not have permanent roofs and doors in some cases (*Table 2.4*).

Collection of Human Waste and Knowledge of Latrine Types

Since pit-latrines are mainly an on-site practice, collection refers to the time when the latrine is full and hence, requires emptying (*section 2.4.3*). The survey results indicated that, some 34% of small children (0-4 years) defecate in house and 37% use the courtyard. The excreta in the courtyard is collected by adults in shovels or in dust-collecting device and thrown into the pit-latrine, if available, or dumped haphazardly in solid waste heap. Among the children from the well-off and more educated knowledgeable families, 5%, defecate in special defecating pots and thereafter, the waste is emptied into the latrine. About 22% of the children utilize the same latrine as adults, whereas, 2% defecate in the street. Water is the medium of transport in the case of sewerage. Almost 99% interviewed said that, the knowledge they have about other types of latrine was gathered by seeing those structures elsewhere. This means, demonstration structures for creation of awareness are important for new latrine structures like anaerobic digesters and ecological sanitation toilets for their success.

Bathing and Anal Cleansing

According to the total number of interviewees, a habit of bathing in the same place as the pit-latrine is practiced by about 52% of the people, while, 32% use separate rooms but, the bath waste water ends up in the same pit as for the latrine. In addition to that, almost 15% of the people bath in separate rooms but dispose their bath water in different pits, whereas about 1% has neither bathroom nor specific place to take bath. Availability of these facilities is a function of the economic status of the person, presence of enough space for construction and whether the house dwellers are owners or tenants. Water is used for anal cleaning by nearly 84% of the city dwellers (water washing society). This situation should be changed and as far as possible less water should be used and bath water diverted otherwise, dilution of concentrated stream occurs and complicates the wastewater treatment. Only 1% of the people uses toilet paper; while the remaining 15% use mixture of toilet paper and water.

Table 2.2: Survey Results: Respondents, Education Level of the Respondents, and Occupation of the Households

Head of Household n = 207		**Respondent n = 207**		**Community Demography (n=207)**				**Education of Respondent n = 207**		**House holds n = 207**	
		Type	**%**	**Age Group**		**% of**					
Gender	**%**			**Years**	**Total (%)**	**Female**	**Male**	**Type**	**%**	**Occupation**	**%**
By women	22.2	House owners	31.8	0 -5	13.4	14.5	13.9	Those who have never been to any formal school	10.3	Peasants/ farmers	9.1
Out of whom: -widows - divorced	 56.3 4.2	House owner's wives	27.1	5 – 10	12.7	13.3	13.5	Other types of formal schools such as quraan madrasats	3.4	Keep livestock	0.8
- separated	16.6	Tenants	17.9	10 – 20	17.1	19.4	16.7	Primary*	71.1	Rearing chicken	1.4
- never been married	4.2	House owner's sons	7.7	20 – 30	22.5	24.1	23.4	'O'Level**	12.0	Formal jobs	25.5
- other reasons (own building effort etc.)	18.7	House owner's daughters	5.8	30 – 40	15.7	15.6	17.9	'A'Level (Form six)	0.8	Self employed and street petty trading (*machinga*)	44.3
				40 – 50	7.3	8.6	6.9	University graduates	1.3	Tailors	5.4
		Relatives (sisters, etc).		50 – 60	3.5	2.7	4.7	Technical college education	0.8	Carpenters	3.9
By men	77.8		9.7	>60	7.8	1.8	3.0	Vocational training schools	0.3	Pit latrine emptier	0.6
										other jobs	9.0
Total	**100**		**100**	**100**	**100**	**100**	**100**		**100**		**100**

* Primary (standards four 17.7%, five 2.1%, six 2.5%, seven 42%, eight 6.8%); ** 'O' Level (Secondary School: Form one 2.1%, two 1.2%, three 0.4%, four 8.3%).

Table 2.3: Household Expenditure per Month According to the Survey

Range of Expenditure (Tsh.) n = 207	Range of Expenditure (USD)	Percentage
Up to 20,000	Up to 25	0.5
20,001 – 40,000	25 – 50	4.3
40,001 – 60,000	50 – 75	15.0
60,001 – 80,000	75 – 100	16.9
80,001 – 100,000	100 – 125	16.9
100,001 – 120,000	125 – 150	15.0
120,001 – 140,000	150 – 175	13.0
140,001 – 160,000	175 – 200	7.2
160,001 – 180,000	200 – 225	3.4
180,001 – 200,000	225 – 250	1.9
Over 200,001	Over 250	9.2
Total		**100**

Table 2.4: Survey Results: Building Materials for Pit-Latrines in Dar es Salaam (n = 207)

Structure Part	Types of material	%	Total %
Roof	No roof	53	100
	Corrugated iron sheets	45	
	Thatches	2	
Superstructure	Sand cement blocks	80	100
	No superstructure	2	
	Thatches; Thatches and sacks; Thatches and corrugated iron sheets	6	
	Wood and clay soil	1	
	Corrugated iron sheets	7	
	Blocks and thatches; Blocks and sacks	1	
	Sacks only, plastics only; Sacks and plastics	3	
Floor finish	Sand cement screed	90	100
	Sand only	5	
	No floor finish rather than timber log reinforcement	4	
	Clay soil floor finish.	1	
Floor slab	Reinforced with timber log (*Mikurunge**).	94	100
	Reinforced with iron bars and *mikurunge*	4	
	Reinforced with iron bars only	1	
	Reinforced with *mikurunge*, wire mesh and concrete.	1	
Pit wall	Constructed with blocks	86	100
	Built with stones	9	
	No walls rather than the natural soil wall	4	
	Constructed with tyres and drums	1	

* Name of local timber logs

2.4.2 Construction, Costs and Condition of Pit-latrines

Table 2.4 and 2.5 summarize the construction, costs and condition of the surveyed latrines as perceived by the users and physically assessed by the study team. Users gave their opinion from the long experience of utilizing the latrines while the study team assessed the on-site situation at the time of interview. The two groups came to the same conclusion about the condition of latrines (*Table 2.5*). Cleanliness was assessed relative to other latrines in the area. Quite a number of them were clean (44% good and 48% fair) and only 8% was poor. This might be the result of the cleanliness campaign going on in the city. All surveyed latrines were within the householder's premises (plot). The oldest pit latrine, still in use, without desludging was constructed in 1966 while the newest ones were constructed in year 2000. The craftsmen constructed most of the latrines (88%). Those who experience problems remarked that it will be good to get a loan or an aid to improve the latrines. However, there are public latrines with multiple chambers of about 2.4 m^3 each located in community places such as bus-stands and markets. These are operated on business bases by private operators and users pay Tsh. 20/= to 100/= (US$ 0.025 - 0.125) per person per visit. This business is recently introduced in the municipal services and so, the latrines are not yet full. However, many operators are expecting to use the municipal councils cesspit emptiers when the latrines are full. This means, the slurry will end up in the available waste stabilization ponds.

Past results by Mwandosya and Meena (1998) showed that, 59% of the pit-latrines have no roof. At present, the situation has changed slightly as evidenced by the outcome of this study (*Table 2.4*) where, the number of latrines without a roof (causes problems during the wet season) dropped to 53%. This drop might imply that, the economic situation of the people and environmental sanitation awareness has changed and therefore people are placing more emphasis in covering their latrines. To keep the water flow to the latrines as low as possible, users have to be convinced about roofing their latrines.

Table 2.6 shows the status of the height of latrines as a function of water table. The measurements were directly taken on-site by the study team from ground level to squatting slab and superstructure to roof for elevated pit-latrines. It was possible to take the measurements since part of the structure was above ground. Sub-structure depth (from ground level (GL) into the pit) for traditional pit-latrines was measured from GL to the bottom of the pit using a long prepared stick. This was only so in cases where the pit had little sludge and the depth was not more than 2.4 meters. The amount of sludge in the pit was judged from the number of users and age of the latrine. Where there was sludge, the owners and craftsmen available assisted in giving the constructed depth of the pits. Many pits were very deep because, people do not have the knowledge of building them otherwise. Shallower pits could facilitate reuse of sludge because they are easier to desludge. There has not been a strong technical assistance backed up with legislation on how to build the latrines. The building costs are high compared to the income levels (*not shown*) of the people. Areas closer to the sea always experience the intrusion of groundwater (GW). Those located inland from the city centre about 20 km. (like some parts of Mbagala area), have low water-table conditions and, hence, the tendency is to construct deeper pits which could be used for a long time without a need to desludge them. However, those pits were constructed without due attention to groundwater pollution. So far, there has not been any serious study towards this effect in many parts of the city.

Table 2.5: Assessment of the Surveyed Pit-latrines in This Study

Construction		Costs	Parameter (n = 207)	Condition % (n = 207)		
By (n = 207)	**%**	Variable from no specific cost to about Tsh. 400,000/= (1998 prices) (US$ 500)		**Good**	**Fair**	**Poor**
Craftsmen	88		Cleanliness	44	48	8
House Owners	10		Privacy	40	51	9
Family members	2		Convenience	31	59	10
			Smell	**Present**	**Not Present**	
				32	68	

Table 2.6: Sub-structure, Squatting Slab and Superstructure Levels of Surveyed Pit Latrines in This Study (n = 207)

Sub-structure		Ground Level to elevated Squatting Slab		Superstructure (squatting slab to roof)	
Depth (m.)	**% of latrines**	**Height (m.)**	**% of latrines**	**Height (m.)**	**% of latrines**
0.0	0.5	0.0	22.3	0.0	1.5
0.1-0.9	1.0	0.1-0.25	37.9	0.8-0.9	1.0
1.0-1.3	1.4	0.3-0.4	9.8	1.0-1.3	1.0
1.4-1.8	1.8	0.5-0.6	16.0	1.4-1.6	23.2
2.0-2.4	2.0	0.7-0.8	2.0	1.7-2.0	68.4
2.5-3.0	29.0	0.9-1.0	4.8	2.1-2.3	3.4
3.1-3.3	2.4	1.2-1.5	7.2	2.4-2.8	1.5
3.4-3.6	43.1	1.6-1.9	0	2.9-3.2	0
3.7-4.0	12.5	2.0-2.3	0	3.3-3.8	0
4.1-5.0	6.3	2.4-2.8	0	3.9-4.3	0
TOTAL	**100**		**100**		**100**

Despite the absence of technical advise, the effects of high water table have forced people to opt for elevated squatting slabs (*Table 2.6*).

2.4.3 Sludge Disposal

The sludge production in Dsm. increases with the population increase (*Table 2.7*). Difference in the data presented arises from the assumptions used as shown in the remarks column of the table. A study by Waste Consultants (1989) revealed that the number of people using the same pit-latrine varies from 4 to 39 (*table not shown*). This means the pits are heavily used in some instances. These figures are so high because there are tenants living on the same plot and use the same toilet facility as the owners/householders. However, data on the size of plot and number of latrines on plot are missing. From the same study, the number of households per plot were found to be between 1-4, 30%; 5-6, 34%; 7-8, 22%; and ≥ 9, 14%. There is no policy detailing the management of faecal sludge in the city. People are still using and will continue to use pit-latrines mainly because of lack of financial resources and space for adoption of other options. Nonetheless, improvement on the existing latrine structures will continue to be seen as the income level of the people rises.

Table 2.7: Sludge Production and Emptying Needs in Dar es Salaam City

Year	Population	# of Pit-latrines	Yearly Sludge (m^3)	Annual** Emptying Demand (m^3)	Source	Remarks
1992	2,000,000 or 450,000*	~170,000	50,000	50,000	Mvano, 1994	3.4 m^3 sludge/pit/year. S/T sludge has not been estimated
1998	3,062,608 or 510,435*	270,000 per 5 years	183,600	183,600	Vreede, 1998	10% need manual emptying, small % is emptied per year by MAPET+
2001	3,850,006 or 641,668*	531,035	254,897	254,897	Author estimate 2001	80% of HH use pit-latrine with emptied volume, 0.48 m^3/pit/yr^

* & HH = Households; **this would mean a residence time of one year in some latrines; +Manual Pit emptying Technology; ^often the pits are not completely emptied due to inferior emptying tools and costs.

Improvements in the form of Decentralized Sanitation (DESA) facilities possibly with anaerobic digestion as core technology (*see Chapter 1*) can assist/facilitate the use of by-products and improve the quality of the environment. Apart of hospitals, there were no people observed to be using buckets for defecation, although, this does not rule out the possibility of bucket latrines in some parts of the city.

In addition to that, from the city configuration and the space available for sanitary facilities, it is quite evident that, mixed sanitation facilities/options should be used in the city. For places like the central business district, the only currently used option is to connect to sewerage system although there are arguments going on about the effectiveness of the sea as a recipient of human waste. In high-density areas without adequate water supply system, dry sanitation systems are a safe possibility. Discussions with people showed that, some of the used systems need improvement, but the technical capacity and financial resources are lacking. It is however, evident that, the richer and more knowledgeable people become, the more expensive human waste disposal systems they use.

Desludging of Pit Latrines, Arrangement and Actors in Sanitation

The high water table have caused about 50% of the pits to be full although mainly with water; whereas, according to survey results, the remaining 50% is caused by many users (filling time varied from 6 months to 1.5 years). Solid wastes (all fractions) are dumped into the pit (latrines) in some occasions. This implies a need to give the users the knowledge on importance of adding the organic fraction only to pit-latrines. About 27% of the pit latrines have not been desludged so far; that is, since they were installed, whereas, others were emptied in the rainy season haphazardly by leading excreta into running rainwater. Cesspit-emptiers (vacuum trucks 5 m^3) have desludged nearly 73% of the latrines and others are emptied by the vomiting method (that is, digging a hole adjacent to the pit and allowing the sludge from the pit latrine to flow into the new pit; then the new pit is covered). Options for handling when pits are full, 72% of the people desludged them, 23%

expect to build a new one and 5% do not know what to do. This means that, there is a serious need to provide guidance on the proper way to handle the sludge in order not to jeopardize the health of the people.

From the survey results full pit latrine-emptying services were arranged by house owners for 94% of cases, tenants 2%, self-arrangement 1%, others like through family members 2% and friends 1%. Cesspit emptying cost ranged from a minimum of Tsh. 25,000/= (US$ 31) to a maximum of Tsh. 70,000/= (US$ 88) per trip, depending on the distance to the disposal site from the residential area (average 10 km.). Cost per m^3 per kilometre is about Tsh. 500/= (US$ 0.6) as judged from money paid by vacuum truck users in 2000. However, costs in 1989 were ranging between Tsh. 25/= to Tsh. 2,000/= (US$ 1-100). The price used to be set by the sewerage authorities; nowadays, it is a free market activity, meaning, the cost is set by negotiation between service providers and the clients. Manual pit emptying (MAPET) costs, in 2000, were Tsh. 10,000/= (12.5 US$) for 4 drums of 200 liters each including labour for digging the adjacent pit as necessary. In 1989, they were Tsh. 300/= (US$ 10) for a drum of 200 litres including the labour for digging the adjacent pit. Waste Consultants (1989) cited that, prices set for MAPET depend on the job to be done and the bargaining made and not on the cost per cubic metre. In some cases house-owners are the ones paying for the service, while in others where they live with tenants, the tenants pay. The costs are very expensive to the poor people and they showed a keen interest in alternatives, which could be cheaper than what they experience now.

The faecal sludge and septage collection in Dsm. used to be done by the then DSSD (Dar es Salaam Sewerage and Sanitation Department); now DAWASA and private operators. DAWASA, was formed in 1998 by merging DSSD and NUWA (National Urban Water Authority) and became operational in end of 1999. Big tankers ($5m^3$ capacity) collect the wastewater from accessible areas, whereas mini-tankers of MAPET (effectively from year 1988 to 1994) using hand-pumps, handles sludge in areas too small for big tankers to get to. MAPET tankers can navigate in roads as narrow as 90 cm. By 2002, only one MAPET crew was available for the service. There were about 28 privately owned cesspit emptiers and 14 city council emptiers (Kirango, 1999) at the time of this study. DAWASA might be interested in frequent emptying because it means business but, people would not like it because it reflects expenditure on their side.

Dsm. city council activities have been decentralized following the restructuring programme to three municipalities namely, Kinondoni, Ilala and Temeke. The clear line of operations and working interrelationships between the municipalities and the council are yet to be smoothened out.

Sludge Disposal and Reuse

Disposal sites used are mainly digging an adjacent pit (by MAPET operators), which is basically distribution of pathogens into the soil. Hydro-geologically in high water table places and loose soils, it destabilizes the existing structures and the problem has not been alleviated since the back infiltration takes place. People are not aware of these facts and so, it is important to give the health education to them. The manhole chambers used for the sewerage system and the DAWASA Waste Stabilization Ponds (WSP) are used for sludge disposal purposes as well. Nonetheless, this practice is very bad for the people living nearby these facilities. However, the WSP (Mikocheni, Mabibo, Kurasini and Lugalo) are over-loaded and adding the sludge from pit-latrines or septic tanks accelerates the operational problems. In year 1999, other WSP were closed due to high level of sludge, which has accumulated, and so the Vingunguti and Kurasini ponds were allowed to receive sludge from desludged pit-latrines and septic tanks. The dumping records (Kirango, 2000) showed that every trip 5 m^3 dumped into the city's WSP is charged Tsh. 3,000/= (3.75 US$), which, until 1999 was paid to DSSD. Now it is paid to DAWASA. The charges have been increased to Tsh. 5000/= (~5 US$, 2002 exchange rate) per trip in 2002. Other costs between the client and operators are negotiated. From the records (*not shown*), most of the desludging is done between February and June (the wettest season of the year). Users desludge without knowledge of what happens hydro-geologically. Tank operators are sucking water instead of sludge without any hindrance from their clients. Most operators said that, they are supposed to take out the liquid part and not the sludge. Technical assistance is therefore very important to the people who do not know what is happening otherwise, people are wasting their resources without any knowledge. Understanding will help them to act otherwise.

A suitable way and place needs to be developed for the treatment of the pit latrine sludge and the end product be reused as much as possible. In Mali, private operators accumulate the sludge and transport it to places where it can be used as manure. They sell the manure to the farmers (cost could not be readily obtained). In this study, it was observed that many residents do not know the final disposal site of the collected sludge from their premises. They apply the principle of "out of site, out of mind" which is a typical system used at the time of study. Additionally, almost 49% are not aware if the faecal sludge can be used as fertilizer while, 48% of the potential users (gardeners and farmers) know the nutrient potential of faecal sludge but they do not want to use it as they are able to get other types of fertilizers. Moreover, 96% of the respondents feel that, reuse will transmit communicable diseases and 4% think there is a health effect in using fecal matter. When explanation was given, 63% of the dwellers were ready to use sludge if education is provided to the people, and proper treatment is effected, while 37% of the surveyed people are not ready since it is not their culture and they believe fecal sludge can cause diseases. This implies that, to some extent, there are some cultural restrictions surrounding the issue of handling human excreta in the city. Where workable technology and education is availed to people, there is a potential of using the fecal sludge in Dsm. (the city has available 37.6% agricultural land). Apart from treatment in pit-latrines, that is "drop and store" system which is known since times immemorial (Nelson, 1983), there are very limited treatment options for faecal sludge in Dsm. Septic tanks and sewerage, available to a small proportion of city residents (*see Table 2.1*), receive wastewater from flush toilets. The authorities feel that it is a good idea if a pilot program for reuse purposes is demonstrated to the people. They felt that, people do not know enough at the moment about reuse of feacal sludge.

2.5 Some Further Thoughts

Sanitation problems in the city should be dealt with in an integrated manner; because even if an individual tries to improve the infrastructure within one's premises, still potential hazards could be imported from upstream or in neighbouring premises. So, decisions about improvement of the settlement should be reached together with the stakeholders by taking into account important aspects of needed infrastructures. Given the complexity of the city of Dsm., application of different excreta disposal systems is possible.

The choice of suitable excreta disposal facility should as well look at seasonal and geographical distribution of diseases. For example, in Tanzania, the peak of cholera outbreak always coincides with the two rainy seasons of October to December and March to May. Understanding this enables the responsible authorities to enforce the environmental sanitation measure that will alleviate the problem. Those seasons reflect the role of water as a transmission route of diseases and hence, avoiding contact between water and human waste by adequate provision of disposal facilities diminishes the problem.

2.6 Conclusions and Recommendations

In conclusion, it is evident from the study that:

- The richer and more knowledgeable people become, the more expensive human waste disposal systems they use.
- People opt for elevated pit-latrines as a result of high water-table without understanding the pollution potentials to groundwater. They have however a habit of building deep pits.
- People do not know enough about reuse potentials of excreta and urine and, hence, the local government leaders feel that demonstration structures will enhance the people's understanding.
- Many farmers (96%) are afraid about the safety of sludge.
- Many people (52%) bath in the same place as the pit-latrine.
- People are still using and will continue to use pit-latrines for the long time.
- Excreta disposal problems in the city are rapid population growth, high water table, pit flood risks, inadequate human and financial resources (poverty), cultural habits, inaccessible settlements (occupied by 70% of the residents), serious lack of centralized data on sanitation in the country, no set places for sludge disposal, no sanitation policy and strong legislation and also the present operation is far from optimal.
- In competition of resources, excreta disposal facilities are not a priority of the people.
- The education level of most of the residents (over 71%) is low.
- Some tanker operators are not aware of what to suck (sludge or water part) from the latrine pits, but they want to suck as frequently as possible.
- Urine separation and rainwater harvesting are minimally practiced in Dsm.

On the basis of the study results, the following recommendations are presented:

1. Knowledgeable people should give health educational campaigns to any technology beneficiaries for creation of awareness.
2. Pilot structures and examples for reusing the faecal sludge are necessary.
3. Further research on the performance of human manure should be done for different agricultural crops.
4. Guidance on proper way of handling the sludge should be developed and availed to the beneficiaries according to the interviewee and local government leaders.
5. Improved pit-latrine technologies (like ecosan) are important in order to reduce air pollution and reuse the resources in sludge.
6. Provision of dry latrines in the city should go hand in hand with hygiene education and provision of separate bathing places.
7. Composted sludge could remove some of the doubts of the farmers about safety of the product.
8. Shallower pits will facilitate the reuse of sludge.
9. Given the diversity nature of the city, application of different excreta disposal systems needs to be given consideration.
10. Loans or a latrine construction fund could assist in changing the current situation for better.
11. Past experiences of the high water table should be used in proposing improved excreta disposal facilities.

CHAPTER 3

ANALYTICAL METHODS

3.1 Determination of COD fractions of the samples

After taking the samples, it was checked to see if visible solids were present. If visible solids were present, the total COD (CODt) of the sample was determined using the titrimetric COD determination as explained in section 3.2.1. If no visible solids were present, the micro-COD method was used to determine the CODt of the sample as shown in section 3.2.2. There has not been a case where the same sample was tested using the two methods to ascertain their level of error. To distinguish between different COD fractions in the samples they were subsequently filtered through a paper filter. For paper filter, the 595 1/2 Schleicher & Schuell Folded Filters diameter 125 mm. Ref. No. 311644 were used. Part of the paper filter samples was used for membrane filtration. The samples were then filtered through the membrane with specifications Schleicher & Schuell ME 25121 STL 090 0.45 µm and diameter 47 mm. Used pump specifications: Balzers, Brown Bover with Optibelt - VB - 13X 1016 A40. Gauge: W. C. Heraeusug. B. H. Hanau a. Main Torr, Made in Germany. Nonetheless, in the absence of electricity an alternative for filtration was to pass the jet of water through a tube (for suction) while filtration is taking place.

3.2 The analytical Methods used

3.2.1 Total Chemical Oxygen Demand Determination via Titration Method

COD serves as a general parameter that covers all organic constituents of sludge. The sludge COD was determined according to titrimetric method which is an adaptation of the NEN normative 3235 5.3 (Standard Methods, 1992); which has the principle that, organic material is oxidized by potassium bichromate in acid conditions with a help of a catalyst (Ag^+). The used procedure was modified for high COD concentrations by weighing the samples between 0.5 to 1.5 g sludge and adding water up to 20 g. A blank using 20 ml. of demi-water only was prepared as well. Subsequently, very little mercury sulphate (a knife tip) and boiling stones were then added followed by 20 ml. $K_2Cr_2O_7$ (1N) plus 40 ml. H_2SO_4/Ag_2SO_4 (30 g Ag_2SO_4/l). After mixing carefully, the samples were boiled at 150^0C for two hours. Ambient air cooling was done after boiling and soonafter, the contents were transferred to the 250 ml. COD volumetric flask and filled up-to-level by demi-water; out of which, 25 ml. were pipetted into a conical flask, demi-water added to 100 ml. mark and then, titrated with ammonium iron (II) sulphate (0.15 N Mohr's salt solution $Fe(NH_4)_2(SO_4)_2.6H_2O$) with 2 drops of ferroin indicator. At the end point of titration, the colour changed from green to brown.

A titre was prepared to determine the concentration of ammonium iron (II) sulphate by pipetting 10 ml. potassium bichromate (0.25 N) into a conical flask and filled up to 100 ml. mark by distilled water. Then, 25 ml. H_2SO_4 18M was added and mixing effected. It was allowed to cool and then, titrated like samples and blank. The exact volume of titrant solution used in titration was recorded. Since the concentration of the titer of Mohr's salt changes with time, its concentration was determined for every analysis (Gaillard, 2002).

Note: The samples which showed varying COD results (especially those from ecological sanitation toilets), the Heidolph Diax 900 machine; Type: DIAX 900; No: 598-02000-00-0; AC 230V; 50/60 Hz; 900W; 8000-24000 1/min.; Ser. No.: 010001104 was used to homogenize the samples.

- **Calculations**

a) Titer (t) = A_{II}*N_o/V = (10*0.25)/V **(3.1)**
where: A_{II} = The amount of $K_2Cr_2O_7$ for the titer (10 ml.)
N_o = The normality of $K_2Cr_2O_7$ for the titre (0.25 N)
V = amount of ammonium iron (II) sulfate used for titration (ml.)

b) COD (mg/l) = ((V_1 - V_2)*t*80,000)/Y **(3.2)**
whereas: V_1 = amount used to titrate blank (ml.)
V_2 = amount used to titrate sample (ml.)
Y = weight of the sample (grams)

3.2.2 Chemical Oxygen Demand Determination via Micro-COD method

The Micro-COD method used was as described by Jirka and Carter (1975) for analysis of unfiltered, paper and membrane COD fractions. The prepared samples were diluted ten times and out of which 5 ml. were pipetted into the duplicate COD test tubes that were clean already. A blank was prepared by pipetting 5 ml. of demi-water only into the COD test tube. Then, 3 ml. of potassium bichromate, 7 ml. Ag_2SO_4/H_2SO_4 (H_2SO_4 M = 98.08 g/mol; 1 litre = 1.84 kg) were added to all test tubes. After mixing well, the samples were placed in the oven at 150^0C for 2 hours. Thereafter, they were cooled for at least 1 hour and the extinction values were determined by 600 nm. wavelength of spectrophotometer (Type: Spectronic Instruments, Spectronic Unicam Model 4001/4, Cat. 4001/4 Sn 3SGC 265041, Spectronic 20 Genesys^{TM}, Made in USA).

- **Calculations**

The different COD fractions of interest were calculated as shown in the following equations:

$COD_{ss} = COD_t – COD_p$ **(3.3)**
$COD_{col} = COD_p – COD_{dis}$ **(3.4)**

whereas: COD_{ss} = COD of suspended solids
COD_t = Total COD
COD_{dis} = COD from membrane filtered samples
COD_{col} = Colloidal COD

3.2.3 Determination of Total and Volatile (Suspended) Solids, {TS(S) & VS(S)}

The TS, VS, SS and VSS were determined according to the Standard Methods (1992) with all measurements done in duplicate samples.

3.2.4 Specific Methanogenic Activity Test (SMA)

Methanogenic activity was determined using acetate as sole substrate (initial concentration 1 g COD/l). In 500 ml serum flasks 2-4 g VSS/l of sludge, nutrients and trace elements was added. The pH was corrected to be between 7.0 – 7.3. All the bottles' contents were topped up with demi-water to 500 ml. mark, and placed in a shaker, Labo Tech, HS 500 with 101 r.p.m. over night. Subsequently, the bottles were taken out of the shaker and were shaken twice per day manually (morning and evening). The gas produced daily was passed through a 3% solution of NaOH (at the time of measuring) and the displaced volume measured in a measuring cylinder as shown in Figure 3.1. It was envisaged that, the CO_2 will be adsorbed and CH_4 would be released to the head-space where its pressure will cause displacement in solution which is equivalent to the amount of methane produced.

Media Preparation and Acetate Solution

The nutrient media prepared was concentrated five times in order to capture the little values needed which are difficult to measure. The composition used was NH_4Cl - 0.28 g/l, K_2HPO_4 - 0.25 g/l, $MgSO_4.7H_2O$ - 0.10 g/l, $CaCl_2.2H_20$ - 0.01 g/l, $NaHCO_3$ - 2.5 g/l, Yeast - 0.05 g/l and trace elements 1 ml. The yeast was added on the day of experiment in order to avoid spoiling of the media. In order to get good dissolvation, the media was mixed using Vario mag Electronicruhrer equipment. The acetate solution was prepared in such a way that, the resulting solution is 100 gCOD/l.

Trace Elements

The trace elements prepared had this composition: $FeCL_3.4H_2O$ - 2000 mg/l, $CoCl_2.6H_20$ - 2000 mg/l, $MnCl_2.4H_2O$ - 500 mg/l, $CuCl_2.2H_2O$ 30 mg/l, $ZnCl_2$ - 50 mg/l,
H_3BO_3 - 50 mg/l, $(NH_4)_6Mo_7O_{24}.4H_2O$ - 90 mg/l, $Na_2SeO_3.5H_2O$ - 100 mg/l, $NiCl_2.6H_2O$ - 1000 mg/l, EDTA - 1 ml/l, Resazurin - 500 mg/l.

3.2.5 Stability Test

The stability Test was determined by firstly measuring the total COD for the initial samples (*as in section 3.2.1*) and TSS and VSS as in section 3.2.3. Subsequently a certain amount of sludge sample (specified in respective chapters) was added to 300 ml. serum bottles. The samples were prepared in duplicate. Soonafter, the pH was corrected to between 7.0 - 7.3, using pH meter 3051 Jenway made in U. K. All the bottles, contents were topped up to 300 ml. mark by demi-water. Then, a blank was prepared by adding distilled water to 300 ml. mark. Then, the bottles were flushed with N_2 each for 5 minutes, after which, they were kept in a shaker with 101 r.p.m at ambient laboratory temperature over night. Soon after, the batch bottles were removed from the shaker and left at ambient temperature where they were shaken manually twice per day and the methane gas monitored as explained in section 3.2.4.

3.2.6 Ascaris Eggs Determination

The ascaris egg determination for ecosan sludge samples was done at the University College of Lands and Architectural Studies (UCLAS) Dispensary. The procedure was as follows: weighed 3 g of the faecal material sample and put in a stoppered bottle containing 42 ml. of distilled water. (If faecal material is hard 42 ml. of 10N NaOH is required instead of distilled water). Placed glass beads in the bottle and shook the bottle vigorously until the faeces are completely broken down. Removed the stopper and stirred the mixture to obtain an even suspension of eggs. While stirring the mixture and immediately pipetted 0.15 ml. of the mixture, placed it in a microscope slide and covered with 22 mm. cover slip. Soonafter, examined the fluid under the whole cover slip systematically with an x10 eye piece and x10 objective, counting all the eggs present and recording them.

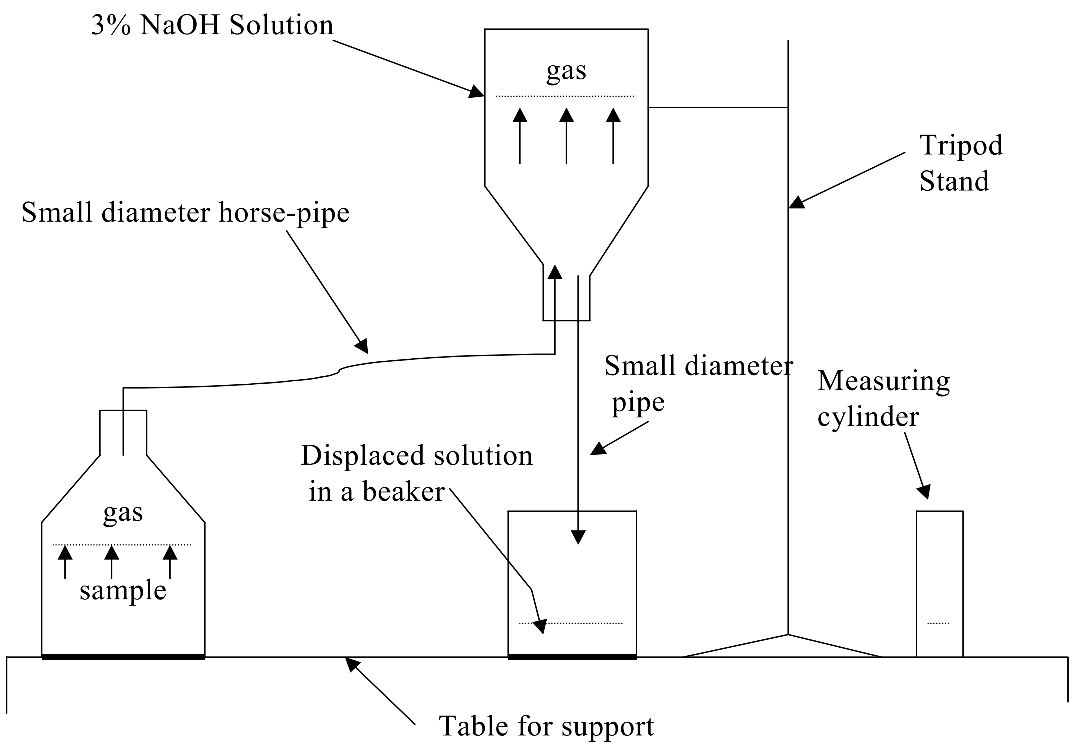

Figure 3.1: Laboratory Experimental Set Up for Methane Gas Volume Determination

- **Calculations**

Since the dilution of the faecal material is 1:15 (3g faecal material in 42 ml. distilled water), and since 0.15 ml. sample is hundredth part of 15, then the number of eggs present in the 0.15 ml. sample multiply by 100 represents the number of eggs present in 1g of faecal material.

3.2.7 *Faecal Coliforms* Determination

Sterilize and label the petri –dishes. Place absorbent pad in the petri-dish. Measure 2ml. of nutrients necessary for faecal coliforms growth and put in the petri–dish containing absorbent pad. Take 1ml. of the sample, 9ml. of distilled water and put them in a beaker. Place a filter paper (pore size = 45 μmm diameter) under the funnel of a vacuum pump. Take the contents from the beaker and pour in vacuum pump funnel and switch on the vacuum pump machine. After filtration, switch off the machine, carefully remove the filter membrane and put it in the petri-dish containing nutrients. Cover the petri-dish and incubate at 40^oC oven. After 24 hours of incubation, counted how many colonies have grown per ml. of the sample.

3.2.8 Determination of TKN (Nkj) and NH_4-N of the Sludge

The Standard Methods (1992) was used for the determination of TKN. The specifications of the used machines were Gerhardt Scrubber Unit Turbosog with behrotest ET1 (for temperature set and revolutions) behr-Labor-Technik and Vapodest machine for distillation.

The titrimetric method was used for determination of NH_4-N according to Standard Methods (1992). Cadmium reduction and diazotization methods were used for determination of NO_3-N and NO_2-N. The total-N was calculated as a sum of NO_3-N, NO_2-N and TKN.

3.2.9 VFA Determination

The volatile fatty acids (VFAs), which are the primary substrate of the methanogenesis, occur as by-products of acetogenesis and acidogenesis. 1.5 ml. sample was put in labelled plastic centrifuge tubes and centrifuged for 10 minutes at 6000 r.p.m. Soonafter, 1ml. of the supernatant was taken and diluted 10 times. Then, 1ml. of diluted sample was put into labelled (code, date and time) glass GC injection vials into which, 0.1 ml. of formic acid was added using 100µl pipette into VFA bottles and covered. The samples were then stored in a fridge at 4^0C awaiting GC analysis. At an appropriate time, the samples were posted to Wageningen University's Laboratory for GC analysis. The gas chromatograph; Hewlet Packard, model 5890A, Palo Alto, USA equipped with a 2m. x 2mm. (inner diameter) glass column, packed with Supelco port (100-120 mesh) coated with 10% Fluorad FC 431 was used. Operating conditions were column, 130^0C; injection port, 200^0C; flame ionization detector, 280^0C. N_2 saturated with formic acid at 20^0C was used as a carrier gas (30 ml/min).

- **Calculations**

The results were recorded in mg/l so the conversion factors used for COD calculations were for: C_2 – 1.0667 mgCOD/l, C_3 – 1.514 mgCOD/l, i-C_4 and n-C_4 – 1.818 mgCOD/l, b-C_5 and n-C_5 – 2.039 mgCOD/l. All the values were multiplied by the dilution factor afterwards.

CHAPTER FOUR

MODELING OF ANAEROBIC CONVERSION OF BLACK WATER AND NIGHT SOIL IN ACCUMULATION SYSTEMS

Abstract

The anaerobic conversion/digestion of night soil and black water in accumulation systems (AC) is becoming more and more popular and attractive for practical applications (Zeeman *et al.*, 2000; Kujawa-Roelveld *et al.*, 2002). This is because anaerobic digestion at high solids concentration (undiluted waste) reduces the reactor volume and also the final material handling problems occurring in liquid wastes are significantly diminished (Molnar and Bartha, 1989). However, because experiments take a long time and the AC reactors are mostly unstirred, it is difficult to assess the course of the concentration of the different COD components produced and degraded in the accumulating sludge. To facilitate the state of sludge at different days of accumulation, a simple model has been developed and used for both black water AC and night soil AC systems conditions. These conditions were chosen as a representative of the actual systems to be applied in tropical countries – and presently investigated in the study area in Dar-es-Salaam, Tanzania. The influent parameters into the model were determined from field data and literature values. With the model, 380 days of accumulation of night soil and black water was simulated. The model has proved to be a suitable and powerful tool in understanding the anaerobic conversion processes going on in the reactors, and –quite important – to estimate the design and operational criteria of these types of digestion systems, for example like pit latrines and septic tank systems.

4.1 Introduction

Often micro-biological experiments require long time and adequate space to perform them depending on the scale needed. However, the engineer who try to learn everything that is known about a topic nowadays will have no time to solve his or her own problems (Walas, 1991). This is because, the systems in the world today continue to be complex and solutions are needed soonest (Shapiro and Gross, 1981). Solutions in environmental protection are also urgently needed to prevent the spread of excreta related infections in many developing countries. Here better sanitation facilities should be supplied or used and since sewerage is very expensive, DESA (Decentralized Sanitation) options are most appropriate, that is, applied either for a house on-site or smaller and larger scale community on-site situations. Amongst the wide variety of DESA systems, the accumulation (AC) systems seem very promising as they are relatively simple and cheap (*see also Chapter 1*). Moreover, the use and operation of AC systems is very similar to the pit-latrine vaults that are currently in use in many undeveloped areas. AC systems are operated as fed-batch systems, there is no daily effluent or sludge to be disposed off apart of the daily produced biogas. The waste(water) is continuously fed and effluent is obtained only once during the time when the reactor is full. Two conditions are possible for a full reactor: a) can be full with liquid + some sludge, and b) full with sludge. For the former condition, the liquid effluent is emptied and part of the sludge left as seed for the next use cycle. The latter condition produces sludge effluent that is emptied and certain amount left at the bottom of the reactor for subsequent use. Basically, in these systems, upon emptying, a certain amount of stabilized sludge is left at the bottom of the reactor as seed sludge for the next use cycle. In principle some time will pass before the AC system is filled up completely, while the research time and finances are limited. Moreover, the processes in the vaults are slow, and the reactors are difficult to do representative sampling as the reactors are expected to have limited mixing. Therefore, modeling on the basis of reliable data obtained from various types of laboratory (digestion) studies brings more insight into what processes are important and taking place and offer some principles for drawing conclusions on the kinetics of biological conversion processes observed (Zeeman and Lens, 2003). Sinclair *et al.* (1987) summarized that, whether one seeks to interpolate "between" measured data, or to extrapolate "beyond" them, or to apply them in a generalized way and after due modification to radically different set-ups, a model is very useful. It is very helpful in experimental observations carried out under circumstances more limited than those to which we would like our conclusions to be applicable and brings attention to factors which otherwise might be overlooked.

In view of these aforementioned views, in this chapter a simple model is developed for AC systems. With the model results of two AC systems were obtained, one fed with black water and the other with night soil. Black water as used in this thesis means faeces plus urine and including water used for cleaning after defecation and urination termed as wash water. The night soil in this respect means faeces and wash water only and urine is collected separately. These conditions were chosen as a representative of the actual systems existing in the tropical study area, Dar-es-Salaam (Dsm.), Tanzania. The influent parameters into the model were determined from field data and literature values.

4.2 Modeling the Biological Conversions in Accumulation Systems

Batstone *et al.* (2002) presented the Anaerobic Digestion Model No. 1 (ADM1). In this ADM1 the anaerobic digestion process of proteins, carbohydrates and lipids is approached separately. Moreover, the production and conversion of the different volatile fatty acids is modeled. In this chapter we present a much simpler but much more relevant model. First of all the digestion of proteins, carbohydrates and lipids is not regarded separately, but they are lumped together and regarded simply as particulate components (X). The reason why we choose this approach is that, for slow rate systems it does not make sense to differentiate so much in detail. Moreover too few reliable kinetic information is available for this type of complex waste. The same is done for the volatile fatty acids. They are lumped together and regarded as soluble component (S). The anaerobic digestion process can be separated into 4 main sub-processes, hydrolysis, acidification, acetogenesis and methanogenesis. When regarding the anaerobic digestion of domestic sewage, black water or night soil in accumulation systems the hydrolysis and methanogenesis are the processes that need to be taken into consideration as they are the ones which are likely to become rate-limiting at some stage during the digestion (Zeeman *et al.*, 2000). Figure 4.1 presents the anaerobic conversion processes considered in the model. In the model it is considered that blackwater and night soil contain degradable particulate components (X_{deg}), inert particulate components (X_i), inert soluble components (S_i) and volatile fatty acids, including also other low molecular weight components like lower alcohols, which frequently are produced in minor amounts (S_{vfa}). During digestion, the degradable suspended solids undergo hydrolysis/acidification in order to produce volatile fatty acids and acidogenic biomass (X_{vfa}). The volatile fatty acids are converted by methanogens mainly into methane (S_{me}) and a small amount of methanogenic biomass (X_{me}). When the biomass decays, the model assumes that they are recycled back to the process. The stochiometry and rate of the processes are presented in Table 4.1. The rate of the hydrolysis is considered to follow first order kinetics. The production of acidogenic biomass is modeled by denoting a fraction (Y_{vfa}) of the hydrolysed particulate components to biomass. The decay processes are also considered to follow first order kinetics. Here it is considered that a fraction (f_{xi}) of the biomass is not biodegradable. The methanogenesis is considered to follow Monod kinetics.

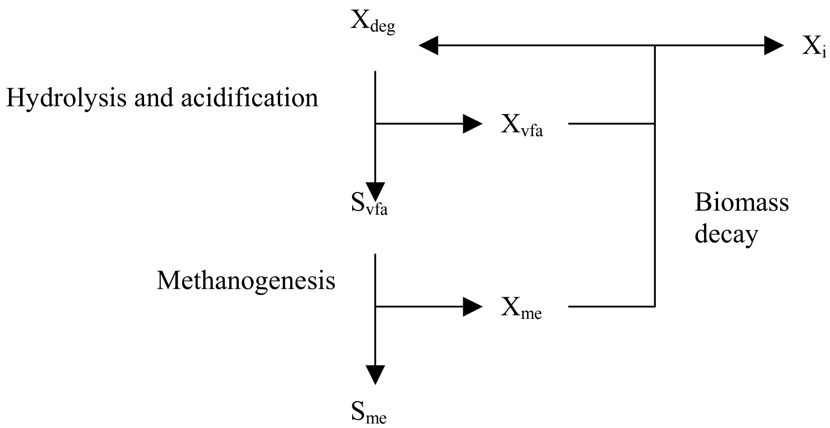

Figure 4.1: Schematic Representation of Anaerobic Conversion Processes described in the model

Table 4.1: The Process Matrix for the Biological Conversions in the Model

Components → **Process ↓**	X_{deg}	X_i	X_{vfa}	X_{me}	S_{vfa}	S_{me}	**Rate**
Hydrolysis/ Acidification	-1		Y_{acid}		$1\text{-}Y_{vfa}$		$k_h X_{deg}$
Methanogenesis				Y_{me}	-1	$1\text{-}Y_{me}$	$\frac{k_m S_{vfa} X_{me}}{K_s + S_{vfa}}$
Decay X_{me}	$1\text{-}f_{xi}$	f_{xi}		-1			$Kd.\ X_{me}$
Decay X_{vfa}	$1\text{-}f_{xi}$	f_{xi}	-1				$Kd.\ X_{vfa}$

where: X_{deg} = Degradable Suspended Solids (g COD/l)
X_i = Inert Suspended Solids (g COD/l)
X_{vfa} = Acidifying biomass (g COD/l)
X_{me} = Methanogenic biomass (g COD/l)
S_{vfa}= Volatile Fatty Acids (g COD/l)
S_{me} = Dissolved methane (g COD/l)
f_{xi} = Fraction inert Solids in biomass
k_h = First order hydrolysis constant (d^{-1})
Y_{acid} = fraction of biomass resulting from the hydrolysis and acidification
Y_{me} = Yield factor of methanogenic biomass (g/g converted)
k_m = Maximum Substrate Utilization rate for methanogenic biomass (COD/COD/d)
k_s = K_s for methanogenic biomass (g COD/l)
k_d = First order decay rate of biomass (d^{-1})

Despite the fact that this thesis focuses on tropical temperatures of 25-37^{0}C it is worthy to mention low temperature effects on anaerobic digestion; as AC systems also find application at psychrophilic temperatures (Kujawa-Roeleveld *et al.*, 2003). A study of **An**aerobic **W**ater **T**reatment (AnWT) of low strength wastewater at psychrophilic conditions revealed a number of issues (as summarized in *Table 4.2*) some will be reflected in the values of the model parameters (k_h, k_m, k_d …etc) when the model is implemented for psychrophilic conditions. However, in this chapter only mesophilic temperatures are addressed.

Table 4.2: Problems/Issues on Anaerobic Digestion of wastewater at Low Temperature (3 to 20 ^{0}C) Conditions

Problem/Issue	Outcome	Reference
Chemical and biological reactions proceed much slower than at mesophilic conditions so low stable sludge production	Considerable higher SRT is needed in order to get longer sludge age for conversion purposes.	Rebac (1998); Zeeman *et al*. (2000); Van Lier, Rebac and Lettinga (1997); Calvacanti (2003); Zeeman and Lettinga (1999)
Most reactions in biodegradation require more energy to proceed	Increased cost of wastewater treatment in order to achieve similar conversion percentage as at 30^{0}C	Rebac (1998); Zeeman *et al*. (2000)
Very low biogas production rate	Low mixing intensity and poor substrate-biomass contact	Van Lier, Rebac and Lettinga (1997)
Lowering the operational temperature leads to maximum specific growth and substrate utilization rates	Effluent of low quality and may increase the biomass yield	Van den Berg (1977); Lin *et al.*, (1987)
Change of physical-chemical properties of wastewater	Affects design and operation of treatment system	Rebac (1998)
Increased solubility of gaseous compounds	Higher dissolved concentration of methane, hydrogen sulphide and hydrogen in effluent	Rebac (1998)
High increase of solubility of CO_2 and low methanogenic sludge activity	Slightly lower pH might be expected in reactor	Rebac (1998); Kato (1994)
High viscosity of liquids	More energy is required for mixing and sludge bed reactors are less easily mixed particularly at low biogas production rates.	Rebac (1998); Mahmoud (2003)
Decreased liquid-solids separation	Slow particle settling	Rebac (1998)
More energy required to bring the wastewater to more optimal mesophilic range (30-40^{0}C)	Heavy burden on the economy of wastewater system	Rebac (1998)
Low degree (rate) of hydrolysis, Lower rate of acidogenesis, and low rate of decay of acidogenic biomass	Accumulation of suspended solids, decreased methanogenic capacity, removal efficiencies, the fraction of organic matter degraded and virtually impossible short HRT	Haandel & Lettinga (1994); Miron *et al.*, (2000); Zeeman and Lettinga (1999); Rebac, (1998); Elmitwalli (2000); Lettinga *et al.* (2001); Bogte *et al.* (1993)
Accumulation of acetate and increased accumulation of SS in the sludge bed	Low activity of acetoclastic methanogens and/or an increased activity of homoacetogenic bacteria, reduced solid retention time	Lettinga, *et al.* 1999); Inamori *et al.*, (1983); Genung *et al.*, (1985); Sanz and Fdz-Polanco (1990); Zeeman and Lettinga (1999)
Low metabolic rates	Psychrophilic sludge stabilization proceeds at a very low rate, drop in the soluble COD removal efficiency	Van Lier, Rebac and Lettinga (1997); Last and Lettinga (1992)

4.3 Implementation of the Model for Accumulation Systems

AC reactors in principle are fed-batch systems. They are started with a certain amount of seed sludge and are subsequently fed with (waste)water until they are full. During this period of filling no effluent leaves the system, but biogas is produced. After filling, the reactor is emptied except for a small amount of seed sludge, after which it is again ready for the next use.

a) Mass Balance

The mass balance over the reactor is determined by the fact that, the waste entering the latrine vault accumulates and methane is the only COD-flow coming out of the reactor. The following relationship depicts the situation:

$$COD_{in}(t) = COD_{acc}(t) + \Delta COD_{me}(t) \qquad \textbf{(4.1)}$$

where:
$COD_{in}(t)$ = total COD input in reactor at time t (g COD)
$COD_{acc}(t)$ = total COD present in reactor at time t (g COD)
$\Delta COD_{me}(t)$ = cumulative methane production at time t (g COD)
t = period of time the reactor has been in operation (days)

The different component parameters of Equation 4.1 are calculated in turn as shown in the following Equations 4.3 to 4.10 together with their assumptions.

b) Reactor Fill-up Volume

The fill-up reactor volume increases as users daily load the waste into the system. The amount of sludge accumulating in the sludge bed or sludge bed volume, is calculated as shown in Equation 4.14. Volume of the reactor at any point in time can therefore be calculated using the following equation:

$$V_t = V_{inoc} + Q*t \qquad \textbf{(4.2)}$$

where:
V_t = Volume of waste in latrine vault at any time during the filling period (litres)
V_{inoc} = Inoculum or seed sludge volume (litres)
Q = Flow entering the toilet vault (l/d)

c) Influent Flow, Q

The influent flow to an AC system treating night soil depends on several parameters. These are:

1. The number of people using the toilet (n_p)
2. The portions of urine supplied to the toilet per person per day (n_u)
3. The portions of faeces supplied to the toilet per person per day (n_f)
4. The volume of the urine supplied (V_u) (in Liter/portion)
5. The volume of the feaces supplied (V_f) (in Liter/portion)
6. The volume of the flush water of the toilet in use (V_{flush}) (in Liter/flush)

With respect to the parameters above two assumptions can be made:

a) Each person defecates only one time per day. This means that $n_f = 1$.
b) Most people also urinate when defecating.

The flow to the AC system can therefore be calculated with Equation 4.3

$$\mathbf{Q = n_p\left(V_f + n_u \cdot V_u + n_u \cdot V_{flush}\right)} \quad \textbf{(4.3)}$$

d) Total COD entering the AC System $COD_{in}(t)$

The amount of COD that has entered the AC system at any point in time (t) can be calculated using Equation 4.4. Note here that Equation 4.4 has been developed with the assumption that, seed sludge has only inert suspended COD (X_i) and methanogenic biomass (X_{me}) meaning that it was a very stabilised sludge.

$$COD_{in}(t) = (t*Q(X_{deg} + X_i + X_{vfa} + X_{me} + S_i + S_{vfa})) + V_{inoc}\,(X_{i(inoc)} + X_{me(inoc)}) \quad \textbf{(4.4)}$$

where: X_{deg} = Influent degradable suspended solids (g COD/l)
X_i = Influent inert suspended solids (g COD/l)
X_{vfa} = Influent acidifying biomass (g COD/l)
X_{me} = Influent methanogenic biomass (g COD/l)
S_i = Influent inert solubles (g COD/l)
S_{vfa} = Influent volatile fatty acids (g COD/l)
$X_{i(inoc)}$ = Inert suspended solids in inoculum or seed sludge (g COD/l)
$X_{me(inoc)}$ = Methanogenic biomass in inoculum or seed sludge (g COD/l)

From Equation 4.4 it can be seen that the influent is considered to consist of several different fractions of COD. However, when in practice only the total suspended, total dissolved COD and volatile fatty acid COD can be assessed directly from a wastewater, the COD fractions needed in the model have to be derived indirectly. The relation between the wastewater characteristics and the influent parameters as needed in the model is presented in Table 4.3.

e) Total COD Fed to the System in the AC System at Time (t), {$COD_{acc}(t)$}

The amount of COD that has accumulated in the AC system at any point in time can be calculated using Equation 4.5.

$$COD_{acc}(t) = V(t)*[X_{deg(t)} + X_{i(t)} + X_{vfa(t)} + X_{me(t)} + S_{i(t)} + S_{vfa(t)}] \quad \textbf{(4.5)}$$

where: t = period of time the reactor has been in operation (days)
$X_{deg(t)}$ = degradable suspended solids after time t (g COD/l)
$X_{i(t)}$ = inert suspended solids after time t (g COD/l)
$X_{vfa(t)}$ = acidifying biomass after time t (g COD/l)
$X_{me(t)}$ = methanogenic biomass after time t (g COD/l)
$S_{i(t)}$ = inert solubles after time t (g COD/l)
$S_{vfa(t)}$ = volatile fatty acids after time t (g COD/l)

Table 4.3: Relationship Between Measurable Wastewater Characteristics and the Model Influent Parameters

Wastewater characteristics			Model influent parameters
	Biodegradable COD		X_{deg}
Total suspended COD	Inert COD		X_i
	Biomass COD	acidogenic biomass	X_{vfa}
		methanogen. biomass	X_{me}
Total dissolved COD	Inert COD		S_i
	Volatile fatty acid COD		S_{vfa}

calculations and assumptions

X_{deg} = Suspended COD * biodegradable fraction of suspended COD

X_i = Suspended COD * (1-biodegradable fraction of suspended COD)

X_{me} = 0

X_{vfa} = Dissolved COD * biodegradable fraction of dissolved COD* Y_{acid}

S_{vfa} = (Dissolved COD*biodegradable fraction of dissolved COD)- X_{vfa}

S_i = Dissolved COD - X_{vfa}-S_{vfa}

Note:

- The biodegradable fraction of the suspended and dissolved COD can be assessed by measuring the methane production from the separate components in a biodegradability assay (Angelidaki and Sanders, submitted).
- For the model only volatile fatty acids and inert dissolved COD are considered. All the biodegradable dissolved COD in the influent is considered to be VFA, taking into account that biomass will yield from this action.

The model as presented in the matrix (*Table 4.1*) can easily be simulated in specially developed simulation software. In this chapter however, it is choosen to present full equations for calculation of the COD fractions during the digestion, as it was found to give better insight in the processes. To simplify the calculations it is assumed that, at any point in time the AC system is in 'steady state', which in this case is defined as the conditions at which always sufficient methanogenic activity is present in the reactor to ensure complete conversion of the volatile fatty acids. This means:

$$S_{vfa}(t) = 0 \qquad \textbf{(4.6)}$$

There is no production of S_i during digestion as seen in the model scheme this means that any of the X_i will not pass in solution (*Figure 4.1*). Moreover, it is assumed that the seed sludge volume contains no S_i. The concentration of inert dissolved COD is therefore merely dependent on the inert dissolved COD in the influent.

$$S_i(t) = \frac{t * Q * S_{i(in)}}{V_t} \qquad \textbf{(4.7)}$$

For further calculation of the accumulation and conversion of the suspended COD fractions it is assumed that the Accumulation System consists of several small batch reactors + one large seed batch reactor. The small reactors represent the daily fed waste, which implies that, these batches have different retention times depending on the day when they were deposited. This assumption is schematically presented in Figure 4.2. The accumulated suspended COD fractions for the whole reactor can in principle then be calculated by the sum of the seed sludge batch and the separate batch reactors from the daily feed. This principle is presented in Equation 4.8. Note that in this equation the conversion of X is assumed to follow first order kinetics (see also *Table 4.1* and *Figure 4.1*).

$$X(t) = \frac{V_{inoc} \cdot X_{inoc} \cdot e^{-kh \cdot time} + Q \cdot X_{influent} \cdot e^{-kh \cdot 1} + Q \cdot X_{influent} \cdot e^{-kh \cdot 2} + \cdots + Q \cdot X_{influent} \cdot e^{-kh \cdot time}}{V(t)}$$

$$X(t) = \frac{V_{inoc} \cdot X_{inoc} \cdot e^{-kh \cdot time} + \sum_{t=1}^{t=time} Q \cdot X_{influent} \cdot e^{-kh \cdot t}}{V(t)} \qquad \textbf{(4.8)}$$

with:
X(t): concentration of X in the AC system over time (days) after reactor start-up (g COD/l)
V_{inoc}: volume of the inoculum or seed sludge (l)
X_{inoc}: concentration of X in the inoculum or seed sludge (g COD/l)
Q: influent flow (l/d)
$X_{influent}$: concentration of X in the influent (g COD/l)
t : period of time the reactor has been in operation (days)
t=1 to t=time represent the summation of the contents of the small reactors from day 1 to a certain time (days) of accumulation.

From Table 4.1 and Figure 4.1 it can be seen that production of acidifying biomass (X_{vfa}) results from the conversion of biodegradable suspended solids (X_{deg}). However, X_{vfa} is also decaying. Both processes are first order relations and $X_{vfa(t)}$ can therefore in analogy to Equation 4.8 be presented as:

$$X_{vfa}(t) = \frac{\sum_{t=1}^{t=time} Q \cdot \left(X_{deg} - X_{deg} e^{-kh \cdot t}\right) \cdot Y_{vfa} \cdot e^{-kd \cdot t} + Q \cdot X_{vfa} \cdot e^{-kd \cdot t}}{V(t)} \qquad \textbf{(4.9)}$$

where:
$X_{vfa}(t)$: concentration of X_{vfa} in the AC system over time (days) after start-up of the reactor (g COD/l)
X_{deg}: Concentration of X_{deg} in the influent (g COD/l)
X_{vfa}: Concentration of X_{vfa} in the influent (g COD/l)
Y_{vfa} = fraction of acidogenic biomass from hydrolysis and acidification
k_h = first order hydrolysis constant (d^{-1})
k_d = first order decay rate of biomass (d^{-1})

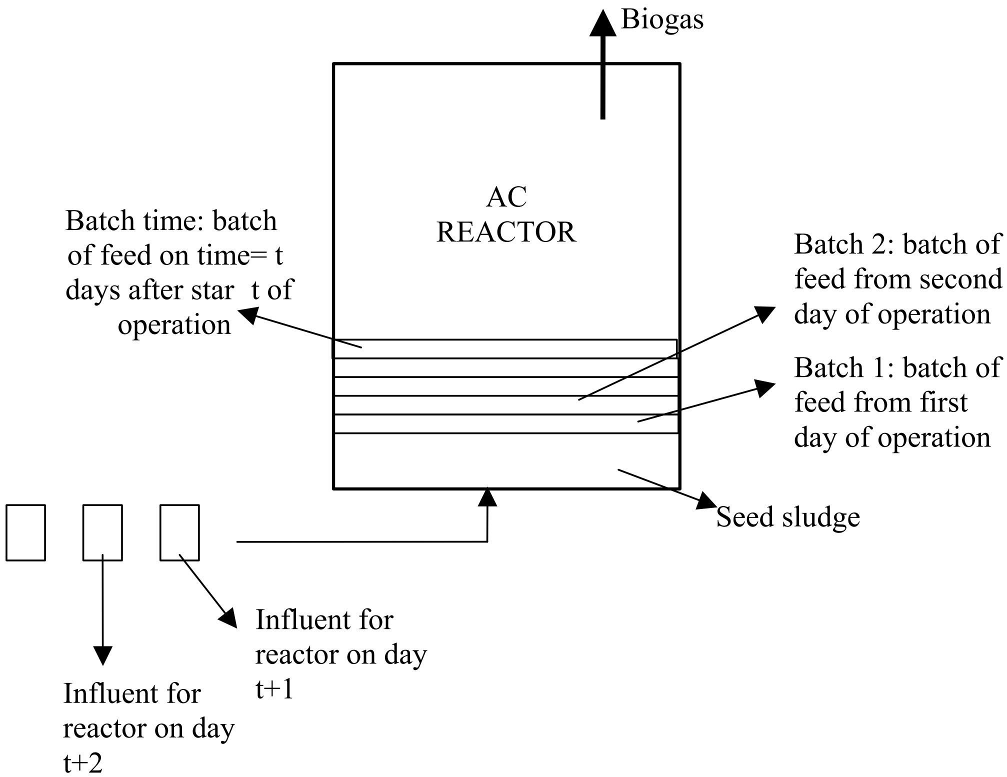

Figure 4.2: Schematic Representation of the Calculation Procedure for the Suspended Solids Fractions in the AC System

The subsequent step in the conversion of biodegradable components is then the yield of methanogenic biomass and production of methane. The concentration of methanogenic biomass in the AC system can be calculated from Equation 4.10. In this equation also the methanogenic biomass in the seed is taken into account.

$$X_{me}(t) = \frac{\sum_{t=1}^{t-time} Q \cdot \Delta X_{\deg} \cdot (\mathbf{1} - Y_{vfa}) \cdot Y_{me} \cdot e^{-kd \cdot t} + V_{inoc} \cdot X_{me(inoc)} \cdot e^{-kd \cdot t} + Q \cdot X_{me} \cdot e^{-kd \cdot t}}{V(t)}$$

(4.10)

where:

$X_{me}(t)$: concentration of X_{me} in the AC system over time (days) after start-up of the reactor (g COD/l)

X_{me}: concentration of X_{me} in the influent (g COD/l)

$X_{me(inoc)}$: Concentration of X_{me} in the inoculum or seed sludge (g COD/l)

Y_{me}: Yield of methanogenic biomass (g/g converted)

$\Delta X_{\deg} : X_{\deg} - X_{\deg} e^{-kh \cdot t}$

The concentration of inert suspended solids, $X_{i(t)}$, results from the decay of X_{vfa} and X_{me}, the influent flow of X_i and the amount of inert suspended solids in the seed sludge. $X_{i(t)}$ can be described with Equation 4.11.

$$X_i(t) = \left(\frac{\sum_{t=1}^{t=time} Q \cdot \Delta X_{\deg} \cdot Y_{vfa} + Q \cdot X_{vfa} - Q \cdot \Delta X_{\deg} \cdot Y_{vfa} \cdot e^{-kd \cdot t} - Q \cdot X_{vfa} \cdot e^{-kd \cdot t}}{V(t)} + \right.$$

$$\frac{\sum_{t=1}^{t=time} Q \cdot \Delta X_{\deg} (1 - Y_{vfa}) \cdot Y_{me} + Q \cdot X_{me} - Q \cdot \Delta X_{\deg} (1 - Y_{vfa}) Y_{me} \cdot e^{-kd \cdot t} - Q \cdot X_{me} \cdot e^{-kd \cdot t}}{V(t)} +$$

$$\left. \frac{V_{inoc} \cdot X_{me(inoc)} - V_{inoc} \cdot X_{me(inoc)} \cdot e^{-kdt}}{V(t)} \right) \cdot f_{xi} + \frac{V_{inoc} \cdot X_{ino}}{V(t)} + \frac{t \cdot Q \cdot X_i}{V_t} \qquad \textbf{(4.11)}$$

with:
$X_i(t)$: concentration of X_i in the AC system over time (days) after start-up of the reactor (g COD/l)
X_i: Concentration of X_i in the influent (g COD/l)
X_{inoc}: Concentration of X_i in the inoculum or seed sludge (g COD/l)

The concentration of degradable suspended solids, $X_{deg(t)}$, is mainly dependent on the hydrolysis rate. But as can be seen from the scheme of the biological conversion (*Figure 4.1*) the decay of biomass contributes to X_{deg}. In reality this X_{deg} produced from decayed biomass will be converted further to methane. However in this theoretical exercise, only one loop of COD conversion has been calculated. This implies that, there was no recalculation made for several loops and therefore, there is a small underestimation of methane produced.

$$X_{\deg}(t) = \frac{\sum_{t=1}^{t=time} Q \cdot X_{\deg} \cdot e^{-kh.t}}{V(t)} + \left(\frac{\sum_{t=1}^{t=time} Q \cdot \Delta X_{\deg} \cdot Y_{vfa} \cdot e^{-kh \cdot t} - Q \cdot \Delta X_{\deg} \cdot Y_{vfa} \cdot e^{-kh \cdot t} \cdot e^{-kd \cdot t}}{V(t)} + \right.$$

$$\frac{\sum_{t=1}^{t=time} Q \cdot \Delta X_{\deg} (1 - Y_{vfa}) \cdot Y_{me} \cdot e^{-kh \cdot t} - Q \cdot \Delta X_{\deg} (1 - Y_{vfa}) Y_{me} \cdot e^{-kh \cdot t} \cdot e^{-kd \cdot t}}{V(t)} + \qquad \textbf{(4.12)}$$

$$\left. \frac{V_{inoc} \cdot X_{me(inoc)} - V_{inoc} \cdot X_{me(inoc)} \cdot e^{-kdt}}{V(t)} \right) \cdot (1 - f_{xi})$$

f) Total Methane Produced in the AC System {$COD_{me}(t)$}

The produced methane at any point in time can be estimated from the mass balance:

$COD_{me}(t) = COD_{in}(t) - COD_{acc}(t)$ **(4.13)**

g) Final Volume of Sludge Produced in the AC System

So far it is assumed that in the AC reactor no settling of sludge takes place. However, in practice it will settle. To calculate the volume of the settled sludge Equation 4.14 can be used. As shown in Equation 4.14, the amount of sludge produced is the difference of the accumulating COD [COD_{acc}(t)] over time and the concentration of soluble inerts and volatile fatty acids. For conversion into litres of sludge, the sludge concentration of the settled sludge bed is used as a dividend.

$$V_{sludge}(t) = \frac{COD_{acc}(t) - V(t) * (S_{i(t)} + S_{vfa(t)})}{Sludge\ concentration} \qquad \textbf{(14)}$$

with:
V_{sludge}(t): volume (l) of the settled sludge in the AC system over time
Sludge concentration: the concentration of the sludge in the AC system after settling (g COD/l)

4.4 Assessment of Values for Influent and Kinetic Parameters to Model the Digestion of Black Water and Night Soil in AC Systems in Dar-Es-Salaam, Tanzania

In general all people daily produce 100-385 g faeces and 1-1.25 of urine in 3-5 portions (this study; Gaillard, 2002; EET Kiemproject, 2002). In Dsm., many people do not use toilet papers for cleaning themselves after the toilet visit for either defecation or urination. Quite often water is used for the purpose although paper might be better, because the system will fill up more slowly. The amount of wash water was therefore assessed in this study basing on the fact that, after urination and defecation, respectively 0.1 litres/person/toilet visit and 0.25 l/faeces drop is used. Experience has shown that, in Dsm. families are large and many people have relatives and in some cases tenants in their house. The number of tenants depends on the size of the house. It was therefore estimated that on the average about 10 people live in the same house using the same toilet facility. In principle this means that, 10 people will use the accumulation digestion system or reactor.

Currently, in the real life situation in Tanzania, urine and excreta are combined together in a storage facility such as a pit latrine (PL). Basically, a PL consists of a pit, a pit cover (slab) and superstructure possibly with some other features like a ventilation system or a toilet seat. However, faeces and urine have different pollution potential properties. Faeces is the one, which contains the pollutants harmful to human beings and environment at large. It is therefore increasingly seen that, treating the concentrated toilet waste (night soil) is a good possibility (Zeeman *et al.*, 2000). Moreover, the current discussion in many places (developing and developed) is to have urine separation toilets, which give, reduced costs to excreta handling. In view of these options, modelling of the digestion of night soil in PL for the case of Dsm. in Tanzania was effected. Following the above-mentioned scenarios, two situations are modelled for the purpose. One is an AC system without urine separation receiving 1 portion of faeces per person per day and 5 portions of urine per person per day (black water AC) and another one the AC system with urine separation (night soil AC) receiving only 1 portion of faeces per person per day.

Based on above mentioned and literature, the composition of the influent parameters into the model was estimated (*Table 4.5*). For the black water AC, influent includes faeces + urine + wash water (F+U+ww). Whereas for the night soil AC urine is separated and so, the influent is faeces only +

wash water (F+ww). From these facts, the volume/amount of wastewater entering into the reactors were firstly calculated per person per day. For urine, the calculations were (amount of wash water + urine) l/toilet visit x frequency/day + (amount of wash water + faeces) l/faeces drop/day x frequency/day. Soonafter, the influent flows into Black water AC and Night soil AC for 10 people per day were estimated as a product of the individual flows and the number of users.

The estimated influent concentration parameters were converted into model influent parameters as COD fractions for degradable suspended solids (X_{deg}), inert suspended solids (X_i), acidifying biomass (X_{vfa}), methanogenic biomass (X_{me}), the volatile fatty acids (S_{vfa}), inert solubles (S_i) as explained in the calculations in Table 4.1. The f_{xi} (fraction inert solids), k_h (first order hydrolysis constant, d^{-1}), Y_{vfa} (fraction of acidogenic biomass), Y_{me} (yield of methanogenic biomass in mg/mg converted), k_m (maximum substrate utilization rate for methanogenic biomass in COD/COD/h) and k_d (first order decay rate of biomass) were all determined from literature (Batstone *et al*., 2002). The kinetic parameters were chosen according to the operating temperature range of the tropics where the actual situation of the study exists. The different biodegradable fractions of suspended solids found in literature are presented in Table 4.4. For the biodegradability of the influent the values assessed by Gaillard (2002, *Table 4.4*), 84% biodegradability respectively for black water AC and night soil AC systems were used. The reactors were simulated without addition of seed sludge.

Table 4.4: The Literature Values for Biodegradability

Type of waste(water)		Parameter	Biodegradability (%)	Remarks
Faeces + water		COD_t	51.87	Gaillard (2002) experiment at a temperature of 30^0C for 140 days of influent without inoculum
		$COD_{particulate}$	71.72	
Faeces + urine + water		COD_t	51.41	
		$COD_{particulate}$	83.93	
Black water (BW)	Polymeric Substrate	Proteins	50	BW has similar composition with domestic primary sewage sludge Zeeman *et al.* (2000)[*]
		Lipids	60	
		Carbohydrates	50	
Black water, Raw Sewage		COD_t	71-74	Elmitwalli *et al.* (2000)[**], at 30^0C for 135 days
		COD_{paper}	71-74	
		COD_{dis}	62	
Domestic Sewage		COD_t	71-74	Elmitwalli (2001), at 30^0C for 80 days
Faeces from UASB reactor		COD_t	36 – 84 (±15.11)[#]	Lettinga *et al.* (1991) digestion between 32-107 days[@]
Khirbit As-Samra wastewater (domestic and industrial)		COD_t	56.1	Halalsheh (2002) at 25^0C and 15^0C for 130 days
			78.4 (±1.1)	Halalsheh (2002) at 25^0C and 15^0C[^] for 224 days
Abu-Nusier wastewater (domestic)		COD_t	75.8 (±8.6)	Halalsheh (2002) at 25^0C and 15^0C[^] for 130 days
Primary sludge[$]		COD_t	50	Mahmoud (2002) at 35^0C for 10-30 days in CSTR
			57	Mahmoud (2002) at 35^0C for 10-30 days in batches
Dairy Cattle manure		COD_t	39.53	Elmashad (2003) at 50^0C[$] for 83 days
		$COD_{particulate}$	30.2 – 69	Elmashad (2003) at 50^0C[$] for 83 days and Zeeman (1991) at mesophilic conditions

*process temperature was controlled at 25 ± 1^0C for three weeks; ** they cited that no reported data are available to compare the results; ^disaggregated results of the two temperatures is not indicated, only one value is given; values in bracket ( ) signify standard deviation; #average value is 57.25%; @the temperature of digestion have not been cited; [$]The biodegradability of primary sewage sludge showed no temperature dependence in the range of 15-35^0C and Biodegradability was merely assessed at 50^0C since from literature it is known that the temperature does not affect biodegradability (Elmashad, 2003).

Table 4.5: the Influent Parameters into the Model and literature composition values (The Faeces, Urine and wash water for going into the Black water AC calculated from 1 portion of faeces and 5 portions of urine per person per day; Night soil computed from 1 portion of faeces only)

Parameter	Average composition of pure urine and faeces (Gaillard, 2002)		Influent composition for model calculations	
	Urine	**Faeces**	**1 faeces + 5 urine + wash water (Black water AC)**	**Faeces Only + Wash water (Night soil AC)**
			For 10 people/day	**For 10 people/day**
Volume/amount	0.2 l/person/toilet visit	0.138 kg/person/toilet visit	18.9 l/d	3.9 l/d
total COD	12.79 gCOD/l	567.43 gCOD/kg	48.2 gCOD/l	201.8 gCOD/l
dissolved COD	11.33 gCOD/l	89.41 gCOD/kg	12.5 gCOD/l	31.8 gCOD/l
suspended COD	1.46 gCOD/l	455.05 gCOD/kg	34.0 gCOD/l	161.8 gCOD/l
VFA	0 gCOD/l	8.46 gCOD/kg	0.6 gCOD/l	3.0 gCOD/l
Nkj	5.29 gN/l	17.82 gCOD/kg	4.1 gN/l	6.3 gN/l
Biodegr.CODss			84%	84%
Wash water*	0.1 l/toilet visit	0.25 l/toilet visit		

CONVERSION OF NIGHT SOIL COMPOSITION INTO MODEL INFLUENT PARAMETERS (see also *Table 1*)

	X_i (gCOD/l)	X_{deg} (gCOD/l)	X_{-vfa} (gCOD/l)	X_{me} (gCOD/l)	S_{-vfa} (gCOD/l)	S_i (gCOD/l)	Q (l/d)
BLACK WATER AC	7.1	28.6	1.2	0	11.9	0	18.9
NIGHT SOIL AC	34.1	136.0	3.2	0	28.6	0	3.9

Kinetic parameters (Batstone *et al.*, 2002)

k_h, (1/d)	Y_{me} (g/g)	Y_{vfa}	k_{d_vfa} (1/d)	k_{d_me}(1/d)	f_{xi}
0.1	0.05	0.1	0.004	0.004	0.25

*amount of wash water was obtained in this study, no toilet paper is used

4.5 Results and Discussion

4.5.1 Results of model calculations (with model influent)

Figure 4.3 depicts the course of different sludge components and production of methane over a filling time of 380 days of black water AC and night soil AC systems. The production of methane is denoted here as 'maximum possible methane production' rate, because in the calculations it is assumed that the methanogenesis is never rate limiting and VFA accumulation never occurs. However in practice VFA accumulation can occur in some cases. It is evident from the results in Figure 4.3 and Table 4.6 that, the black water AC methane production stabilized after 100 days at a value of about 670 g COD/day. The methane production in the night soil AC stabilized at day 100 at only 550 g COD/day, due to the fact that this reactor receives only faeces. Nonetheless, the concentration of the sludge components in the night soil reactor is higher, due to less dilution by urine.

Table 4.6: The Summary of Model Results after 380 days of accumulation for Black water AC and Night soil AC Systems

Influent Type	X_{deg} (gCOD/l)	% Sludge stabilization*	Total reactor volume (litre)**	Maximum possible gas production gCOD/day
Black water	0.9	97	7319	672
Night soil	4.4	97	1619	554

*Degradation of X_{deg} expressed as % of X_{deg} in the influent; **Volume is for sludge and liquid part together

The main goal of the AC reactors is to achieve maximum stabilization of the black water or night soil. In this case it is defined as X_{deg} = 0 g COD/l or 100% removal of X_{deg}. From the results presented in Figure 4.3 it can be seen that if the reactors had been emptied after one year of filling, the sludge would not have been fully stable. At day 365 still a significant amount of X_{deg} was present in both the night soil and black water reactors. The amount of time required to obtain a certain stability of the sludge depends on the hydrolysis rate of X_{deg}. Figure 4.4 presents the relation between the stability of the sludge (as % removal of X_{deg}), the hydrolysis constant for X_{deg} and the accumulation period as it was assessed with the model. From Figure 4.4 it can be observed that in case of the two simulated AC systems (kh = 0.1 1/day) the accumulation period needs to be 2½ years to achieve 99% stability. In practice 2½ years storage of the black water is not feasible, as it would require $17m^3$ reactor volume. The night soil reactor would require $3.5m^3$. In the practical sense, it would be wiser to leave the sludge in the reactor for some time after closing to allow for complete stabilization. After the reactor receives no daily feed it becomes a genuine batch reactor and the required stabilization period can be easily calculated with the first order relation for batch reactors:

$$X_{deg(t)} = X_{deg\ (at\ closing\ time)} * e^{-kh.t} \qquad \textbf{(4.15)}$$

with t = number of days after closing.

In case of the two simulated AC systems at day 380, X_{deg}(at day 380) = 0.9 g COD/l for black water AC and 4.4 gCOD/l for night soil AC systems and kh = 0.1 1/d this means that after reactor closure it takes 14 days to remove most of the remaining X_{deg} and achieve 99% sludge stability. Of course, the systems cannot be loaded with new influent during this time so that an alternative toilet facility must be provided for the users during the time of stabilization.

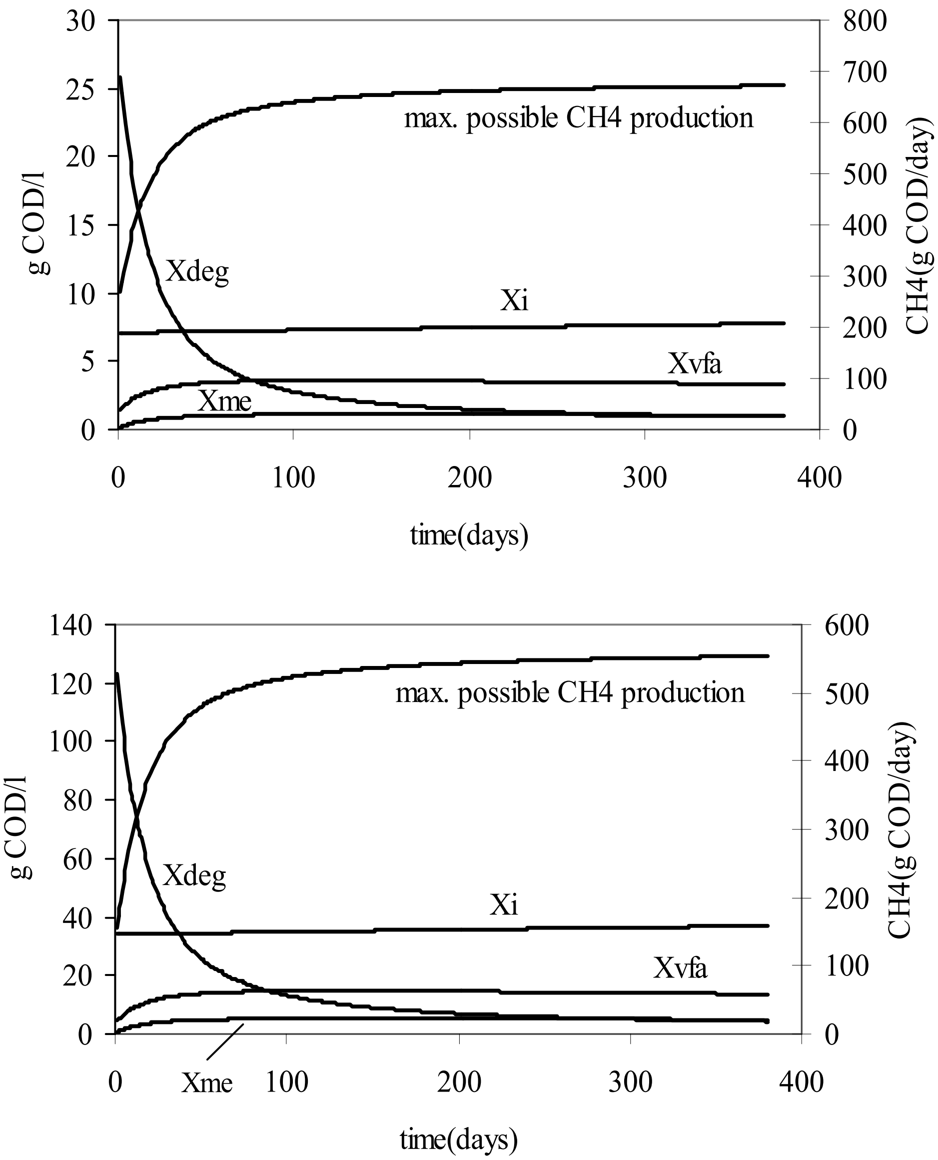

Figure 4.3: The Different COD Fractions and Maximum Possible Methane Production as Determined by Equations 4.1 to 4.14 for Black Water AC (top) and Night Soil AC (bottom) for 380 Filling Days. Influent Model Parameters in gCOD/l were Xi=7.1 & 34.1 Xdeg = 28.6 & 136; Xvfa = 1.2 & 3.2; Svfa = 11.9 & 28.6 with Flows 18.9 & 3.9 l/d Correspondingly for Black Water and Night Soil AC Systems (*Table 4.5*)

From Figure 4.3 it can also be observed that there is a period of about 100 and 80 days respectively for black water AC and night soil AC systems before the possible methane production reaches the maximum level. For reuse purposes this has an implication that, the residents will have to wait for a long period before they get adequate gas for their use purposes.

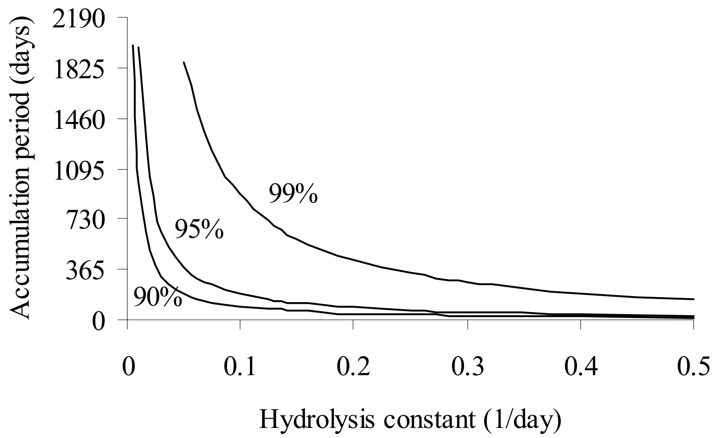

Figure 4.4: Relationship Between the Degree of Sludge Stabilization (expressed as % of X_{deg} removal), the First Order Hydrolysis Constant and the Accumulation Period in the Reactor

4.5.2 Sludge Production

After X_{deg} has been converted, the sludge in reactor consists of inert suspended solids (X_i) and biomass (X_{me} and X_{vfa}). For the simulated black water and night soil reactors, the sum of the remaining sludge components (calculated from $V_{reactor}$ * $\{X_i+X_{me}+X_{vfa}\}$) after all X_{deg} has been removed was 90 kg COD in both cases. In the model it is assumed that the reactor is completely mixed, however most of the suspended solids will settle and form a sludge bed. The volume of this sludge bed will depend on the existing sludge concentration as presented in Equation 4.14. Typical sludge concentrations found in literature for domestic waste water range from 15 to 84 gTS/l (Calvacanti, 2003; Haskoning, 1989; Haandel and Lettinga, 1994; Vieira and Garcia, 1991; Mgana, 2003; Lee *et al.*, 2001)). Assuming a VS:TS ratio of 0.8 and 1.42 kgCOD/kgVS, the total sludge volume in the simulated reactors is therefore expected to be 943 to 5282 litre.

4.5.3 The Effect of Temperature on Gas Production

In the model presented in this chapter it is assumed that, the amount of methanogenic activity is never rate limiting. Therefore, the effect of temperature on biogas production rate can be simulated through different hydrolysis rates (k_h); Figure 4.5 presents the results, which clearly shows that, at low temperatures and subsequent low k_h, the gas production at the start of the accumulation period is low. If the purpose of the reactor is to reuse the gas, it means that people will have to wait for >100 days in order to get the maximum production or adequate gas for use at low temperatures. This will require them to have an alternative source of energy, which means additional cost to families. Higher temperatures result in higher gas production shortly after starting the accumulation of "waste" and hence, possibilities of reuse right from the beginning of reactor use. Tropical conditions are very favourable for high temperatures and the variation of temperatures is not much as in temperate and semi-temperate conditions. Accumulation systems with reuse options for CH_4 are therefore very favourable for those conditions.

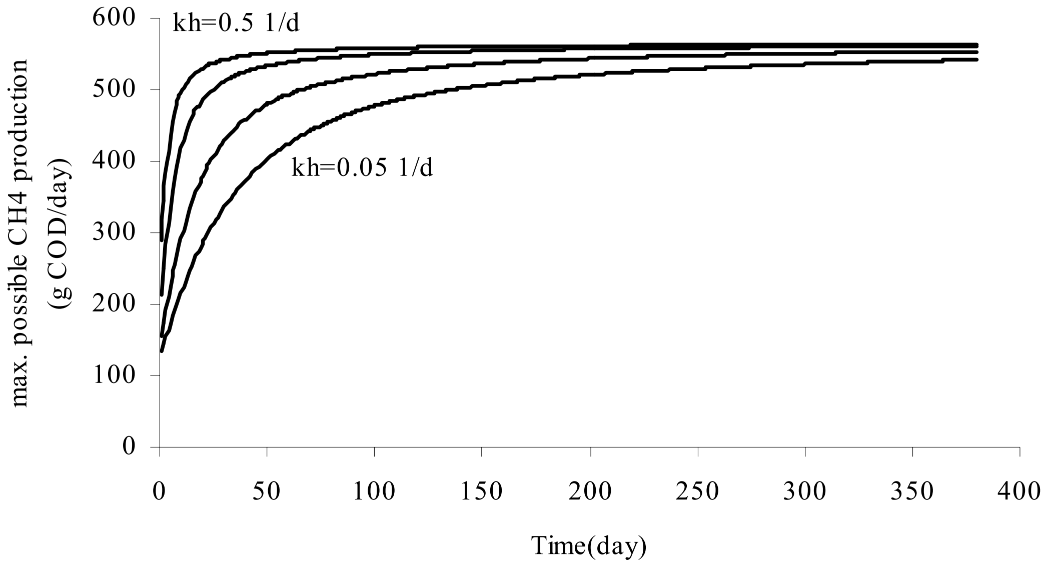

Figure 4.5: The Expected Maximum Achievable Biogas Production in the Night Soil AC from Accumulated Particulates at a Hydrolysis Constant of 0.05; 0.1; 0.25; 0.5 d^{-1}

4.5.4 The Amount of Seed Sludge

So far it has been assumed that during the anaerobic stabilization of human excreta the hydrolysis of the biodegradable suspended solids is the rate-limiting process. This is however only the case if the reactor has been started with seed sludge with sufficient methanogenic activity to convert the VFA at all times. The necessity to add seed sludge depends on the fact of if the aim of the reactor is to reuse biogas. If reuse of biogas is not desired and one only aims at conversion of all VFA at the time of desludging, then seed sludge with sufficient methanogenic activity is not required. On the other hand if reuse is the aim, then sufficient seed sludge has to be added to optimize methane production from the start of operation of the reactors.

In general, it can be stated that the amount of methanogenic activity (sum of the most important catabolic reactions of the methanogens, van Lier *et al.*, 1997) that is supplied with the seed sludge must match the sum of the production rate of volatile fatty acids from biodegradable solids and the rate of volatile fatty acids supply via the biodegradable dissolved components in the influent. The required amount of seed sludge can be estimated from Equation 4.16.

$$V_{inoc} = \frac{(daily\ VFA\ production\ from\ X_{\deg} + daily\ VFA\ from\ \inf luent)}{VSS_{inoc} \cdot SMA_{inoc}} \qquad \textbf{(4.16)}$$

with:
VSS_{inoc} = Volatile suspended solids content of the inoculum or seed sludge (g/l)
SMA_{inoc} = Specific Methanogenic Activity of the inoculum or seed sludge (at applied reactor temperature) (gCOD/gVSS/day)

Daily VFA production from X_{deg} = amount of VFA produced from accumulated biodegradable solids (gCOD/d)
Daily VFA from influent = amount of VFA loaded to reactor with influent every day (gCOD/l)

The maximum daily VFA production from X_{deg} was determined pursuance of Equation 4.16 as shown in Table 4.7. Similarly, the daily influent of VFA was determined using influent parameters indicated in Table 4.5. The VSS_{inoc} and SMA_{inoc} have been assumed as presented in Table 4.7. In the case of Tanzania the hydrolysis constant was assumed to be 0.1 1/d. From Figure 4.5 it can be observed that, at this k_h value the maximum biogas production (and thus VFA production) is achieved within several weeks. Therefore, it is advisable to supply sufficient methanogenic activity with the seed sludge in order to deal with the maximum VFA load. It is clear from the results in Table 4.7 that, the lower the specific methanogenic activity the higher the volume of seed sludge is required. If much seed sludge is needed it means a bigger volume of reactor is necessary and therefore, a more expensive system. Much seed sludge reduces the effective volume of the reactor. A reasonable seed sludge volume would be maximum 10% of the total reactor volume (Zeeman, 1991). In case of the Tanzanian situation (10 persons per AC system, 365 days filling period) this would mean a seed sludge volume of (3.9 l/day*365 days*10%=) 142 liter for an AC treating night soil and (18.9 l/day*365 days*10%=) 690 liter for an AC treating black water. According to Table 4.7 this means that for the first run the night soil reactor should be inoculated with a sludge that has a minimum SMA of 0.5 gCOD/gVSS/d and VSS content of at least 8 gVSS/l. The black water AC should be seeded with a sludge that has a minimum SMA of 0.1 gCOD/gVSS/day and a VSS content of 11 g VSS/l. Other possibilities can be obtained from Table 4.7. For subsequent runs the volume that needs to be left in the reactor after desludging depends on the SMA of the sludge in the reactor. When assuming Monod kinetics with k_m= 1 $gCOD \cdot gCOD^{-1} \cdot d^{-1}$ (Batstone *et al.,* 2002) it can be calculated that for the black water reactor the SMA of the sludge after reactor closure will be about 0.09 g COD-CH_4/g COD-VSS/day or 0.12 g COD/g VSS/day (assuming 1 g VSS=1.42 g COD). At a sludge concentration of 30 g VSS/l the volume to be left in the reactor is about 250 litres.

4.6 Conclusion

The model used in this section offers a wide range of possibilities of determination of sludge composition, interpretation and comparison of different sludge COD fractions, gas produced and sludge production from different waste(water) accumulation systems. The results from model application to black water AC and night soil AC systems exposed that, an accumulation period of 1 year is sufficient to achieve 97% sludge stabilization. If a stability of 99% is required, a stabilization period of 14 days after closing the reactor is needed. For simulated conditions the AC reactor fed with black water should be inoculated with a sludge that has a minimum VSS content of 11 gVSS/l and a SMA of 0.10 gCOD/gVSS/d. The night soil reactor should be seeded with a sludge that has a minimum VSS content of 8 g VSS/l and a SMA of 0.5 gCOD/gVSS/d. Furthermore, it was evident that, the lower the VSS concentration and SMA, the higher the volume of seed sludge and vice-versa. Other desired values can be obtained from Table 4.7.

Acknowledgement

We would like to acknowledge CORETECH and EVEN Project for the financial support of this study.

Table 4.7: The Volume of Seed Sludge needed in the Black water AC and Night soil AC as computed from influent data and Equation 4.16

	Black water AC Reactor												
	Maximum daily VFA load in reactor: VFA from $X_{deg(in)}$: 28.6*18.9 = 540.54 gCOD/d; VFA from $S_{vfa(inf)}$: 11.9*18.9 = 224.91 gCOD/d												
	Volume of Seed Sludge needed (litres)												
$VSS^{\#}_{ino.}$→ $SMA_{ino.}^{@}$↓	1	3	5	8	10	13	15	18	20	23	25	28	30
0.01	76545	25515	15309	9568	7655	5103	4784	4253	3827	3328	3062	2734	2552
0.025	30618	10206	6124	3827	3062	2041	1914	1701	1531	1331	1225	1094	1021
0.05	15309	5103	3062	1914	1531	1021	957	851	765	666	612	547	510
0.1	7655	2552	1531	957	765	510	478	425	383	333	306	273	255
0.25	3062	1021	612	383	306	204	191	170	153	133	122	109	102
0.5	1531	510	306	191	153	102	96	85	77	67	61	55	51
	Night Soil AC Reactor												
	Maximum daily VFA load in reactor: VFA from $X_{deg(in)}$: 116.5*3.9 = 454.35 gCOD/d; VFA from $S_{vfa(inf)}$: 31.6*3.9 = 123.24 gCOD/d												
	Volume of Seed Sludge needed (litres)												
$VSS_{ino.}$→ $SMA_{ino.}^{@}$↓	1	3	5	8	10	13	15	18	20	23	25	28	30
0.01	57759	19253	11552	7220	5776	4443	3851	3209	2888	2511	2310	2063	1925
0.025	23104	7701	4621	2888	2310	1777	1540	1284	1155	1005	925	825	770
0.05	11552	3851	2310	1444	1155	889	770	642	576	502	462	413	385
0.1	5776	1925	1155	722	576	444	385	321	289	251	231	206	193
0.25	2310	770	462	289	231	178	154	128	116	100	92	83	77
0.5	1155	385	231	144	116	89	77	64	58	50	46	41	39

[#] VSS is expressed in gVSS/l [@]SMA is expressed in gCOD-CH_4/gVSS/day

CHAPTER 5

ANAEROBIC STABILIZATION OF BLACK WATER IN ACCUMULATION SYSTEMS "THE DEMONSTRATION REACTOR"

Abstract

The anaerobic digestion of "human waste" was studied in pilot improved pit-latrines at Mlalakuwa residential settlement in Dar-es-Salaam (Dsm), Tanzania at ambient tropical temperatures of 26-30^{0}C. This settlement experiences high water table to an extent that, during the rainy season pit contents flooding is a common phenomenon. Furthermore, householders have to empty the latrine pits (or vaults) at a frequency of once per every month, which is a very costly undertaking. To improve the situation, two plastic tanks of 3000 litres capacity were used as pit-vaults for pilot purposes. They were regarded as pilot **Im**proved **P**it-**L**atrines **W**ithout **U**rine **S**eparation (IMPLWUS); that is, they receive a mixture of faeces + urine + wash-water. While one tank is in use, the other one is on stand-by basis. They are basically accumulation systems. Aims of accumulations systems are to: end up with stable sludge at the time when the latrine or reactor is full with faecal sludge, have zero VFA at the time of emptying the reactor contents and reuse the produced biogas. The tanks were placed under the constructed (within household premises) raised sub-structure and were directly used by households as normal pit-latrines. The IMPLWUS was inoculated with the septic tank sludge as a start-up. Recording of influent flow, different COD fractions (total, paper and membrane), volatile fatty acids, ammonium nitrogen, kjeldhal nitrogen, stability of sludge, methanogenic activity, pH, temperature, methane gas produced, sludge bed height and accumulation were determined during the time when the waste was daily entering the vault.

The stability results showed that, by day 354 the sludge was not yet completely stable. The incubated samples produced 0.2-0.4 gCOD-CH_4. The model results showed that X_{deg} at that day was ~1.96 gCOD/l (97.1% conversion of influent X_{deg}). VFA was 100 mgCOD/l at day 380 when the reactor was closed indicating that the reactor contents have not yet been completely degraded and hence, more time is needed for complete degradation. Due to leakages in the reactor no biogas production could be detected. From the incubated samples results and literature, it has to be concluded that the gas production will not be adequate to completely substitute the existing amount of energy needed for cooking meals for 5-6 people per day. Organized sludge disposal/reuse place at emptying time is necessary. However, educating the users to know what to do when the reactor is filled with sludge and at the sludge emptying stage is necessary.

Key words: Performance, Improved pit-latrines, tropical conditions, human waste, model.

5.1 Introduction

The use of pit-latrines (PL) is the most common and simplest form of excreta disposal, widely used by many residents in Tanzania both in urban and rural areas. Since one of their basic structural component is a pit in the ground, in high water table areas (HWT), they are often completely filled with underground water and therefore inconvenience the users and pollute the groundwater (GW). In these cases, people solve this problem by improving their traditional PLs into elevated pit-latrines (EPL). This is basically increasing the height of the substructure above ground level (*see chapter 2 for details*). Nonetheless, this practice solves only the problem of convenience but does not take away the other problems of seeping dirty water, which ends up polluting the GW. So, in order to avoid GW pollution, the pit has to be completely sealed; a situation which makes it a genuine accumulation (AC) system. Sludge in such an AC system has got different ages as they accumulate in different times. The sludge age and not the liquid retention time were found by Cavalcanti (2003) to be fundamental operational parameter in waste stabilization ponds. Different liquid retention times at the same sludge age, would tend to have the same efficiency.

In chapter 4, a model to assess the course of the concentration of different COD components of the black water produced and degraded in AC has been presented in detail. The desired level of stabilisation can be determined from the model and the quality and amount of inoculum needed for an AC reactor for black water can be obtained up-front. At higher temperatures the biogas production is faster than in lower temperature cases.

The already investigated accumulation systems include a study on mesophilic and psychrophilic digestion of liquid manure; TS <100 gTS/l (Zeeman, 1991), wastewater characterisation and estimation of digestion kinetics for the anaerobic digestion of concentrated domestic wastewater streams in an accumulation system (Gaillard, 2002) anaerobic digestion of solid animal manure at mesophilic and thermophilic conditions start up (Elmashad, 2003) and co-digestion of concentrated black water and kitchen refuse in an accumulation system within a DESAR concept (Kujawa-Roeleveld *et al.*, 2002). The AC system is the simplest system for on farm use; it combines storage and digestion, needed because, manure cannot be used during winter in the Netherlands (Zeeman, 1991). Elmashad (2003) noted that, during the digestion of solid cow manure in an AC system, at 60 days filling time followed by 50 days batch digestion a total hydrolysis, acidification and methanogenesis of 45, 33 and 32% occurred correspondingly at 40^0C, and 50, 35 and 35% occurred at 50^0C respectively. The black water studied by Kujawa-Roeleveld *et al.* (2002) was collected with the use of vacuum toilet as collection and transport system. This means that, electricity is an important component for the system to function. This is not a suitable system for developing countries (DC) where electricity is not widely distributed, very expensive where available and supplied intermittently. There have not been many tested options locally to give wider solution choices of the experienced problems.

In this chapter, the practical demonstration of an AC in the form of **Im**proved **p**it-**l**atrine **w**ithout **u**rine **s**eparation (IMPLWUS) reactor, which is similar to the reactor simulated in the above-mentioned model, is shown. Positive features, which are advantageous to the developing countries of IMPLWUS is that, no electricity is needed to load the reactor, is constructed using locally available materials and local labour. Hence, the system is relatively cheap than as compared to traditional PL in HWT which requires monthly emptying due to filled pit. Furthermore, it is water-tight avoiding or solving the problem of GW contamination, quick filling of PL from intrusion of seepage from storm and GW, reduces the frequency of desludging and nuisance for the users. In order to complete the useful circle of nutrients and energy, reuse of digested blackwater and biogas is important. Despite their importance, the latter has not yet been demonstrated in this study.

This study therefore focuses on the performance of an experimental IMPLWUS under ambient tropical temperature (26-30^{0}C) conditions. The main objective of this study was to assess the design criteria for anaerobic accumulation of faeces and urine in PL type AC system. These criteria were assessed via studying the implementation and performance of an IMPLWUS in a 'real life' situation.

5.2 Materials and Methods

5.2.1 A Short Description of the Study Area

To provide for the above-mentioned necessary improvements to the conventional pit latrine, demonstration reactors were constructed. The location of the demonstration reactor was chosen to be in an unplanned settlement; namely Mlalakuwa in Dar-es-Salaam (Dsm.) an area that experience very HWT. In this place, the residents desludge their pit-vaults once every month. Quite often, it is water that is taken out of the pit. This frequency is too high. They pay ~37 US$ (1999 *exchange rates*) for the pit emptying which is very expensive for them as most of them do not have paid jobs (*see chapter 2*). Since the area is experiencing HWT, the pit did not take long to fill again and so, quite often, the emptying was done mainly on the liquid part of the contents. Such place was regarded as ideal for getting the technical and social out-puts of the provided improved latrines. At that area, a demonstration reactor was constructed, namely IMPLWUS.

5.2.2 Set-up of the Demonstration Reactor

As the wastewater is allowed to accumulate in AC systems, there is no daily sludge or liquid effluent with an exception of the produced biogas. The effluent is taken only after the reactor has completely filled. Therefore, the total volume of the AC system depends primarily on the amount of provided wastewater, demanded storage period and seed sludge volume (*chapter 4*).

The house at which the IMPLWUS system was installed has got a total number of 10 people at the time of the research and hence, it was envisaged that 10 persons would daily use the system. From field study and literature it was assessed that each person produced 5 portions of urine per day with a total volume of 1.25 liters (*see Table 4.5 chapter 4*). Besides that each person produces 0.138 kg of feaces per day (1 portion) (Wijst en Groot-Marcus, 1998). In the study area (Mlalakuwa) water is mostly used for cleaning after toilet use and not toilet paper. For this study, 0.25 liters of cleaning water was estimated to be used after every defecation and 0.1 liter after urination was estimated as “wash water” (ww). Based on these values it can be calculated that, the IMPLWUS reactor has to store (10*(1.638+0.5)) = 21.38 liters of wastewater/day.

The aim of this research was to construct and demonstrate an AC system built from locally available materials. The IMPLWUS reactor was therefore constructed from cylindrical plastic tanks produced by *Simba* (Swahili word meaning Lion) Plastics Company Limited in Tanzania. The company named the tanks SIMTANK. The available size locally in the market is 3000 litre. In chapter 4 it was argued that the maximum seed sludge volume is 10% of the total volume and hence, 300 liters was reserved for seed sludge leaving 2700 liters for accumulation of black water. At a flow of 21.38 liters per day this means that, the reactor can store black water supply of 126 days. From Figure 4.3 it can be expected that at day 126 the amount of degradable suspended solids (X_{deg}) in the AC system will be 2.4 g COD/l. At an influent concentration of 28.6 gCOD/l (X_{deg},

Table 4.5) the stability of the sludge will then be 91.6 % according to the model (*in chapter 4*), implying that, the sludge will need further stabilisation after closing the reactor.

The main problem of the traditional and elevated pit latrines is the possible contact of the stored waste with the ground water. In case of the IMPLWUS systems the tanks were kept in constructed above ground pits or vaults; which means the sub-structures are above the normal ground level. In case of the normal or traditional PL the sub-structure is a hole in the ground for storage and degradation of faecal matter. EPLs are constructed by owners' effort without any technical guidance (*see Table 2.6 Chapter 2*). Part of the sub-structure of those latrines is underground and a part of them is raised above ground. In both cases the walls of the substructure allow penetration of groundwater into the latrine. The tanks of IMPLWUS are made of plastic so that the faeces and urine are sealed off from the environment. The schematic representation of the reactors is shown in Figure 5.1 and the main features are summarized in Table 5.1.

The influent of IMPLWUS enters through the inlet pipe (diameter 152.4 mm. or 6-inches) and drops to the bottom of the vault (pit). Faeces stay there and the new incoming matter always continue to come in a similar manner and the accumulation continue over time. There is no forced mixing. Little mixing will occur when the incoming matter (faeces and urine) drops down and due to gas bubbling from the settled sludge.

The gas collection in IMPLWUS case is through the fixed plastic pipe at the top part of the tank (*see Figure 5.1*). The seed sludge used for IMPLWUS came from a septic tank which is about 15 years old located at a distance of ~1km. from the study site. A sample of one litre was taken from the seed sludge to assess the following parameters: total COD, filtered COD, dissolved COD, COD_{ss}, COD_{col}, specific methanogenic activity (SMA), total-N, TSS and VSS. Analytical methods are explained in Chapter 3. The results are presented in Section 5.3 of this chapter. 10% of the reactor vault volume was filled with seed sludge. This means, 300 litres for the 3000-litre tank.

Table 5.1: The Main Features of Improved Pit-Latrine Without Urine Separation (IMPLWUS)

Feature		IMPLWUS
Tank Material		Plastic (SIMTANK)[*]
Capacity		3000 litres
Placed		Above ground sub-structure[**]
Rooms or vaults		Twin-vaults
Mode of Operation		Mixed faeces + urine + washwater
Extra Provision		One Stand-by vault
Methane Gas Outlet		Collector at top of tank
Thermometer Fit		The mid side of the tank (back)
Sampling points		4[#] (bottom, middle, top, above top)
Inlet Mode		Top Inlet pipe Ø 15.24 cm. (6”)
Squatting Place		Direct Squatting hole inlet with down-pipe
Fittings material		All PVC after changing from former ones
Loading population		10 people
Height of the tank[/]		1665 (mm)
Width[/] (Ø) of the tank		1700 (mm)
~ weight of the tank with water[/]		3090 kgs.
Sampling points	Top[@] control	34
	Top	33
	Middle	30
	Bottom	26 cm.
Height of Housing Slab		192 cm.

[*]SIMTANK is a factory given name. The Factory is *Simba* (Lion) Plastic Ltd. Located in Dar-es-Salaam; [**]but, under the squatting slab; [#]There is a fifth point but used as a contol point to see when the vault is full. [/]Company Dimensions; [@]Top control is a valve inserted in order to know when the tank is full. It was not used as a sampling point.

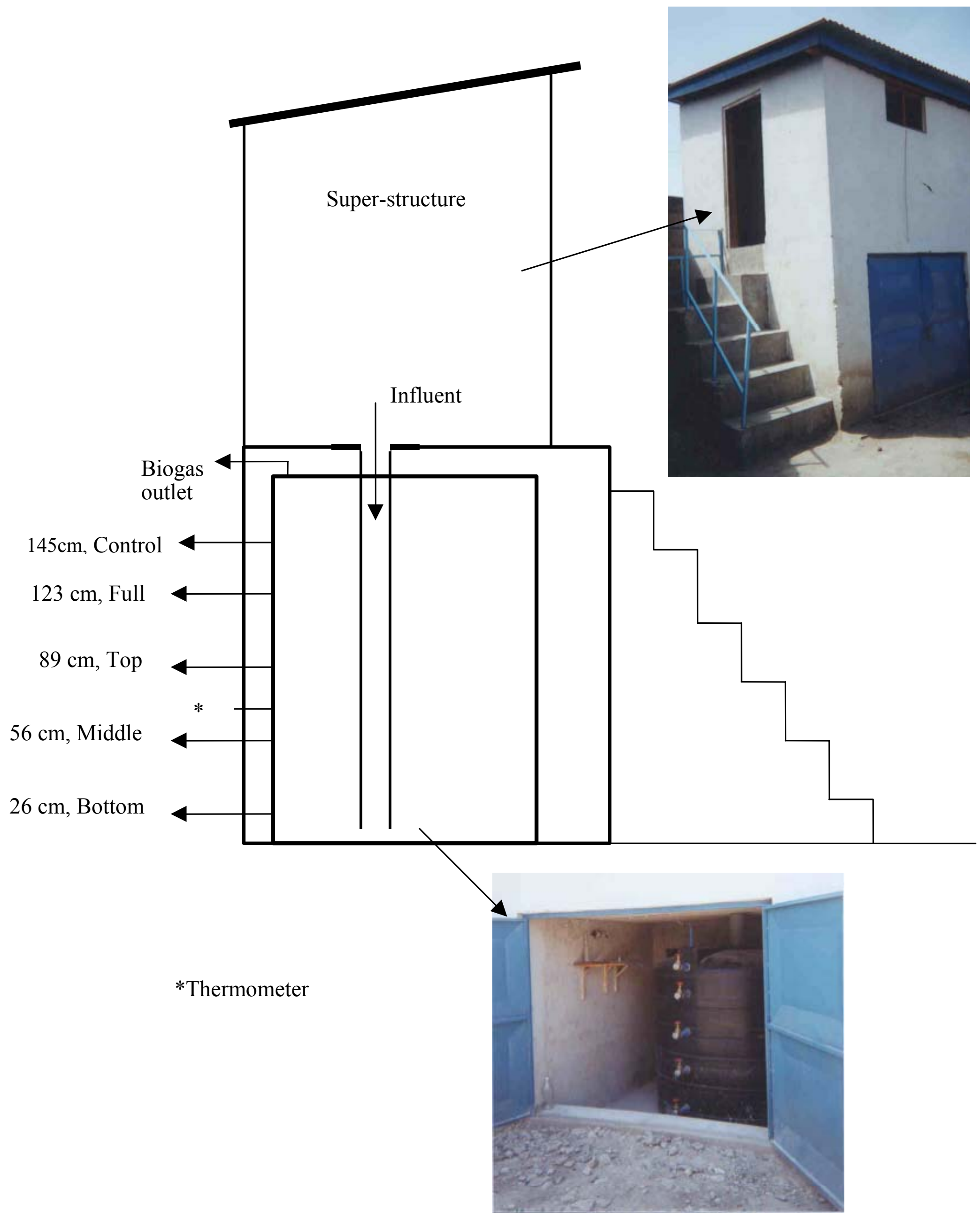

Figure 5.1: Schematic Diagram of a 3000 litre Improved Pit-Latrine Without Urine Separation (IMPLWUS) at Mlalakuwa Area in Dar-es-Salaam

5.2.3 Analyses Done on the Demonstration Reactor

5.2.3.1 Recordings of Influent

The seed sludge was added to the IMPLWUS before the residents started using the reactor. During the use of the AC systems, each user was requested to fill an up-front prepared sheet indicating whether (s)he deposits urine and faeces, date, time, adult or child. The explanation was given to the users before they started filling the sheet. It was left in the toilet superstructure wall for users to fill after every use. The so obtained information assisted in understanding the easiness and consistency of filling the data by the communities and served as a guide to see whether people were using the research latrines or not. Nonetheless, this exercise was very much dependent on whether the user knows how to read and write or not. Inhabitants were requested to give assistance when the users are not educated, and if it is a child who uses the toilet, the parents were kindly asked to help in filling the data. Unplanned spot checks were made in order to see how the whole pattern goes and to solve any difficulty faced by residents (users) on-site.

Residents were directly using the latrine vault with a specified amount of water for cleansing themselves; 0.25 litres of ww were estimated per defecation and 0.1 litres ww was allowed as cleansing water after urination. Squatting floor slab cleaning water was not directed into the latrine vault. Water saving increases the concentration of various pollutants in wastewater and decrease treatment costs (Henze, 1997). Mahmoud (2002), Halalsheh (2002) and Elmitwalli *et al.* (2003), noted that, in developing countries, water used for toilet flushing seems limited as compared to that in developed countries, as municipal wastewater of developing countries is more concentrated.

Furthermore, the assessment of the actual filling of the reactor was noted from the accumulated amount of wastewater at certain set sampling point (*Figure 5.1*) level using the relationship detailed in Equation 4.2. This relationship assisted in determining the missing average values in the community filled forms. The actual date of the full reactor was noted from the field study. From this knowledge, together with Equation 4.2 and community filled data, the average flow that was going into the IMPLWUS during use time was calculated.

5.2.3.2 Samples Taken

The samples taken for laboratory work were for COD_{dis} and VFA for the first three months once/week and thereafter, once per month. The pH was determined every sampling time on-site using pH meter (3051 Jenway made in U. K.). It was reading the temperature at the same time. However, the reactor temperature was recorded continuously through the fitted thermometer in the reactor side (*see Figure 5.1*). In the laboratory, a thermometer was placed in order to determine the ambient temperature constantly. The total suspended solids/volatile solids were done when the solids were available. Nkj and NH_4^+-N were analysed out at every sampling time. The methodology of assessment used is shown in Chapter 3.

5.3 Results and Discussion

5.3.1 Seed sludge Results

The results (*Table 5.2*) of the used seed sludge from a septic tank revealed that, the activity of the sludge was 0.06 (±0.039) gCOD/gVSS/d. During a start-up of the UASB reactor without inoculation in Indonesia, it was evident that, processes take place at a low rate so that more time (approximately 30 days) is needed before an actively digesting sludge will have been produced (Lettinga *et al.*, 1991) but, using seed sludge shortens the start-up period (Zeeman, 1991). However, comparing the data (*Table 5.2*) with those of other seed sludges proposed in Table 4.7 for black water, that is minimum VSS content 11 g VSS/l and a SMA of 0.1 gCOD-CH_4/gVSS/d. with seed sludge volume of 690 liters; the 300 litres and the seed sludge activity used in this study are inadequate (relative to model results in *Chapter 4*) and hence, VFA accumulation is expected in the beginning period of the reactor use. From Table 5.2 it can be seen that the seed sludge used in the experiment contained a significant amount of dissolved COD. Unfortunately the VFA were not assessed in the seed sludge, so it is unclear if some VFA was introduced to the system with the seed sludge.

Table 5.2: Characterization of Seed Sludge Used for IMPLWUS

Parameter	Amount Determined
Total COD	8.23 ($gCOD_t$/l)
Dissolved COD	5.833 ($gCOD_{dis}$/l)
Particulate COD	1.447 ($gCOD_{ss}$/l)
Colloidal COD	0.950 ($gCOD_{col}$/l)
SMA* at 30^0C	0.06 gCOD/gVSS/d
Nkj	0.543 (g/l)
NH_4	0.0602 (g/l)
Total Suspended Solids	6.287 (gTSS/l)
Volatile Suspended Solids	1.292 (gVSS/l)

*Specific Methanogenic Activity

5.3.2 Influent Flow and Urine:Faeces Ratio

It was assessed based upon the recordings of the toilet users that, on average 9.68 portions of faeces per day were supplied to the system. Assuming that each person defecates only once per day, it can be concluded that about 10 persons were actually making use of the toilet. However, a lot of variations in feaces deposit were observed ranging from 0-36 portions per day. From day 155 to 185 the amount of faeces deposits increased to 18.6 portions per day. During that time a baby was born in the house and many people came for the parties. Although the supply of feaces to the system seemed to be varying, the observed filling of the reactor via the sampling points was very gradual (*Figure 5.2*). The different heights (sampling points) of the IMPLWUS were cumulatively filled, as waste was daily entering (accumulating) in the pit. The time for the wastewater to reach to the bottom, middle, top and full sampling points is presented in Figure 5.2. In Table 5.3 the subsequent average daily flow with standard deviation in the bracket, during the filling periods is presented. The calculated (*section 5.2.3.1*) 380 days filling time showed that the total average daily flow entering the IMPLWUS was 6.67 liter/day according to Equation 4.2.

In Figure 5.3, the daily urine to feaces ratio is depicted. From this figure it is very evident that, the residents did not fill the needed data sheet continuously. From the days that the data sheet was filled it can be calculated that the average urine to faeces ratio was 1.344. Only in two cases the ratio reached a value as high as 3.5 - 4. During the time of the party the urine to feaces ratio did not change. Before the community started to use the IMPLWUS, the results indicated that, people urinate on average 3-5 times per day.

Table 5.3: Influent Flow Into IMPLWUS Reactor As Assessed From the Height of the Wastewater in the Reactor

Period (Days)	Loads Urine + Faeces (l/d)
1-28	10.7
28-166	5.8
166-275	6.9
275-380	7.3
Average*	**6.67 (±2.538)**

*determined with Equation 4.2

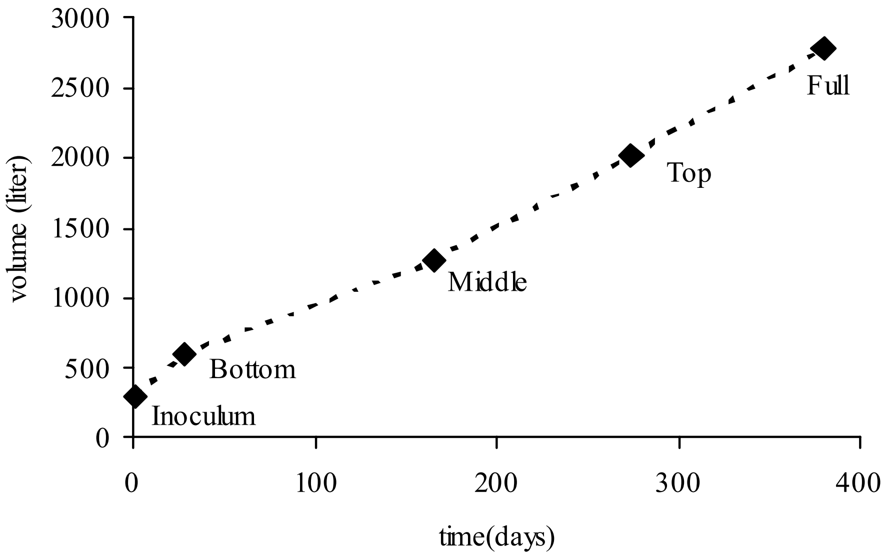

Figure 5.2: Cumulative Height of Wastewater in the Improved Pit-Latrine Without Urine Separation (IMPLWUS) Determined for 380 days

The actual recordings during full-scale use revealed a different picture for the studied area. This result means that, for urination, it is evident that, the households were not always using the IMPLWUS especially for those who are most of the time at home. This can be explained by the reality that, the old unhygienic latrine was not closed, did not have stairs and was at the back of the house and possibly, people were using it for urination and so, a low urine:faeces ratio. Moreover, this ratio suggests that, most of the urine is dropped during faeces deposit.

During the time of the research, spot-checks were made in order to assist the users on any difficulty they had on-site. From the flow results (*Figure 5.2*) it can be concluded that the vault of IMPLWUS took a longer time to fill (380 days) than the formerly anticipated time (126 days) (*see Section 5.2.2*) due to less urine that entered the vault. This emphasizes the gap between researchers anticipations and community involvement. Frequent reminding the community on the importance of filling the data is necessary in order to get good outputs.

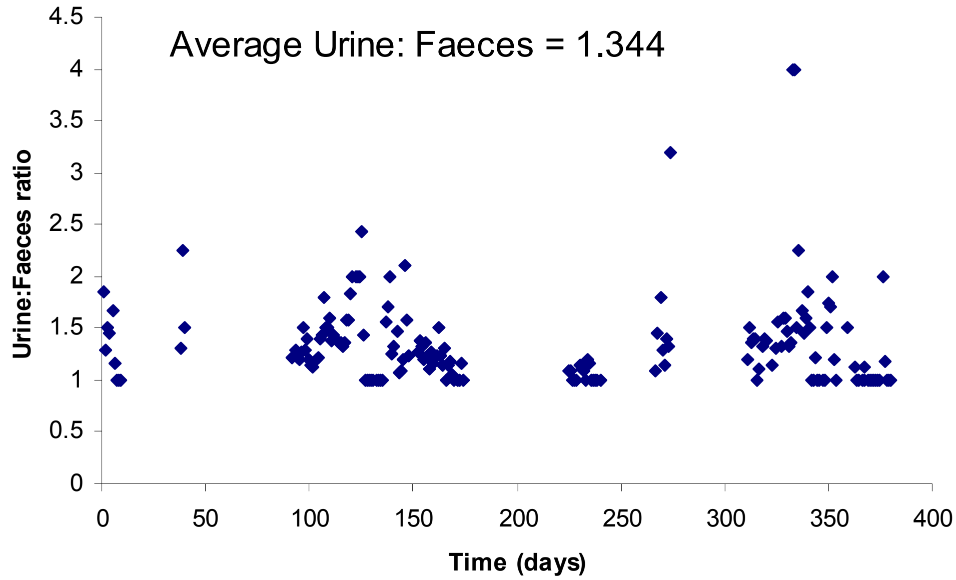

Figure 5.3: The IMPLWUS Influent Urine to Faeces Ratio as Calculated from the Recorded Deposits to the Reactor Done by the Users

5.3.3 Estimated Influent Composition

The actual composition of the wastewater entering IMPLWUS could not be determined under field conditions. Instead it was calculated based on the composition of feaces and urine as assessed by Gaillard (2002). The results of this assessment together with the determined average influent flow from the field, were used to estimate the influent composition into IMPLWUS; results of which are presented in Table 5.4.

5.3.4 COD Profiles of IMPLWUS

Figure 5.4 summarizes the course of various distinguished COD fractions determined at various days and for the different sampling points during the reactor filling time. The COD-profiles assessed for sampling points show that, suspended COD (COD_{ss}), dissolved COD (COD_{dis}) and Volatile fatty acid COD (COD_{VFA}) were fluctuating over the whole period of waste accumulation in the IMPLWUS. The COD_{ss} remained relatively low at all taps during the whole period of loading (380 days), suggesting that the amount of sludge in the reactor was small and settled below the bottom-sampling tap. However, the COD_{dis} remained relatively high throughout the filling period. At the closing time of the reactor, the COD_{dis} was still ~8 g COD/l, but only 100 mgCOD/l of this consisted of VFA's. This amount (8 gCOD/l) apparently show that, about 50% of the dissolved COD in the influent has been degraded. The remaining COD_{dis} could be slowly biodegradable COD. On day 354, samples for stability test were taken for bottom, middle and top sampling points and incubated in serum bottles at ambient tropical temperature.

Table 5.4: the Influent Parameters into the Model and literature composition values (The Faeces, Urine and wash water for going into the IMPLWUS AC system as calculated from a Urine to Faeces ratio of 1.344)

Parameter	Average composition of pure urine and faeces (Gaillard, 2002)		Influent into IMPLWUS**
			1 faeces + 1.344 urine + wash water
	Urine	**Faeces**	For 10 people/day
Volume/amount	0.2 l/person/toilet visit	0.138 kg/person/toilet visit	6.67^ l/d
total COD	12.79 gCOD/l	567.43 gCOD/kg	103.3 gCOD/l
dissolved COD	11.33 gCOD/l	89.41 gCOD/kg	19.4 gCOD/l
suspended COD	1.46 gCOD/l	455.05 gCOD/kg	79.9 gCOD/l
VFA	0 gCOD/l	8.46 gCOD/kg	1.5 gCOD/l
Nkj	5.29 gN/l	17.82 gN/kg	4.9 gN/l
Biodegr.COD_{ss}			84%
Biodegr.COD_{dis}			100%
Wash water*	0.1 l/toilet visit	0.25 l/toilet visit	

CONVERSION OF IMPLWUS COMPOSITION INTO MODEL INFLUENT PARAMETERS (see also Tables 4.3 & 4.5 Chapter 4)

	X_i (gCOD/l)	X_{deg} (gCOD/l)	X_{-vfa} (gCOD/l)	X_{me} (gCOD/l)	S_{-vfa} (gCOD/l)	S_i (gCOD/l)	Q (l/d)
IMPLWUS AC system	12.8	67.1	1.8	0	16.4	0	6.67

Kinetic parameters (Batstone *et al.*, 2002)

k_h (1/d)	Y_{me} (g/g)	Y_{vfa}	k_{d_vfa} (1/d)	k_{d_me}(1/d)	f_{xi}
0.1	0.05	0.1	0.004	0.004	0.25

*This research; **Estimated average composition and flow based on field results and assuming 1.0 kg/l for faeces; ^see Table 5.3

The COD_{dis} on this day amounted to ~7522 mgCOD/l for the bottom level, which meant that, here ca. 61% of the influent COD_{dis}, have been degraded. Kujawa-Roeleveld *et al.* (2003) digested black water together with kitchen refuse at 20^0C in an AC system for 150 days. After 150 days of accumulation the VFA concentration was low (<100 mg COD/l) however, the COD_{dis} was still around 800 mg COD/l. Unfortunately Kujawa-Roeleveld *et al.* did not mention if the remaining COD_{dis} was degraded after the reactor was closed. Nonetheless, 17 days after the closure of IMPLWUS reactor, the COD_{dis} went down to 4763 mgCOD/l (for the bottom) confirming that, the accumulated COD_{dis} at the time of reactor closing was not inert but slowly biodegrading. This situation further ascertains that, with time, the COD_{dis} continues to be degraded.

As expected, the COD_{VFA} in the first 30 days of the reactor use increased to above 1160 mgCOD-VFA/l but continued to decrease over the accumulation period to almost 100 mgCOD-VFA/l at the bottom and middle tap at the time of reactor closing. High COD_{VFA} was probably due to low methanogenic activity of the seed sludge used as compared to that suggested by the model in Chapter 4 Table 4.7. Furthermore, possibly some VFA were introduced to the reactor via the seed sludge. The VFA in the sample at the top tap remained high suggesting that the liquid phase in the reactor was poorly mixed. The results depict that, the C2 was the higher concentration as compared to the other VFA-fractions. C2-VFA (as percentage of Total COD-VFA) ranged (with standard deviation in bracket) from about 19 to 100% (±22.65) with an average of 80.67%. Sum of C3-C5 results showed in similar manner, a variation of 0 to ~81% (±22.67) with an average of ~19%.

During the time of the party, on the average 18.6 people used the latrine without accumulation of the VFA concentration as noted from the actual values (*Figure 5.4 bottom*). On the other hand, the party was at day 155 till day 185 after start-up of IMPLWUS, meaning that, enough methanogenic activity has been built in the reactor.

5.3.5 NH_4^+-N and Nkj Results

The experimental results (*Figure 5.5*) clearly indicate that, ammonia was increasing during the filling time of the IMPLWUS vault. This is due to de-ammonification of organic compounds containing organic nitrogen in faeces and the conversion of urea in the urine. From the estimated composition of the wastewater going into IMPLWUS (*Table 5.4*) it can be calculated that, the 37% of the total kjeldahl nitrogen in the influent originated from Urine (Urea) and 63% originates from faeces. As urea is a very unstable compound that is quickly converted to ammonia (Lentner, 1981), it can be assumed that all nitrogen in urea in the influent is rapidly converted to NH_4^+. The hydrolysis process limits the rate of de-ammonification of organic components and can be described via first order kinetics. Taking the above into account and using the same approach as in chapter 4, the NH_4-N in the reactor can be described by Equation 5.1.

$$\mathbf{NH_4(t)} = \frac{\left(\mathbf{NH_4}_{\mathbf{inoc}} \cdot \mathbf{V_{inoc}}\right) + \left(\mathbf{t} \cdot \mathbf{Q} \cdot \mathbf{Nkj_{urine}}\right)}{\mathbf{V_{inoc}} + \mathbf{t} \cdot \mathbf{Q}} + \mathbf{NH_4}_{\mathbf{feaces}}(\mathbf{t})$$

$$\textbf{with} \quad \mathbf{NH_4}_{\mathbf{feaces}}(\mathbf{t}) = \left(\frac{\mathbf{Q} \cdot \mathbf{Nkj_{feaces}} \cdot f}{\mathbf{V_{inoc}} + \mathbf{t} \cdot \mathbf{Q}}\right) - \left(\frac{\sum_{\mathbf{t=1}}^{\mathbf{t=time}} \mathbf{Q} \cdot \mathbf{Nkj_{feaces}} \cdot f \cdot \mathbf{e}^{-\mathbf{kh} \cdot \mathbf{t}}}{\left(\mathbf{V_{inoc}} + \mathbf{t} \cdot \mathbf{Q}\right)}\right) \qquad \textbf{(5.1)}$$

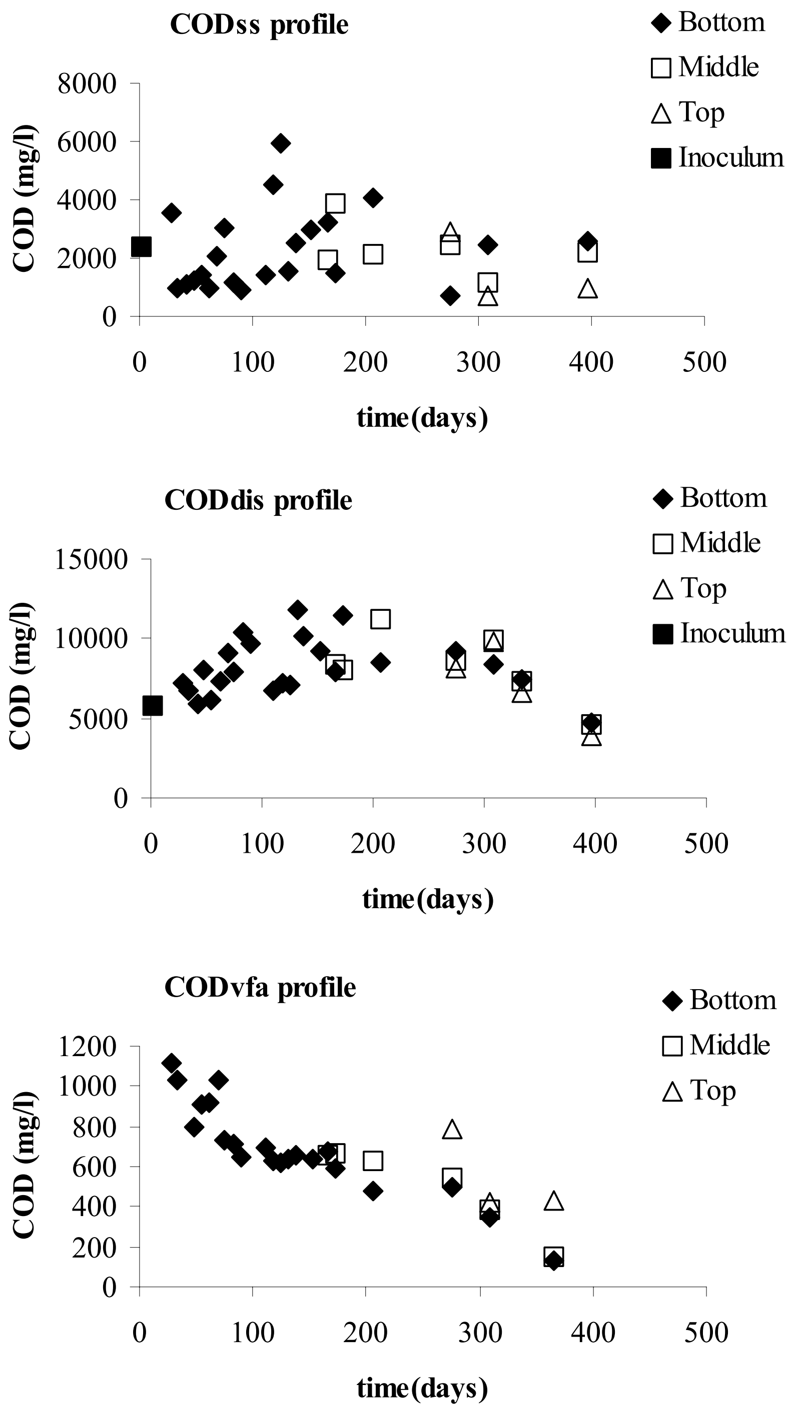

Figure 5.4: The CODss (top), CODdis (middle) and COD_{VFA} (bottom) Profiles as Determined During the Filling Time of the IMPLWUS

and:

$NH_4(t)$ = Total ammonia concentration in the reactor during filling of the reactor (mg N/l),
NH_{4inoc} = Ammonia concentration of the inoculum sludge (mg N/l),
Nkj_{urine} = Nkj concentration of the urine (mg N/l),
$NH_{4feaces}(t)$ = Ammonia concentration resulting from hydrolysis of Nkj in feaces (mg N/l) as a function of time,
Nkj_{feaces} = Nkj concentration of the feaces (mg N/l),
f = biodegradable fraction of the Nkj_{feaces},
t = time (days),
kh = first order hydrolysis constant for the biodegradable fraction of the Nkj_{feaces} (1/day),
Q = Influent flow to reactor (l/day),
V_{inoc} = Volume of the inoculum sludge (l).

The values for the parameters in Equation 5.1 as they were obtained from this study and literature are listed in Table 5.5. Only the first order hydrolysis constant kh is an unknown parameter in the equation and was assessed by fitting it to the reactor data (*Figure 5.5*). The result was a kh value of 0.017 day^{-1}. This value is lower than literature value of 0.1 day^{-1} (Batstone *et al.,* 2002) for protein hydrolysis in primary sludge at mesophilic temperature.

Table 5.5: Values for the parameters in Equation 5.1

Parameter	Value	Remark
Nkj_{urine}	1813 mg N/l	37% of 4900 mg Nkj/l, see Table 5.4
Nkj_{faeces}	3087 mg N/l	63% of 4900 mg Nkj/l, see Table 5.4
$NH_{4\ inoc}$	60.2 mg N/l	Table 5.1*
f	0.5	Gaillard (2002)
Q	6.7 litre/day	Table 5.4
V_{inoc}	300 litre	Section 5.3.1
k_h	0.017 1/day	Assessed from fit of Equation 5.1 to field data

*It assumed that the Nkj of the seed sludge is inert and will not be further hydrolysed during reactor filling

Figure 5.5 shows that, the Total NH_4^+-N reached a level of about 2800 mg-N/l at the time of reactor closing from an initial value of 60.2 mg-N/l which originated from the seed sludge. This phenomenon of rapid increase of the NH_4^+-N concentration indicates a possibility of inhibition of methanogenesis and the hydrolysis by ammonia. McCarty and McKinney (1961) reported that ammonia inhibition occurs at total ammonia concentrations between 1500 – 3000 mg-N/l at pH level exceeding 7.4, but adaptation to high ammonia concentrations is very well possible. Elmashad (2003) noted that, the presence of higher concentrations of ammonium nitrogen causes the inhibition of hydrolysis. Strauss *et al.* (1999) proposed that, the ammonia nitrogen threshold levels in the influent of anaerobic ponds in the tropics should not exceed 400 - 500 mg-N/l to avoid toxicity of ammonia. From the VFA concentration depicted in Figure 5.5 it seems that ammonia inhibition on the methanogenesis does occur. As it can be observed in the initial 75 days of reactor filling the VFA concentration decreases indicating that methanogenesis takes place. However from about day 75 and at an ammonia concentration above 1500 mg N/l the VFA concentration remains on the same level indicating that methanogenesis is inhibited. From day 160 onwards the VFA concentration decreases again suggesting that the methanogenic bacteria have adapted to high ammonia concentrations.

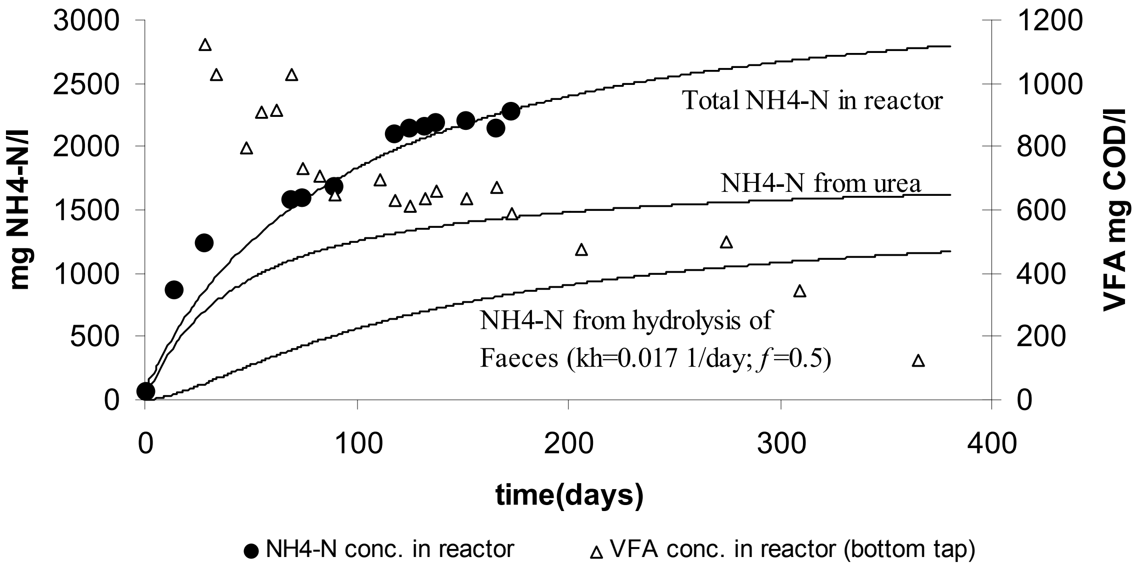

Figure 5.5: The Course of Ammonia Production During the IMPLWUS filling. (• NH_4^+-N analysed from reactor; — Results from the calculations with Equation 5.1 with $NH4_{inoc}$ =60.2 mg N/l; Nkj_{urine} = 37% of total Nkj; Nkj_{feaces} = 63% of total Nkj; *f* = 0.5 (Gaillard, 2002); kh = 0.017 (1/day); Q = 6.7 l/day; V_{inoc} = 300 liters)

5.3.6 Gas Production

It appeared that, there was gas leakage in the IMPLWUS system that could not be spotted so that, on-site no gas measurements could be obtained. The biogas production was therefore estimated with the use of the model presented in Chapter 4. The result presented in Figure 5.6 shows the course of expected daily biogas (if no VFA accumulation would have taken place) production in IMPLWUS as determined from the model. Input values into the model (*Equations 4.1-4.14*) are as presented in Table 5.4 and the seed sludge amount of 300 litres, X_i = 232 mgCOD/l and X_{me} = 99.57 mgCOD/l. The results show that the methane gas rate as predicted by the model was increasing with accumulation time. Figure 5.6 shows that in the first 100 days of reactor operation, the gas production was low and reached 500 gCOD-CH_4/day by day 100, while the maximum value of ~544 gCOD-CH_4/day was reached at day 380 when the reactor was closed (*Table 5.6*) or about 0.2 m^3 CH_4/day and stabilized at that level. This slow biogas production condition is (as already indicated in *Chapter 4*) not good if the biogas is to be reused. People would like to get the energy faster otherwise it will mean an alternative energy source has to be made available in the lag phase meaning an added cost. From the results it can be seen that, one latrine user produces ~0.02 m^3 CH_4/d of biogas which is not enough for domestic use. One m^3 is enough to cook 3 meals for a family of 5-6 persons (van Buren *et al.*, 1979). This means that, about 333 litres of CH_4/meal is needed. It can therefore be determined that, 17 people are enough to produce adequate gas of one meal and subsequently 51 persons will suffice for gas production of the three meals for 5-6 people. This means that, for the produced gas to be useful as energy, a decentralized digester for a number of people will be useful.

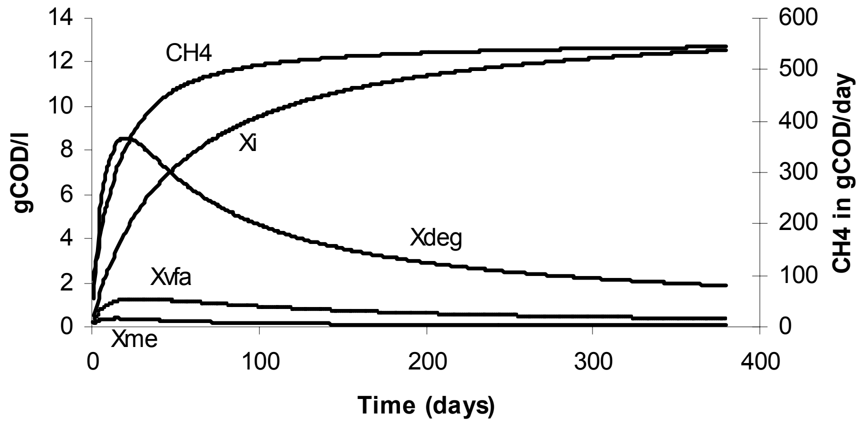

Figure 5.6: The different COD Fractions Determined by Equations 4.1 to 4.14 for Improved Pit-Latrine Without Urine Separation IMPLWUS for 380 Filling Days

Table 5.6: The Summary of IMPLWUS AC System Field Data Results Fitted into Model After 380 Days of Accumulation of Black Water

Influent Type	X_{deg} (gCOD/l)	Sludge Stabilization* (%)	Total Reactor Volume (litres)**	Maximum possible gas production (gCOD/day)
Black water	1.89	97.2	2835	544

* Degradation of X_{deg} expressed as % of X_{deg} in the influent; **Volume is for sludge and liquid part together

5.3.7 Sludge Stability

On day 354, the reactor was mixed and one-litre samples were taken from each of the three sampling points (bottom, middle and top, *see Figure 5.1*). Then, 300 ml. (0.3 litres) samples from a well-mixed sample from each litre, were taken for stability test as detailed in chapter 3 and later, incubated at ambient temperature in serum bottles. The gas production from these samples was monitored over a period of 56 days (*Figure 5.7*). According to the model calculations presented in Figure 5.6 the sludge samples should be rather stable at day 354 with X_{deg} of about 1.96 gCOD/l (meaning 97.1% of influent X_{deg} has been converted). The 0.3 ml. sample of this sludge could then still produce 0.3*1.96 = 0.59 g COD of methane from the samples. The actual methane produced observed from the samples was only 0.2-0.4 g COD (*Fig. 5.7*) indicating that, not all biodegradable suspended solids were converted in 56 days or more. From the rate of methane production in Figure 5.7 it can be estimated that the hydrolysis of the suspended solids was taking place at a rate of 0.013 d^{-1}. Which is about the same as the protein hydrolysis rate that was estimated from the NH_4^+ accumulation in the reactor (*section 5.3.5*). However, from Figure 5.4 it can be observed that the samples taken from the reactor at day 354, also contain dissolved COD. The samples for Top, Middle and Bottom contained 9994, 6059, 7521 mg COD_{dis}/l, respectively of which VFA was only 300 mg COD_{vfa}/l. Some of this dissolved COD was still degradable as it appeared after reactor was closed (*see also section 5.3.4*). Therefore, it remains unclear if the methane production from the incubated samples originated from conversion of the suspended or the dissolved COD in the samples.

From this section and section 5.3.4 a discrepancy between the model assumptions and the actual digestion process in the AC system appears. Namely, a fraction of biodegradable dissolved non-acidified COD. The model only accounts for inert dissolved COD and volatile fatty acids. For the model it is assumed that the biodegradable non-acidified dissolved COD present in the influent is very fast degradable and is therefore added to the VFA fraction during modeling. However, from the results with the demonstration reactor it seems that the influent also contains some slowly degradable non-acidified COD_{dis}. The demonstration reactor was seeded with septic tank sludge that was not adapted to high NH_4 concentrations. Because a higher free ammonia concentration inhibits all conversion processes during the digestion process (Elmashad, 2003) it could be that, the appearance of a slowly biodegradable non-acidified dissolved COD_{dis} fraction is the result of the unadapted sludge and that during a second run of the system with adapted sludge it will not be present. The results reported by Kujawa-Roeleveld *et al.* (2003) were also obtained during a first run of an AC system with unadapted sludge.

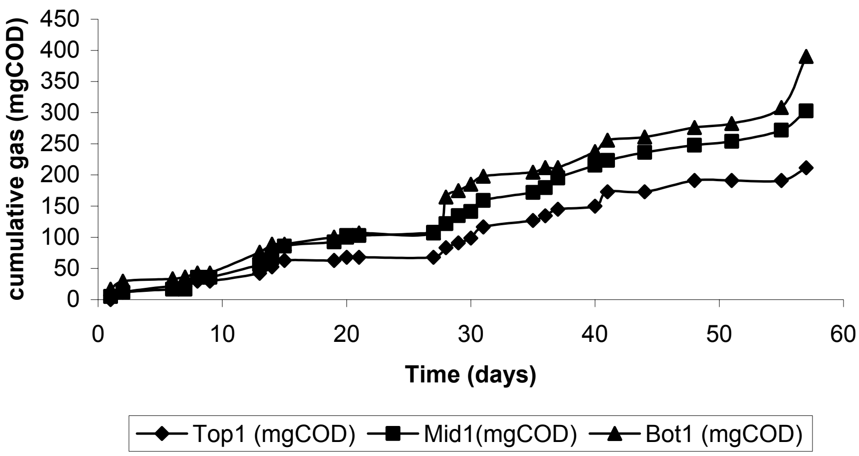

Figure 5.7: Stability Results for Top, Middle and Bottom Sampling Points of IMPLWUS as Determined from 300 ml. Reactor Samples on Day 354 of Reactor Operation at Ambient Average Temperatures of 28.6 ^{0}C

Stability is defined as the maximum percentage of COD converted to CH_4 of the digested sludge (Mahmoud, 2002). EPA (1992) defines stable sludge (for use in agriculture) " as sludge with the mass of volatile solids in the sewage sludge reduced by at least 38% during sludge treatment" or "if it looses less than 17% additional volatile solids when it is anaerobically batch-digested in the laboratory in a bench-scale unit at 30^{0}C to 37^{0}C for an additional 17 days" (stability test). Guidelines or procedures for termination of a stability experiments are not clear (Mgana, 2003). Haskoning (1989) proposed to continue the experiment until the biogas production has reached its endogenic level of about 2 ml-CH_4/gVSS/day. At endogenic level all the degradable components that were initially present in the sludge are degraded and the only source of biogas production comes from decay of biomass. However, the suggested endogenic gas production of 2 ml-CH_4/gVSS/d is only arbitrary as it depends very much on the ratio between biomass and organic inerts in the sludge.

5.4 Conclusions

The aims of accumulations systems are to:
1. End up with stable sludge at the time when the reactor is full with faecal sludge
2. Have zero VFA at the time of emptying the reactor contents
3. Reuse the produced biogas.

Although the demonstration reactor, IMPLWUS used in order to ascertain these aims was still under start-up conditions the following conclusions can be made with respect to the three aims mentioned above:

a) The stability test revealed that by day 354 the sludge was not yet completely stable. The model results showed that X_{deg} at that day was ~1.96 gCOD/l, implying 97.1% conversion of influent X_{deg}. The incubated samples produced 0.2-0.4 gCOD-CH_4, which is less than the value set by the model of 0.59 gCOD-CH_4. The estimated hydrolysis of suspended solids from stability results was 0.013 d^{-1}.
b) At day 380 of reactor use when the reactor was closed, the VFA was 100 mgCOD/l indicating that, the reactor contents have not yet been completely degraded and so more time is needed without adding new material to the reactor. Non-acidified dissolved COD is present which can only be removed when there is no new material added to the reactor (at closing). This is the first run of the reactor, during the second run of the reactor this fraction can disappear as the sludge is adapted.
c) Due to leakages in the reactor no biogas production could be detected. From the theoretical gas production it has to be concluded that the gas production will not be adequate for completely substitute the existing amount of energy needed for cooking meals for 5-6 people per day.

Furthermore:

i) The reactor can be constructed with locally available materials and labour. Moreover it does not require specialized personnel during operation. This favours the application of this reactor in tropical developing countries.
ii) In high water table areas IMPLWUS is cheaper than the traditional pit latrine which requires monthly emptying. Complete diversion of urine and decrease of the amount of wash water going into the tank will reduce the emptying frequency and consequently will make the reactor even cheaper as compared to the traditional pit-latrine.
iii) It needs organized sludge disposal/reuse place at emptying time.
iv) IMPLWUS is applicable at any site (planned and unplanned) and the scale depends on the number of users.
v) The demonstration reactor is new to the users and hence, giving education to the users so that they know what to do when the reactor is filled with sludge and at the sludge emptying stage is necessary.
vi) Little co-operation of the users on the amount of water to be used, ends up with the reactor filled with water instead of sludge and so, high frequency of emptying the water fraction which will consequently be expensive.

5.5 Notation

AC	= Accumulation systems
PL	= Pit-latrines
DC	= Developing countries
HWT	= High water table
IMPLWUS	= Improved Pit-latrine Without Urine Separation
SIMTANK	= *Simba* Plastic Tank
EPL	= Elevated Pit-Latrines
COD_t	= Total Chemical Oxygen Demand (mg/l)
COD_{ss}	= Total Chemical Oxygen Demand of suspended solids (mg/l) or ($COD_{particulate}$)
COD_{col}	= Colloidal Chemical Oxygen Demand (mg/l)
COD_{dis}	= Dissolved Chemical Oxygen Demand (mg/l)
COD-VFA	= Volatile Fatty Acids ($mgCOD_{VFA}$/l)
N	= Nitrogen
P	= Phosphorus
Total-N	= Total Nitrogen (mgN/l)
Nkj	= Kjedalh Nitrogen (mgN/l)
NH_4	= Ammonia Concentration (mgN/l)
TSS	= Total Suspended Solids
VSS	= Volatile Suspended Solids
SMA	= Specific Methanogenic Activity (gCOD/gVSS/d)
X	= Complex Suspended Solids (mgCOD/l)
X_{deg}	= Degradable Suspended Solids (mgCOD/l)
X_i	= Inerts Suspended Solids (mgCOD/l)
X_{vfa}	= Acidifying biomass (mgCOD/l)
X_{me}	= Methanogenic biomass (mgCOD/l)
S_{vfa}	= Volatile Fatty Acids (mgCOD/l)
S_{me}	= Dissolved methane (mgCOD/l)
S_i	= Inert Solubles (mgCOD/l)
f_{xi}	= Fraction inert Solids in X
k_h	= First order hydrolysis constant (h^{-1})
Y_{vfa}	= Yield of Acidified biomass (mg/mg) = 0.1
Y_{me}	= Yield of methanogenic biomass = 0.05
k_{d_vfa}	= decay constant of acidogenic biomass (h^{-1})
k_{d_me}	= decay constant of methanogenic biomass (h^{-1})
C_2	= acetate
C_3	= propionate
C_4	= butyrate
C_5	= valeric acid
Q	= Flow into the reactor (l/d)
t	= time (days)

CHAPTER SIX

PERFORMANCE OF COMPOSTING LATRINES IN MAJUMBASITA UNPLANNED SETTLEMENT IN DAR ES SALAAM – TANZANIA

Abstract

The performance of composting latrines, in the form of ecological sanitation toilets, in an unplanned settlement, Majumbasita in Dar es Salaam, Tanzania was evaluated in order to assess the feasibility of this system for low cost and effective environmental protection in the region. The studied parameters for urine and faecal sludge were pH, temperature, different COD fractions, TS, VS, SMA, Stability, *E-coli* and *ascaris eggs*, TKN, nitrates, nitrites, phosphorus, potassium and VFA. The results show that faecal contents in the latrines have a very high pH (up to 10.4) due to addition of ashes. The temperature values were within the tropical conditions of 27^{0}C – 31.7^{0}C during the whole period of study. The results of the total COD measurements varied between 32.7 and 74.1 gCOD/l, while TS and VS were respectively 15.4 – 134.3 gTS/l and 16.1 – 97.5 gVS/l. The TS values were far less than expected indicating a possible dilution of the faeces with urine. The extent of biological sludge stabilization likely is small in view of the prevailing high pH values. The toilet vault likely mainly acts as a chemical preservation chamber. *Ascaris eggs* and *E-Coli* are efficiently removed from the sludge in ecosan toilets due to high pH. The separated urine can be used directly as fertiliser in tree growing, but not for fertilising food crops, which are consumed raw, due to presence of pathogens. Advocacy on the use of ecosan toilets improves the separated urine quality.

6.1 Introduction

Environmental sanitation problems have continued to grow in complexity although they have received little attention in Tanzania. The hygienic disposal of excreta that does not endanger health and welfare of the community (Franceys *et al.* 1992; Cotton *et al*., 1995) is important. There are many constraints in improving the existing sanitation situation that centre on political, economic, social and cultural contexts of health and disease. Serious constraints (Francey *et al.*, 1992), which are still prevalent to-date, are: funding limitations; insufficiency of trained personnel; operation and maintenance; logistics; inadequate cost-recovery framework; insufficient health education efforts; inappropriate institutional framework; intermittent water service and non-involvement of communities.

Given the inherent unsustainability of large scale sewerage (*see Chapter 1*), on-site sanitation concepts, dealing with excreta collection and treatment of human excreta on-site, that is, the location where it is deposited, can provide a hygienic and satisfactory solution (Franceys, *et al.*, 1992; Esrey *et al.*, 1998 & 2001; Lettinga *et al.*, 2001), because it is not an expensive and high technology, but a low cost and technically plain. Perceptions of the low technologies meeting environmental protection and resource conservation (EPRC) criteria have resulted in various terminologies in different places; DESAR concepts in The Netherlands (Lens *et al.,* 2001); SUSSAN (Sustainable Sanitation) in Austria (Starkl and Haberl, 2003); ECOSAN (ecological sanitation) in Germany, Sweden and some other parts of the world, (Esrey *et al.,* 1998; Werner and Mang, 2003). All the developed technologies are based on the insight that with respect to life on earth we are dealing with a closed ecological system where nothing permanently disappears.

These concepts avoid hiding human excreta in deep pits or diluting them with water and exporting them to the neighbouring premises downstream (Winblad, 2000; Lettinga *et al.*, 2001) by closing the flow of nutrients (*Figure 6.1*) and treating the excreta on-site for safe reuse. This means, the excreta is regarded as a “resource” rather than as a “waste” product (Zeeman and Lettinga, 2001; Lettinga *et al.*, 2001; Esrey *et al.*, 1998 and 2001).

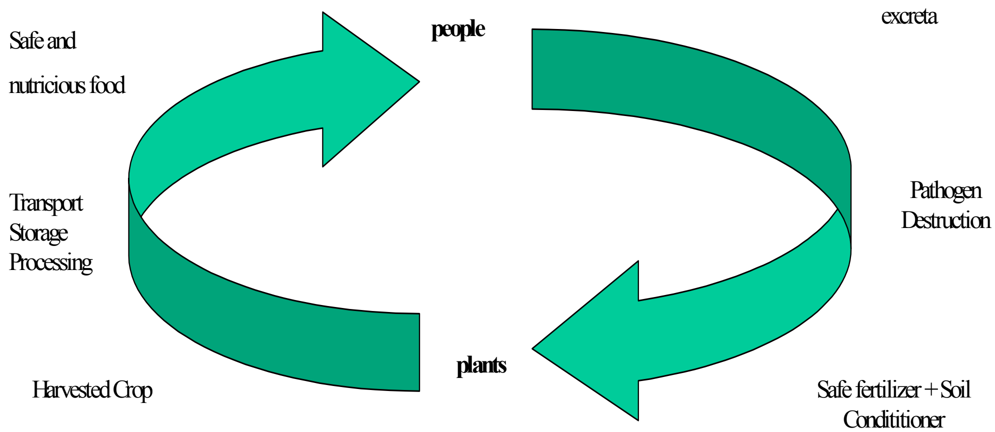

Figure 6.1: The Ecosystem Loop (after Esrey *et al.* 2001)

The concepts are applicable in the North and the South, for rural and urban areas, and for rich and poor alike (Lettinga *et al.*, 2001; Esrey *et al.*, 2001) with modifications of the structures to suit local conditions. Pollution problems are prevented at the source rather than dealing with them at the end of a pipe by complete utilisation of all possible “waste” resources and finding a proper final destination for any type of residue (Winblad, 2000; Lettinga *et al.*, 2001).

For reuse of human "waste" and turning it into something "useful and valuable" (Morgan, 1999), ECOSAN has been introduced recently on a pilot scale in Majumbasita unplanned settlement in Dsm, Tanzania by EEPCO (Environmental Engineering and Pollution Control Organisation - Non Governmental Organisation) through UNICEF funding. The toilet systems that have been introduced are in the category of improved pit-latrines. They are 'dry' accumulation systems or so-called composting latrines (Franceys *et al.*, 1992), which receive only faeces. Moreover, after faeces deposit, ashes are added to increase the pH. If the moisture content and ashes additions are balanced, it is believed that the faeces will decompose to form a soil conditioner in about four months (Franceys *et al.,* 1992). This idea of decomposition was given out without thorough exploration of the conditions needed for biodegradation to proceed and will further be ascertained in this study. Pathogens are killed in the dry alkaline compost that can be used as a soil fertilizer.

The urine is collected separately and can also be used as fertilizer. In Majumbasita about 110 ECOSAN toilets (appearance see *Figure 6.2*) have been constructed, but only 44% were in use by the time of the study. Other potential users’ latrines were either still under construction, had old traditional pit-latrine or wanted to overcome their initial reservations by waiting to see the performance of the used toilets. With increased participatory learning, the percentages of users were growing (Shayo, 2003). To get an insight in the performance of these structures the following study objectives were set in this work as to:

- Get the baseline information related to composting toilet systems in the country,
- Check the performance of composting toilets in pre-treatment of human excreta, as it is not yet determined in the country.

- Verify the quality of separated human urine. As it is believed to be sterile, people are using it directly in agriculture without knowing the safety associated with its re–use.

Parameters observed included the pH level in the separated urine and faecal sludge, the methanogenic activity and stability of collected human faeces from the pit-vault, the TS- and VS-content of the sludge and concentration of parasite eggs (*ascaris* and *helminth eggs*), NH_4-N, TKN, Total-N, PO_4-P, K and VFA-concentration of the sludge. The reuse aspects of urine and faeces are explained in Chapter 1. Gender perspectives on ECOSAN or accumulation (AC) sanitation systems have not been well established in this study.

6.2 Materials and Methods

6.2.1 Description of the Research Area

Majumbasita, is one of the unplanned settlements at the peri-urban part of the Dar-es-Salaam (Dsm.) city in Tanzania. It is located about 11 km. from the city centre, in the western direction and closer to the Dar-es-Salaam International Airport (DIA) in Kipawa ward, Ilala Municipality; with a population of about 23,000 inhabitants (Chaggu and John, 2002). Houses are mostly occupied by owners, with an exception of few, which are inhabited by tenants. The size of plots varies from about 170 - 400 square metres (John, 2001) at the moment.

The piped water supply from the city network caters for only a small proportion of the inhabitants; 85% of the people depend on well water (John, 2001) and are forced to use hand-dug wells even if these are polluted, because the quality of the well water is doubtful (Chaggu *et al.*, 1993; Mato, 2002). Chaggu, *et al.* (1993) found out that the frequency of water supply from the network is intermittent per week; that is, supplied for 2-4 hours only per supply. Only 5% of the residents get it once per week, 63.2% two days/week, 28.0% three days/week, 2% four days/week and only 1.2% manage to get water for more than four days/week. Moreover, their experiment showed that, *E-Coli* count for samples from boreholes with depths 1.8 metres and 6.75 metres were 3000 FC/100 ml. and 178 FC/100 ml. respectively. The intensity of *E-Coli* showed a decreasing trend with depth. The wells deeper than 6.75 metres were free from faecal contamination implying that, water from deeper soil layers was bacteriologically safe for drinking purposes at that moment. Similarly, for the piped water supply in that area, it was observed that, there is an increase in faecal pollution in the distribution main and service pipes (values ranged from 3 - 76 FC/100 ml. for 25 sampling points chosen in the distribution system). Furthermore, faecal coliform counts increased with time and decrease in pressure. The area experiences high water table (HWT) evidenced by the raised pit – latrines (more details of these latrines *see Chapter 2*) in the area, which accounts for 75% while, some dwellers (4.8%) did not have any latrine facility; they use neighbours latrines or bush sanitation (Chaggu *et al.*, 1993; John, 2001).

6.2.2 Schematic Presentation and Functioning of Ecosan Toilets

The schematic presentation of ECOSAN toilet at Majumbasita is as shown in Figure 6.2 with dimensions and other details shown in Table 6.1. The table raw data was obtained from EEPCO (2002) and Mahenge (2002). Another type, which is an extension of a number of chambers in order to suit the primary school use at Majumbasita, has been constructed. The school units had a similar basic structure as shown in Figure 6.2.

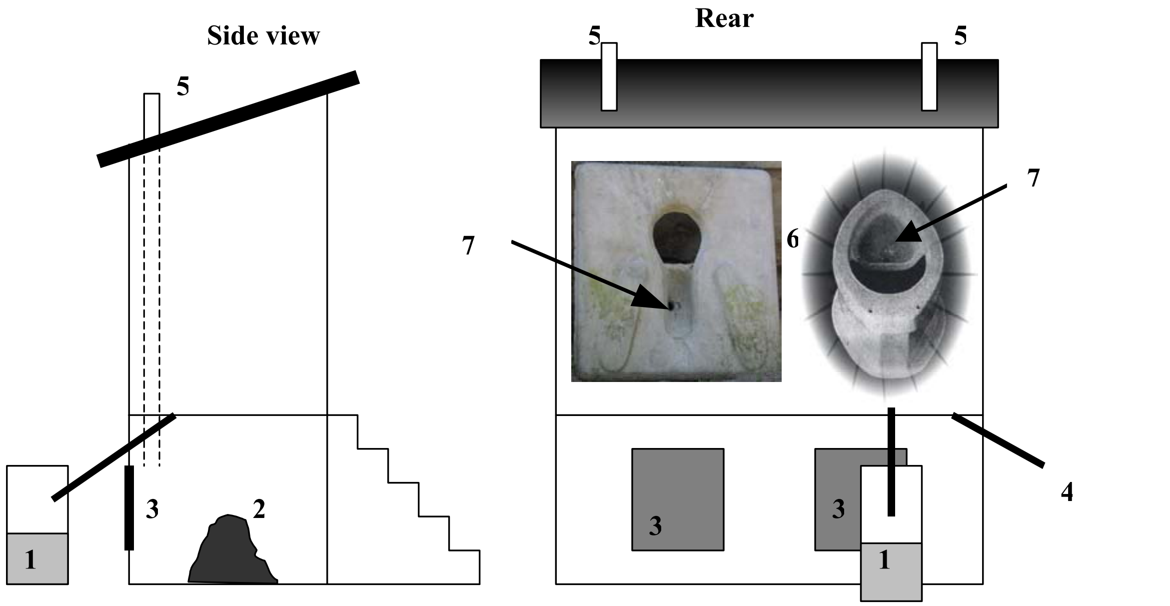

Figure 6.2: Photographs of Caption of the Ecological Sanitation Toilet at Majumbasita (rear view inscribed with the drop hole types) Courtesy of EEPCO.

Symbol´s Explanation:

1 - Urine tank of 20 litres capacity
2 - Accumulating faeces and ashes heap in the latrine vault
3 - Doors at the back of the pit-chamber for desludging purposes
4 - Wash water outlet
5 - Vent pipe
6 - Drop hole slabs (squatting and seating type)
7 - Separated Urine hole

The components of the ecological toilets include two pits, two openings for removal of dehydrated faecal material, two vent pipes (for each pit), two squatting pans or one squatting pan and one seat riser, or two seat risers, two urine drain pipes and one drain pipe for anal cleansing water, one plastic container for urine, superstructure, squatting slab and roof. The components are provided in duplicate because when one component is in use, the other one is on stand-by basis. If one pit in use is full, it is closed for a time and the other stand-by pit is opened for use. It is expected that, the dehydrated material in the closed pit decomposes for a period of not less than 6 months and then the system will be desludged and the discharged sludge can be used in agriculture. This concept has been taken on-board without further technical considerations about possibilities of biodegradation in the presence of ashes, which increases the pH. So far none of the systems has been desludged with an exception of one of the 110 structures, which was closed out because it was full according to the information availed to us. Normally, after defecation, a handful of ashes from charcoal stoves or burnt wood ashes are poured into the pit. Ashes (charcoal/plant ash) are added inside the faecal chamber to raise pH (for pathogen destruction), reduce odour and dehydrate the faecal material. The pH must be = or > 9 because it is unfavourable pH for most pathogens especially *ascaris* (Esrey *et al.*, 1998).

Table 6.1: The Dimensions of Squatting Ecological Sanitation Toilet at Majumbasita

Component		Dimension (m.)			
		Length	Width	Height	Depth
Superstructure	General	2	1.2		-
	Front View	-	-	2.0	-
	Back View	-	-	1.7	-
Squatting Slab (pre-cast)		0.97	0.88		
Floor Slab		2	1.2	-	-
Pit (2.4 m^3)		2	1.2	1.0	-
Pit relative to ground level		-	-	1.0	0*
Openings for removing dehydrated faecal material		0.6	0.45	-	-
Urine and anal cleaning pipe		25 cm. (1") PVC at a slope of 1:75 to 1:110			
Vent pipe		100 mm. PVC pipe with a plastic cap** with holes on top (protrusion ~0.5 m. above the roof cover)			
Angle of foot-rest		30^0 from normal direction of the foot			
Size of the hole		20 cm. diameter			
Urine container		20 – 60 litres (but mostly 20 litres for easy lifting)			

*Zero depth indicates that, the pit structure is above ground with an exception of some cm. for foundation, **EEPCO Engineers locally make the plastic caps with holes bored in them on-site.

The amount of ashes that are added per day is 0.5 – 1 litre per 3-5 people, that is, ~ 0.1-0.33 litres/person/day. These values were observed in the field. There is no formal control exercised as to how much ash should be poured into the pit after defecation. The charcoal ashes are kept inside the superstructure on the squatting slab (closer to the squatting pit) in order to avoid inconveniences. No water or any liquid material is allowed to mix with faeces inside the chamber (EEPCO, 2002; Mahenge, 2002). However, it was observed from the religious beliefs of some people that, water **must** be used for anal cleansing. Hence, a place in between the two squatting holes (one in use and one stand-by) was specifically modified to cater for cleaning purposes and the wash-water led to the outside through a pipe. A clear indication is inscribed in the floor that, "wash yourself here" in order not to wet the faecal matter in the vault. For this purpose, a small container (plastic) of about 5 litres of water is kept at the corner of the squatting slab for this need. The wash water is not treated but ends up in the surrounding area signifying a need for proper disposal. The 20-litre urine tank is kept outside and usually emptied when it is full.

The urine pipes at Majumbasita are 25 cm. (1") in diameter laid at a slope of 1:75 to 1:110. However, these gradients are too high especially if the pipes are to be used for longer distances. For shorter distances of Majumbasita structures they suffice. Nonetheless, Johansson (2000) proposed that, the pipes for urine should be laid at a sufficient slope of at least 1% and the diameter of the pipe needs to be about 110 mm. The experiences with urine separation so far show that, blockages of the stench traps and pipes, caused by inorganic precipitates, are frequent and persistent (Hellsröm and Johansson, 1999). Struvite, hydroxyapatite (HAP, $Ca_{10}(PO_4)_6(OH)_2$) and Calcite ($CaCO_3$) are precipitate compounds in urine and microbial urea hydrolysis – also called ureolysis – triggers precipitation (Udert *et al.*, 2002). Struvite is less susceptible to inhibition (Udert *et al.*, 2003). This indicates a need to check and clean the urine pipes as necessary.

6.2.3 Design Considerations of 'ECOSAN' Composting Toilets and Use Principles

The ECOSAN composting toilet systems discussed in this chapter were constructed by EEPCO as forementioned. The design of the systems was based on the design criteria of improved pit latrine (VIP). In this section some design criteria are discussed in more detail.

The composting toilet systems can be regarded as AC systems. From the results presented in Chapter 4, it can be seen that, for these types of systems the required reactor volume is determined by the daily-accumulated volume, the demanded storage period (DSP), and a possible amount of seed sludge. As explained in Chapter 4, addition of seed can be desirable in order to prevent the accumulation of VFAs in the reactors, but in general, there is no seed sludge added to composting toilets.

1) Accumulated sludge volume

The accumulated volume of faeces and ash solids in an ECOSAN composting toilet system depends on several parameters namely, the:

a) influent flow (faeces deposits and addition of wood or charcoal ashes)
b) extent of biological conversion of faeces
c) evaporation of moisture.

These parameters are discussed in turn.

A) The influent flow parameters

The influent flow parameters to an ecosan toilet is similar to those mentioned for AC systems in Chapter 4 and the criteria used for the design of ventilated improved pit latrine by Mara (1984) which are:

i) The number people who will use the toilet (p)
ii) The portions of faeces supplied to the toilet per person per day (n_f)
iii) The volume of the feaces supplied (V_f) (in Liter/portion)
iv) Amount of ashes (V_a) (liters/use)

This can symbolically be presented as shown in Equation 6.1. The assumptions underlining Equation 6.1 are that, each person defecates once per day; wash water does not enter into the faeces vault and ashes are put into the vault after defecation. Diarrhoea cases are not taken into consideration.

$$\mathbf{Q(t) = p \cdot (V_f + V_a)} \qquad \mathbf{(6.1)}$$

with: Q_t = The flow that goes into the vault at any time t
p = number of persons using toilet system
V_f = volume of feaces per person/day
V_a = volume of ashes per person/day

Among the four mentioned parameters above, the problematic one to be determined is the amount of ashes. There are no definite researched figures regarding the amount of ashes to be added to the latrine vault after defecation. Franceys *et al.* (1992) remarked that, estimating the volume of ash is difficult. Vietnam experience indicates that approximately twice the volume of faeces has to be added (Jeeyaseelan *et al.*, 1987) while, Rybczynski (1981) suggested five times the volume of faeces and Kalbermatten *et al.* (1980) recommended 0.3 m^3 per person per year for all waste. In the case of Majumbasita about 0.1-0.33 litre/person/day is added. But, people may use more or little ashes depending on their wishes. In fact where the children are using the latrine unattended, they may pour a lot of ashes, as they will feel that it is part of the game. For this case, it will be good to have an apparatus like a cup in the latrine superstructure (closer to the ashes) that people can use. Users should formerly be informed that, after defecation, they should pour only a cup full of ashes into the vault. In this way, with the users' co-operation, the amount can be controlled.

Wood contains only small amounts of ash (0.5-5%, w/w), this ash can be rather troublesome to handle (Steenari *et al.*, 1999; FAO, 2003). Similarly, charcoal contains 23% volatiles and 0.7% ash content (Strehler, 1999). More than 80% of wood ash is composed of particles <1.0 mm., the remainder being non-incinerated wood (Etiegni *et al.*, 1991a; Etiegni and Cambell, 1991). However, wood ash can contain all particles ranging from coarse sand to clay. The bulk density varies from 0.27 g/cm^3 for ash originating from wood (Huang *et al.*, 1992) to 0.51 g/cm^3 for ash originating from pulp and paper waste (Muse and Mitchell, 1995). The mineralogy revealed that, Calcite ($CaCO_3$) is the major compound of wood ash (Etiegni and Campbell, 1991; Ohno, 1992; Erich and Ohno, 1992a; Ulery *et al.*, 1993). Lime (CaO), riebeckite ($(NaCa)_2(FeMn)_3Fe_2(SiAl)_8$), portlandite ($Ca(OH)_2$), Calcium silicate ($Ca_2SiO_4$), hydrotalcite ($Mg_6Al_{12}CO_3(OH)_{16}.4H_2$)) and serandite ($Na(MnCa)_2Si_3O_8(OH)$) were identified as additional constituents (Etiegni and Campbell, 1991). Additionally, wood ash generally contains high levels of soluble salts (Steenari *et al.*, 1999).

The alkalinity or neutralizing capacity of wood ash is high (Demeyer, 2001). For macro elements, Sulfur can be in the order of 0.3% present in ash (Someshwar, 1996), while, Si and Al are structural components of ash (Ohno, 1992; Ohno and Erich, 1993). Ashes from direct wood combustion generally have higher contents of major elements than those originating from pulp and paper. The concentrations of microelements in wood ash are as variable as the major elements. Iron is the most abundantly present microelement (Demeyer *et al.*, 2001) and wood-fired boiler-ashes can contain up to 21 g/kg Fe (Someshwar, 1996).

Currently, in Majumbasita the used ashes are mostly from the user community's cooking stoves. The requirement of firewood per capita per year is about 250-300 kg in China (Eggeling and Stephan, 1981), 275-365 kg in India (Makhijani, 1977), 0.7-0.83 m^3 in Indonesia (Wiersum, 1979) and 700 kg or one m^3 in Nepal (IDC, 1981). A hectare of forest supports about 50 tonnes of wood (Prasad *et al.*, 1974), which can therefore supply firewood to about 160 persons. Five tonnes of wood are required to make one tonne of charcoal with two thirds of energy stored in the wood lost to the atmosphere (Geocities, 2003). Tanzania needs 43 Mm^3/year of fuel wood (Chaggu, 2002). With the current population of Tanzania of 36 million (Census, 2002) it means that, 836 kg/person/year (2.3 kg/person/day) implying ~1.2 m^3/person per year of wood which is slightly higher than the average East Africa per capita consumption of wood fuel, which is, 1.14 m^3/person/year (Arnold and Jongma, 1978).

From the fact that, the density of ash is 0.27 g/cm^3 and the average volume of faeces is 0.138 l/visit, it can be calculated that, the amount of ash required to be put into the ECOSAN vault is 0.138 * 270 g/l = 37.26 g-ashes/faeces. For five times application, this amounts to 186.3 g-ashes/faeces. The ash content of wood is ~5%, and hence, the amount of wood required to produce the needed amount of ashes per faeces is 186.3/0.05 = 3.7 kg-wood/faeces. At an ash to faeces ratio above 3 the amount of ashes exceeds the amount produced from normal domestic use (cooking etc.) meaning that, the produced amount of ash is not sufficient for toilet use in case everybody uses the ECOSAN toilet. Such a situation will mean that, more wood has to be burnt deliberately to get the amount of ash required, a fact that will accelerate deforestation. Furthermore, ash will quickly be a marketable commodity that may prove to be unaffordable by the needy. It is therefore important to look ahead for an alternative supplement to be used in ecosan composting toilets in Tanzania. In Mexico (Drangert, 2003), lime, dried faecal material (is being returned to the used bin) and soil is used as an additive material. However, lime is a high-alkaline additive material and so, the end product may be too alkaline for some land applications. The chemical additives have been used in some places like South Africa (Mang, 2003) but they pose environmental concerns. Saw dust, peat and wood chips are most popularly added to the faecal matter in Finland either alone or mixed with each other (Mattila, 2003). However, very few studies on efficiency of additives is available (Drangert, 2003) and hence, further studies into this aspect of dry toilet material additive are necessary.

From an inventory of 26 wood ash analyses from 15 different sources, Someshwar (1996) found that, the mean levels of Mn and Zn were the highest of all microelements, with average values of 4370 and 443 mg/kg respectively, whereas, the mean concentrations of Cu, B and Mo were 75, 110 and 15 mg/kg, correspondingly. Concerning the non-essential trace elements, the mean levels of Se and Hg in wood ash were very low (<0.5 mg/kg) and Cd and Co relatively low (<10 mg/kg). The mean levels of As, Ni, Cr and Pb were more elevated, ranging from 23.2 mg/kg for As to 65 mg/kg for Pb. Wood ash may also contain some organic compounds, notably polyaromatic hydrocarbons, chlorobenzynes, chlorophenols and so on, but in negligible concentrations. Despite this fact, the cumulative application of ashes in the toilets and thereafter, the reuse of sludge in agriculture may raise the levels of the heavy metals, which were formerly in negligible amounts. Marchioretto (2003) realized that, there is no cheap technology to remove heavy metals from sewage sludges. So avoiding their introduction into the sludges is very important from the practical point of view. Nonetheless, FAO (2003) noted that, normal wood charcoal is not very active adsorption material for either liquids or vapours because some residues block its fines structure.

B) Extent of Biological Conversion

The extent of biological conversion of the accumulated faeces is an unknown parameter that has been very difficult to determine in the present study due to the fact that, the existing structures are not controlled. They were not designed for research purposes. They are vented so that foul gases could escape easily from them. On the upper surface-air interface part of the accumulated heap of faeces, aerobic conditions prevail, while, at the inside the heap anaerobic conditions prevail. Franceys *et al*. (1992) remarked that, the difficulty with vault design is that very little information exists on sludge accumulation rate in vaults where excreta are mixed with ash and other organic material. Nonetheless, the factors that could affect the extent of biological conversion achieved in composting toilets include biodegradability of the faeces, pH, temperature, storage period of the sludge, and moisture content.

In case of Majumbasita the most important parameter is the increased pH due to addition of ashes. So far, there is nobody who has tested the composting process above pH 9.5 (Hamelers, 2003) and hence, it is difficult to conclude that at high pH values like those obtained in ECOSAN toilet composting will still go on. Obviously, at high pH, methanogenesis will completely stop. Biological conversion in the case of Majumbasita is therefore unlikely.

C) Evaporation of Moisture

Undoubtedly evaporation of moisture from the accumulating faeces in the latrine vaults will occur, especially under tropical conditions. The rate of evaporation of moisture from composting latrines with addition of ashes has not been substantiated. However, it can be assumed that, the evaporation rate reduces as the faeces heap grows. This is because, as accumulation continues, the voids are reduced and so lack of enough air movement in the stationed heap of faeces. The factors affecting the rate of evaporation in the pits are temperature, wind, amount of moisture in faeces and solar radiation. Faeces contains on average 75% moisture (*see Chapter 1*) so with the increased tropical temperatures, this moisture will go off. Since the latrines are in tropical areas, the temperatures are most of the time between 25-37^{0}C. These high temperatures will be absorbed into the deposited faeces and warm it up and hence, loose the moisture. The solar radiation as well will heat the block-work (used for building the substructure) and cause warm moisture in the faeces to leave the vault. Possibly the addition of ashes will reduce the evaporation rate due to absorption of moisture from the faecal sludge.

2) The Demanded Storage Period (DSP) for Faeces

In Chapter 4 the demanded storage period (DSP) was defined as the storage time needed to achieve a certain degree of anaerobic sludge stabilisation. However, as only a limited amount of biological conversion will take place (*see previous section*) the storage period can be suited to the needs of the user. According to Franceys, *et al.* (1992) as a general rule, pits should be designed to last as long as possible. They noted that, pits designed to last 25-30 years as not uncommon and a design life of 15-20 years as perfectly reasonable. Mara (1984) proposed a design period of not less than 10 years for VIP. The sustainability criteria (*see Chapter 1*) and people would like to get vaults, which could take longer time to fill. Longer filling up time is good as it is less work for the residents and the faecal material will get enough time for removal of pathogens. However, for people who would like to reuse the faecal sludge, longer period of time will not be beneficial to them. Franceys *et al.* (1992) proposed that, if the maximum possible design life is <10 years, serious considerations should be given to using an alternating double-pit system with a minimum design life of 2 years.

For the existing pilot structures at Majumbasita, design period means two things: one, the toilet chamber is built of permanent/durable materials, which will last for between 15 to 20 years. Secondly, the design period as regards frequency of emptying termed as the DSP in this study. This implies that, after that storage period, the sludge is removed and the latrine vault continues to be used for another cycle without constructing a new vault. The second meaning, DSP is used in the subsequent explanation. The DSP was to be 2 years in order to get enough use time and to be able to reuse the faecal sludge. The design period was not substantiated by course of biodegradation pattern taking place in the pit. There are twin vaults used at Majumbasita.

The minimum volume (excluding freeboard) for the pit required to store the produced faeces can be calculated as presented in Equation 6.3.

$$\mathbf{V_{pit} = DSP \cdot p \cdot (V_f + V_a) - V_{evaporation} - V_{conversion}} \qquad \mathbf{(6.3)}$$

With:
$V_{evaporation}$ = volume decrease due to evaporation of water
$V_{conversion}$ = volume decrease due to biological conversion of organic matter

In this study,
p = 7,
V_f = 0.138 l/p/day,

V_a = 3 times volume of faeces (This is the maximum as calculated from the wood used by residents)
$V_{conversion}$ = neglectable (pH > 9)
$V_{evaporation}$ = unknown, but Gaillard (2002) determined for fresh faeces 255 gTS/kg, implying that, since faeces is about 75% water, this is then the maximum volume that can be reduced by evaporation.

Therefore, $V_{evaporation} = 0.75*0.138*DSP*p$ **(6.4)**

Using Equations 6.3, 6.4 and the above mentioned data, the volume of the pit required for Majumbasita can therefore be determined as:

$V_{pit} = (2*365)*7*(0.138+(3*0.138))-(0.75*0.138*2*365*7)-0 = 2291$ litres ~2.3 m^3.

The pit volume determined for Majumbasita without taking into consideration the evaporation and conversion was 2.4 m^3, which is a good estimate.

6.2.4 Storage of Urine

The separate collection and treatment of urine is a possible way to reform today's wastewater management (Udert, *et al.*, 2003). The ECOSAN system involves the separation of urine at the source of production (No Mix Toilets) and it is necessary to handle this fraction properly. Issues of suitability of urine as a fertilizer are discussed in Chapter 1. The volume of container for urine storage can be calculated using the amount that is contributed by the user community. The size depends on:

- the storage duration demanded or
- frequency of emptying anticipated
- the container size that can be lifted manually by user community (this is especially in developing countries where mechanization is not readily available but human labour is plenty specifically at the moment)
- whether wash water goes into the storage container or not.

In the case of Majumbasita, neither wash water (ww) or slab cleaning water does go into the storage container at the moment. Nonetheless, the improved version of the existing ecosan structures will have to handle the ww because it contains pathogens and so, it will be nice to have a small-scale sand filter in order to handle this fraction. Adding the ww to the urine tank will mean an increased volume to be handled and hence, big container and contamination of urine by pathogens. It may be good to have a separate place for urination only. That is, if somebody wants to produce urine only, then (s)he can use that place and leave the minimum amount of urine to be passed through the urine separation squatting hole only when faeces is deposited. This depends on availability of space and capital finances. The required volume of container for urine can therefore be calculated as shown in Equation 6.5. Contributing portions are the:

- portions of urine supplied to the toilet per person per day (n_u)
- volume of the urine supplied (V_u) (in Liter/portion)
- number of people producing the portions (p)

$V_{urine\ storage} = p*V_u*n_u$ **(6.5)**

With: $V_{urine\ storage}$ = Volume of urine storage container needed (litres/day or m^3/day)

It is envisaged that, at Majumbasita, people will urinate 5 times per day (*see Chapter 4*) and the production is for urine 0.2 l/toilet visit. This means that, one person will need a storage volume of one litre per day. The 0.2 l/toilet visit is for adults; the age of the users was not considered for the determination of the required volume despite the reality that, children and adults produce different amounts. The 20 litre containers used in the study area were based on the easiness of lifting by one person for emptying purposes. From experience, women are used to lift 20 litre buckets of water and hence, the 20 litres was regarded adequate for urine storage. Further gender considerations were not detailed in this study. On average the household size is 5-7 people at Majumbasita implying that, for using the upper value of 7, the 20 litre containers will suffice urine storage of only 3 days. It means that, the containers will have to be emptied every three days. This is a very high frequency for the people who use to deposit the faeces and urine and "forget". Nonetheless, the people said that it is not a problem on their part. "*Where there is a will, there is a way*" (Swahili and Dutch saying). If people say so, it means that they will co-operate in making their toilets a success. Time of use will tell the goodness of the co-operation. Nevertheless, it is important to use a number of 20 litre containers if there is enough space for keeping them longer even though, changing them after every three days will be necessary. A simple hand operated device for keeping the containers, which is manually operated, for rotation can be a good option. This option needs an interested person to work it out in very simple affordable terms by the users. A non-governmental organisation (NGO) or community-based organisation (CBO) may be good parties to handle this matter if their financial capacity is enhanced.

6.2.5 Considerations for Urine Reuse

Between mid-March to mid-June, Dar-es-salaam experiences very heavy rains. Despite the fact that, urban agriculture needs the nutrients, which are particularly in the urine, it will be very difficult to fertilize in that period continuously. Fertilization requires no excessive rains to avoid the leaching of nutrients although soil moisture is important for nutrient uptake by the plants. This means that, bigger storage facility will be needed for that period of time for urine. That is storage for 90 days with a total volume of 560 litres of urine for a family of 7 people; that is equivalent to about 28 containers of twenty-litre capacity. These could be stored at the edges of the outer walls of the house (aesthetic value?) or a centralised place within the easy reach of a number of households (~400 metres from the furthest house), a place considered as a community container centre for the neighbourhood. Notwithstanding, since each specific location is unique, management modalities have to be worked out. It should be in the hands of an NGO or CBO. However, Johansson (2000) proposed storage of six months of urine at 20^0C without the addition of any new urine in order to get its sufficient quality (with respect to pathogens for fertilising any type of crop but no further arguments have been given in the write-up). This time appears to be too long especially if the purpose is to remove the *E-coli* only which may be present in urine (*see section 6.3.4*) specifically for tropical conditions.

6.2.6 Sampling and Analysis

The faeces accumulating in these ecological toilets, was thick. For sampling a device with an auger end, similar as those used for digging wells (with specifications: Model – Eijcamp; Made is Agrisearch Equipment, P. O. Box 4 – 6987 ZG Glesbeek, The Nederlands) was used. This was the only good way of getting the sample from the centre of the pile of faeces through the desludging door of the pit (*Figure 6.1*), which was opened for that purpose only at that juncture. An important aspect in the sampling procedure was to contact a key man who is well known by the villagers, and he is the ecosan contact person in the settlement, before getting into the settlement for sampling, because without him it is very difficult to conduct the sampling job in the area. The contact person appeared to be very enthusiastic about the ecosan structures. He also monitors the progress of the filling up of latrines by frequently visiting the toilet places and checking them visually and discusses with the owners. He is the person, who knows and reported to, by the residents when any one is full or not. He was a great help during the sampling process that requires house-to-house visits.

The samples taken for the laboratory analysis were one kilogram of faecal sludge from each sampled vault and one litre sample of urine from each of the twenty litre containers sampled. Both samples (faeces and urine) were taken at the same location. The urine storage containers did not have sampling points, and therefore they were shaken before collecting the sample in each case. Within a period of two hours the samples reached the laboratory. The pH was determined both in-situ and in the laboratory. Other determined parameters were ambient temperature of the samples (in-situ and the in laboratory) different COD fractions, TS, VS, SMA, Stability test, TKN, NH_4^+-N, nitrite, nitrates, and VFA. The analytical procedures were as indicated in Chapter 3. However, most of the procedures were according to the Standard Methods.

In order to know the in-situ temperatures of the pit chamber headspace and in urine storage tanks, 13 ecosan toilets and 13 urine tanks (20 litres) were additionally measured on-site at one hot and one dry day due to time constraint. The pH meter used reads the temperature at the same time. The type of device used for the headspace temperature measurements was a similar one used for a compost pile temperature determination. It has a long arm and connected to a reading meter.

6.3 Results and Discussion

6.3.1 Operational Problems of Ecosan Toilets

Operational problems observed in the study area can be regarded as minor since they were all within the handling capacity of the users or householders. They included, a leaking pipe in one premise for the urine tank; a family who forgot to empty the urine tank and so it was overflowing. Their residence is located closer to the valley and the empty space was very big. The surrounding area was full of nice green grass meaning that the nutrients in urine were up-taken by the plants. This shows that, sometimes the users forget to empty their urine containers especially where the space is not a problem. On the other hand, frequent emptying competes with other duties faced by the householders. If they work far from home, frequent emptying becomes a bother to them. Quite often, users wait until they see that the containers are full and then empty them. Nobody is keeping records about how many days it took them to fill it, neither when they emptied them. Generally, judging from talking to the residents they have a positive attitude for emptying the storage containers. This should be an entry point into assisting them with hygienic ways of handling the urine and sludge. Currently, ~46% of the people are reusing the urine in the gardens/plants (Shayo, 2003) within their premises.

Other problems include possibilities of overuse/misuse during gatherings, drawing many people like funerals, parties like weddings as persons from other parts of the city or regions come who do not know the system as yet. In the primary school cleanliness of one compartment was not very good, since the pupils were urinating closer to the entrance door of the squatting slab. This clearly demonstrates the need to continue with advocacy, before the system is sufficiently understood by residents (ward, municipality, district, regional to national level). Notwithstanding, a wider and more appropriate dissemination means like through community meetings, visiting the pilot structures, posters, radio, TV, news-media programmes and posters on use modalities is necessary. This is because for the household it is not possible to guide every person who comes to the big gatherings. Johansson, (2000) observed that, the higher the resident's motivation, the greater the amounts of nutrient collected. Winblad (2000) also stressed that, any attempt to introduce an ecological sanitation system must be accompanied by a substantial amount of social marketing, instruction of builders, users and operators and follow-up.

6.3.2. Analysis of the Sludge in the Ecosan Toilets

The results of the analysis done on the sludge in the 16 out of 44 Ecosan toilets, which were in use during the time of the research, are depicted in Tables 6.2 and 6.3. In these tables the age of latrines, refers to the duration of faeces storage in the respective toilet. More specifically the length of time the bottom faecal sludge has spent in the latrine chamber. The pilot ecosan toilets were investigated during their initial stage of 4, 6 and 8 months since there was no other option of ecosan toilets in the city and country at the moment of the research with higher age. The arithmetic mean of the results obtained at these different latrine ages are shown in Table 6.3 denoted as "4 months average", "6 months average" and "8 months average", respectively. The association between observed parameters was further checked by regression model using SPSS (Statistical Package for Social Science) Version 10.0. The results are presented in subsequent sub-sections.

6.3.2.1 pH Results and Temperature

The results (*Table 6.3*) show that, faecal sludge from ecosan latrines as measured from 16 ecosan toilets at Majumbasita have high pH values that ranged from 6.0 - 10.4. The plant/charcoal ashes that are added to the toilet vault after every use, adds to the pH-value in faecal material from ecological toilets. The ashes are alkaline in nature since they are plant/charcoal combustion residues. From the calculated 4, 6 and 8 months average it can be seen that the pH of the sludge increases with the increasing latrine age. Checking validation of results by SPSS software, it was evident that the correlation between pH and age of sludge is highly significant at the probability (P) level of $P<0.001$. The results show that, the pH increases with increasing age of sludge in the latrine vault. Similarly, the ANOVA (Analysis of Variance) show the same conclusions with R^2 of 63%. Tropical condition temperatures observed 27 - 29.9^{0}C coupled with the pH suggests that, it is possible to have mesophilic digestion in the bottom part of the heap of feaces in ecosan pit only during the first months of operation. After that the pH goes up and it is logical to assume that no digestion goes on.

6.3.2.2 COD, TS and VS Results in the Faecal Sludge for 16 Ecosan Latrines

TS and VS were determined instead of TSS and VSS because the sample was far too thick and hence, it was not possible to be filtered. The results, summarized in Table 6.2 and Table 6.3 indicate a TS range of ~20 to 134 gTS/l. These figures are low when it is considered that the TS-content of fresh faeces is about 254.62 (±4.19) gTS/kg (Gaillard 2002). Given the nature of toilet use, that is, with addition of ashes, it was anticipated to find higher TS values, and therefore apparently the urine was not completely separated. Even a small amount of urine going cumulatively into the faeces vault can lead to relatively low TS values. The calculated 4, 6 and 8 months average TS-values indicate an increase in with time.

The total COD concentration in faecal material ranged from 32 to 74 g COD/l whereas the values for VS were between 16 - 97.5 gVS/l. The pattern for VS and COD is opposite to that of the TS.

The VS and COD concentration decreased with time due to the addition of the ashes (dilution). When a Student T-test (this is performed if the variance of two compared data are equal but there is a third one that is different from the others) was performed with 95% confidence limit on the results (*Table 6.2*), all the COD average values differ significantly. For the VS, only 4-month average is significantly different from 8-month average. In the case of pH, the 4 and 6-month averages are significantly different from 8-month average, whereas, the sixth-month average is not significantly different from the fourth-month one. However, for the TS results, all averages are not significantly different, while the VS/TS ratio averages are significantly different.

Table 6.2: The Average Data for pH, COD, TS, VS and VS/TS for Accumulated Faecal Sludge of Ecosan Latrines at Majumbasita

Months	pH	COD	VS	COD/ VS	VS/TS
4	7.3	73.7	46.1	1.6	81
6	9.0	51.8			51.8
8	10.3	33.3	20.6	1.6	25.5

The obtained results (*see Table 6.3*) are within the literature reported values for faecal sludge from latrines and unsewered public toilets quality in different cities noted by Water Resources Research Institute (WRRI) in Accra, Ghana and SANDEC (Water and Sanitation in Developing Countries) who conducted numerous analyses of untreated septage and public toilet sludges (WRRI/SANDEC, 1994) and results reported by Heinss *et al.* (1998), which varied from 49-97 gCOD/l. This also indicates that, the ECOSAN faeces accumulation chamber suffered from an intrusion of urine.

The COD:VS ratio was on average 1.77 gCOD/gVS, but fluctuated between 0.67-2.89 gCOD/gVS (±0.556). Such a condition might be due to the fact that ashes are added after defecation, meaning the sludge in the vault is very inhomogeneous. Samples taken for COD and VS determination may have higher or low contents of faecal sludge or ashes, which explains the high variations in the results. In other words, the different inhomogeneous samples for VS and COD have been obtained due to varying ash:COD ratio.

Table 6.3: The Experimental Results of Human Faeces for Ecological Toilets at Majumbasita

Sample code	Age of Latrine (months)	pH	Total COD (g/l)	TS (g/l)	VS (g/l)	VS/TS (%)	COD/VS	NH_4^+-N (mg/l)	Total N (mg/l)	PO_4^{3-}-P (mg/l)	K (mg/l)	Ascaris eggs (/1000 mg)
J1	6	9.54	50.20	38.95	32.37	83.12	1.55	2912	3790	55	205	200
J2	6	10.23	32.70	19.78	16.81	84.99	1.94	3471	6500	90	170	0
J3	6	8.34	69.86	64.20	41.98	65.38	1.66	4368	6555	70	170	400
J4	4	7.99	74.13	43.53	31.34	72.00	2.36	5852	6080	60	105	600
J5	6	9.15	36.53	64.13	19.70	30.72	1.85	3696	7465	65	160	200
J6	6	9.33	53.76	60.90	19.76	32.45	2.72	4368				200
J7	4	7.77	73.36	77.47	56.97	73.54	1.29	8092				600
J8	8	10.39	32.87	62.02	16.12	25.99	2.04	5768				nd
J9	6	9.13	40.13	134.32	29.85	22.22	1.34	3976				200
J10	8	10.26	33.79	100.00	25.00	25.00	1.35	5068				nd
J11	6	8.15	61.80	107.37	37.45	34.88	1.65	7700				400
J12	6	8.42	54.08	52.44	18.73	35.72	2.89	6244				400
J13	6	9.13	45.73	57.53	28.73	49.94	1.59	4135				200
J14	6	8.26	59.37	67.67	31.14	46.02	1.91	6608				400
J15	6	8.91	65.13	115.17	97.50	84.66	0.67	9800				400
J16	4	6.05	73.47	51.44	50.13	97.45	1.47	3528				800
4 months average		7.3 (1.1)*	74 (0.4)	57 (17.8)	46 (13.3)	81 (14.3)	1.7 (0.6)	5852 (2282)	6080	60	105	667 (115)
6 months average		9.0 (0.6)	52 (12)	71 (34.2)	34 (22.6)	52 (23.7)	1.8 (0.6)	5207 (2120)	6077 (1588)	70 (15)	176 (20)	273 (135)
8 months average		10.3 (0.1)	33 (0.7)	81 (26.9)	21 (6.3)	25 (0.7)	1.7 (0.5)	5418 (495)				nd

n.d – not determined *standard deviation values in bracket

6.3.2.3 VFA Results

The results in Table 6.4 show an accumulation of VFAs in the contents of the ecosan toilets. This implies that the methanogenic capacity in the reactor does not suffice in achieving a complete degradation of VFA. This however, was expected in view of the high pH due to addition of ashes, that is, above the required range of methanogens.

Table 6.4: VFA Results for the Sludge in 4 Ecosan Toilets at Majumbasita of Different Latrine Sludge Age

Storage Time* (months)	Sample Code	C2: gCOD/l	C3: gCOD/l	i-C4: gCOD/l	n-C4: gCOD/l	b-C5: gCOD/l	n-C5: gCOD/l	Total gCOD/l
6	J1	0.77	0.38	0	0.30	0.10	0.07	1.62
	J3	2.37	1.63	0	3.31	0.83	0.56	8.71
	J4	2.08	1.43	0	1.32	0.60	0.43	5.87
6.6	J1	1.17	0.60	0	0.60	0.40	0.51	3.43
	J2	1.77	0.51	0.14	0.19	0.33	0.07	2.88
	J3	3.58	2.68	0	4.16	1.20	0.72	12.34
	J4	0.85	0.17	0.05	0.07	0.15	0.02	1.71
7	J1	0.66	0	0	0.48	0.18	0.19	1.11

* Storage time refers to the time the bottom sludge has been in the pit chamber

6.3.2.4 Specific Methanogenic Activity (SMA)

The specific methanogenic activity (SMA) was measured in duplicate samples from two Ecosan latrines (J1 and J3) at the sludge age of 6 months for both cases. Into a serum batch bottle of 500 ml., 100 ml. of media was poured, then, 52.5 ml. of the sludge samples (approx. 4 g VS/l) were added and followed by 5 ml. of NaAc solution (100 gCOD/l), after which the pH was corrected to between 7.0 - 7.3. The bottle contents were topped up by demi-water to 500 ml. The gas produced was monitored by the liquid displacement method described in Chapter 3. The gas production results revealed that SMA varied with standard deviation in bracket from 0.014 (±0.005) gCH_4-COD/gVSS.d for J1 and 0.009 (±0.003) gCH_4-COD/gVSS.d. at 27^0C. Although these values are very low (compared to values generally found for sludge cultivated on sewage in UASB-reactors, there clearly is a potential of biogas production in the accumulated faeces heap in the Ecosan chambers. However, in order to accomplish methanogenesis, the pH should have been in the proper range, that is, lower than the values measured. Since hardly any methanogenesis can be expected at the prevailing pH (except possibly in specific niches with lower pH), consequently little if any growth, major part of the methanogenic bacteria present in the sludge likely originated from the fresh faeces.

6.3.2.5 Stability

The stability of the sludge is determined by putting the batch sludge in specified temperature conditions for a long period of time while monitoring the amount of methane gas produced until no further gas is produced. The liquid displacement method, described by Lettinga *et al.* (1991) and arrangement of which is shown in Chapter 3 was used to monitor the methane gas production. The stability of sludge is a function of the characteristics of "raw waste(water)" and treatment process background that generated the sludge (Mgana, 2003). In this study, 25 ml. of sample from J1, J3 and J4 (in duplicate) were poured into 100 ml. media and topped to 300 ml. with demi-water. The pH was corrected to between 7 - 7.3. From the data in Table 6.3 it can be calculated that, the added samples were correspondingly equivalent to 1255, 1746 and 1861 mgCOD. The samples were thereafter incubated at ambient temperature of 27-30^{0}C (*as observed during the time of study*). The results of the cumulative gas production are presented in Figure 6.3. From this figure, it can be seen that 375, 1400, 375 mgCH_4-COD was produced respectively for J1, J3 and J4 with a corresponding conversion of 30, 80 and 20% of the initial COD supplied to the bottles. These enormous differences might be due to inhomogenity of the samples. J3 sample might have more degradables than the others. J1 and J4 might have more ashes than convertible matter. This indicates (as expected) that, the samples were not stable. For a well-stabilised sludge, the stability value amounts to 2 ml-CH_4/gVSS (Haskoning, 1989). Nonetheless, it depends on where the sludge is reused (*guidelines in Table 6.6*).

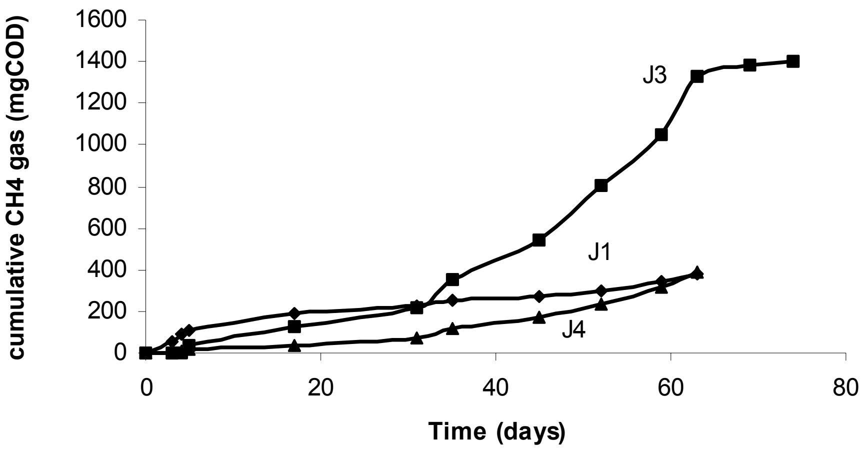

Figure 6.3: Stability Results from three ecosan latrines (*J1, J3 J4)* with corresponding sludge-COD as put in the serum bottles of 1255, 1746 and 1861 mgCOD) at Majumbasita

6.3.2.6 Kjedahl Nitrogen, Total Nitrogen, Phosphorus and ammonia in faeces

The total Kjeldahl Nitrogen (TKN) and phosphorus were measured using Standard Methods (1992). The ammonia-nitrogen concentrations for faeces from undiluted samples from Ecosan toilets show results (*Table 6.3*) in the range between 2912 - 5852 mgNH_4-N/l (±1129.41) with an average of 4060 mg/l on the day of sampling. Obtained TKN values as assessed in this study ranged from 3055-5045 (±882.7) mg/l, values that are similar to those obtained in a study conducted by Strauss and Heinss (1995) for sludges from latrines and unsewered public toilets. Their result ranged between 2800 – 6000 mg/l. However, the phosphorus results (*Table 6.3*) found in our study are comparable with those found by Mashauri and Senzia (2000) for Ecosan toilets at Majumbasita, that is, 28.72 (±28.36) mg/l with standard deviation in the bracket. For potassium, they found 166.43 (±82.51) mg/l. Johansson, (2000) noted that, ammonia emission application should be <1% - 10% (average 5%). The application for 20-30cm. high cereals works fine. However, heavy metals, hormones and antibiotics in faecal sludge are important unresolved issues to be explored especially for reuse purposes.

6.3.3. Analysis of the Urine in the Storage Tanks

The results of the analyses done on the undiluted urine in 10 storage tanks of ecosan toilets are shown in Table 6.5 and Figure 6.4. It is clear from this table that, different from expectation, the diverted urine contained high numbers of *E-Coli.* The detection of *E-Coli* counts in the urine storage tanks indicates contamination by faeces, which means a problem in separating faeces and urine during use. With adequate separation, the "pure" urine is expected to be free of pathogens (Esrey *et al.*, 2001) meaning zero *E-coli* count, but about 50% of the toilet (10) samples were out of the maximum WHO Guidelines for unrestricted reuse in agriculture (1000/100ml.) especially for crops, which are eaten raw, this could be risky. The result suggest that, direct use of urine separated in Majumbasita into the gardens could introduce pathogens into the soil and may infect vegetables, which then obviously represents a health hazard (further discussion *see section 6.3.4*). Nonetheless, the assessed pH of the collected urine ranged between 6.27-11.80 (±1.9501) and the temperature from 26.1-31.7 (±1) ^{0}C. From the fact that, the urine pH was 6 – 7 when excreted, but during its storage would raise to between 9 - 9.4 as a result of the degradation of urea (Johansson, 2000), the higher values found in our measurements implies that, there is a certain amount of ashes which went into the urine tank. The results however compares with those found by Moe & Izurieta (2003) for double vault-urine diverting (DVUD) toilet where the pH varied from 6.2 – 13.0 due to additives. Addition of lime, ash and soil resulted in corresponding pH values of 10.5, 9.4 and 8.8 respectively. However, Boost and Poon (1998) found that, pH of 11 – 12 is reached in treatment methods using supply of lime.

The Total-N for urine and TKN are determined as shown in Chapter 3. The PO_4-P in the urine results (*Table 6.5*) are comparable with those obtained by Gaillard (2002) for AC systems with standard deviations in the bracket, 0.20 (±0.01) (g PO_4-P/l) while the TKN values are higher in Gaillard's case 5.29 (±1.05) g-N/l than in this study (*Table 6.5*).

Table 6.5: The Results for pH, Nitrogen Compounds, Phosphorus, Potassium and *E-Coli* of the Samples taken from the Stored Urine at 10 Ecological Sanitation Toilets places at Majumbasita

Sample	pH	Total-N (mg/l)	PO_4-P (mg/l)	Potassium (mg/l)	E-Coli (no./100ml.)
J1	11.8	4360	111	251	50
J2	11.8	4957	177	190	100
J3	9.6	4385	134	239	600
J4	8.6	4285	122	202	1700
J5	10.3	5010	195	206	400
J6	11.2				200
J7	8.6				1700
J8	6.8				3900
J9	6.3				4500
J10	8.5				2100

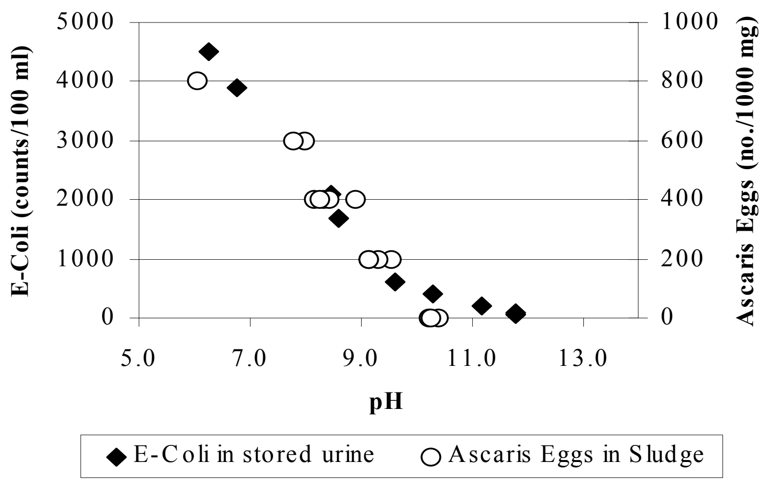

Figure 6.4: The *E-Coli*, *Ascaris eggs* and pH Results in Sludge and Urine of Ecosan Latrines at Majumbasita

6.3.4. Analysis of the Pathogens in the Sludge and Urine

A substantial reduction of *Ascaris* and *helminths eggs* together with faecal coliforms obviously is of great importance, especially if the aim of the treated FS and urine is to be used in agriculture. Results from this study and those found in literature for high strength sludge's are presented in Table 6.6. There is only a very limited literature on the presence of faecal sludge pathogens in AC systems, emphasizing a need to do more research works in this area. The table highlights that handling of faecal sludge presently in developing countries comprises yet a big unresolved issue. The values of the egg counts found for *Ascaris* and helminth eggs (*Table 6.5* and *Figure 6.4*) imply a big burden of diseases possible for Tanzania and hence, it is very important to carefully handle faeces and faeces contaminated urine from ecosan structures as well. However, from the measurements of *Ascaris eggs*, it is clear that the sludge from ecosan systems has lower values, indicating a high capacity of these systems in removing *Ascaris* eggs. It appears that there exists an interrelation between the *Ascaris* eggs and the pH prevailing in the faeces sludge and urine (*Figure 6.4*), that is, the higher the pH values the lower the *Ascaris* eggs number. This means that, the *Ascaris* do not favour higher pH conditions and therefore, this situation can be capitalized in order to remove them in the FS. Lan *et al.* (2001) found that, at pH-values >8 inactivation of *Ascaris* proceeds within 120 days (in faecal material), while according to Moe and Izurieta (2003), higher temperatures represent a strong, even may be the strongest predictor of *Ascaris* die-off and obviously the storage time in DVUD is also an important factor affecting *Ascaris* ova concentration. The diversion of urine and the addition of ashes result in significant dehydration of faecal material in the collection chamber; and this process further deprives the *Ascaris eggs* the moisture, they need to develop. All those mentioned factors (high pH, tropical temperatures, long storage time of sludge) prevail in ecosan toilets at Majumbasita and hence, a significant reduction in health risks is achieved in these systems. The *helminth eggs* determination was not done in depth but the results from the few samples checked had zero values.

With respect to the urine storage tanks the main interest was to see the effective use of the urine separation structures as regards *E-coli* in order not to jeopardize the health of the people through the reused urine. Only very few studies so far have been made on the effective use of human urine as fertilizer in agriculture meaning that there still is limited understanding of how human urine works and how it should be handled (Johansson, 2000) in different locations. Ten ecosan urine storage facilities sampled before recent advocacy showed a clear contamination by faeces. *E-Coli* counts (*Table 6.5*) were on average 15250 no./L, with a maximum value of 45000 no./L and minimum 500 no./L. Standard deviation was rather high (±1600 no./100ml). Results from 22 urine storage facilities reported by Shayo (2003) with standard deviation in the bracket, from Majumbasita shortly after advocacy campaign showed lower values of *E-Coli* with average of 89 no./100ml. and a range of 20 – 190 (±45) no./100ml. These results stress the importance of repeated advocacy until the users are used to the system and use it appropriately. However, similarly as with the situation for *ascaris* eggs in the faeces sludge, the *E-Coli* counts in the urine also are highly correlated with the pH (*Figure 6.4*), once again the higher the pH the low the numbers according to the counts. Höglund *et al.* (1998) found that for pH values the furthest from neutral the most negative effect on survival of organisms is obtained. They reported that, faecal bacteria added to stored urine died off more quickly at pH 8.9 and 10.5 than at pH 6.0. However, the hygiene standards applied to wastes reuse in the past, based solely on potential pathogen survival, have been far stricter than really necessary (Calvacanti, 2003). At the moment, it is expected that, the new WHO standards that are expected to come out in 2004 will rectify the standards. Johansson (2000) observed that, at 20^0C a storage period of ≥ 1 month in case the urine mixture is contaminated with pathogens and viruses (gram-positive and sporulating bacteria are not included) are recommended for food crops that are to be processed and forage crops. If the period is ≥ 6 months, then urine can be used in all crops fertilization but for food crops eaten raw fertilization should stop at least one month prior to harvesting (WHO, 1989). Since the results of Johansson were obtained at 20^0C, it is possible to have higher removal of *E-Coli* and *Ascaris* eggs at tropical conditions (average temperatures are between 26 - 30^0C) of Tanzania. Furthermore, Figure 6.4 suggests that at higher pH, viz. exceeding 10, the reductions of *E-coli* counts are significantly very high (up to zero counts/l). This means that, less time than six months in tropical conditions suffices for *E-Coli* and *Ascaris* eggs removal. This conclusion agrees with literature results by Strauss and Blumenthal (1997) who found that, the faecal coliform's average survival time in wet sludge at ambient temperature of 20-30^0C is <50 days. Urea (H_2NCONH_2), ammonium bicarbonate (NH_4HCO_3) and carbide ($HNC(NH_2)_2$ have also been found to enhance die-off. They however also found that, *Ascaris eggs* at the same tropical temperatures survive for a period of 10-12 months in wet sludge, but since the ecosan latrine's FS is dry, a substantially higher die-off may be expected and hence a better removal.

Compared with the results from UASB effluent for total sewage treatment, which has *E-Coli* values between 1.3 x 10^6 – 1.3 x 10^5/100ml., the ecosan toilets with the *E-coli* results shown in Table 6.3 are performing better in that aspect. The implication of these results is that, the urine from storage facilities of ecosan should be stored before application to the vegetable gardens in order to render the pathogens ineffective. Nonetheless, according to Höglund *et al.* (1998), the die-off *E-coli* proceeds rapidly and so they proposed that are not suitable for indicating faecal contamination of the collected urine. As well, Total *Coli* as faecal indicator looks of little relevance since the bacteria may emanate from sources other than faecal contamination such as urinary infections and technical system itself. Quantification of faecal sterols may represent a possible alternative to microbial analysis according to Höglund *et al*. (1998). They found Faecal Streptococci to be with concentrations up to 10^5/ml. in the urine, whereas Geldreich (1978) seldom found *E-coli* but Faecal *Streptococci* up to an amount equivalent to 100% of faecal material. *E-coli* had a five-fold longer survival in dilution of 1:9 than in undiluted urine solution. This means, the dilution of urine should be avoided as much as it is practicable. The parameters that may affect the presence of pathogenic micro-organisms in urine collection and storage tanks according to Höglund *et al.* (2002) are primarily the temperature, dilution and pH.

6.4 Conclusions

The objective of getting the baseline information related to the use of the ecological sanitation (ecosan) composting toilet system has been achieved and from the information collected we can draw the following useful conclusions:

- By using the ecosan toilets, such as those installed in Majumbasita, groundwater contamination can be avoided, since they are constructed above ground.
- More information needs to collected as to the amount of ash(es) to be added to the latrine vault, the proposed 3 times the volume of faeces will occupy the main part of the volume of the chamber.
- A complete separation of pure urine seems to be difficult for users as evidenced by faecal coliforms observed in urine.
- The separated urine can be used directly as fertiliser in tree growing, but not for fertilising food crops that are consumed raw, due to presence of pathogens.
- The extent of biological sludge stabilization likely is small in view of the prevailing high pH values. The toilet vault likely mainly acts as a chemical preservation chamber.
- A lot of urban agriculture needs to be developed in order to enable the reuse of all the collected sludge and urine. Otherwise, transport for reuse outside the city is necessary.
- *Ascaris eggs* and *E-Coli* are efficiently removed in ecosan toilets due to high pH.
- Advocacy on the use of ecosan toilets improves the separated urine quality.

Table 6.6: The Comparison of *Faecal-Coli Ascaris* and *Helminth Eggs* Results and Those in Literature

Country	Ascaris eggs (no./l)	Helminth eggs (no./l)	Urine E-Coli (no./l)	References	Remarks
Japan	40-100	n.m.	n.m.	Yao (1978),	OSS$^{@}$
China	18,000-360,000	n.m.	n.m.	Shiru & Bo (1990)	OSS
Guatemala	1,000	n.m.	n.m.	CEMAT (1992)	OSS
Asia	n.m.	n.m.	10^{5}-10^{7}	Arifin (1982) and Liu (1986)	OSS
Tanzania	200-800	n.d	50-4500	This Study (2003)	Values are from ecological toilets with urine separation.
Accra (Ghana)	29,000-62,000	$4000^{/}$-25000	n.m	Strauss, *et al.* (1999)	Public Toilet Sludge
Developing Countries	20,000-600,000	4,000-60,000		Faechem *et al.* (1983); Strauss, *et al.* (1997)	OSS
Industrialized Countries	n.m	0-20	n.m		OSS
Suggested Guidelines for reuse (Heinss, Larmie and Strauss, 1998)		Helminth eggs	$\leq 1^{*}$ (number/l)		Out of 250 mil. people infected with ascaris lumbricoides, annual mortality is 60,000; & 46 mil. infected people with associated morbidity, annual mortality is 10,000 (WHO, 1998).
			$\leq 1^{**}$ (number/l)		
			$\leq 3\text{-}8^{***}$ (/gTS)		
		Faecal Coliforms (no./100 ml)	$\leq 10^{5*}$, $\leq 10^{3**}$, $\leq 1000^{\#}$		

*Values for restricted irrigation for liquid effluents (on arithmetic mean basis); **Values for irrigation of vegetable; ***Faecal Coli will be safe level if egg standard is met. Treated plant sludge use in agriculture (Heinss, Larmie & Strauss, 1998), and on average manuring rate of 2-3 tons TS/ha.year (Xanthoulis and Strauss (1991), #WHO (1989) Standard for unrestricted irrigation (on a geometric mean basis), $^{/}$septage, $^{@}$On site sanitation system

CHAPTER 7

SUMMARY AND DISCUSSION

7.1 Introduction

Outbreak of fatal diseases like cholera, typhus and diarrhoea which have no sign of fast departure in Tanzania, are a result of people's actions in secret which produce human "waste" or excreta. The effects of these actions can be of big public concerns. Indiscriminate disposal of excreta results in contamination of water, direct/indirect contact with people through fingers, food and fluids. This urges or calls for improved sanitation in a sustainable manner, care about human health and the environment (Lettinga *et al.*, 2001; Drangert, 2003). In the past, on-site sewage treatment options at household level have been implemented with a false expectation in some urban areas of Tanzania that, in future, the systems could be upgraded to sewerage, which is a "drop and forget" concept. The economic reality pushes this option even further than the anticipated possible realizable time. Increased urbanization and population growth, which does not tally with provision of sanitation services, poses pollution potential to the surface as well as ground water. Since the majority of the people use pit-latrines and it is economically not possible to use sewerage and from the view point of sustainable development highly undesirable to pass in this expensive resource consuming "Western" concept, improved versions of pit latrines are necessary, as well as adequate operational and management strategies for these systems. In that respect anaerobic digestion of human waste in anaerobic accumulation systems, could be highly attractive in tropical conditions. They store human excreta for a long period of time and produce only periodically effluent. The main aim of AC systems is to end up with a stable sludge (= no degradable suspended solids) after it has completely filled and to convert all produced volatile fatty acids to biogas. The anaerobic by-products in terms of biogas and stabilised sludge have a significant reuse potential that contributes to the sustainability of these systems.

The main objectives of this study were to 1) carry out a socio-cultural and economic study of the sanitation conditions with emphasis on pit-latrines in Dar-es-Salaam, Tanzania and their interrelationships with regard to faecal sludge management, urine separation and reuse; 2) improve the understanding of the biological stabilization processes proceeding in the pit-latrines; 3) cite out proper operational guidelines for pit-latrines with respect to emptying practices 4) come up with adapted designs and construction aspects for community on-site latrines which enable biogas collection and 5) suggest the potentials of safe re-use/recycling of sludge from pit-latrines for urban and peri-urban farming after subjecting it to some further (low-cost) treatment.

7.2 Excreta Disposal in Dar-es-Salaam

Socio-cultural aspects are very important since correct management of excreta depends on technical, environmental and social aspects. Some traditional beliefs are discouraging the use of sanitation facilities like those observed in Terai Communities (Bolt, 2003) in Nepal which stated that: "we do not defecate at the same place as Rhino or Blue Cow does" and " Only sick or person with broken leg goes for defecation repeatedly at the same place". In many occasions, it has been proven that, without adequate considerations of social aspects suitable technologies even for excreta handling may fail miserably. It is very difficult to change the habit of the people pertaining to excreta disposal (Faechem and Cairncross, 1978). Chapter 2 deals with excreta disposal in Dar es Salaam where this study has been made. It highlights on the existing socio-cultural and –economic situation and realities of faecal sludge handling. In this chapter the results are presented of a survey on excreta handling amongst 207 households in 9 of the 52 wards of Dar es Salaam. Issues that are dealt with include education level, income and expenditure, knowledge of latrine types, habit of bathing and anal cleansing, construction materials and costs, production of sludge and disposal, issues of pit-latrines desludging, actors in sanitation and reuse aspects. In the study areas 84.8% of the residents have primary school education level, that is, seven years of elementary education, while 12.8% have secondary education and only a small fraction of 2.4% have University, technical and vocational education. This fact suggested that one may have some difficulty in introducing any technology in those localities due to the fact that, the understanding capacity of the people is low. Suitable techniques will therefore be important in order to put the needed message across like introduction of pilot programs, which assist the people in understanding the issues of excreta management. When people see the working scheme, their reservations often disappear (Chaggu and John, 2002). In competition of resources, normally the sanitation gets the least priority. Presented in this chapter also are different kinds of pit latrines and sludge production in Dar-es-Salaam. Over 80% of Dar-es-Salaam urban dwellers use pit-latrines while, 10% of middle and upper class populations use septic tanks, 5% are connected to sewerage and 5% of the poorest have no proper sanitation. Those without sanitary facilities use neighbours toilets or open spaces nearby their premises. Sludge production increases with increasing population while the desludging methods are almost stagnant. It increased from 50,000 m^3 in 1992 to 183,600 m^3 in 1998 and 254,897 m^3 in 2001. Recycling or reuse of nutrients has recently come to the fore, and certainly not for the first time in history (Drangert, 2003) but, there is limited understanding of these aspects in Tanzania.

7.3 Modelling of Anaerobic Conversion of Black Water and Night Soil in Accumulation systems

Application of models are ever increasing due to the reality that, complex situations are experienced in the world today, the solutions are needed soonest, experiments take a long time and need adequate space, and learning everything about a desired topic is increasingly becoming difficult if not impossible. A model is very useful, provided it adequately describes the ‘situation’, whether one seeks to interpolate “between” measured data, or to extrapolate “beyond” them, or to apply them in a generalized way and after due modification to radically different set-ups (Sinclair *et al.*, 1987). Given these facts, a simple model was therefore developed, which enabled determination of the course of the concentration of different COD fractions in the accumulating sludge in AC reactors for black water and night soil. The assumption made for the model is that, the waste entering the vault accumulates as influent and methane is the only COD-flow coming out of the reactor. Model results indicated that, under tropical conditions 97% sludge stabilization is achievable within 1 year of reactor use. If 99% or more stability is desired, an accumulation period of 2.5 years is required or closing the reactor without adding any new materials for at least two weeks before desludging is necessary.

For the first run or beginning of reactor use, the black water and night soil reactors should be seeded with a sludge that has a minimum SMA of 0.1 gCOD-CH_4/gCOD-VSS/d at 27^0C and VSS content of about 11 gVSS/l with seed sludge volume of 690 for black water and correspondingly for night soil 0.5 gCOD-CH_4/gVSS/d with 8 gVSS/l and 142 litres of seed sludge volume. These values are however, very high from the practical possibilities. For subsequent runs the volume that needs to be left in the reactor after desludging depends on the SMA of the sludge in the reactor. When assuming Monod kinetics with k_m= 1 gCOD·gCOD^{-1}·d^{-1} (Batstone *et al.* 2002) it can be calculated that for the black water reactor the SMA of the sludge after reactor closure will be about 0.09 gCOD-CH_4/gCOD-VSS/day or 0.12 gCOD/gVSS/day (assuming 1 g VSS=1.42 g COD). At a sludge concentration of 30 g VSS/l the volume to be left in the reactor is about 250 litres.

7.4 Anaerobic Stabilization of Black Water in Accumulation Systems "The Demonstration Reactor"

In Chapter 4 theoretical calculations were made with respect to the use of anaerobic accumulation systems for the stabilization of black water. In Chapter 5 a practical application of an accumulation (AC) system in the form of **Im**proved **P**it **L**atrine **W**ithout **U**rine **S**eparation (IMPLWUS) in a 'real life' situation was demonstrated. The reactor was constructed at a 10 persons household in Mlalakuwa settlement in Dar-es-Salaam (Dsm.), Tanzania. It was constructed from a 3000 litres plastic tank called SIMTANK after factory name based in Dsm. The tank was kept underneath a raised floor slab for squatting purposes. The IMPLWUS is completely sealed from seepage and retains the sludge in the reactor for all the use time with an exception of biogas, which goes out as the only effluent from the reactor. There is a limited mixing taking place that is partly (at a small scale) effected by the dropped incoming matter and the produced biogas. Influent contained urine and faeces in the ratio of ratio of 1.3:1. To enhance the methane production the reactor was seeded with 300 litre sludge from a 15 year-old septic tank. The system was operated under ambient temperature conditions (26-31^{0}C) and with an average influent flow of 6.7 l/day, the reactor was full in 380 days.

The IMPLWUS reactor was sampled regularly and the results showed that initially the VFA concentration was about 1200 mg COD/l but decreased very slowly during the operation of the reactor. Nonetheless, at the time when the reactor was closed; day 380, the VFA was not yet zero, it was 100 mg COD/l. Moreover, about 8000 mg COD/l of non-acidified dissolved COD was present in the liquid phase of the reactor, which was a clear sign that the reactor contents had not yet been completely degraded, consequently that the system is still under start-up. This could be due to ammonia inhibition as the ammonia increased from 65 mg N/l to about 2500 mg N/l in 380 days. However, since this was the first run of the reactor, it is assumed that, during the subsequent runs or cycles, the VFA and other dissolved components will be zero at closing time since the sludge will be more adapted to the operational conditions. This situation leads to a need of retaining this sludge at emptying. This means, when IMPLWUS is full with either liquid + sludge or sludge alone, at emptying, people should leave the bottom sludge of the reactor as seed sludge of the next use-phase.

Biogas production from the IMPLWUS reactor could not be determined due to a small leakage in the headspace of the reactor. However, samples from the reactor that were incubated in the lab did show gas production. A stability test with the sludge in the IMPLWUS reactor was not yet completely stable by day 354 of reactor use. The incubated samples produced 0.67-1.3 gCOD-CH_4/l which was a little bit less than could be expected from calculations with the AC model presented in Chapter 4. This situation implies that more stabilization time is required depending on the envisaged disposal of the sludge. The reuse aspects of the produced sludge have not been looked at in this section of the study although they are very necessary specifically at emptying time, when organized sludge disposal/reuse place is required.

The IMPLWUS offers a possible wide application in high water table areas of Tanzania since the reactor can be constructed with locally available materials and labour. It is applicable at any site (planned and unplanned) and the scale depends on the number of users. Moreover, it does not require specialized personnel during operation and monthly emptying as in the case of traditional pit-latrine in high water table locations. High frequency of emptying the latrines is very costly. Additionally a complete diversion of urine and particularly a decreased amount of wash water into the tank will very significantly reduce the needed volume and consequently will make the reactor even cheaper as compared to the traditional pit-latrine. Moreover the risk of environmental pollution also is very substantially reduced.

7.5 Performance of Composting Latrines in Majumbasita Unplanned Settlement in Dar-es-Salaam - Tanzania

In another initiative to overcome groundwater pollution problems due the high water table in Dar es salaam a project was started comprising the installation of 110 composting latrines in the form of ecological sanitation (Ecosan) toilets at Majumbasita unplanned settlement in Dar-es-Salaam, Tanzania. They were constructed by a non-governmental organisation (NGO) called Environmental Engineering Pollution Control Organisation (EEPCO) with a financial support of UNICEF. In Chapter 6 a short survey of 16 of these latrines is presented. The studied Ecosan toilets are basically AC systems, which receive faeces daily in proportion of the number of users. To keep the accumulating faeces as dry as possible, urine is collected separately in a 20-litre storage container and wood or charcoal ashes are added after every faeces deposit. The volume of the tanks for storage of urine was sufficient for approximately 3 days of storage. The Ecosan toilets were constructed quite recently and therefore only the first 8 months of faeces accumulation could be observed. Studied quality parameters revealed that, the pH of the faeces ranged from 6 to 10.4 while that of the separately stored urine was 6.3-11.8. The high values of pH in urine might be due to incorrect application of ashes used in the faeces vault coming into contact with urine. With such high values of pH there is no biological conversion that could take place implying that, there is no biological sludge stabilization achievable and the toilet vault acts like a chemical preservation chamber. Nonetheless, the results of a stability test with the sludge showed that when the pH is brought back to neutral, it is still possible to have biological conversion.

Urine separation is not complete at Majumbasita as evidenced by the low solids content of the accumulated faeces and the occurence of *Faecal coliforms* (FC) in the separated urine; on average 1525 no./100ml. *E-Coli* and *Ascaris eggs* in the collected samples decreased with increasing pH meaning that, addition of ashes to ecosan toilets is effective in reducing/removing *E-Coli* and *Ascaris eggs* in faecal sludges. This seems to be the only advantages of addition of ashes to the latrines, because, the use of ashes in ecosan latrines does not only pose a future challenge in case of changed cooking energy but also, brings in environmental concerns for reuse of the sludge. The pH is too high for application on land unless if it is a land where the pH is low and hence, a remedial measure will be to use high pH sludge. This is because, it has been cited in literature that, the alkalinity of ashes is high and they contain variable concentrations of micro- and macro-elements (Ohno, 1992; Ohno and Erich, 1996; Someshwar, 1996). A lot of urban agriculture is needed for reuse of sludge and urine, otherwise, an alternative way is to transport it outside the city as necessary despite the reality that it will be costly. At the moment, the separated urine is used in fertilizing the vegetable gardens, hedges and tree fruits. Nonetheless, it has been observed that, advocacy is very important on how to use the ecosan toilets and it should be repeated as frequently as it is necessary.

7.6 Discussion

The results of the study presented in this thesis, indicate clearly that, accumulation systems (AC), IMPLWUS and Ecosan operated at tropical conditions of Tanzania (26-31^{0}C) substantially alleviates the problem of groundwater pollution (*Chapters 5 and 6*) experienced by about 45% of the Dar-es-Salaam City area. There is no biological stabilization however, in Ecosan latrines due to increased pH by addition of ashes. It may be good to stabilize the sludge without addition of ashes for possibilities of reuse. In Finland, the popular additives to dry toilets are peat, wood chips and saw dust either alone or mixed with each other (Mattila, 2003). The impact of these additives to stabilization or their suitability is yet a subject of study. What can be practically said is that, the application of these additives given their bulky nature will increase the reactor volume and so, additional cost to users. High pH sludge is not suitable for land application. The users of urine separation structures do not adequately separate the urine, which clearly shows that, there is a great need not only to continue with advocacy but also to improve the squatting hole place to be suitable for easy separation. Furthermore, a separate place for urine only could assist in separation. That is, if someone wants to urinate only without defecation, then (s)he can use that area. The differences between IMPLWUS and ECOSAN are presented in Table 7.1 below. It is clear from the table that, despite the reality that both systems have got their own advantages and limitations, from the usage point of view, IMPLWUS offers easy use but requires a big volume container due to high flows meaning more investment which might not be forth coming to the users. Ecosan needs high user input, which is not always available especially where there is competition of time between economic activities and servicing Ecosan toilet. Nonetheless, both systems are at their start-up conditions so, further research work is necessary.

In Table 7.1 it is shown that, the urine to faeces ratio should be as low as possible since urine has low contribution to gas production but adds significantly to the volume of reactor. Small ratio means small reactor and subsequently lowered capital cost. This is advantageous if users have small plots so small reactors or else, if the user has got a big plot, likes to store the faeces and urine for longer period of time and has a financial capacity to do so, big urine storage containers and faeces reactors can be used. Nonetheless, small reactors may serve the initial capital costs but end up with high operational costs due to high frequency of emptying the reactors, which is not on-line with the sustainable criteria (*see Chapter 1*).

However, if one intends to reuse the biogas, one of the main drawbacks of the AC system observed in this study is the fluctuating daily methane production rate over the filling time with black water. The reuse of gas needs continuous adequate production and constant supply. There is no production of gas expected during the continued use of Ecosan toilets due to presence of high pH. In IMPLWUS, the produced biogas is small from a household of 10 people in relation to the domestic need and thus, it is not possible to reuse the biogas produced by the demonstration reactor. Since biogas is one of the green house gases, if not used, they should not be left to the atmosphere untreated. A methane sink is needed if it is not reused. Possible options to handle the produced biogas include:

- to use the anaerobic battery in order to produce electricity (very undeveloped concept and cost?). Someone may take it up as a job to collect and store biogas in mobile containers, charge the batteries and sell them later to the needy especially in areas with intermittent/without electricity. The financial benefits of this activity need to be looked at.
- Add other components like household organic waste or cattle manure (where available) in order to improve the production of biogas for domestic use.
- Use a centralised community digester for about 50 people and the produced biogas be used on rotational basis by the producing community (tedious? Possible social conflict? and need for another supplementary energy source?). This is because, the gas produced by 50 people if no other organic wastes are added to increase the gas production, is sufficient to cook 3 meals for 5-6 people only.

IMPLWUS is not susceptible to misuse when compared with Ecosan. Ecosan requires a lot of input from the users and hence, a need for advocating while, IMPLWUS needs more thought in technical part before it is put into operation. Misuse may end up with very wet sludge in Ecosan, which means smell, increased reactor volume, failure of anticipated result, messy and will be disliked by the users. The gender concerns, that is, needs and contribution of men and women in operationalisation of Ecosan toilets are very important for good use and output of advocation. If the different needs are not catered for, the use of the toilets will be jeopardized.

Management aspect is very important for workability of the IMPLWUS and Ecosan toilets. Duqqah (2002) proposed creating an adequate institutional framework that should always control, supervise and advise on any scheme involving its use, in order to ensure that such use is safe and optimal with respect to environmental quality protection. However, the institutional framework should be designed to suit local conditions (Ministry of Health, 1995), being well defined and having a clearly specified distribution of responsibilities. The management of excreta as a health problem, together with the interaction of major elements are depicted in Figure 7.1. Health problems and needs (HPN) are largely determined by the ecosystem the community lives in (geographic, economic, social, cultural and political environments). In turn, HPN determine services input requirements (physical infrastructure to run the services and service program). Proper functioning of inputs like IMPLWUS and Ecosan at community level needs a support system (reliable technology and patience). At the moment both IMPLWUS and ecosan technologies are undeveloped. Once they are fully developed, they need a workable market strategy. Therefore, the input distribution designates both accessibility (geographic, financial, social) as well as availability (in terms of the number and convenience) of services. In order for the service input to have any effect on the health situation, it requires to be translated into a sufficient number and quality, that is, service outputs (Kielmann, 1995). Some legal control will usually be required, although it is easier to make regulations than to enforce them (WHO, 1989).

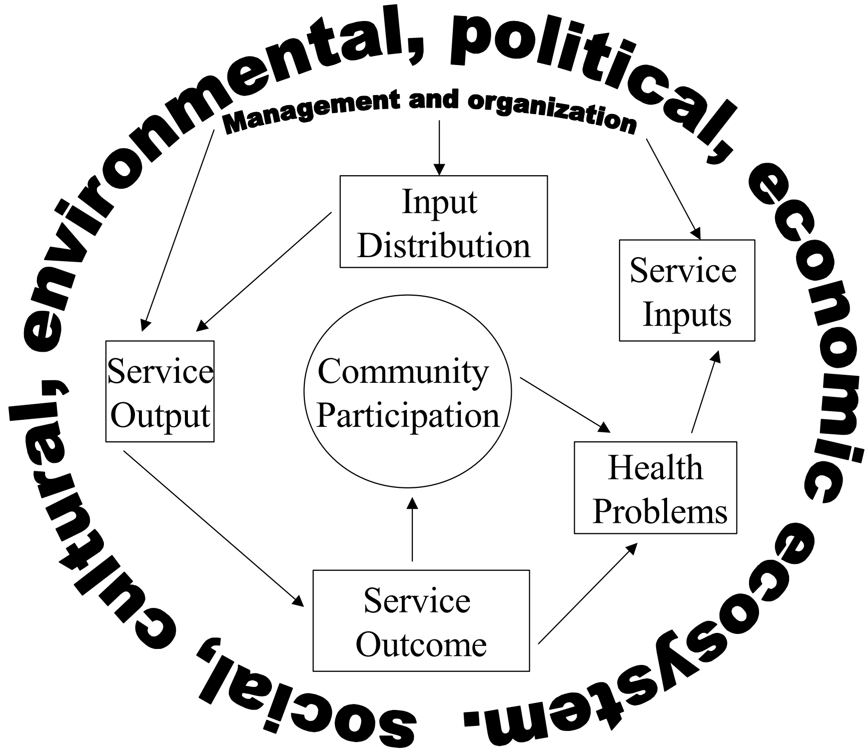

Figure 7.1: Interaction of Major Elements Comprising the Health Service Delivery in Tanzania and Excreta Management as a Health Problem (after Kielmann, 1995)

Table 7.1: The Comparison of IMPLWUS and ECOSAN Toilets as They are Present in Dar-es-Salaam, Tanzania

Parameter	**IMPLWUS**	**ECOSAN**	**Remarks**
Flow	High, due to faeces + urine + wash water that enter the vault	Low, as only faeces and ashes go into the vault	Low flow means small reactor volume and so, less capital investment, and much better protection of the environment
Easiness of use	Controlling the amount of wash water is a problem	A lot of input from users in controlling the amount of ashes and separating urine	IMPLWUS appears simple despite the mentioned problem in this aspect, while, Ecosan needs continuous advocation due to high users' input requirement.
Costs	Expected to be higher than Ecosan due to usage of plastic tank to ensure gas tightness and equipment for gas reuse or gas sink	Lower as reactor consists only of blockwork and faeces drops directly to the pit chamber	Costs might be increased after several years of use in maintaining the block-work wall of ECOSAN toilets which is not needed for IMPLWUS
Urine to Faeces Ratio	Preferably as low as possible and use a urine separation squatting slab meaning a need for urine storage tank	Zero	No urine goes into ECOSAN toilets. A low urine:faeces in IMPLWUS decrease the flow implying that the reactor can be smaller or the storage period can be increased. Both systems need user's co-operation.
Misuse Susceptibility	Less susceptible^	Immediate failure	Misuse can quickly result in clogged urine separation pipes and wet sludge.
Clogging of down-pipe	Less likely but if urine separation is used, then, clogging of urine pipe is possible	Very likely for urine pipe	As no liquid goes into the vault, depending on size and type of down-pipe is used for separated urine, clogging is likely and so frequent cleaning.
Collection of biogas for reuse	Possible but single family do not produce adequate gas for reuse	No	Considerations of ECOSAN should be mainly on sludge and separated urine reuse. IMPLWUS little family gas produced should be treated before discharge to atmosphere.
Sludge reuse	Possible after stabilization	Doubtful due to quality of ashes and high pH of sludge	Ecosan sludge could be applied as remedial measure for very low pH soils or land but further research is necessary
Urine Reuse	Only if urine is separated	Yes	

Emptying	Slurry material so sucking by vacuum tanker is possible	Very dry, cake material and so can be raked	Vacuum tanker can empty IMPLWUS and labour intensive work for ECOSAN.
Hygienic handling of urine	Only needed if urine is separately collected	Needed but unpleasant	Frequency of handling urine is too high and competes with other economic activities.
Hygienic handling of faeces	Applied after sludge is stabilized once at emptying.	Applied once after the design period has been attained	Different desludging times are applicable. Present ECOSAN toilets are two years.
Affordability to many residents	Possible part payment	Possible part payment	Need for subsidization of some parts of the reactors.
Smell	No	No, if well managed[*]	Good management and advocacy are necessary.
Control and security	No	No[*]	Unless if the systems are indoors or in a hedged yard.
Management actors	Household, NGO[**] or CBO[#]	Household, NGO or CBO	NGO and CBO can assist on the aspect of desludging and disposal/reuse aspects.

[*]Drangert (2003); [**]Non Governmental Organisation; [#]Community based Organisation; [^]high level of misuse can make it a complete failure; [~]If biogas is desired from Ecosan toilets, additive material other than ashes should be used. In Finland they use peat, wood chips and saw-dust either alone or mixed with each other. There is however no detailed study to evaluate the suitability of these additives (Mattila, 2003).

7.7 Overall Important Conclusions

In view of the results obtained in this study, the following important conclusions are specified:

1. In the light of Sustainable Development but also in view of cost and economy, the use of simple sanitary systems like improved pit latrines (IMPLWUS and Ecosan) in a city like Dar es Salaam, but likely in many other cities and regions in developing countries, is the correct approach. This is especially so provided these systems are well designed and constructed, and above all, operated and maintained in the proper way, which implies:
    a. To keep the volume of the reactor as small as possible, the set amount of wash water is limited to 0.25 l/faeces drop and 0.1 l/urine production into IMPLWUS should be carefully adhered to. Nonetheless, using the toilet papers is better if the economic status of the people allows.
    b. If the desire of the families is to reuse the biogas for cooking, a one family gas production is not adequate. To cook 3 meals for a family of 5-6 people, ~50 people's gas produced is necessary meaning a centralized unit for 50 people's "human waste". A plan of who uses the gas when, will then be important. Single families's (about 7 people) gas can be used for rationed lighting purposes.
    c. At emptying stage, for IMPLWUS the percentage of sludge to be left in the reactor for next run depends on the methanogenic activity and sludge concentration after subsequent run but should not exceed 10% of the reactor volume in order not to reduce the effective volume of the reactor.
    d. Stability of sludge in IMPLWUS after one year of use is about 96% according to model results. This means, if the reuse of sludge is desired, to reduce the cost and need of stand-by reactor, the sludge can be emptied and stored in a different location to complete the stabilization. Sludge drying beds is a good possibility since Tanzania as a tropical country have prolonged hours of sun exposure. It is a cheaper option than mechanized sludge drying beds.
    e. Available sludge reuse/disposal place prepared upfront for use at emptying stage.
    f. A quite satisfactory environmental protection can be achieved at the residential areas through sealed improved pit latrines.
    g. Correct separation of urine in Ecosan toilets as advocated to avoid wetting the sludge in the vault, which will complicate the desired outcome, is necessary.

2. Despite the reality that both improved systems were at their start-up stage of operation, IMPLWUS looks satisfactory from a hygienic point of view but is technically more complex due to collection of gas, although it is easy and cheap in operation from users' point of view. Nonetheless, IMPLWUS can become sustainable when biogas is dealt with. In very dry areas, Ecosan is the good option. It is simple in construction as no need of gas tight facilities. However, it needs a great deal of input from users due to the need of separation of urine. For less educated people, it is even difficult to get adequate co-operation on use of Ecosan. There is an environmental concern on reusing sludge from Ecosan toilets due to addition of ashes unless if it is used in low pH soils as a corrective measure.

7.8 Recommendations

- Application of improved pit-latrine without urine separation for black water at ambient temperature conditions of the tropics needs to be repeated for several use cycles after emptying the liquid phase of the reactor.
- An in-depth study of pathogens destruction in AC systems is necessary.
- Look into possibilities of addition of kitchen refuse organic waste to improve gas production in AC systems.
- The fertilizing implication and effect of using ashes and other additives in urine separation toilets (dry toilets) needs further research.
- The financial benefits in quantitative terms of anaerobic digestion of black water and night soil in accumulation systems require further exploration.
- Epidemiological studies of AC systems are required.
- Gender concerns in IMPLWUS and ECOSAN toilets should be done.
- Handling modalities of biogas from AC systems, that is, collection, storage and reuse needs further in-depth work.

Samenvatting en discussie

Inleiding

De productie van menselijke excreties is een privé-zaak, maar een zorgvuldige verwijdering en behandeling van de excreties is zaak van algemeen belang. Een foutieve of onzorgvuldige omgang met excreties kan tot gevolg hebben dat oppervlakte-, grond- en drinkwater met ziektekiemen besmet raakt. Bovendien kan door direct of indirect contact met excreties ook voedsel besmet raken. De uitbraak van ziekten zoals, cholera, tyfus en diarree zijn in Tanzania dan ook het gevolg van de slechte sanitaire omstandigheden en deze ziekten zullen dan ook alleen verdwijnen wanneer de verwijdering en behandeling van excreties in Tanzania wordt verbeterd. Dit laatste moet dan wel op een duurzame manier, dus niet alleen vanuit een gezondheidoogpunt maar ook vanuit een milieuoogpunt (Lettinga 2001, Drangert 2003). In het verleden zijn in sommige stedelijke gebieden van Tanzania decentrale afvalwaterzuiveringssystemen toegepast met de valse verwachting dat deze binnen een afzienbare tijd opgewaardeerd zouden kunnen worden tot centrale rioleringssystemen en zuiveringen. Echter gezien de economische situatie en de sterk toegenomen verstedelijking en bevolkingsgroei lijkt dit echter niet haalbaar. Bovendien is de aanleg van dure centrale rioleringstelsels vanuit het duurzaamheidperspectief ongewenst. In dit opzicht lijkt de verbetering van het huidig gebruikte systeem van pitlatrines een veel betere optie. Hierbij moeten dan echter zowel de constructie van de pitlatrines als de operationele en management aspecten van de systemen worden verbeterd. Anaërobe vergisting van de excreties in anaërobe accumulatie systemen lijkt een goede optie, zeker onder tropische temperatuur condities. In anaërobe accumulatie systemen worden, net als in pitlatrines, excreties gedurende langere tijd opgeslagen. Hoewel elke dag nieuw materiaal toegevoegd kan worden, wordt de reactor slechts periodiek geleegd. Gedurende de opslagperiode wordt het materiaal anaëroob vergist en is het geproduceerde biogas de enige stroom die de reactor verlaat. Het belangrijkste doel van toepassing van accumulatiesystemen bij de behandeling van excreties in Tanzania is de stabilisatie van het materiaal. De productie van biogas en hergebruik van het gestabiliseerde materiaal in de landbouw draagt echter wel bij aan de duurzaamheid van het systeem.

De belangrijkste doelstellingen van het hier gepresenteerde onderzoek zijn

1) Het bestuderen van de sociaal-culturele en economische aspecten van de behandeling van menselijke excreties met name in pitlatrines in Dar-es-salaam, Tanzania.
2) Het verbeteren van het inzicht in de biologische stabilisatieprocessen die plaatsvinden in pitlatrines
3) Het opstellen van richtlijnen voor het leeghalen van pitlatrines
4) Het voorstellen van aangepaste ontwerpen en constructieaspecten voor community-on-site pitlatrines.
5) Aangeven in wat de mogelijkheden zijn voor hergebruik van slib uit pitlatrines in de landbouw in de stad en buitenwijken.

De verwijdering en verwerking van menselijke excreties in Dar-es-Salaam

Bij de behandeling van menselijke excreties moeten niet alleen de technische en milieuaspecten worden bekeken, maar ook de sociaal-culturele aspecten. In sommige gevallen is het zelfs gebleken dat ondanks een uitstekende technische en milieuhygiënische uitvoering van de sanitaire voorzieningen het project volledig mislukte doordat de voorzieningen niet aansloten bij de sociaal-culturele omstandigheden van de doelgroep. Het is namelijk zeer moeilijk om ontlastingsgewoonten van mensen te veranderen (Faechem en Cairncross, 1978). In sommige culturen wordt het gebruik van sanitairevoorzieningen zelfs ontmoedigd zoals bijvoorbeeld in de Tenia gemeenschap in Nepal (Drangert, 2003). In deze gemeenschap gelden gezegden als,,Wij ontlasten ons niet telkens op dezelfde plaats zoals de neushoorn doet." en „Alleen zieken of mensen met een gebroken been ontlasten zich steeds op dezelfde plaats.".

In Hoofdstuk 2 wordt de bestaande sociaal-culturele en economische situatie in Dar-es-Salaam met betrekking tot behandeling van menselijke excreties en de verwijdering van fecaal slib door middel van een enquête en literatuuronderzoek belicht. In de enquête, waaraan 207 huishoudens in 9 van de 52 stadswijken van Dar-es-Salaam deelnamen, komen onderwerpen als opleidingsniveau, inkomen, uitgavenpatroon, badgewoonten, manier van anale reiniging na ontlasting, kennis van de verschillende typen pitlatrines, constructie en kosten van de gebruikte sanitatievoorziening, slibproductie, slibverwijdering en hergebruik van fecaal slib aanbod.

Uit de resultaten van het onderzoek is gebleken dat 84,8% van de ondervraagden de basisschool had doorlopen, 12,8% had ook middelbaar onderwijs genoten en slechts 2,4% van de ondervraagden had een beroeps-, technische of universitaire opleiding. Het lage opleidingsniveau suggereert dat de introductie van nieuwe technologieën niet eenvoudig zal zijn. Het kan daarom nodig zijn om een demonstratieprogramma te starten alvorens een nieuwe technologie te introduceren. Over het algemeen blijkt dat wanneer mensen via een dergelijk programma met de techniek kennis kunnen maken hun bedenkingen jegens nieuwe technieken verdwijnen (Chaggu and John, 2002). Uit de enquête komen ook de verschillende soorten sanitatiesystemen die worden gebruikt naar voren. 80% van de huishoudens gebruikt pitlatrines, 10% gebruikt septic tanks, 5% van de huishoudens is aangesloten op de riolering, terwijl 5% geen eigen sanitaire voorzieningen heeft. Deze laatste groep gebruikt de sanitaire voorzieningen van de buren of ontlast zich in de natuur rond het huis. Uit literatuuronderzoek blijkt verder dat de slibproductie is toegenomen met de bevolkingsgroei (van 50000m3 in 1992 tot 254987m3 in 2001) terwijl de verwerkingscapaciteit voor het slib gelijk is gebleven. Hergebruik van nutriënten in urine en fecaal slib staat in Tanzania in de belangstelling (Drangert, 2003), hoewel de kennis op dit gebied beperkt is.

Modellering van de anaërobe omzetting van zwart water en night soil in accumulatie systemen

Modellen kunnen nuttig zijn bij het begrijpen en oplossen van complexe problemen. Bovendien kunnen ze een oplossing bieden in die gevallen waar de mogelijkheid tot het doen van fysieke experimenten beperkt is. Daarbij moet natuurlijk wel worden uitgegaan van een model wat de werkelijkheid adequaat beschrijft, of men nu het model gebruikt om te interpoleren tussen experimentele data, om te extrapoleren buiten de experimentele waarden, of om de uitkomst van geheel verschillende experimenten te voorspellen (Sinclair et al. 1987). In hoofdstuk 4 is een eenvoudig mathematisch model opgesteld waarmee het lot van de verschillende CZV fracties tijdens de anaërobe stabilisatie van organische componenten in accumulatiesystemen beschreven wordt. Hierbij werd aangenomen dat gedurende de gehele vulperiode het influent in het systeem accumuleert en het geproduceerde biogas de enige stroom is die het systeem verlaat. Na de vulperiode wordt de reactor geleegd en kan opnieuw influent worden geaccumuleerd. Met behulp van het model werd de anerobe omzetting van twee soorten influent bestudeerd.
(1)Urine, feces en anaal reinigingswater, aangeduid als zijnde zwart water.
(2)Feces en anaal reinigingswater, aangeduid als zijnde night soil.
De resultaten van de modelsimulaties toonden aan dat bij tropische temperaturen binnen 1 jaar 97% van het gesuspendeerde CZV gestabiliseerd zal zijn. Echter wanneer men 99% stabilisatie of meer zou willen bereiken moet men meer een vulperiode van 2,5 jaar worden toegepast of men moet bij een vulperiode van 1 jaar gedurende 2 weken geen nieuw afvalwater meer toevoegen alvorens de reactor te legen. Wanneer men het biogas van het accumulatiesysteem wil hergebruiken zal er vanaf

de eerste dag voldoende methanogene activiteit aanwezig moeten zijn om al de geproduceerde vluchtige vetzuren om te zetten. Bij de eerste opstart van een accumulatiesysteem voor zwart water van een 10- persoonshuishouden zal dan ook 690 liter slib nodig zijn met een droge stofgehalte ongeveer 11 g/l en een minimale activiteit van 0.1 g CZV/g droge stof/dag.Voor night soil zal bij de eerste opstart 142 liter slib nodig zijn met een droge stofgehalte ongeveer 8 g/l en een minimale activiteit van 0.5 g CZV/g droge stof/dag. Deze waarden zijn echter voor de praktijk vrij hoog, zodat er rekening mee moet worden gehouden dat een optimaal hergebruik van biogas tijdens de eerste vulperiode van het AC systeem niet altijd mogelijk is. Het slibvolume wat aan het eind van de vulperiode in de reactor moet worden achtergelaten om voldoende methanogene activiteit voor de daaropvolgende vulperiode te waarborgen hangt af van de het droge stofgehalte van het slib en de methanogene activiteit. Wanneer wordt aangenomen dat de methanogenese volgens Monod kinetiek verloopt waarbij geldt k_m=1 g CZV/gCZV/dag (Batstone et al., 2002) en 1 g biomass-VSS=1.42 g CZV kan voor de reactor met zwart water werd berekend dat aan het eind van de eerste vulperiode de methanogene activiteit 0.12 g CZV/g organische stof/dag bedraagt. Bij een organisch stofgehalte van 30 g/l zou dan 250 liter slib als entslib voor de volgende vulperiode in de reactor moeten achterblijven.

Anaërobe stabilisatie van zwart water in accumulatie systemen„de demonstratie reactor"

In hoofdstuk 4 werd de anaerobe stabilisatie van zwart water in accumulatiesystemen bestudeerd door middel van modelberekeningen. In hoofdstuk 5 wordt de anaerobe stabilisatie in accumulatie systemen in de praktijk gedemonstreerd. Daartoe is een verbeterde versie van de pitlatrine (improved pit latrine without urine separation, IMPLWUS) gebouwd bij een 10-persoons huishouden in de wijk Mlalakuwa in Dar-es-Salaam, Tanzania. De reactor bestaat uit een 3000 liter plastic vat (een zogenaamde SIMTANK die lokaal geproduceerd wordt) met daarboven op een vloer met een hurktoilet. De ontlasting wordt met een verticale buis onder vrij verval direct onder in het accumulatievat gebracht, waar het wordt opgeslagen totdat het gehele vat gevuld is. Het biogas wat tijdens de anaërobe stabilisatie van de geaccumuleerde ontlasting wordt geproduceerd is de enige stroom die uit de reactor kan ontwijken. De menging in de reactor is zeer beperkt en wordt uitsluitend veroorzaakt door het inkomende influent en de het geproduceerde biogas. Tijdens de beschreven vulperiode (380 dagen) bedroeg het influentdebiet 6.7 liter/dag en bestond in de praktijk uit feces en urine in een verhouding van 1,3:1. Aan het begin van de vulperiode werd de methanogene capaciteit verhoogd door toevoegen van 300 liter slib uit een 15 jaar oude septic tank.

De reactor werd regelmatig bemonsterd en de resultaten van de analyses lieten zien dat de VFA concentratie in het begin van de vulperiode ongeveer 1200 mg CZV/liter was, maar gedurende de 380 dagen langzaam daalde tot 100 mg CZV/l. De hoeveelheid opgelost niet-verzuurde CZV bleef echter hoog, zo'n 8000 mg CZV/liter. Aangezien dit niet-verzuurde opgelost CZV wel (deels) afbreekbaar bleek te zijn, werd aangenomen dat de trage omzetting van deze CZV fractie werd veroorzaakt door de hoge ammoniaconcentratie in de reactor. Deze steeg namelijk van 65 mg N/liter naar meer dan 2500 mg N/l op 380 dag. Echter omdat het de eerste vulperiode van de reactor betrof en het entslib niet aan hoge ammoniak concentraties was geadapteerd is het aannemelijk dat bij een tweede en daaropvolgende vulperiode de omzetting van niet-verzuurde opgelost CZV sneller zal verlopen. Daarvoor moet dan natuurlijk wel een deel van het slib na de eerste periode in de reactor blijven om als entslib dienst te doen in de tweede vulperiode.

Door een klein gaslek in de headspace van de reactor kon helaas geen gasproductie worden waargenomen. Monsters die uit de reactor waren genomen en in het lab waren geïnduceerd vertoonden echter wel gasproductie. Een stabilisatietest met een slibmonster genomen op dag 354 toonde aan dat het slib nog 0.67-1.3 g CH_4-CZV/liter produceerde. Dit was iets minder dan verwacht kon worden in vergelijking met modelberekeningen gedaan met het model wat werd gepresenteerd in hoofdstuk 4. Er werd verder geen aandacht besteedt aan de hergebruikaspecten van het gestabiliseerde slib uit de IMPLWUS reactor.

Uit de resultaten van het onderzoek kan geconcludeerd worden dat de IMPLWUS reactor geschikt is om in alle gebieden van Tanzania met een hoge grondwaterstand te implementeren. De redenen hiervoor zijn:

- De reactor kan gefabriceerd en geconstrueerd worden met lokaal beschikbare materialen en arbeidskrachten.
- De reactor kan zowel in geplande als in ongeplande gebieden worden gebruikt.
- De grote van de reactor kan bij de bouw aan het aantal gebruikers worden aangepast.
- Er is geen geschoold personeel nodig bij het bedrijven van de reactor.
- De reactor is waterdicht en hoeft, bij toepassing in gebieden met een hoge grondwater stand, minder vaak geleegd te worden dan de conventionele pitlatrine. Wanneer er de urine apart zou worden opgevangen en de hoeveelheid reinigingswater zoveel mogelijk beperkt wordt kan de vulperiode verder verlengd worden (of het volume van accumulatievat gereduceerd).

Het gebruik van compostlatrines in Majumbasita, Dar-es-salaam, Tanzania

In een ander initiatief om de grondwatervervuiling door van het gebruik van conventionele pitlatrines in gebieden van Dar-es-salaam met een hoog grondwaterniveau de baas te worden zijn in de wijk Majumbasita 110 compostlatrines gebouwd. Deze latrines werden gerealiseerd door de Environmental Engineering Pollution Control Organisation (EEPCO), een niet-gouvermentele organisatie. UNICEF financierde het project. In hoofdstuk 6 is een kort onderzoek naar de werking van deze compostlatrines gepresenteerd. De latrines, ook wel ECOSAN latrines genoemd, zijn recentelijk gebouwd en alleen de eerste acht maanden van het gebruik kon worden gevolgd. ECOSAN zijn in principe accumulatiesystemen. Ze ontvangen een dagelijkse hoeveelheid feces naar ratio van het aantal gebruikers. De urine wordt apart gehouden om de feces zo droog mogelijk te houden, en opgeslagen in 20 liter vaten, wat op een opslag van ongeveer 3 dagen neerkomt. Na ontlasting wordt een hoeveelheid as van kool of hout aan de feces toegevoegd. Dit zorgt voor een verhoging van de pH. De pH van de geaccumuleerde feces in de ECOSAN lagen tussen de 6 en 10.4, waarbij de latrines die het langst gebruikt werden de hoogste pH hadden. Het kan worden aangenomen dat in deze latrines geen biologische slibstabilisatie meer plaatsvindt, maar alleen chemische stabilisatie. Al bleek in een labexperiment dat monsters die weer naar neutrale pH werden gebracht wel anaërobe biologische stabilisatie vertoonden. De pH van de opgeslagen urine lag tussen de 6.3 en 11.8. De hoge waarden zijn waarschijnlijk te wijten aan onzorgvuldig gebruik van de latrines waardoor as in de urineopslagtank terecht is gekomen. Dit onzorgvuldige gebruik van de latrines was ook af te leiden uit het lage droge stofgehalte van de geaccumuleerde feces en de aanwezigheid van *E-Coli* in de urineopslagtanks (gem.1525/100ml). De hoeveelheden *E-Coli* en spoelwormeieren bleken te dalen met een stijgende pH. Dit laatste bleek dan ook het enige voordeel van het gebruik van as in de ECOSAN te zijn. Door de hoge pH van de geaccumuleerde feces zijn de hergebruikmogelijkheden in de landbouw beperkt. De urine wordt nu gebruikt als meststof in groentetuinen, bij fruitbomen en heggen. De hoeveelheid stadslandbouw Dar-es-salaam is echter te beperkt voor grotere hoeveelheden urine en feces en zal buiten de stad moeten worden gebruikt. Wanneer hout of kool niet meer als energiebron voor het koken gebruikt wordt en er geen as meer beschikbaar is of wanneer men biologische stabilisatie van de feces mogelijk wil maken zal een alternatief additief gezocht moeten worden. In Finland worden houtsnippers, zaagsel en turf gebruikt als toevoeging aan ECOSAN (Mattila, 2003). Het effect van deze alternatieven op de

stabilisatie van de feces moet nog wel onderzocht worden. Bovendien zijn deze additieven vrij volumineus wat een groter benodigd reactorvolume tot gevolg heeft.
De slechte afscheiding van urine in de ECOSAN suggereert dat de gebruikers herhaaldelijk voorgelicht moeten worden. Daarnaast zou de constructie van de urineafscheiding in de hurktoiletten van de ECOSAN nog verbeterd kunnen worden.

Discussie
45% van Dar-es-Salaam heeft problemen met een hoge grondwaterstand. De resultaten van de hier gepresenteerde studie laat zien dat accumulatiesystemen zoals de IMPLWUS en ECOSAN latrines een substantiële bijdrage kunnen leveren aan het terugdringen van de grondwatervervuiling. De onderlinge verschillen tussen de ECOSAN en IMPLWUS latrines zijn weergegeven in Tabel 1. Beide systemen hebben hun voor-en nadelen. Vanuit het oogpunt van de gebruiker biedt het IMPLWUS systeem het meeste gebruiksgemak. De urine en het reinigingswater hoeven niet apart te worden opgevangen en ook hoeven geen additieven aan het systeem te worden toegevoegd. Het influentdebiet naar de IMPLWUS reactor is daardoor wel groter, zodat het accumulatievat vaker geleegd moet worden of dat het groter moet zijn dan het accumulatievat van het ECOSAN systeem. Echter door toepassen van urineafscheiding en het beperken van de hoeveelheid reinigingswater kan het influentdebiet aanzienlijk worden verlaagd zonder dat de biogasproductie van het IMPLWUS systeem sterk zal dalen. Het IMPLWUS systeem is technisch gezien complexer dan het ECOSAN systeem doordat het gasdicht moet zijn en het hergebruik van biogas mogelijk gemaakt moet worden. Het IMPLWUS systeem is wel robuuster, waarmee in dit geval wordt bedoeld dat de anaërobe vergisting in het IMPLWUS systeem beter bestand zijn dan tegen misbruik dan de compostering in het ECOSAN systeem (in dit geval te veel vocht in het accumulatievat door slechte afscheiding van urine en reinigingswater).

Met betrekking tot het hergebruik van biogas kan worden gesteld dat de hoeveelheid biogas die dagelijks in een 10 persoon IMPLWUS reactor geproduceerd kan worden onvoldoende is voor hergebruik in het betreffende gezin. Daarbij komt nog dat aan het begin van de vulperiode de gasproductie laag is en dat deze gedurende periode zal stijging naar een maximum. Ook dit bemoeilijkt het hergebruik van het biogas van een kleine IMPLWUS reactor. Het is mogelijk om het biogas te oxideren in een compostfilter maar dit draagt niet bij aan de duurzaamheid van het systeem. Andere mogelijke opties zijn:

- Het verhogen van de biogas productie door toevoegen van andere organische afvalstromen, zoals keukenafval en mest (indien beschikbaar)
- Het gebruiken van een centraal accumulatiesysteem geschikt voor ongeveer 50 mensen en het geproduceerde gas in toerbeurten hergebruiken.
- Een systeem ontwikkelen waarbij iemand huis-aan-huis het biogas met behulp van een verplaatsbare gasmotor omzet naar elektriciteit en accu's oplaad.

Tabel 7.1: De vergelijking van IMPLWUS en ECOSAN toiletten in Dar-es-Salaam, Tanzania

Parameter	IMPLWUS	ECOSAN	Opmerkingen
Influentdebiet	Hoog, door toestaan van urine en reinigingswater.	Low, alleen feces en as gaan in het accumulatievat	Bij een laag influentdebiet is het mogelijk een kleinere reactor toe te passen, dus investeringskosten
Gebruiks-gemak	Goed, maar hoeveelheid reinigingswater moet beperkt worden	Urine en reinigingswater moet apart gehouden worden en as moet worden toegevoegd na ontlasting	Het gebruik van IMPLWUS is simpel
Kosten	Bouwkosten zijn hoger dan ECOSAN door gebruik plastic accumulatietank en biogasverwerking	Lagere bouwkosten omdat de reactor uitsluitend uit stenen constuctie bestaat.	Na een aantal jaren zal de constructie van het ECOSAN systeem moeten worden bijgewerkt, daar er corrosie van het materiaal van het accumulatievat optreedt.
Urine to Faeces Ratio	Zo laag mogelijk, eventueel door toepassen van urineafscheiding	Geen urine	In beide gevallen is medewerking van de gebruikers nodig
Robuustheid	Robuust	niet robuust	Het ECOSAN systeem is niet bestand tegen teveel urine of reinigingswater in het accumulatievat
Verstoppingen van de pijpen	Nee, alleen bij toepassen van urine afscheiding kan de urineafvoer pijp verstopt raken.	Urineafvoerpijp kan makkelijk verstopt raken	Urineafvoerpijp is gevoelig voor verstopping door afzetting van zouten.
Biogas productie voor hergebruik	Mogelijk maar biogasproductie van een enkel huishouden is te weinig voor hergebruik	Nee	Het ECOSAN systeem is voornamelijk gericht op hergebruik van urine in de landbouw. Wanneer het biogas uit de IMPLWUS reactor niet wordt hergebruikt moet het worden afgefakkeld of door een compostfilter worden geleid.
Hergebruik van slib	Mogelijk na stabilisatie	Onwaarschijnlijk door hoge pH	ECOSAN slib is alleen toe te passen op zeer zure gronden
Hergebruik van urine	Alleen wanneer urineafscheiding wordt	Ja	

	toegepast		
Legen van accumulatievat	Met pomp	Steekvast, dus handmatig	
Contact van gebruikers met urine	Nee, alleen bij urine afscheiding	Ja	De opslagvaten met urine in de ECOSAN systemen moeten zeer vaak geleegd worden
Contact van gebruikers met feces	Bij legen van het accumulatievat.	Bij legen van het accumulatievat	
Stank	Nee	Nee, alleen bij misbruik*	ECOSAN gebruikers moeten herhaaldelijk worden gewezen op de noodzaak van een goede urineafscheiding
Management actoren	Huishouden, NGO** of CBO#	Huishouden, NGO** of CBO#	NGO and CBO kunnen assisteren/adviseren bij het legen van de accumulatievaten en hergebruik van aspecten

*Drangert (2003); **Non Governmental Organisation; #Community based Organisation;

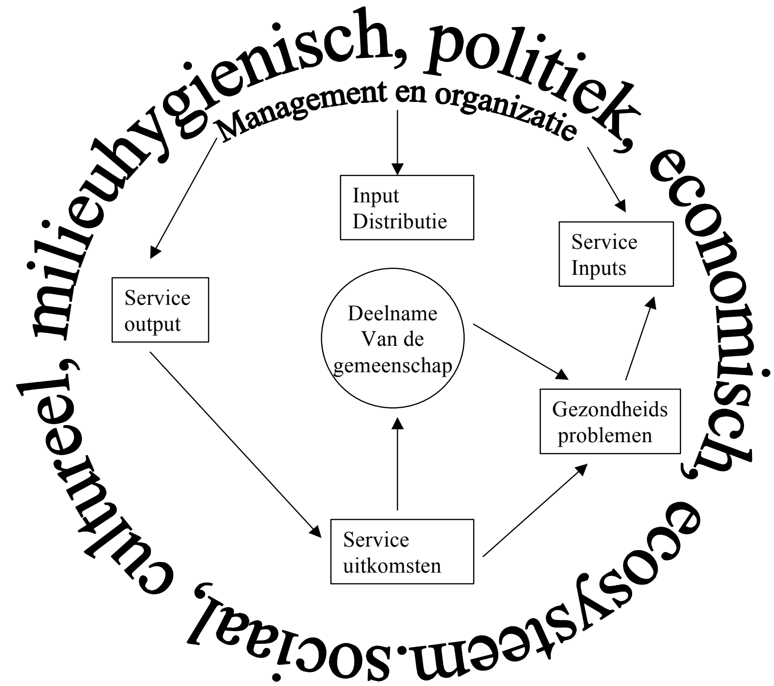

Figure 7.1: Overzicht van de verschillende elementen die van belang zijn bij het management van gezondheidsproblemen (after Kielmann, 1995)

Het management aspect is erg belangrijk als het gaat om het goed functioneren van de IMPLWUS en ECOSAN systemen. Duqqah (2002) stelde voor om een institutioneel raamwerk de creeeren waarbinnen controle, begeleiding en advies gegeven moeten worden, zodat de veiligheid en milieuhygienische kwaliteiten gewaarborgd blijven. Zo'n institutioneel raamwerk moet wel aansluiten bij de lokale situatie (Ministry of Health, 1995), goed afgekaderd zijn en de verschillende verantwoordelijkheden moeten goed gespecificeerd worden. In Figuur 1 zijn de belangrijkste elementen van met betrekking tot het management van menselijke excreties in relatie tot gezondheid weergegeven. Gezondheidsproblemen en behoeften worden voornamelijk bepaald door het ecosysteem waar men in leeft (de geografische, economische, sociale, culturele en politieke omgeving). Daarentegen wordt de service input bepaald door de gezondheidsproblemen en behoeften (de infrastructuur om de service en het service programma te laten werken). Voor het goed functioneren van de service inputs zoals het IMPLWUS en ECOSAN systeem is een ondersteunend systeem nodig (betrouwbare technologie input en geduld). Op het moment zijn zowel het IMPLWUS als het ECOSAN systeem zijn nog in hun opstart fase, maar op het moment dat ze volledig ontwikkeld zijn is een goede marketing strategie nodig.

Algemene conclusies

Uit het hier beschreven onderzoek kunnen de volgende algemene conclusies worden getrokken:

1) In het licht van duurzame ontwikkeling, maar ook met betrekking tot de economische situatie is het toepassen van simpele sanitatie systemen zoals de verbeterde pitlatrines (IMPLWUS en ECOSAN) in een stad als Dar es Salaam, maar ook in andere steden en gebieden in ontwikkelingslanden, de juiste werkwijze. Dit geldt met name wanneer deze systemen goed zijn ontworpen en gebouwd en bovenal correct worden gebruikt en onderhouden. Dit houdt in:

a) Dat bij het gebruik van de IMPLWUS reactor de hoeveelheid reinigingswater beperkt moet worden tot maximaal 0.25 liter per portie feces en 0.1 liter per portie urine. Desalniettemin wordt het gebruik van toiletpapier geprefereerd als de economische status van de gebruikers het toe staat.
b) Wanneer men beoogt het geproduceerde biogas te gebruiken om op te koken zal het nodig zijn om grotere IMPLWUS reactoren te bouwen (voor ongeveer 50 mensen). Daarbij moet dan ook een plan worden opgesteld wie van het biogas gebruik zal kunnen maken. De hoeveelheid gas die wordt geproduceerd in een IMPLWUS reactor van 1 gezin is voldoende voor een beperkte verlichting.
c) Bij het legen van de IMPLWUS reactor moet een hoeveelheid slib worden achtergelaten als entmateriaal voor de volgende vulperiode. Hoewel de hoeveelheid afhangt van het droge stofgehalte en de methanogene activiteit van het slib mag de hoeveelheid nooit meer dan 10% van de totale reactor volume bedragen, om het effectieve reactor volume niet te verkleinen
d) De resultaten van de modelsimulaties toonden aan dat bij tropische temperaturen binnen 1 jaar 97% van het gesuspendeerde CZV gestabiliseerd zal zijn. Voor hergebruik in de landbouw kan het nodig zijn om het slib verder te stabiliseren. Om te voorkomen dat de latrine gedurende de stabililisatieperiode niet meer gebruikt kan worden kan de stabilisatie van het slib elders plaatsvinden. Droogbedden zijn dan ook een geschikte optie.
e) De locaties waar het slib hergebruikt of opgeslagen kan worden moeten beschikbaar zijn op het moment van legen.
f) Door het gebruik van verbeterde pitlatrines kan de milieuhygiënische situatie in woonwijken naar een zeer aanvaardbaar niveau worden gebracht.
g) Het is nodig om de gebruikers van de ECOSAN systemen te blijven wijzen op de noodzaak van een goede urineafscheiding.

2) Ondanks dat de verbeterde latrines nog in ontwikkeling zijn kan worden geconcludeerd dat het IMPLWUS systeem het meest robuust en hygienisch is. Technisch gezien is het IMPLWUS systeem complexer omdat er biogas geproduceerd wordt. Hergebruik van biogas maakt het systeem wel duurzamer. Het ECOSAN systeem is vooral gecshikt voor de zeer droge gebieden. Het is technisch gezien een simpel systeem, maar vereist wel een goede medewerking van de gebruikers. Dit laatste is niet altijd eenvoudig en vereist herhaaldelijk overleg met de gebruikers, zeker wanneer deze een laag opleidingsniveau hebben.

Aanbevelingen

- De experimenten met het IMPLWUS systeem zouden herhaald moeten worden, waarbij dan meerdere opeenvolgende vulperioden onderzocht moeten worden.
- Het verdient de aanbeveling om verder onderzoek te doen naar:
- De afsterving van pathogene microorganismen in accumulatiesystemen
- Het toevoegen van keukenafval ten behoeve van een verhoging van de biogas productie.
- Afvang, opslag, en hergebruik van biogas.
- Het effect van toevoegen van as en andere additieven aan compostlatrines op het gebruik van het slib als meststof.
- Gender aspecten
- epidemiologische aspecten
- Tevens zouden de kosten en baten van de verbeterde pitlatrines zou beter gekwantificeerd moeten worden.

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ACKNOWLEDGEMENTS

"Ebenezer", thus far the Lord has helped us (*1 Samuel 7:12*). I thank God for this long journey, which was characterized by valleys and mountains that were filled and pulled down by many people who believed that "there is no tall tree without an apex". I sincerely express my deepest gratitude to Prof. Gatze Lettinga, my Promotor, for giving me an upper hand in working in anaerobic digestion field at the department that led to the completion of this thesis. His excellent guidance, continuous support, very valuable comments and encouragement while here in the Netherlands and during data collection in Tanzania are highly appreciated. Without his support, I could not have made it. Sincere thanks are due to his wife Dorah who was always very friendly to us and prepared nice barbeques that relaxed us away from academics for a period of time. Further thanks are due to Joost van Buuren who has been very instrumental in shaping the research proposal in the early days of my stay in Wageningen, organized useful contacts of people and spent a lot of time in choosing the right equipment and chemicals to be sent to Dar-es-Salaam, Tanzania for the research work.

It will be a great ingratitude not to thank Dr. Wendy Sanders, my "daily" supervisor and co-promotor whose exceptionally remarkable input into this work, her guidance, support, valuable discussion, advice, serious comments and detailed review of drafts of this thesis, filled up knowledge gaps and offered me enough confidence during the writing time. She is one of the good-will persons I ever came into contact with in my life. Sincere thanks are also due to Prof. Damas Mashauri my second co-promotor for the useful time and assistance he availed to me during the research time while in Tanzania.

My deep acknowledgement goes to NUFFIC who through the MHO (EVEN) project funded my study. Without this important component, the study could virtually be impossible. I am very thankful to Ir. Jan Cranenbroek (before changing his post) and Prof. Jamidu H. Y. Katima for the excellent co-ordination, administration and facilitation of the financial input into the study, as it was necessary. Ir. Patrick Schijndel, successor of Jan, is particularly thanked for handling the last part of co-ordination of financial input, which he as well did very nicely.

Acknowledgements will never be complete without mentioning Heleen Vos who was efficiently handling the administrative part of the study between Wageningen, University of Dar es Salaam and Eindhoven for a period of four years. Thanks to Liesbeth Kesaulya and Anita who in Hellen's absence, assisted on managerial issues quite often. Marjo Lexmond is particularly thanked for library introduction and assistance. Additionally, thanks are due to Drs. Salih Rebac, Grietje Zeeman, Tarek Elmitwalli, Nidal Mahmoud, and Ahmed Tawfijk who gave me prio-training for laboratory work. Unspeakable gratefulness goes to the members of the analytical staff and technicians: Ilse Gerrits-Bennehey and Johannes van der laan for assistance during chromatographic determinations, Rob Roersema and Bert Willemsen for technical support, Vinnie de Wilde for fixing the laboratory equipment in Tanzania, handling some chemical purchases and receiving the VFA samples from Tanzania for analysis in Wageningen, Sjoerd Hobma for chemical purchases; Hans Donker, Andre dos Santos, Martijn, Dr. Masanja, Dr. Njau, Prof. Mrema and Litto for computer assistance; Kahemela, Ullomi, Kamara, Msololo, Mwakasege, Omari, Komba for technical assistance, Rose Mwamkonda for secretarial assistance and Stewart for tireless driving to site in Dar-es-Salaam, Tanzania. It was furthermore a great pleasure and opportunity to work in a friendly atmosphere with all the members and students of the Sub-department of Environmental Technology based both in Biotechnion and Bennekom Experimental Hall in Wageningen and in Chemical and Process Engineering Department at the University of Dar-es-Salaam, Tanzania. Additionally, thanks are due to Moses, Hebert, Anesi and Enock for assistance during data collection. Martin Strauss of EAWAG Switzerland and Prof. Duncan Mara of Leeds University, UK. are particularly thanked for availing me with necessary information whenever requested. EEPCO (Environmental Engineering Pollution Control, an NGO Organization) is particularly thanked for allowing the researchers to use their pilot ecosan latrines as study case, assistance during the sampling, availing requested data and holding useful discussions with the researchers. Your input into this study can never be under estimated.

Living in Wageningen has given me an immense chance of meeting different people of different nationalities and languages, which were not a hindrance to friendship, kindness and good will. I enjoyed the company of Dr. Katarzyna Kujawa, Dr. Hardy Temmik, Dr. Adrie Veeken, Dr. Bert Hamelers (office mate), Dr. Jules van Lier, Arie Janssen, Iemke Bisschops, Gusta de Kaste, Marleen van de Weerd, Utomo Sudarno and Ph.D colleagues: Lucas Seghezzo, Renato Leitao, Hamed El-Mashad, Violeta Astratinei, Jurate Virkutyte, Jap Sipma, Johan Vermeulen and Paula Paulo. I am very thankful to International Christian Fellowship (ICF), particularly the family of Samson Nibi and Ware, Salem and Mwenge Churches; specifically families of Max, Wim, Hans, Willem, Kobus, Buddingh, Margret, Chikanda, Rumond, Corine, Nel, Maaike and interpreters for spiritual food, assistance and friendship, which meant a lot to me. Notwithstanding, I have been blessed to have Mkamilo who taught me how to bike, was always a close spiritual friend and advisor in many mountains and valleys that occurred during the initial and writing part of the study. My sincere and heartfelt thanks are due to intercessors some of whom I knew and the others whom I did not know who assisted me to stand this far. The company of WESA and Watz is highly appreciated as it assisted in many occasions to ease the tensing times of writing. It suffices to say thank you very much and God bless you all.

I am speechless to my family members; mother, father, sisters, brothers, my in-laws and other relatives, friends and staff members of University College of Lands and Architectural Studies (UCLAS), for continuous support during the time of study. "*Asanteni sana kwa yote*" (thanks for everything).

Sincerely, I would like to thank my children Alexander, Bernard and Christian who contained my absence during my study period away from home and above all, my deepest love gratitude goes to my late husband James, whose part presence with me taught me greatly how to trust God in many avenues of my life.

Lastly but not the least, my gratitude are due to everybody who assisted in one-way or another in this study. It is very difficult to mention all who contributed to the success of this work and please, take it from me that, not mentioning your name is not an act of ingratitude. It suffices to say thank you very much to all of you.

Curriculum Vitae

The author of this thesis, Esnati James Chaggu, was born on 22nd December, 1957 in Tanzania. In 1983 she obtained her Bachelor of Science Degree in Civil Engineering, from the Faculty of Engineering, The University of Dar-es-Salaam, Tanzania. In 1987 she obtained her Master of Science Degree in Water and Waste Engineering from WEDC, Loughborough University, United Kingdom. She is an academic staff member at the Environmental Engineering Department of the University College of Lands and Architectural Studies (UCLAS, formerly, Ardhi Institute), Tanzania. In October 1998, she got a scholarship from NUFFIC through EVEN Project to pursue a PhD in sand-wich mode. Between October 1998 to mid-December, 1999 she worked at the Sub-Department of Environmental Technology of Wageningen University, The Netherlands for development of proposal and to learn anaerobic laboratory experimental set-ups to be used in Tanzania for the research work. In the second part of December 1999 she went back to Tanzania for the actual research work, which ended in late January 2003. She came back to The Netherlands for the final part of the PhD in late January, 2003.

Financial Support: NUFFIC through MHO Programme