H2O

Magazine for water supply and water management

MBR SPECIAL III

April * 2005

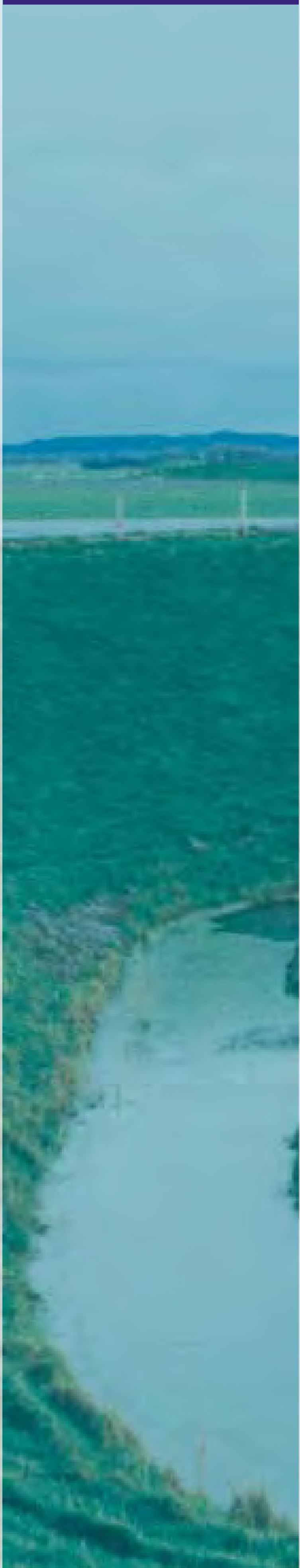
Dutch MBR grows to maturity

Innovation by co-operation

Future research directions

Overview of developments and projects

FOUNDATION
FOR APPLIED WATER RESEARCH



The STOWA is an organisation for the initation, coordination and embedment of applied research for the benefit of all water authorities being responsible for water management in The Netherlands.

The products of the STOWA are scientific publications in the fields of:

- urban water management
- wastewater treatment
- sludge disposal
- surface water
- groundwater
- aquatic ecology
- flood protection

The finances needed for the research programme and the STOWA secretariat are provided bij the water authorities in the foundation.

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Innovation by co-operation

Water: the most essential requirement for all living organisms. Along with the growth of the world's population and prosperity the demand for clean, fresh water increases. Water is scarce in various places across the globe. However, it can also lead to opportunities, such as for companies specialised in the purification and supply of water.

The Netherlands and water are often referred to as synonymous. Even today we are still known for our Delta Works and dikes. But in addition to reclaiming land from the sea, water management is equally important in a densely populated country like the Netherlands. This is an area of expertise in which the Netherlands historically has a great deal of experience and do excel at international level.

Water management is a field of business stimulated by the Dutch government. I recently applied to study the importance and potential of water treatment technology for our economy. I also asked to analyse patent applications and to examine the research projects supported by the government. You can find the results on internet. I concluded that the Netherlands has considerable knowledge, skills and experience for water purification.

The Dutch authorities have high demands on the quality of both drinking water and of wastewater to be discharged. Water quality requirements will only become stricter in the future because of new types of pollution and greater focus on health and environment. The implementation of the European Water Framework Directive will lead to urgent calls for innovative water purification techniques.

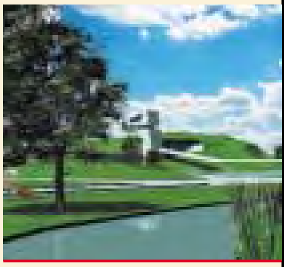
Innovation is necessary to comply with the strict legislation on water quality. And close co-operation is needed to realise such ambitious innovations. The membrane bioreactor is a good example of Dutch innovation by co-operation. This concept is created by combining biotechnology, membrane technology and process control. However, the dedicated teamwork of potential consumers, suppliers of knowledge (such as universities, institutes and consultants), manufacturers of components, contractors and authorities also plays a key role. This collaboration resulted in further development of the MBR technology which improves the quality of purified water, on a smaller footprint. You can find more details on this innovation in this magazine.

The studies and above-mentioned example prove that the right conditions and appropriate parties are available in the Netherlands to realise innovations for water purification. An integrated approach and co-operation are needed to take full advantage of these conditions, to produce new processes, services and products that can be applied and marketed in many parts of the world.

I challenge all parties involved to work together on innovations that contribute to competitiveness and sustainability. The results of that co-operation will be beneficial for people, planet and profit.

Laurens Jan Brinkhorst
Minister for Economic Affairs



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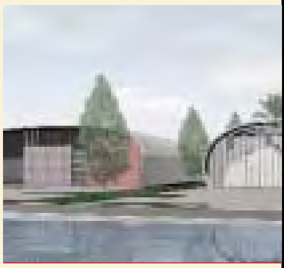

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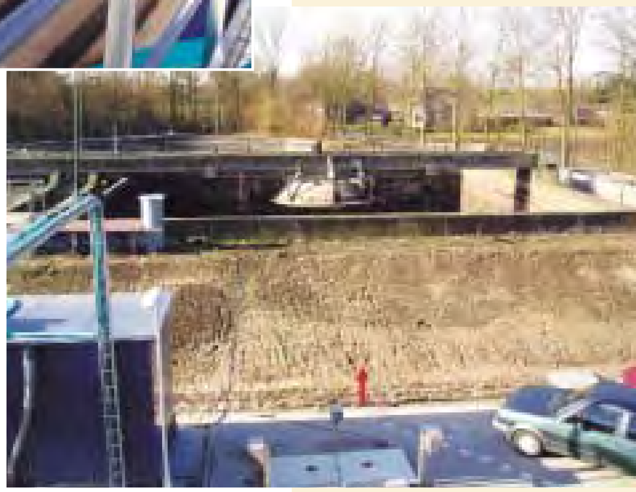

Photo on the frontpage:
Future quality effluent (photo: DHV Water)

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Dutch MBR development enters next phase

Co-operation and innovation for a sustainable and safe living environment

Within the Dutch wastewater sector the national MBR development programme has grown into a classic example of co-operation and innovation, where fundamental research organisations, suppliers, consultants and water boards have been involved. With the official opening of the demonstration installation at Varsseveld on May 3, the second phase of the Dutch development programme shall commence. Here, amongst others, an intensive research programme will be carried out to address scale up issues. It has been seen that co-operation in the Dutch wastewater sector is of great importance and should be copied for other developments within the water sector.

As an introduction to the official opening of MBR Varsseveld, the third H_2O MBR special has been created. After the first and second MBR specials in 2001 and 2003 this edition will effectively close the first MBR development phase, which dealt with the possibilities of the MBR technology for the specific Dutch wastewater situation. The realisation of the MBR Varsseveld represents the beginning of the second phase of the national MBR development, which will demonstrate all the facets of scale up.

MBR Varsseveld can be seen as a product of a combined effort from the Dutch wastewater sector. Since the year 2000, fundamental scientific organisations, suppliers, consultants and water boards have all been involved with the development of the technology, and a positive spin off is that this has spread beyond the Dutch borders. In recent years the Dutch contribution to the MBR development has received worldwide recognition, and through this third edition of the H_2O MBR special, the initiators, water board Rijn en IJssel (WRIJ), the Foundation for Applied Water Research (STOWA) and DHV Water BV (DHV) hope to give an increased impulse to the technology. We are proud to present you this H_2O MBR Special and wish you pleasant reading.

MBR technology

The MBR technology is based on the combination of the activated sludge process and membrane filtration in one treatment step, where the separation of the activated sludge and effluent is achieved with the help of membranes. The MBR technology maintains the good performance and flexibility of the conventional activated sludge process, but also has two major advantages:

- The required space is small as secondary clarification is not necessary and the sludge concentration in the aeration tank is two to three times that of conventional systems;
- The effluent quality is significantly better as all the suspended and colloidal material is removed. Furthermore extra removal of heavy metals, micro contaminants, bacteria, viruses and colour is achieved and sludge disturbances no longer cause poor effluent quality.

Especially in Holland where almost all wastewater treatment plants are of the activated sludge type, where space is limited and the quality of surface waters must be strongly improved, the MBR technology has great potential. Until now, the Dutch have focused on possible improvements in the effluent quality and the space saving was considered less important. However, the MBR technology offers potentially compact solutions where space saving can offer advantages. The latter, particularly in situations where the treatment works is located in or nearby large cities where innovative solutions with MBR can be feasible.

National development

The national MBR development in the Netherlands began in 2000, and five years later can be considered to have pushed the technology to new levels. The now worldwide famous pilot research at the treatment works Beverwijk was the starting point of the first phase of the Dutch MBR development. During an extremely short period of seven months the MBR technology had to be proven viable for the specific Dutch municipal wastewater characteristics and give reliable data for scale up. Water board Hollands Noorderkwartier and DHV in co-operation with four membrane suppliers and a number of foreign parties initiated this challenge, and within the first

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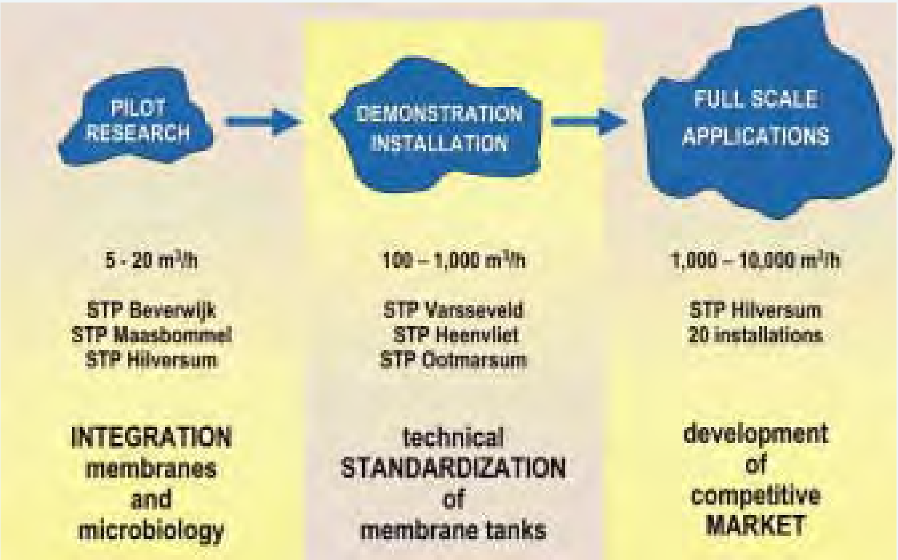

Figure 1: Development of MBR technology in the Netherlands (2000-2010).

year of the study the group was expanded to include other Water Authorities and fell under the coordination of the STOWA for the national MBR development programme.

From an economic perspective, the potential impact for the environment, innovation power and co-operation throughout the water sector, the significance of the MBR technology was addressed at administrative and political level. At the end of 2000 it brought the water sector and policy bodies together. It was understood that only through 'togetherness', a technology could be developed whereby the technical and financial risks were not for the individual but rather for the group. Shortly thereafter an innovation fund was created to initiate the correct start for the technology and not limit it's further development. Based on these initiatives the Dutch water boards and the Ministry of Traffic and Public Works were able to agree on long term financial commitments.

We are now a few years down the line and the national MBR development is at full steam. After the successful completion of the research phase the commissioning of the demonstration plant Varsseveld signals the start of phase II. In the next 1.5 years WRIJ, STOWA, DHV, TNO, Delft University of Technology and Wetsus shall cooperate in intensive research in order to address the consequences of scale up. The water authorities Hollandse Delta and Regge en Dinkel will also realise MBR installations in 2005 to address the applicability of various hybrid configurations. All three full-scale projects are being supported out of the innovation fund.

Already, preparation is being made for the realisation of the full-scale system of MBR Hilversum and will signal the start of phase III of the National development. This phase has the goal of generating a mature product for the MBR market with an emphasis on economics. Figure 1 is a schematic of the national MBR development.

All activities in the MBR development programme are coordinated via the STOWA, and through a steering committee, a supervisory commission and platform meetings, all the participants are informed regarding knowledge dissemination and project progress. The educational branch Wateropleidingen has been carrying out courses over the last few years to ensure the future of the technology.

The future for MBR?

The future of the MBR technology depends on many factors. The fact that cost plays an important role is obvious, even though the membrane cost has significantly reduced in recent years. The latter is reinforced by further developments in countries such as China, Korea and Taiwan, and together with the rapid technical and technological development the cost differential between MBR and conventional technologies is narrowing, and in some cases the MBR is a viable economic alternative. Future European guidelines, the drive for innovation in combination with economic perspectives, possibilities to free up expensive inner city ground, can all lead to arguments for further MBR development, despite the fact that on the short term the technology is more expensive than available traditional technologies.

Further technical and technological developments will concentrate on solving everyday problems and expanding the MBR advantages, and through a combined focus on the development issue the progress will be accelerated. For this it will be clear that courage at managerial level is indispensable, the example of the Dutch MBR programme has shown the positive consequences. It is of great importance that the generated co-operation in the Dutch wastewater branch can be learnt from, and applied to other (technological) developments, so that the water authorities can develop a beautiful perspective for the future.

Book marker

This third edition of the H_2O MBR special is a celebration of the official opening of the MBR Varsseveld and also to give an idea into the current activities surrounding the Dutch MBR development programme. This edition is in English and also available as a complete pdf-format on the world wide web (www.mbrvarsseveld.nl), which was especially set up by WRIJ, STOWA and DHV for the Varsseveld project. The website will be available until July 2006.

All participants in the development programme will be addressed in the this edition of the H_2O MBR special. The first five articles will describe the vision of the government, water authorities, fundamental research institutions, consultants and industry. Thereafter, a short overview of the development of other countries outside of the Netherlands is enlightened, and an insight given to two articles covering the first two phases of the national development programme. Lastly, in six articles the running MBR projects in the Netherlands will be openly described, where the last deals with the educational aspect. Once again the initiators, water board Rijn en IJssel, STOWA and DHV are proud to present you this H_2O MBR special and wish you pleasant reading. ¶

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The MBR in broad Dutch perspective

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The path that leads from theoretical innovation to practical implementation is often a troubled one. This also applies to MBR technology. However, the Dutch wastewater sector has succeeded in further developing this (in the Dutch wastewater field) new technology into a system that can be applied to the Dutch context in a relatively short timeframe. The article below gives a brief overview of water board developments which have contributed to MBR technology. It also reviews MBR developments in the Netherlands, starting with the MBR aspirations of (the former) Water Board of Uitwaterende Sluizen in Hollands Noorderkwartier, and leading right up to the present. Furthermore, an overview is given of current and recently completed STOWA research projects, and the purpose and development of the water boards' innovation fund as an important success factor is also briefly explained. Finally, the article also discusses a second important success factor for the further development of new technology, i.e. broad co-operation. This means sharing expertise amongst the water boards, but also includes collaboration with commercial parties, consultancy companies and research institutions, both in the Netherlands and abroad.

Technological innovations often arise from a desire to optimise and/or increase efficiency. In the industrial sector in particular, innovations are often driven by technology push. Besides these incentives, innovations in domestic wastewater treatment, which in the Netherlands is the exclusive domain of the water boards, are also determined by policy development (national and international).

Policy developments

At the national level the recent Fourth Policy Document on Water Management includes an explanation of the Maximum Tolerable Risk (MTR) standards for surface water. Purification technology research aims primarily at removing phosphate and nitrogen. Until now relatively little attention has been given to the other substances mentioned in the MTR standards. We must realise though that surface water standards are not effluent standards. Nevertheless, surface water standards are used in practice as reference values against which the performance of (new) purification technologies is measured.

Phosphate and nitrogen were highlighted with the introduction of the discharge policy for urban wastewater and the European directive on urban wastewater. The limits of current purification systems are now being tested by shifting the focus to lower effluent concentrations (instead of 10 mg/l nitrogen the target is 2.2 mg/l and the phosphate target for research projects is 0.15 instead of the usual 1 or 2 mg/l). Besides nutrients, more and more attention is being given to priority substances (heavy metals, organic micro-pollution and hormone-disruptive substances, amongst others). These substances will also get the attention they deserve during implementation of the EU Water Framework Directive and they will throw new light on purification technology and techniques. The role of purification in this framework still has to be weighed against other measures (tackling the source of the problem, for example).

It may be concluded that the issue of the reuse of effluent is getting sufficient attention within the water boards recently. There are various initiatives/studies which are examining the (partial) closing of the aquatic cycle.

The comparison of purification management operations is an important source of inspiration for the water boards' innovation-consciousness. This has partly contributed to participation in research into innovative technologies gaining greater support.

External succes factors

Besides the general policy developments mentioned and the need for commercial optimalisation and a desire for purification techniques which lead to better effluent quality in general, there are also other important factors for successfully getting innovative technology operational. Firstly, it is vitally important that sufficient confidence is generated in the considered technology. Experience with pilot projects helps to engender this confidence. Design

Dutch delegation visits MBR plants in the United Kingdom (October 2003).

fundamentals can be substantiated through pilot studies and specific questions are more easily answered with test installations than in practice (for example, initiating an MBR can be effectively imitated with a test installation).

Positive business experience leads to the necessary confidence in the technology. Visits by water quality managers to MBR plants in the UK, for example, have definitely contributed to confidence in the technology[1]. This despite the fact that the application of the technology is different in the UK than is envisaged for the Netherlands.

A positive incentive for embracing the new technology also includes the compactness of an MBR. This plays an unmistakably important role in MBR development. MBR will score highly against conventional sewage treatment plants where purification space is at a premium. Possibilities for multifunctional ground use are also created.

Otherwise cost remains the most appealing factor, though this is usually less favourable during development when compared to conventional technology. To ensure broader application of this innovative technology in the future, these technologies will also have to compete economically with conventional technology. As the market expands, free-market processes will arise.

The above-mentioned developments and success factors can reinforce each other. Confidence in the technology can lead to more applications to which the market can react, both economically but certainly also technically. It may be concluded that this was indeed the case for MBR technology development. Running through the various development phases, much 'profit' has been achieved both economically and in terms of product improvement. Furthermore, a three-phase structured approach has played an important part. The knowledge acquired in various studies is further expanded upon with simultaneous scale enlargement to the eventual large-scale application. The great advantage of this structured and phased approach is that damage risk stays limited and increasing understanding can easily be integrated in subsequent development phases.

MBR development in the Netherlands in terms of scale

The development of MBR technology for the Dutch context has therefore been tested in various research set-ups. This raised important research questions such as those regarding effluent quality and operational management aspects (performance under different conditions, cleaning procedures in relation to the use of chemicals, energy consumption, etc.). The first Dutch MBR for domestic wastewater on a working model scale is now operational in Varsseveld. This installation fulfils a demonstrative function for Dutch water quality managers. It is the first project realised using the innovation fund set up for this very purpose by the water boards.

A couple of hybrid MBR plants in Heenvliet and Ootmarsum are also under construction now. These projects are also supported by the previously mentioned innovation fund. They are both relatively small plants. Both projects also have a demonstrative function for the hybrid application of MBR systems.

The first large scale working model MBR will probably be the Hilversum STP. Serious plans for the construction of an MBR plant are being prepared. The current STP is to be moved, and there is only a limited surface area available at the new location. Integration in the surroundings and effluent quality play a role in the decision to switch to MBR. Research has already been carried out for some time at this location using a pilot plant.

A review of MBR development in the Netherlands

A large study was carried out in 2000/2001 at the Beverwijk STP into the application of MBR for domestic wastewater in the Dutch context. For this purpose, MBR pilot plants from four different suppliers were tested under various conditions[2)]. Within an extremely short timescale of seven months, it had to be shown whether MBR technology in the Dutch context was both applicable and expandable. These challenges were at first tackled by the then Water Board of Uitwaterende Sluizen in Hollands Noorderkwartier and DHV in collaboration with four membrane suppliers (Zenon, Kubota, Mitsubishi and Norit). In that same year, STOWA took over coordination of national MBR development the group of water managers was expanded with the inclusion of the then Water Treatment Board of Hollandse Eilanden en Waarden (now the Hollandse Delta Water Board), the Veluwe Water Board, the Rijn en IJssel Water Board, the Regge en Dinkel Water Board and the Water Board Amstel, Gooi en Vecht/DWR. This was extensively covered in the last two H_2O-MBR-specials[3),4)].

The promising research results of these pilot studies at the Beverwijk STP led to the decision to build a working model of an MBR demonstration plant at Rijn en IJssel Water Board's Varsseveld STP. In order to make this demonstration plant a successful working model, and to keep damage risks to a minimum, research projects were initiated at Varsseveld and elsewhere at various pilot plants to further expand (still somewhat lacking) expertise.

Simultaneous research projects

In order to get a broader understanding of the possibilities and limits of MBRs, as well as to ensure the success of the Varsseveld demonstration plant, various parallel studies were conducted at different locations besides Beverwijk STP, as has already been mentioned. Therefore, research was started in 2002 by the STOWA in co-operation with the Rivierenland Water Board at the Maasbommel STP to study the applicability of a membrane bioreactor compared to a conventional active sludge system with linked sand filtration[5)]. During the two-year-long study, both systems proved that it is possible to remove most phosphate and nitrogen. Besides removing nitrogen and phosphate, the study increased insight into the removal of various other components. The study has offered a great deal of useful information about the possibilities and limitations of both methods. A pilot study has also been started in Hilversum to prepare for the MBR plant to be constructed there.

In the province of Friesland, STOWA is carrying out research in co-operation with Fryslân Water Board into the working of a linked MBR. In this pilot study at the Leeuwarden STP, an MBR is linked to a conventional active sludge plant. Central to this is the removal of special substances (non-biodegradable organic micro-pollution). In this sense, it is an innovative application of MBR.

Finally, it should be mentioned that in 2002 STOWA carried out market research into MBR technology for use with domestic wastewater[6)]. Through interviews and surveys 23 of the 26 regional water managers present in the Netherlands were approached. For the longer term (2020) 69 projects with an average/high probability were assessed by the water managers. This study revealed that the Netherlands is primarily a market for small-scale custom builds and does not support large-scale construction.

Hybrid applications

Besides the Varsseveld demonstration plant two demonstrations have now been started with MBR hybrid applications. This concerns a joint project of the Regge en Dinkel Water Board and the Hollandse Delta Water Board at Ootmarsum STP and Heenvliet STP respectively. Hybrid systems combine the advantages of MBR (high effluent quality, space savings) with the advantages of conventional active sludge plants which can process large volumes of wet weather discharges. During dry periods, all wastewater (or at least most of it) is processed by an MBR. During wet periods, rainwater is also discharged via the 'conventional path'. In this way, it is expected that, compared to an MBR plant through which wastewater is continuously flowing, energy would be used more efficiently with slightly lower total removal efficiencies. Especially at those locations in the Netherlands where wastewater and rainwater are often collected together, much will be expected of this hybrid application. The application will be installed in particular in plants needing attention due to capacity problems. However, it will also offer a solution which could be used to improve existing conventional purification where effluent is discharged into fragile surface waters. The Heenvliet STP and Ootmarsum STP joint project runs to the end of 2006. After Varsseveld STP, the MBR hybrid application demonstration project is the second one to be supported by the innovation fund set up by the water boards.

Innovation fund

Since they are still in the development stage, innovative techniques like MBR cannot yet compete with conventional technology and, by extension, do not have sufficient market profile. This means that scaling up of the technology to working models is not without risk and there is consequently a certain damage risk. Finally, the water boards' infrastructure must be used to scale up the technology. To spread the damage risk and extra costs, the water boards set up the so-called innovation fund in 2001. The fund works as follows: the plant to be developed is budgeted and this is then debited from the estimated costs of a comparable fictional conventional plant. After payment of a substantial extra contribution from the 'host water board', the difference is paid by the fund. In the unlikely event that the project is a total failure, recovery costs are also borne jointly by the fund. The fund has been assigned to the STOWA and is financed on the basis of the number of pollution units in a water board's managed area. The annual contribution has been based on the costs of the Varsseveld project. The commitment of the water boards applied for four years, and was at first exclusively designated to upscaling the MBR. It was agreed with the water boards that, after four years, the fund's function would be evaluated and, on the basis of this, decisions for the future would be made. When the innovation fund was set up, the Ministry of Transport and Public Works contributed about 1.4 million Euros. The water quality managers collected more than 4.4 million Euros in the period 2002-2005.

The Maasbommel research report is officially given out at the third Dutch MBR conference (Echteld, November 2004).

Within the Varsseveld project subsidies were received as part of LIFE (EU subsidy) and EINP (Ministry of Economic Affairs subsidy for energy investment deductions for non-profit organisations). After deducting the Varsseveld contribution, the balance has recently been assigned to the hybrid MBR projects: Heenvliet and Ootmarsum.

Future of innovation fund

As has previously already been mentioned, the water boards committed themselves to conducting both an evaluation of the fund's function and further decision-making regarding the fund's continuation. On 15 April 2004 there was a meeting of the participants of the STOWA, that is all water boards, where amongst other things the innovation fund's aim, scope and finance were considered. During this meeting it was also suggested to continue contributing to the innovation fund after 2005. A desire was also stated to widen the fund's objective: not only for MBR applications or projects related to wastewater systems. All the various tasks of the water board (water chain, water systems and water barriers) should be considered. Projects which are not specifically technical ('alpha' like applications), should also be considered for a donation from the fund. In the summer of 2004 STOWA's management decided in the light of this suggestion that from the 2005 fiscal year the innovation fund would be integrated with the STOWA's research program so that a mature R&D policy can be developed for the water boards. Innovation forms a separate theme throughout all the tasks in the multi-year planning.

Co-operation

The course followed by the research into development of the MBR in the Dutch context is an outstanding example of successful co-operation. This co-operation has taken various forms during the different phases of the study. Besides the STOWA this included involvement by various water boards, nearly all the large Dutch advisory agencies, all suppliers of MBR plants and many technical universities (national TU Delft, Wageningen UR and TU Twente and international TU Aachen) and technological top-institutes like TNO and Wetsus.

All those (who have been) involved with the study are convinced that this broad co-operation partly ensured the results achieved.

Co-operation and information exchange are central to STOWA projects. Around the MBR theme, various supervisory committees and a steering committee were created. Twice a year, a symposium is organised for all those involved in STOWA MBR-studies. Information exchange is central to this. When bringing a new development onto the market, it is important to learn from each other's experiences in order to prevent unnecessarily negative signals thwarting the developments.

Water boards work mutually with MBR projects; an example of this is the previously mentioned co-operation between the Hollandse Delta Water Board and the Regge en Dinkel Water Board in the field of hybrid MBR plants. Lastly, the co-operation with the Stichting Wateropleidingen is also an example of this. Stichting Wateropleidingen has already been holding an MBR course for a couple of years, ensuring the required education for future users.

International joint ventures

Co-operation also occurs at an international level, besides the above named specific co-operation in the study into MBR in the Dutch context. The STOWA participates, together with KIWA in the Global Water Research Coalition (GWRC), a collaboration between twelve global information institutions involved in research in the field of the water chain (UK, USA, South Africa, Australia, France, Germany, Switzerland and the Netherlands, amongst others).

MBR has been placed on the collective research agenda. Currently, a 'state of the science' report is being prepared, in which are assessed, besides current expertise, gaps and needs in expertise. This report is evaluated in an international workshop, after which the GWRC will review which of the joint projects should be tackled. The said workshop is linked to an international symposium about MBR that will be held on site on the occasion of the opening of the Varsseveld STP. In this way strengths are combined, preventing the wheel from being invented twice. More and more co-operation is occurring in Europe. Various research projects discover how to collaborate in an European context. The Varsseveld MBR demonstration project (Life subsidy) is an example of this.

Conclusions

Stagnation means decline. In order to progress, it is important to reposition one's horizons by focusing on the long(er) term. Current MBR applications are maybe (still) expensive. But in the long term, MBR can be economical. Flexibility, effluent quality, space saving and potential for multiple ground use and development of membrane prices all play a part in this. It is expected that a temporary high investment in MBR is justified.

New technology must be handled with care. Research is necessary to ascertain what the possibilities are, and especially what is not possible with the technology. It is important that the appropriate expectations are assumed for a new technology. Disappointing experiences do not help technological development. Research and practical experience contribute to realistic expectations.

Study results must be seen in their correct perspective as local conditions can have a strong influence on whether a technology is attainable.

A precondition for new technology is that the water sector should generate greater collaboration and expertise. Confidence in a new technology arises as joint experience is acquired. The impulse to win over confidence in the MBR comes from pilot studies and demonstration plants.

Furthermore, co-operation in innovation can form an important stimulus to strive jointly for greater progress. The sum 1 + 1 = 3 (more than the sum of its parts) applies here.

The merits of innovative applications must be assessed in a wise manner. Here lies the challenge for the water world: give MBR the chance to prove itself for applications in the Netherlands. ¶

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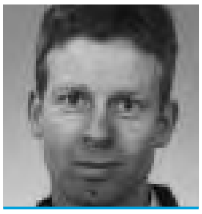
Samenvatting

De weg die bewandeld moet worden om innovaties in de praktijk tot uitvoering te laten komen is doorgaans een moeilijke. Zo ook voor de MBR-technologie. De Nederlandse afvalwatersector is er echter in geslaagd om in een relatief kort tijdsbestek deze, voor de Nederlandse afvalwaterwereld, nieuwe technologie verder te ontwikkelen tot een systeem dat onder Nederlandse omstandigheden kan worden toegepast. In onderstaand artikel wordt hiervan een beeld geschetst door in vogelvlucht aan te geven welke ontwikkelingen in de omgeving van waterschappen hebben geleid tot een bijdrage aan de ontwikkeling van de MBR-technologie. Er wordt een terugblik gegeven op de MBR-ontwikkeling in Nederland, beginnend bij de MBR-aspiraties van (destijds) het Hoogheemraadschap van Uitwaterende Sluizen in Hollands Noorderkwartier tot de dag van vandaag. Daarbij wordt een overzicht gegeven van de lopende en de recent afgeronde STOWA-onderzoeksprojecten en wordt kort de opzet en ontwikkeling van het innovatiefonds van de waterschappen als belangrijke succesfactor toelicht. Tenslotte wordt stilgestaan bij een tweede belangrijke succesfactor voor de verdere ontwikkeling van een nieuwe technologie, zijnde de brede samenwerking, binnen de waterschappen onderling om kennis te bundelen, maar ook samenwerking met marktpartijen, adviesbureaus en onderzoeksinstellingen, zowel in Nederland als daarbuiten.




Membrane bioreactor for domestic wastewater: current expectations from the Dutch Water Authorities

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In 2000, a large-scale pilot study was started into the use of membrane bioreactors (MBR) for the treatment of municipal wastewater in the Netherlands. Under Dutch conditions, with wastewater treatment plants having to handle large volumes of rainwater, a very compact plant should be able to bring about a considerable improvement in effluent quality. Lower membrane costs were also predicted. Moreover, significant cuts in energy consumption appeared feasible. It was found that the flux can be increased, so that less membrane surface area is needed. The membrane cleaning procedure can also be improved. Furthermore, it was found that a significant improvement in the quality of the effluent can be achieved, although some expectations, especially with regard to micro pollutants, could not be fulfilled. It proved possible to reduce energy consumption, but not to the extent required, and this, together with the higher costs of an MBR, is still a major bottleneck with regard to future (large-scale) applications. In certain situations, however, an MBR, possibly in hybrid form, may be the best solution.

Artist's impression of the Hilversum WWTP's office building; the plant itself will be constructed in the hill (contaminated soil).

Pilot research has been carried out in the Netherlands since the beginning of 2000 on the use of membrane bioreactor (MBR) technology for domestic wastewater treatment[4].

Based on experiences abroad, full-scale applications were expected to be possible in the short term. Several wastewater treatment plants were scheduled for an MBR upgrade for different reasons[3,6,8]. With respect to the WWTPs at Beverwijk (452,000 p.e.), Hilversum (91,000 p.e., 1,500 m^3/h) and Dordrecht (265,000 p.e.), lack of space to accommodate an extension played an important role. For the Hilversum and Varsseveld (23,150 p.e.) WWTPs and the smaller Maasbommel WWTP (7,400 p.e.), another reason to consider MBR technology as an option was the required effluent quality.

One major expectation with respect to the MBR was a superior effluent quality. The aim was to achieve maximum tolerable risk (MTR) quality without major problems, and the expectation was that many micro pollutants would be removed more efficiently when compared to conventional techniques. Examples of micro pollutants are heavy metals, pesticides and endocrine-disrupting compounds. These expectations were not based on research data, however, and the ongoing research programme was expected to confirm them. Neither process engineers nor decision-makers had any serious doubts about the potential of the MBR.

Problems in development

Although the aim was to develop a large-scale practical application, some problems had to be solved five years ago. The MBR was much more expensive than conventional techniques, especially when treating large hydraulic peak flows. Combined sewerage systems dominate in the Netherlands, resulting in large-volume flows during storm weather. Another disadvantage was the higher energy requirement caused by intensive membrane aeration and by lower aeration efficiency in the activated sludge tanks.

Some uncertainties remained, for example various operational aspects and the lifetime of membranes. There were several membrane suppliers, but it was uncertain which supplier and which system were favourable.

Foreign experiences

As many MBR facilities had been built abroad prior to 2000, the suggestion was to copy such concepts and use them in the Netherlands. It became clear that further research was required for several reasons before MBR technology could be applied in the Netherlands.

The first reason was the scale of application. Many of the previous plants were built in Japan and have a very small capacity. Factors such as costs and energy requirement are less decisive at smaller scales. Copying such concepts for large-scale applications would result in extremely expensive MBR facilities.

The second reason was the required effluent quality. Several MBR plants have been built in the UK, for example, but none of them has reached MTR quality. In some cases, the plants are not even required to remove nitrate. As a result, such MBR plants are of a much simpler construction than those built to meet MTR quality.

Several MBR plants in Germany were built to produce an improved effluent quality. The same problems arose at those plants as during the pilot research programme in the Netherlands, with the conclusion being that some of them could have been built more efficiently with the knowledge we have now acquired.

MBR pilot plant at the Maasbommel WWTP.

Results of five years of research

Research involving pilot plants has been carried out at Beverwijk, Hilversum and Maasbommel for the past five years[5),7)]. A large number of suppliers have demonstrated their MBR systems and it was possible to achieve many optimisations. The research has brought MBR technology for MTR quality to the point where large-scale application is now possible. Note that five years ago, it was already expected that the technology would advance almost to this point.

Membrane performance improved impressively following the research, resulting in higher permissible fluxes and, as a result, in only a limited membrane surface being required. This has had a favourable impact on investment costs, operational costs and the energy requirement.

The energy requirement itself has also been optimised. Discontinuous aeration in the membrane tanks limits the energy requirement. Improving the biology may have a favourable effect on the alpha factor, and therefore on the aeration efficiency in the activated sludge tanks. Sludge concentrations of 20 g mlss/l turned out to be unfavourable, and design concentrations are currently limited to approximately 10 g mlss/l. Even with this restriction, the MBR can still be considered very compact.

Improved pre-treatment is essential for safe operation. Screening at less than 1 mm will considerably reduce the risk of membrane failure. In addition, knowledge of chemical cleaning contributes to the safer operation of MBR plants.

The effluent quality was less favourable than expected, however. It may still be possible to achieve MTR quality for nitrogen (2.2 mg/l) and phosphorus (0.15 mg/l), although several pilot plants were only able to reach these values after addition of an external carbon source and an iron salt.

With respect to micro pollutants, the results were disappointing. At Maasbommel, the effluent of the pilot MBR was compared to the effluent of the conventional WWTP[1),7)], and no significant difference was found in the removal of micro pollutants. Most of these components may well be dissolved or adsorbed to natural organic matter and thus able to bypass the membranes. Although the MBR and the conventional effluent did not differ significantly with respect to the measured concentration of endocrine disrupting components, the endocrine potential was 70% lower.

The MBR was an effective disinfection option. Both bacteria and viruses were found to have been reduced to very low effluent concentrations.

Present status

Although much progress has been made, MBR plants are still more expensive than conventional activated sludge systems built according to the latest designs. More effort will be required to achieve a further cost reduction. Costs can be reduced by improving membrane performance, and the unit costs of the membrane surface may also decrease in the future due to the larger-scale application of MBR. More full-scale plants will have to be built to achieve both factors.

The energy requirement for MBR still exceeds the requirement for conventional activated sludge systems. The requirement can be further optimised to some extent by limiting the membrane surface, but also by optimising the performance of the biology, improving the alpha factor and consequently the aeration efficiency. Full-scale applications can contribute to both developments. From the point of view of sustainability, it should be noted that a further reduction of the energy requirement is considered essential.

Several pilot and full-scale experiences demonstrate that the operation of an MBR is much more critical than the operation of a conventional plant. Well-trained process operators are required, as well as a sophisticated process control and automation system. Basically, this is an issue that can be solved, but it will require more attention. It will be easier to handle this aspect when more full-scale MBR plants are in operation.

The effluent quality falls short of the expectations of five years ago. There is hardly any doubt as to the potential of the MBR with respect to nitrogen and phosphorus removal, but it is unlikely to remove micro pollutants effectively enough. On the other hand, MBR effluent is free of suspended solids and is suitable as a starting point for more advanced techniques when further treatment is indicated. Clarifier overflow is less suitable at this point. The MBR was also shown to be an efficient technology for disinfection.

What is the future?

Because MBR still has two major disadvantages (costs and energy requirement), the question is whether the MBR technology has a future in the Netherlands. In spite of these disadvantages, there are still several good reasons to embark on the full-scale application of MBR. The main reasons will be discussed below.

Although effluent quality does not live up to the original expectations, especially in respect of micro pollutants, it is still better than the quality achieved by conventional treatment. Suspended solids are absent in the effluent; as a result, nitrogen, phosphorus and heavy metals, part of the suspended solids, are reduced to some extent. In theory, the concentration of micro pollutants can also be reduced, as these components will be partly adsorbed to suspended solids. Further research on this possibility is necessary.

The MBR blocks all bacteria and some viruses. Disinfection is not very common in the Netherlands, but is favourable from a hygienic point of view.

A second reason to select MBR technology is the compact set-up of MBR plants. The space available to upgrade WWTPs is sometimes limited. This problem is expected to grow in the future, as the population figures rise and urban areas expand quickly.

A further advantage besides the space-saving aspect is that MBR plants can be covered more easily than conventional plants, thereby limiting the environmental impact in terms of noise and odour. Occasionally, it may be easier to introduce a short-term extension in an MBR plant than a conventional one.

A third reason in favour of MBR is the possibility of reusing WWTP effluent. MBR effluent in itself may not yet be suitable for direct reuse, but in combination with other techniques MBR can play an important role in the production of water for several different purposes, for example agricultural use and industrial water of different qualities. Its direct reuse in drinking water production is not very likely in the Netherlands, but it may be a possibility in more drought-prone regions of the world. An example of the direct reuse of wastewater to produce drinking water can be found in Namibia and Singapore.

Further development

In view of the potential of the MBR, more research will be necessary to solve the cost and energy requirement problems. These two aspects have been optimised in the pilot research carried out during the past five years. Further optimisation can only be achieved by building full-scale applications and by optimising these MBR plants on a practical level. For this reason, the Dutch water boards co-operated in setting up a full-scale MBR facility at the Varsseveld WWTP. This will result in an improved design for the next generation. In addition, the cost price for membrane modules will fall when membranes are produced on a larger scale.

MBR Varsseveld with old aeration tanks and clarifier in the background (photo: Aerofoto Brouwer - Brummen).

Further optimisation will not cease with the development of MBR systems. Wastewater properties can also have an important effect on the cost effectiveness of the MBR, as well as the energy requirement.

An important factor influencing wastewater properties is the sewerage system. In the Netherlands, combined sewers dominate, resulting in large RWF to DWF ratios. Disconnecting rainwater drainage from wastewater sewers will result in much smaller hydraulic capacities, which is favourable for the MBR. There has been a trend in the Netherlands to disconnect rainwater drainage from the sewers, but separate collection has had only a minor impact as yet. It will in any event take several decades before there is any substantial effect on the RWF/DWF ratio.

A second factor involved in wastewater collection is the inflow of infiltration water into sewers, for example groundwater and surface water. A study by STOWA pointed out that the dry weather flow increases by 60% on average owing to other water sources[2),9)]. Even when rainwater is disconnected from sewers, the hydraulic capacity can be further reduced if the sewers are in good condition, preventing the inflow of groundwater and surface water. This would naturally be favourable for MBR applications.

Another development is the hybrid MBR. This concept is suitable when a conventional WWTP is upgraded with an MBR. Two hybrid plants are currently under construction at WWTPs in Heenvliet and Ootmarsum. In this concept, the MBR is not supposed to receive the entire hydraulic load, nor, consequently, the entire organic load. Wastewater is distributed between the MBR and the conventional plant. In dry weather, the MBR receives relatively more wastewater and membrane capacity is therefore used efficiently. In storms, the MBR has limited hydraulic capacity and receives relatively less wastewater. The overall effluent quality results from mixing the MBR effluent and effluent from the conventional plant, so removal efficiency will be a compromise between costs and result. By using a wastewater storage tank in dry weather conditions, or even in storms, the compromise can be optimised further.

The end result must be borne in mind in any further development. The present designs will become obsolete and suboptimal after a few years, but they can play a decisive role in the MBR development. It would be well to bear in mind the status of MBR technology that we will have achieved in the future, for example after ten years of practical use.

The DWR deignteam visits the Varsseveld MBR.

Conclusions

The following conclusions can be drawn, based on five years of research in the Netherlands:

- Owing to more stringent effluent requirements, more advanced designs and operational aspects are needed for MBR plants in the Netherlands compared to plants in most other countries;
- Pilot research appeared to be essential in order to make MBR technology suitable for the Dutch situation. Experiences abroad are inadequate by themselves;
- After five years of pilot research, the time is right to construct the first full-scale MBR plants. The first plant recently came on stream at the Varsseveld WWTP. The time schedule seems to make sense;
- The present state of MBR technology means that it is still not suitable for widespread, large-scale application. Further optimisation must be achieved, especially with respect to costs and energy requirement. This only becomes possible by building full-scale plants and learning from them. The experience gained operating the Varsseveld WWTP and, next year, the Heenvliet and Ootmarsum WWTPs, and the research data produced at these WWTPs will contribute to such optimisation;
- The future of MBR technology has to be borne in mind, both with respect to wastewater collection and the status of MBR technology. Existing and upcoming MBR plants will not be fully representative of the future. Close co-operation within the Dutch water sector and financial incentives within a span of about eight years after the start of the Dutch MBR research should produce enough expertise and experience to achieve a competitive and reliable MBR system. ¶

Samenvatting

In 2000 begon een grootschalig pilotonderzoek naar de toepassing van de membraanbioreactor voor de zuivering van communaal afvalwater in Nederland. De verwachtingen waren hooggespannen. In een zeer compacte installatie zou onder Nederlandse condities, met onder andere veel regenwater op de rwzi, een belangrijke verbetering van de effluentkwaliteit kunnen worden bereikt. Het pilotonderzoek heeft de nodige resultaten opgeleverd. Zo kon de flux worden opgevoerd, waardoor minder membraanoppervlak nodig is. Ook kon de reinigingsprocedure voor de membranen worden geoptimaliseerd. Daarnaast bleek een belangrijke verbetering van de effluentkwaliteit mogelijk, hoewel sommige verwachtingen, met name voor wat betreft de microverontreinigingen, niet waar konden worden gemaakt. Het energiegebruik kon weliswaar worden verlaagd, maar nog in onvoldoende mate, en vormt samen met de hogere kosten van een MBR nog steeds een hindernis voor toekomstige (grootschalige) toepassingen. Daar waar sprake is van bijzondere situaties zal een MBR echter, al dan niet in hybridevorm, uitkomst kunnen bieden.

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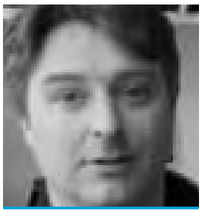
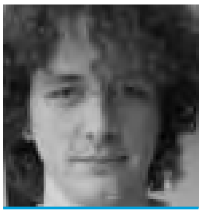
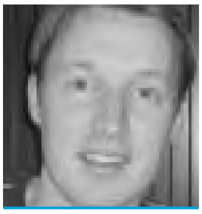

MBR technology: future research directions

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The last decade R&D on MBR technology has shown a rapid development. In spite of its advantages compared to conventional treatment systems, MBR does not yet provide a competitive alternative. The smaller required footprint and the excellent water quality are partially counteracted by high costs for membrane filtration and inefficient oxygen transfer. Reduction of costs will be the main driver for R&D on MBR technology the next years. R&D should be directed into three areas: fouling, filtration and aeration. Long-term research should focus on the improvement of the sustainability of MBR technology by exploring new concepts of wastewater treatment. Examples worthwhile to be explored are decentralised treatment of wastewater offering possibilities to treat separate streams of grey and black water to enable water reuse; anaerobic water treatment to minimize emission of greenhouse gasses and to decrease energy requirements and sludge production and to use MBR in combination with electricity production in a fuel cell to produce electricity and treat wastewater simultaneously.

Despite tremendous research efforts towards development of new MBR technology, a worldwide technological breakthrough, especially towards domestic wastewater treatment is lacking. The most important reason is the high costs of MBR technology in comparison with conventional wastewater treatment concepts. Cost reduction will be the main driver for research and development on MBR technology in the coming years. Short term research should focus on identification, characterisation and behaviour of foulants. The mechanisms of fouling should be studied. This will yield knowledge for required membrane operation, membrane properties to be chosen and new module design & operations that finally will result in reduction of costs and energy. New methods to improve the aeration efficiency at high sludge concentrations should be developed and attention is required for the effluent quality. Long term research should focus on much more sustainable MBR concepts. New MBR concepts to treat different wastewaters (e.g. grey and black) or to treat wastewater anaerobically should be explored. MBR technology offers opportunities to produce energy out of waste (membrane fuel cells) and to minimize emission of greenhouse gasses. Cutting down the operational costs of MBR technology will be the key driver for research. This article outlines some research areas and specific topics that potentially will contribute to lower costs. Special attention to these topics should be given the coming years. Long term research should focus on sustainable MBR concepts. A few innovative developments will be presented.

Research drivers and topics

For a real worldwide breakthrough of MBR technology in domestic water treatment a significant cost reduction is necessary. The present generation membranes show very low permeabilities due to a high degree of fouling. Besides, operation of membranes is energy demanding and, although prices are decreasing, membranes are still relatively expensive. In addition, one of the advantages of MBR, i.e. a high sludge concentration is counteracted by inefficient aeration at high sludge concentrations. To reduce the operational costs of MBR technology research should be directed into three areas: fouling, filtration and aeration. Within these areas several research topics can be defined.

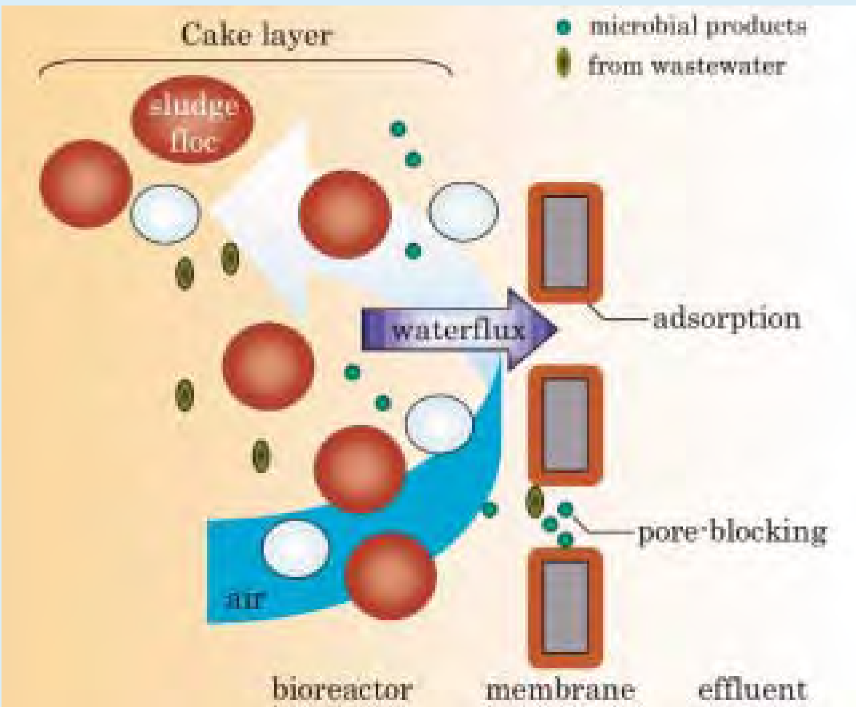
Fouling

When research regarding membrane fouling in MBRs is critically reviewed the conclusion must be that the main questions still are not answered. Even today it is unclear which group of compounds dominates the fouling process, whether these compounds have their origin in the wastewater or are produced by the biology, and what the most important fouling mechanisms are (figure 1).

Origin fouling

Without supporting scientific evidence the

Figure 1: Membrane fouling in MBR.



literature mentions dominant foulants varying in size or molecular weight (flocs, colloidal matter en solubles) and in chemical nature (extracellular polymers such as proteins, polysaccharides and humic compounds and inorganic precipitants). The origin of the foulants still is subject to debate although for domestic wastewater it seems that biological material such as colloidal matter produced by shear and (soluble) metabolites or lysis products are more important than wastewater constituents. In a way this is an advantage as this implies a generic character of fouling which also may allow for a generic solution.

Fouling mechanisms

The mechanism of membrane fouling in MBRs is extremely complex. Formation of a cake or gellayer, pore blocking, adsorption on the membrane surface or in the membrane pores could all be important. Equally important could be the interaction between these mechanisms. For instance, a (dynamic) cakelayer provides an additional resistance against filtration, but at the same time may protect the membrane against (irreversible) fouling. Figure 2 and table 1 provide an example of such behaviour.

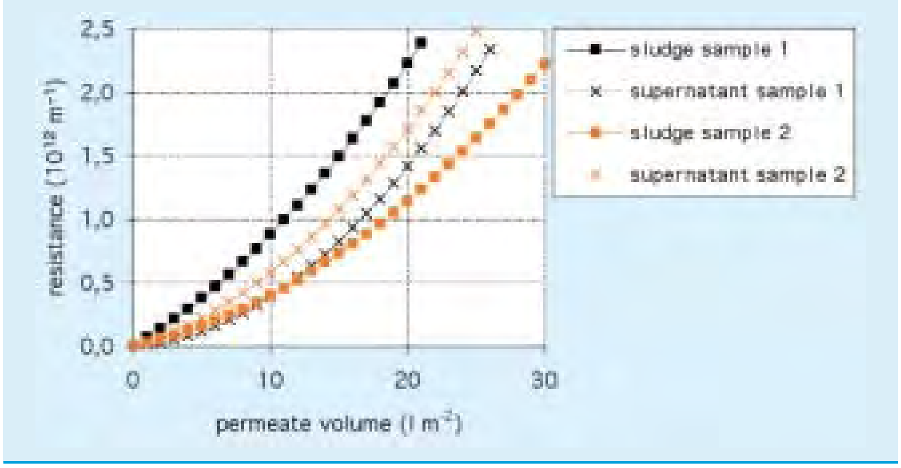


Figure 2: Filtration resistance as function of filtered permeate volume.

Table 1: Composition sludge samples 1 and 2.

	sample 1 bound $mg.gVSS^{-1}$	free $mg.l^{-1}$	sample 2 bound $mg.gVSS^{-1}$	free $mg.l^{-1}$
polysaccharides	64	118	49	170
proteins	53	17	40	62

Two sludge samples were taken from the membrane tank in the same MBR, operated at different conditions. The sludge samples and the supernatant of these samples were filtered in a specifically designed set-up and the resistance against filtration was monitored as a function of the permeate volume during cross-flow filtration (Figure 2). In addition, free and sludge bound proteins and polysaccharides were determined (Table 1). The supernatant of sample 2 exhibited a higher resistance than the supernatant of sample 1. Possibly, this can be attributed to higher concentrations of free proteins or polysaccharides present in sample 2. However, for the (total) sludge samples the opposite applies with a much higher resistance for sample 1 than for sample 2. This suggests that with sludge sample 2 a cake layer was formed which was much more protective against fouling than with sludge sample 1 and at the same time this cake layer was more permeable than the cake layer with sample 1.

Foulant process interaction

The example above illustrates that identification and characterisation of the main foulants allow a better focus towards the problem of fouling. First of all this concerns research towards design and operation of the biological reactor with the objective to reduce the concentrations of these foulants. Today the biological reactors of MBRs are not designed and operated differently from conventional systems applying secondary settlers. This seems odd as the microbial population in MBRs can be expected to be different from conventional systems and much higher sludge concentrations are maintained. Shear, water hardness, sludge and hydraulic retention time, the substrate gradient, the COD/P/N ratio of the wastewater and the redox regime all are expected to be important factors determining the concentration of foulants. Knowledge about the behaviour of these foulants in response to such factors is extremely important to allow modification of the design and operation of the biological reactors in MBR systems with the objective to minimize fouling.

In situ foulant monitoring

A second approach is to study membrane fouling more in detail, preferably using in situ and direct monitoring techniques. It is appreciated that this is extremely difficult but may become feasible once more information is available about the dominant foulants. This approach should lead to better membrane operation, not only during stable conditions, but particularly in response to varying conditions such as rain weather incidents which are known causes of severe fouling problems.

Also, this will result in a more fundamental basis for the selection of the appropriate membrane properties such as pore size, membrane material, etc., and for the development and design of new membrane modules which nowadays more or less is based on a trial-and-error approach.

Filtration

Foulants will undoubtedly have their impact on the permeability of the membranes. Other parameters that affect the permeability are the trans-membrane-pressure (TMP), shear rate, temperature and sludge composition. Especially membrane properties and membrane material are crucial elements that influence the membrane permeability.

Enhanced hydrodynamics

Current developments in membrane operation are aimed at reducing membrane fouling by selecting the proper hydrodynamic conditions. Generally this is done by creating turbulent flow conditions near the membrane surface. The shear flow rate along the boundary layer of the membrane strongly affects the membrane flux. A standard method to promote shear nowadays is to dose air bubbles. Although air bubbles enhance the membrane flux, they also have their impact on the particle size distribution and floc structure. Moreover, enforced aeration demands energy. Research should be directed to optimisation of the current coarse aeration methods for submerged membrane modules. Secondly, alternative filtration concepts to promote shear locally near the membrane surface, e.g. by mechanical means, should be developed.

Improved membrane properties

The past few decades the main areas of attention for membrane development were membrane morphology, hydrophobicity or hydrophilicity and charge. In time fouling leads to changes in porosity and pore size distribution. The size of pores decreases as a result of pore narrowing due to internal adsorption. The number of small pores also decreases due to clogging. Therefore flux and selectivity are changing during the filtration process and during the lifetime of membranes. Very little is known about the interaction between foulants and membrane properties. Understanding of the relation between foulants and membrane properties will be a challenging research item the coming years.

Aeration

Conventional activated sludge processes have an insufficient aeration performance. Less then 10-15% of the oxygen supplied is transferred to the water phase using fine bubble diffusers[1]. Hence, the electricity needed for aeration provides more than 50% of the total energy costs of municipal water treatment. In MBR systems the oxygen transfer is even less efficient due to the high concentrations of solids and therefore the energy requirements even will be higher. This stresses the need for a better understanding of the potential causes and measures to be taken to improve the poor aeration efficiency in MBR systems.

Understanding nature and impact on α-factor

MBR has many advantages over conventional treatment. One of them is the ability to apply high concentrations of activated sludge, over 10 g/l and higher. However, high levels of biomass will decrease the efficiency of oxygen transfer. The research in Beverwijk has shown there is a correlation between high viscosity and low aeration efficiency. The contribution of EPS towards lower oxygen transfer efficiencies was less obvious. More knowledge is required to allow translation of these observations to a better operation of the biology in order to improve the aeration efficiency.

New efficient oxygen transfer devices

The most efficient aeration devices currently being employed in activated sludge processes are fine pore aeration systems, either using ceramic or membrane rubber materials. Membrane diffuser technology offers the highest oxygen transfer efficiencies compared to other type of aeration systems like coarse bubble diffusers, surface aerators, brush aerators, jet aeration and venturi aeration systems.

However, the oxygen transfer efficiency at high solids concentration not only depends on the type of aeration but also on sludge characteristics. Especially mechanical stress enforced by shear could promote the oxygen transfer efficiency. On the other hand mechanical stress will change the sludge structure and will require energy. More research is needed, preferably on full scale, to explore the possibilities and limitations of new and existing aeration systems.

Enhanced oxygen transfer new configured flat sheet-frame modules

The depths of conventional activated sludge processes are usually in range of 3 to 4 meter. In case of diffused air aeration, consequently, there is a limited time for oxygen transfer from gas to liquid phase. Transfer of oxygen can be improved by new designs of flat sheet and frame modules. The idea is to increase the retention time of the air bubbles. Potential energy savings for aeration could be in the range 10-30%.

Direct production of electricity out of wastewater using microbial fuel cells (TNO).

Enhanced oxygen transfer by new reactor designs

An example of a new reactor design that could promote the oxygen transfer efficiency spectacularly is the deep-shaft MBR, which could be a unique modification of the conventional MBR with even smaller footprints and oxygen transfer rates that are significantly higher. The main objective of this system is to increase the efficiency of oxygen transfer. The deep-shaft configuration increases the partial pressure of oxygen, thereby causing a high saturation concentration in the reactor. The deep-shaft technology has been successfully applied for high strength polluted wastewaters. More then 80 full-scale references are known. Possibilities for domestic water treatment could be explored.

New innovative future MBR treatment concepts

The present generation of MBR systems is far from sustainable. The treatment process is energy demanding, produces an immense amount of waste sludge, nutrients are destroyed, greenhouse gasses are produced and potential energy sources are wasted. More sustainable solutions are needed in order to recycle the water in dry areas, in order to recover nutrients like phosphates and nitrogen, and in order to produce or minimize the energy use to prevent production of greenhouse gasses. For future sustainable water treatment new concept approaches are necessary.

Decentralised sanitation

Newly developed decentralised sanitation concepts[2],[3] offers possibilities for MBR technology. Within the decentralised sanitation concept wastewater is treated close to a household with a strong focus on sustainable use of resources. Generally three wastewater streams with different origin are collected and treated: grey water (shower, kitchen), yellow water (urine) and brown water (toilet water without urine). These wastewater streams differ strongly in amount and composition. Especially towards water reuse opportunities new MBR applications should be developed.

Anaerobic MBR

Generally anaerobic treatment of wastewater has two main benefits: low energy requirements (no aeration, formation of biogas) and low sludge production. Both features are very attractive for the development of anaerobic MBR concepts for domestic water treatment. The role of fouling will be crucial, even more then with aerobic MBR systems. Anaerobic conditions promote the formation of struvite, an insoluble salt built up from magnesium, ammonium and phosphate. Especially near the membrane surface where concentration polarisation (accumulation of compounds) occurs, the danger of struvite being precipitated on the membrane is high[4]. Another point of interest is the way the membrane configuration is chosen. Due to the absence of air, submerged modules, attractive from an energy point of view, are less appropriate. Most anaerobic MBR concepts use hollow fiber cross flow configurations that are energy demanding. New alternative filtration / operation modules should be developed: e.g. recirculation of biogas to enhance shear locally on the membrane surface[5].

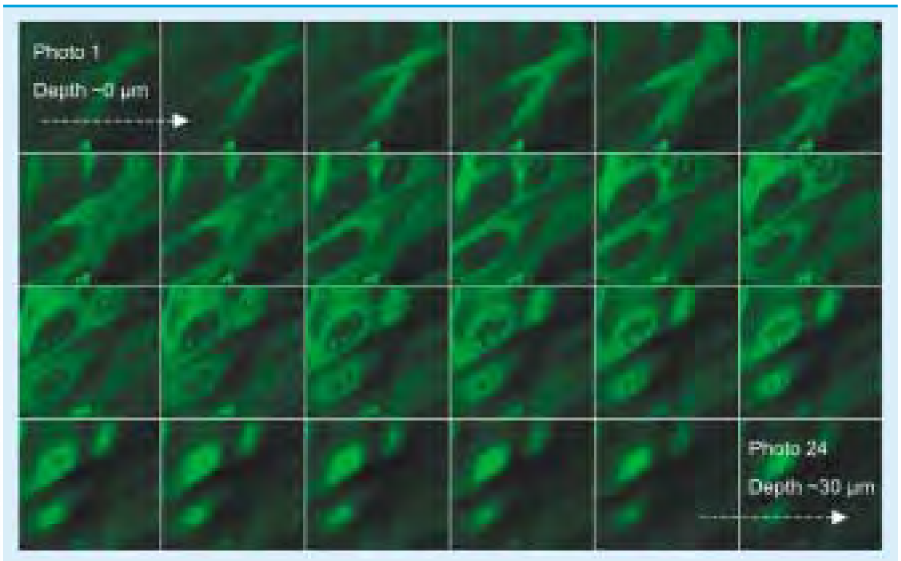
Microbial Fuel Cell

The present generation water treatment systems are wasting potential energy sources. Theoretically the combination of MBR with the microbial fuel cell principle could be used to produce electricity directly from wastewater[6], while at the same time accomplish water treatment[7]. This new approach could lead to significant reduction of operation costs, but also creates opportunities to produce products with market value. Proof of principle is demonstrated. The next step to be taken is to study the technological and economic feasibility of the process[8]. Wetsus as well as TNO are working on the production of energy from wastewater in bio-fuel cells, which is one of their main research themes.

Conclusions

In spite of its advantages compared to conventional treatment systems, MBR does not yet provide a competitive alternative. The smaller required footprint and the excellent water quality are partially counteracted by high costs for membrane filtration and inefficient oxygen transfer. Therefore the coming years MBR research should be directed towards minimization of costs for filtration and aeration. Further it would be worthwhile to improve the sustainability of MBR technology by exploring new concepts of wastewater treatment. Examples are decentralised treatment of wastewater offering possibilities to treat separate streams of grey and black water; anaerobic water treatment with low energy requirements and low sludge production and direct energy production by combining MBR with microbial fuel cell technology. ¶

3D-analysis of flat sheet and frame membrane with Confocal laser scanning microscopy. Microbes (DNA) are visible as green.



Samenvatting

De laatste decennia is wereldwijd veel onderzoek verricht naar de MBR-technologie. Desondanks ontbreekt vooralsnog een technologische doorbraak voor zuivering van communaal afvalwater. De kosten van de MBR-technologie blijven hoger dan voor de conventionele zuiveringstechnieken. Kostenvermindering zal de komende jaren dan ook de belangrijkste stimulans zijn voor verder onderzoek en ontwikkeling van MBR-technologie voor communale waterzuivering. De aandacht zal zich moeten richten op drie gebieden: vervuiling, filtratie en beluchting. Naast onderzoek gericht op kostenreductie is ontwikkeling van innovatieve, meer duurzame MBR-concepten gewenst. Voorbeelden hiervan zijn decentrale zuivering om te komen tot gedeeltelijk hergebruik van water en wellicht nutriënten, anaërobe zuivering van afvalwater en het toepassen van MBR-technologie in combinatie met de productie van elektriciteit in een brandstofcel. De potentiële voordelen legitimeren een verdere verkenning van deze innovatieve MBR-concepten.

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  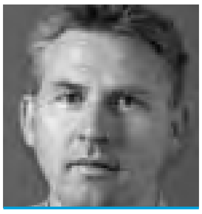 

The role of consultancy firms in the application of new wastewater purification technology

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The Netherlands has a strong foundation in the field of wastewater treatment. The country has a long history of developing and introducing new biological wastewater purification technologies on a practical scale. Some of the most talked about examples of these technologies, which are well known throughout the whole world, are anaerobic wastewater purification in accordance with the UASB principle, the Carrousel system, BCFS, and the Sharon and Anammox nitrogen removal technologies. Important success factors in these are the traditionally strong microbiological basis in the Netherlands and a unique work method that aims to integrate disciplines. The primary matter of importance is that only a practice-oriented application of scientific developments to the practical scale will lead to a successful application for the end user. In the Netherlands, consultancy and engineering firms fulfil a pivotal role in this application.

The responsibility for the purification of household wastewater in the Netherlands has been incorporated in approximately 25 water boards. The traditional procedure in the Netherlands when adapting a regional water purification installation can be generally described as follows.

First, a technological concept is chosen based on the end user's requirements. This is then fleshed out in a basic design, a detail design and a specification. Finally, after tendering, realisation and start-up are commenced. Consultancy firms are involved by end users in all these steps as designers and managers of the construction phase.

In essence, the activities of the consultancy firms in the typical project route described above are multidisciplinary by nature. Integration between the disciplines concerned and co-operation in the design and construction process are essential for a good price/quality ratio. Consultancy firms are the liaison between knowledge institutions, suppliers and end users. In this role the consultancy firms constantly look out for global developments in both technical and technological fields. The market supply of suppliers is closely monitored and developments among suppliers and knowledge institutions are also identified in good time. Initiating and redirecting developments into relevant practical conditions is performed by many consultancy firms. Because they are involved in the construction, start-up and optimisation of regional water purification installations, consultancy firms possess knowledge about the practical situation; they are excellent discussion partners for the end users. As intermediaries, consultancy firms can ensure the correct communication level in a project thanks to their knowledge about the customer's circumstances. This is because the consultancy firms are more willing and able to create an open atmosphere for specific knowledge transfer, whereas confidentiality and secrecy of information play a much greater role among suppliers.

Carrousel, Geestmerambacht.

MBR and other new developments

In 2000, a start has been made in the Netherlands with the pilot research on the regional water purification installation in Beverwijk, with a plan for the development and large-scale introduction of MBR technology for the treatment of household wastewater. The pilot research has lead to new insights into the design and the operational management of MBR. These insights have been implemented in practise at the recently opened MBR Varsseveld. Furthermore, the preparations for the realisation of another three large-scale MBRs for household wastewater are in full progress. This concerns the projects in Heenvliet, Ootmarsum and Hilversum. The plan mentioned above is characteristic for the 'Dutch school' and for the role of consultancy firms in applying new wastewater purification technology.

Sharon, Zwolle.

A typical feature of an MBR is the interaction and harmony between biology and membranes. Particularly the focus on this interaction and the multidisciplinary approach has formed the foundations of crucial improvements in the design of MBR. The outstanding Dutch microbiological and process technological knowledge and the actions taken in service of total solutions geared to practical situations have proven themselves again.

You could compare an MBR with an orchestra in some ways. In order to realise a symphony, co-operation and harmony between the soloists under the leadership of a conductor is vital. And so, as you can guess, consultancy firms are the leaders of orchestras. The leader of the orchestra knows which instruments to use and which musicians will be selected to play these. An MBR is a fine example of an integrated wastewater purification concept. Biological, technological, civil and mechanical aspects, membrane technique and management form the backbone for a smoothly operating MBR. It is clear that the consultancy firms possess integrated knowledge of the purification process.

New developments and project risks

The development and large-scale introduction of new technology is characterised by various learning curves. This is inevitably accompanied by risks. At first, during laboratory and pilot-scale research, the (harmful) risks are still limited. But in the first large-scale applications, both the financial and the technical (harmful) risks are on a very different level. Minimizing these risks is vital - and this is where professional and integrated advice comes into play.

End user's must be made aware of possible risks and must accept part of these. Setting realistic requirements is essential. An important question is how long it is actually possible during the phases of a project to include various systems and to introduce new developments: liberty versus clarity. A consultant can present new technologies and suppliers from rough to fine, determine and evaluate distinguishing characteristics. During the supervision of the system choice process it will be determined which choices will be fixed and which will be left to the market and left open during the tendering phase. In the design phase a decision will have to be made about whether a chosen concept will be maintained or that flexibility will be built in to include various systems and new developments. Certainly in the case of new technologies, a realistic responsibility for the result must be placed with the supplier/builder of vital components. This must be taken into account when a choice is made about the form of tendering and the contract. Is a functional specification suitable for a development project, or is a detailed specification better to minimize the risks? It is certainly important that the aspects mentioned above link up with the culture and work method of the end user.

Conclusion

The consultancy firms see a role for themselves as leaders of the 'wastewater Purification Orchestra'. It is clear that this orchestra can only be successful given a good quality of the leader of the orchestra as well as the members of the orchestra. Communication and co-operation between the members of the orchestra, the public and the principal are essential in this.

The Dutch 'wastewater Purification Orchestra' has already proven on numerous occasions with different symphonies (MBR, UASB, Carrousel, BCFS, Sharon) that it deserves to play on the world's stages. In order to keep on doing this in the future, continuous and structural work must be performed on the quality and commercial strength of the water sector.

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Samenvatting

Nederland kent een lange en succesvolle traditie op afvalwaterbehandeling. De advies- en ingenieursbureaus vormen een belangrijke functie in de vertaling van nieuwe ontwikkelingen naar de praktijkschaal. Door de betrokkenheid bij de bouw, opstart en optimalisatie van rwzi's hebben de Nederlandse adviesbureaus kennis van de praktijk en zijn een volwaardige gesprekspartner voor de waterbeheerders. De recente MBR-ontwikkelingen in Nederland zijn kenmerkend voor de Nederlandse werkwijze en de rol van adviesbureaus in de toepassing van nieuwe afvalwaterzuiveringstechnologie. Een multidisciplinaire aanpak en integrale kennis van het zuiveringsproces zijn hierin cruciaal. Adviesbureaus bieden integrale advisering met kennis en kunde waardoor eventuele risico's bij nieuwe ontwikkelingen kunnen worden geminimaliseerd. Om het succes van de Nederlandse afvalwatertechnologie ook naar de toekomst toe te verzekeren dient de aandacht voor investeringen in kwaliteit en commerciële slagkracht van de Nederlandse watersector niet te verslappen.

Industry is ready for MBR

Henk Brons, VEMW

In the Netherlands about twenty highly diverse industrial MBRs have been realised in the past ten years. This respectable number could have been even higher if the water policy of Dutch authorities had given more support to the industrial initiatives. Why do companies consider investing in MBR and does governmental policy hinder them? VEMW, the Dutch Association of non-domestic water users, pleads for clear guidelines on fees and market conditions to enable investment in MBR. Industry is ready for innovation; an active approach from the water authorities is called for.

At Water Quality Europe (the annual Dutch conference for industrial water), the central issue was how to boost Dutch innovation in the water sector. Due to the new European Water Framework Directive demands on wastewater discharge and a continuing motivation to improve cost performance, there is a permanent drive for innovation in industry. MBR was one of the most promising technologies discussed at the conference.

Important criteria for investment in water technology in the process industry are the contribution to the continuity of the operations (the so called 'license to operate'), cost minimisation and customer satisfaction, local stakeholders included. Under what circumstances can MBR meet these criteria? Companies have different reasons to consider an investment in MBR. As in the case of treatment of wastewater from households, a stable quality of the effluent is an important argument and the compact design of MBR is attractive. However, the most promising seems to be the application of MBR for water reuse. Last year, most of the respondents to a VEMW questionnaire saw the future for MBR in industry in in-process applications. Companies still need more information about operational costs of MBR and about expected developments in energy consumption and sludge reduction. Although compact and flexible systems have the future, not all questions have been answered. Industry however, is confident that suppliers will come with sufficient solutions in coming years.

Johan Raap of CSM comments on the website of the Dutch Ministry of Economic Affairs on innovation in the water sector that companies experience "a gap between what the industry develops and what is permitted by the authorities." There is tension between the implementation of solutions and discharge permits. "There is a lack of reason behind many water rules: these rules might even prove to be contra-productive to their initial aim." In his view a critical flaw in the current water policy is a lack of an overall vision on the so-called water chain. This water chain extends from intake of water to discharge after treatment. Industrial water usage, with its practice of reuse and (process) water treatment, forms an essential element of the water chain. In legislation and discharge permits, the contribution of industry to the water system should be recognised in full.

In a water chain orientated approach, the use of more flexible and cost oriented instruments is essential. In the existing legislative framework real barriers to such an approach are the rigid and non-transparent financing schemes of municipal sewers in combination with a narrow view in the discharge permit, focussing on the receiving sewer service. A cost oriented fee should accommodate an environmental and economic beneficial option, where pre-treatment of industrial wastewater occurs. In these cases current restrictions to further treatment of 'thin' or diluted industrial wastewater should be mitigated in order to encourage treatment facilities. A cost oriented fee contributes to the predictability of tariffs and fees and therefore improves the investment climate.

Cargill

In Bergen op Zoom in the southern part of the Netherlands, Cerestar, a Cargill company, operates a factory where both maize and wheat are used as raw material to supply customers with food and non-food products. Their MBR came online in 2001 with a capacity of 35 m^3/h and is used to upgrade process water for cooling purposes, and lead to a water saving of 270,000 m^3/year, or 20 % of the total water usage. The total projects costs were about one million Euro.

Subsidies turned out to be a real incentive to the project, and the Dutch authorities financed about 30 % of the investment costs. On the other hand, a problem is the requirement in the discharge permit for what is called 'thin' or diluted water, where the treated wastewater should not be diluted further than 350 l/pollution equivalent (p.e.) and limits the back up-provision for the MBR-facility. At the moment, the company has to bypass the MBR if there is no or reduced

Cerestar.

demand for cooling water in the production process. Although the MBR has both a higher efficiency and a better environmental performance than the receiving communal wastewater treatment plant Cerestar is forced to bypass contaminated wastewater.

Due to the presence of salts, the treated water cannot be directly discharged into receiving waters. Cerestar would like to consider replacing the existing aerobic treatment plant with a second MBR-facility.

This investment should contribute to lower costs; due to higher efficiency and saving of the fee per discharged population equivalent payable to the water board, a lower sludge production and a better performance on COD-reduction, where the energy balance has to be considered. However, this option will be blocked by the discharge requirement for thin wastewater and therefore Cerestar have not prepared an investment decision until now.

Recently Cargill constructed a MBR at the oil seed crushing plant in Saint Nazaire (France). Cargill started the MBR last January. It is a submerged MBR with tubular PVDF coated membranes with a capacity of 850 kg/d COD. This design was selected due to plant effluent characteristics, small footprint (space limitation) and minimal sludge production. The choice for a submerged MBR reduced energy consumption compared with the alternative external cross-flow membranes. The tubular type membranes allow reversed flow at regular time intervals while coarse bubble aeration creates enough turbulence to avoid biomass built-up at the surface of the membranes. The effluent quality should allow reusage as a make-up water-source to provide cooling water in the near future.

In Amsterdam Cargill is investigating the option of using MBR technology for aerobic side stream treatment of plant effluent containing sulphates in the range of 20,000-40,000 ppm. The objective is to discharge the sulphates directly into the dock and consequently to eliminate the constraints to discharge via the municipal sewer. Sulphates may contribute to corrosion as sulphates are biologically reduced to sulphides under anaerobic conditions. Also H_2S-formation raises concerns regarding occupational health and safety conditions at wastewater treatment plant Westpoort. In this application MBR looks promising as the biomass is retained in the reactor as in the classical design, sludge-settling characteristics are poor due to dispersed growth. A pilot plant trial has been successfully completed and now that the salts containing water can be discharged into the receiving brackish water, the approval by the authorities is to be expected.

Diosynth Oss

Diosynth is an Akzo Nobel company and produces active pharmaceutical ingredients. The manufacturing facility in Oss produces wastewater (20,000 p.e.) that contains priority substances. Anticipating on expected limitations on effluent components under the Water Framework Directive, Diosynth aimed to improve knowledge on stabilising effluent quality. Diosynth therefore installed an MBR-

Tabel 1: MBR *in waste treatment.*

company	location	sector	year	capacity (m^3/h)
Essent	Landgraaf	landfill	1995	13
Essent	Montfort	landfill	1996	10
Afvalzorg	Middenmeer	landfill	1996	5
Recept	Rotterdam	composting	1996	2
Nijhoff Wassink	Rijssen	tank cleaning	1997	1
Smink	Hoogland	landfill	1996	20
Den Ouden OTT	Alblasserdam	tank cleaning	1999	1
Royal Dutch Navy	Den Helder	bilgewater	1999	5
Dekker Transport	Oudekerk a/d IJssel	tank cleaning	1999	1,5
Dekker Transport	Dendermonde	tank cleaning	2000	2
Vos Logistics	Zuidbroek	tank cleaning	2000	2,5
Vos Logistics	Rotterdam	tank cleaning	2000	12
Gentenaar	Moerdijk	tank cleaning	2000	4
Biocel	Lelystad	compost	2001	2
Pieter Bon	Zaandam	tank cleaning	2002	8
Van Gansewinkel	Weert	liquid waste treatment	2002	16
TCL	Maastricht	tank cleaning	2003	3
Ecopark De Wierde	Oudehaske	landfill	2003	30
Essent	Haps	landfill	2004	5
Hoyer	Rotterdam	tank cleaning	2004	8
ATM	Botlek	tank cleaning	2004	7,5
Vos Logistics	Hoogerheide	tank cleaning	2004	1,5
3e Merwedehaven	Dordrecht	landfill	2004	36
Stubbe	Gouda	tankcleaning	2005	2

Sources: DHV, Triqua, Logisticon, Zenon, Solis, RWB Afvalwater, TNO-MEP

Tabel 2: MBR *in industry.*

company	location	sector	year	capacity (m^3/h)
Noviant	Nijmegen	coatings	1996	20
SCA	Suameer	paper	1998	0,7
Driessen	Dongen	leather	1998	10
Rendac	Bergum	rendering	1999	40
VWS	Broek op Langedijk	flowerbulb cleaning	1999	3
VHP	Ugchelen	paper	2000	12
Platvis	Volendam	food	2000	2
Cerestar	Bergen op Zoom	wheat refinery	2001	35
Rentex Floron	Bolsward	textile cleaning	2002	35
Astra Faam	Harlingen	food	2002	2,5
Rendac	Son	rendering	2003	100
Akzo Nobel	Oss	pharmaceutical	2003	1,2
Du Pont / Invista	Dordrecht	chemical	2003	60
Fuji	Tilburg	photo/film	2004	35
Bavaria	Eemsmond	malt	2005	55
Noviant	Nijmegen	coatings	2005	3
Cargill	Amsterdam	soja bean crushing	2005	3

Sources: DHV, Triqua, Logisticon, Zenon, Solis, RWB Afvalwater, TNO-MEP, VEMW

Diosynth.

pilot with a capacity (membrane flow) of 1,200 litres per hour.

The pilot aimed to investigate the biodegradability of substances in the wastewater streams in the production process using MBR-technology. The research programme was specifically aimed at the biodegradability of COD, nitrogen and priority substances (volatile organic solvents, chlorinated carbon-hydrogen and toluene). The pilot also gave information about operational costs, the necessary maintenance and operation tasks and the capacity of the installation. During the pilot also technical questions had to be answered which led to modifications of the design. This was the case for e.g. the composition of the membranes, the aeration and adaptations to improve the operations (e.g. cleaning of the membranes, tuning of the process parameters and maintenance schemes). Diosynth paid much attention to stabilise operations and to the training of operators.

The pilot was evaluated at the end of 2003. The MBR led to a reduction of contamination to 3,500 p.e. The pilot was run without subsidy. The Water Board was very interested in the results of the pilot, especially in its contribution to improving the effluent quality. New environmental standards were expected according to the Water Framework Directive, and the wastewater of Diosynth complied entirely with the discharge permit submitted by the Water Board, also on the aspects of thin water. A possible replacement of the pilot with a definitive plant might have consequences for the wastewater profile.

Changes in the water sector

As the Dutch representative for non-domestic water users, VEMW has concerns about exclusive rights of dominant suppliers of water services covering industrial water users in the Netherlands. These rights lead to efficiency loss in the water market and therefore to unnecessary high prices. Prices that are not set by the market are as such not a clear indicator for investment for industry. This lack of both transparency and efficiency implies a strong need for an independent authority with sufficient and effective instruments to enhance efficiency and lower prices in water services. To counter this inefficiency in the water market, VEMW calls for an independent supervisor to stimulate the investment climate.

As illustrated in the cases, a possible conflict of interest in the wastewater sector emerges as the water boards combine both economic dominant positions in wastewater treatment and granting wastewater discharge licences. In combination with the legal monopoly on treatment of domestic sewage, this competence for granting permits is a serious threat to industrial initiatives for the treatment and reuse of processwater. Due to the ability of water boards to place restrictions to industrial initiatives, in order to protect their own sewage treatment plants (i.e.: of the water boards), they can prevent or discourage initiatives for water reuse which are as such beneficial both for economic and environmental reasons. This combination of functions of the water boards leads to the undesirable situation in which the referee is also a player in the match. Therefore, the current combination in the Netherlands of responsibilities in the field of operations, permits and inspections of the treatment of wastewater, should be separated. Clear options on permit-conditions are necessary to improve the investment climate.

Due to geographic circumstances, water availability should be an incentive for companies to settle in the Netherlands. Specialised and applicable knowledge about water technology is widely available. Changing the water sector in order to reach transparent and structural low tariffs, and eliminating conflicts of interest will boost innovation. Industry is ready for MBR -The government must now set the right conditions. ¶

Henk Boenink (AKZO Nobel), Chris Velzeboer (Cargill), Ernst Covers (Cerestar), Johan Raap (CSM) and Joan Brouwer (Diosynth) made this article possible by adding information.

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Samenvatting

Vanaf 1995 zijn circa 20 industriële toepassingen van de membraanbioreactor gerealiseerd. Met name voor wat betreft het sluiten van de waterkringloop is de MBR kansrijk in de industrie. Cerestar te Bergen op Zoom realiseert sinds 2001 door gebruik van een MBR hergebruik van proceswater voor koeling. Diosynth te Oss heeft in een pilotinstallatie een aanzienlijke reductie van prioritaire stoffen bereikt. Toepassing van MBR binnen de industrie wordt echter beperkt doordat vanuit het beleid onvoldoende oog is voor de rol van industriële waterbehandeling in de waterketen. Het waterschap kan in de lozingsvergunning de mogelijkheden van voorzuivering door bedrijven beperken, bijvoorbeeld door een eis voor 'dun water'. Bovendien is de financieringsstructuur in de waterketen star en ondoorzichtig, wat investeringsbeslissingen bemoeilijkt. Doordat economische machtsposities in de watersector bestaande inefficiënties in stand houden of zelfs bevorderen, zijn watertarieven te hoog. Onafhankelijk toezicht op de watersector draagt bij aan het terugbrengen van deze inefficiënties, geeft meer kostentransparantie en levert door beter voorspelbare watertarieven een bijdrage aan het investeringsklimaat. Een beter investeringsklimaat draagt bij aan de toepassing van MBR in de industrie.

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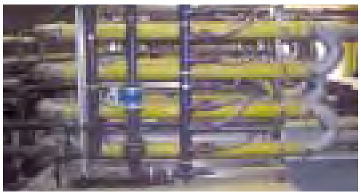

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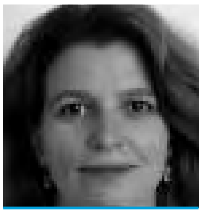
  

MBR applications outside the Netherlands: drivers and case studies

Berend Reitsma, Tauw
Luc Kox, DHV Water
Cora Uijterlinde, STOWA

Today countries have different drivers for application and development of Membrane BioReactor technology. Due to changes in legislation, enforcing strict discharge requirements is the main driver for Northern America, Germany and the Netherlands. In water scarce areas like Israel, Southern Europe and even Japan, the application of the MBR is driven mainly by the need for water reclamation. In the UK (case study 1) the effluent quality driver focuses mainly on a high hygienic quality, giving less attention to the removal of nitrogen and phosphate. This is different from the Netherlands where possibilities towards far reaching nutrient removal are the key driver for the developments regarding MBR. In the UK additional drivers are compact and simple facilities, fitting into the landscape, with zero emission for odour. For the Ben Gurion International Airport (case study 2) compactness and superior product water quality are the drivers. The reclaimed water will be used in both irrigation purposes and industrial applications on the airport.

First applications of MBR technology were established in the 1960s. The first installations were mainly found in Northern America and Japan and were accomplished in two distinctly different settings. In Northern America the initial application of MBR technology comprised treatment of wastewater originating from the petrochemical industry. In Japan first experience with MBR technology was gained by applying the concept as a wastewater treatment concept for apartment blocks. One thing the initial applications all had in common was the limited scale on which the technology was applied; the drivers to choose for MBR technology were different however. This article addresses the different drivers for the application and development of MBR technology over the years in different countries. Furthermore two case studies are highlighted: MBR in the UK and water reclamation at Ben Gurion International Airport (Tel Aviv).

MBR Lowestoft.

In line with the differences in the motives for choosing MBR technology in the first applications as mentioned above, today countries have different drivers for application and further development of MBR technology. In this first paragraph the global drivers for MBR technology are stipulated from East to West.

Asia

MBR technology is being considered at many locations all over Asia, the main driver being water reclamation. Examples of settings vary from small-scale applications in Japan, where MBR product water is reused as toilet flushing water in apartment blocks, medium sized industrial applications in various countries and large-scale municipal wastewater treatment plants in China.

Middle East

Clean water shortages are the obvious main driver for MBR applications in the Middle East, in treatment of both municipal as well as industrial (petrochemical) wastewater.

Europe

In Western Europe water reclamation is not the main driver. In the UK an important driver is compactness (e.g. Swanage) and strict discharge limits due to bathing water requirements. In Germany and the Netherlands important push factors are strict discharge requirements due to ecologically sensitive surface waters and the innovative character of the technological developments related to MBR. In Southern Europe water reclamation can be considered as the main driver.

Northern America

In the U.S. and Canada MBR initiatives are predominantly driven by strict discharge requirements due to ecologically sensitive surface waters. At some locations water reclamation is another important driver.

MBR in the United Kingdom

There are currently more than 15 operational urban MBRs in the UK. Most of these have a capacity of 500-1,500 m^3/d. The two largest MBRs each have a capacity of about 12,000 m^3/d (Swanage and Glasgow).

At the end of 2003, ten Dutch water boards and five consultancies visited the MBRs in Lowestoft, Porlock and Westbury. This case study presents the findings of this visit. The emphasis is laid on describing the drivers for an MBR on these sites.

MBR Porlock.

The Lowestoft WWTP is a demonstration project with three different compact wastewater treatment processes. Seventy percent of the wastewater is industrial. The MBR has a treatment capacity of 46,800 p.e. and a maximum hydraulic flow of 590 m^3/h.

The facility was to be fitted into the landscape with a zero emission for odour. The treated wastewater is discharged into the North Sea. The effluent requirements are lenient compared to the Netherlands, as long as the water is hygienically safe (bathing water standard). The EC standard for non-vulnerable surface water must be met, which means that BOD must be reduced to 25 mg/l, and dry matter to 30 mg/l. There are no effluent requirements for nitrogen and phosphate.

Porlock is a small seaside resort (3,800 inhabitants) in Exmoor National Park on the coast of Somerset. In connection with its function as seaside resort, Wessex Water considered the discharge of untreated wastewater unacceptable. Determining factors in choosing the system for the facility were the effluent quality for viruses and bacteria and the minimum space demand. Furthermore, the system was cheaper than a long pipeline into the sea. In 1998, the Porlock MBR facility was put into service and has been working to the full satisfaction of Wessex Water ever since.

Effluent requirements pertain to BOD (40 mg/l) and suspended solids (60 mg/l), not to nitrogen and phosphate. It was decided to install an MBR in Porlock mainly to achieve a good hygienic effluent quality. Ammonia is removed to a reasonable extent. Good results were presented for the removal of coliforms and bacteriophages (a measure for virus removal), up to log 6 and log 4 reductions, respectively.

Porlock WWTP was built in a protected area near a tourist beach, which is why the starting points for its design were completely different from those at Lowestoft. The exterior of the facility was to merge with its environment and the effluent outlet was not to disturb the tourists. The MBR facility is situated close to the town centre near some farms. Given its location and the tourist function of the area, it was decided to minimize the MBR facility's conspicuousness in the landscape. This starting point yielded an exceptionable design. The facility was placed in a building designed according to the style of the surrounding farms. The coarse screens were built in a basement and the sludge storage tanks were made as flat as possible.

The Westbury WWTP consists of a treatment plant of trickling filters and a recently constructed MBR parallel with the existing plant. The existing facility was extended on account of the connection and extension of a dairy plant. First, the dairy wastewater is pretreated with a flotation unit and pH correction. The pretreated wastewater is discharged to the WWTP for further treatment. The driver for the application of an MBR is that the high effluent quality of the MBR causes the combined effluent to meet the effluent standards.

Because the flat sheet membranes need intense aeration to prevent contamination normally one tank with membranes is used. The oxygenation for the oxidation is usually completely provided by the coarse bubble aeration for the membranes. However, on account of the specific influent composition to be expected at Westbury (dairy industry and percolate), i.e. concentrated wastewater, a larger activated sludge system (four tanks) was realized. Only 1/3 is taken up by the membranes (12 sets of 200 flat sheets per tank). The remainder is intensively aerated with fine bubble aeration.

The combined effluent must meet the requirements for BOD (13 mg/l), suspended solids (20 mg/l) and NH_4-N (5 mg/l). For the MBR the effluent requirement for phosphorus is 1.5 mg P_{total}/l. This requirement is being met by means of chemical phosphate removal. The guaranteed effluent quality for the MBR is 5 mg/l for BOD, suspended solids and ammonia.

Some MBRs in the UK have been operational for over five years. The systems seem to function without problems and the irreversible contamination of the membranes also seems to be no problem. In the UK MBRs are mainly used to remove organic compounds (BOD) and solids (suspended matter) and to obtain disinfected effluent. The discharge requirements for permeate are very lenient compared to Dutch requirements. Often, there are no requirements for nitrogen or phosphate. Sometimes a requirement for ammonia applies and even less often one for phosphate.

The available surface area for WWTPs is often limited and this means that the treatment process has to take place in a compact facility. This results in a very simple structure consisting of one aeration tank in which also the membranes are placed. The membrane aeration in the British facilities provides a significant part of the required oxygen input. In addition, fitting the facilities into the landscape and the zero emission for odour are important.

In the Netherlands, however, the interest in the MBR is mainly for its extensive capacity of removing nutrients and suspended matter, sometimes even to the maximum allowable risk requirements for N and P for the receiving surface water (2.2 and 0.15 mg/l, respectively). This means that the biological process in the Netherlands will be more important than in the UK, which will require a structure with membranes in a separate membrane tank.

MBR Westbury.

Especially in case of very stringent effluent requirements, the nitrogen removal must then largely take place outside the membrane tanks. As a result, the structure of the aeration tank will be more complex, with anoxic compartments, aeration control, recirculation flows, process control, influencing of the sludge volume index and perhaps even additional carbon source dosing. The dependency on measuring instruments (such as nitrate, ammonia and oxygen measurements) plays a much greater role in controlling the process. In addition, little attention was paid in the UK to the optimisation of the energy consumption.

Water reclamation in Israel

Israel suffers from a lack of sufficient clean water resources. In recent years the application of MBR technology has received a lot of attention. The drive for this attention is obvious: water reclamation. In the year 2003 DHV was involved with the development of the plans for the wastewater treatment plant for Ben Gurion International Airport in Tel Aviv (Israel).

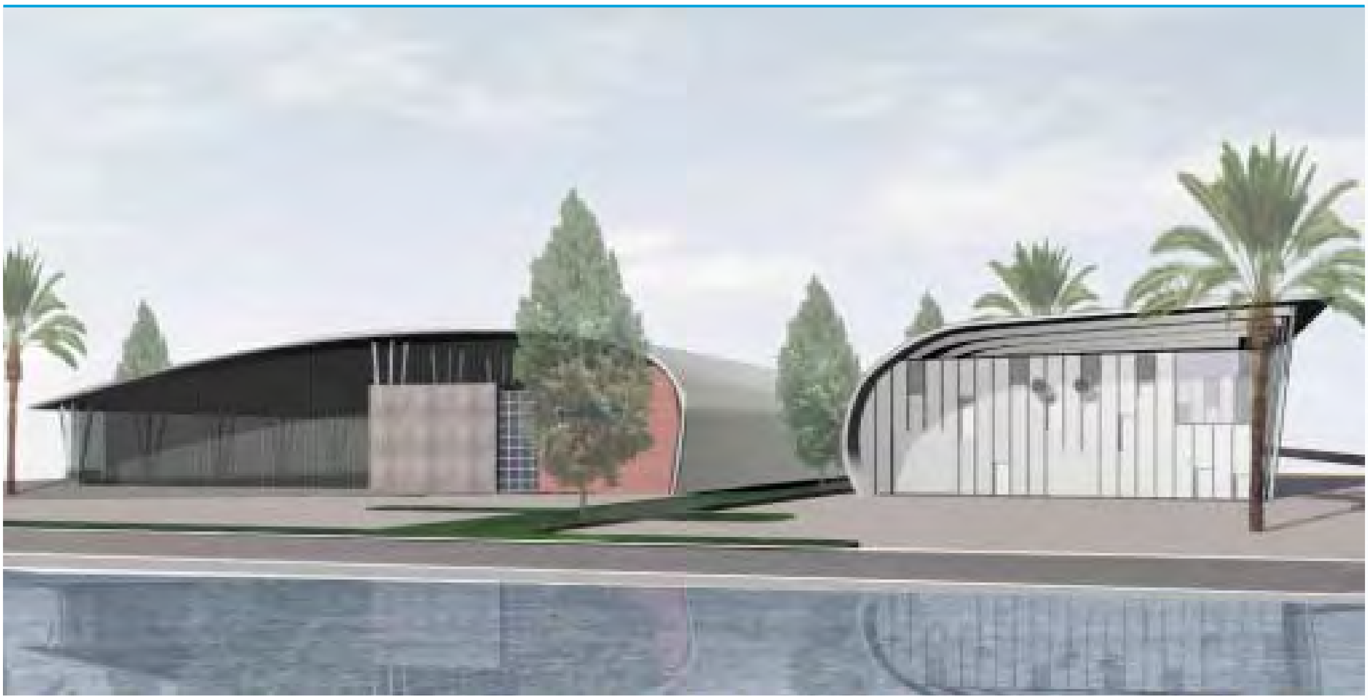
In some years time Ben Gurion International Airport will process 16 million passengers per annum. The existing airport and facilities will not meet the future requirements, therefore it was decided that new infrastructure was to be built. After the performance of an Environmental Impact Assessment study the Israel Airport Authority, owner of the airport, was forced to apply wastewater treatment technologies that would enable water reclamation by the Israeli Government. In a feasibility study MBR technology was selected, due to the two strongest advantages MBR technology offers over conventional technologies: compactness and superior product water quality.

The wastewater to be treated in the MBR at the airport originates from three individual contributors: the terminal building, food processing by catering facilities and industrial activities related to the aircraft industry.

The design capacity of the MBR installation is 1,200 m^3/h and 59,300 population equivalents. The required effluent standards are 10 mg/l for nitrogen and 0.2 mg/l for phosphorous. In the plant set-up special attention was paid to the pretreatment of the raw wastewater. Since the feed water may contain toxic wastes from heavy industrial production processes and product water requirements are to be met at all time, an equalisation tank is incorporated.

The product water of the MBR plant, reclaimed water, will be used in both irrigation purposes and industrial applications on the airport. No additional treatment

Ben Gurion Airport MBR building.



process is required for this type of reuse. Only when the product water will be used as boiler feed water application of Reverse Osmosis will be required.

A special feature for the design of the MBR plant is the architectural design. To create uniformity this needed to comply with the overall architectural design for all the buildings on the airport. So, instead of the common looks of a water treatment facility: concrete and steel tanks and buildings, this plant is housed in a modern building. The building's exterior is finished with glass walls and aluminium roofing in the shape of an airplane wing. The latter is influenced by the top view of the buildings, as seen by passengers in the airplanes.

When the new airport will be used, water reclamation will be put to practice by the wastewater treatment concept of the future: MBR technology. This example shows the strong advantages MBR offers and the environmentally sustainable solution it can bring to areas suffering from clean water shortages.

Epilogue

This article intends to give an introduction to the drivers of the attention that MBR technology receives. This positive attention is growing continuously and subsequently pushes further development of the technology, which enhances the possibilities for applications in different settings.

As indicated, the first applications of MBR in the UK were mainly driven by the demand for a reliable and compact treatment concept that reaches strict discharge requirements regarding hygienic parameters. However, high levels of nutrient removal are not driving these initiatives. Possibilities towards far reaching nutrient removal are the key driver for the developments regarding MBR in the Netherlands. This is mainly due to future on changes in legislation, in which ecologically sensitive surface waters will be protected by means of enforcing strict discharge requirements.

Obviously the drivers in a water scarce area like Israel are of a different kind. The superior water quality that is produced by MBR installation enables water reclamation to be put to practise. Without doubt this will be the major pushing factor for MBR technology all over the world. The technology can contribute to relieving the current pressure on the environment and contribute to sustainable development of our living surroundings. ¶

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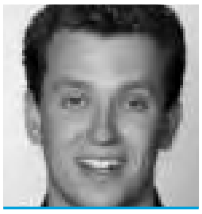
Nordkanal, the world largest MBR (Erftverband).

Samenvatting

Op het moment zijn er in diverse landen verschillende motieven voor de toepassing en ontwikkeling van membraanbioreactoren. In Noord-Amerika, Duitsland en Nederland is de voornaamste drijfveer de strengere lozingseisen die door veranderende wetgeving van kracht zullen worden. In waterschaarse gebieden, zoals Zuid-Europa, het Midden-Oosten en zelfs Japan, is waterhergebruik de voornaamste drijfveer. In Groot-Brittannië (casestudie 1) wordt de goede effluentkwaliteit met name beschouwd met betrekking tot hygiënische kwaliteit en niet ten aanzien van de verwijdering van stikstof en fosfaat. Dit wijkt af van de Nederlandse situatie, waar juist de mogelijkheden voor vergaande stikstof- en fosfaatverwijdering de voornaamste drijfveer vormen. In Groot-Brittannië bestaat daarnaast nog de mogelijkheid van compacte en eenvoudige installaties die goed landschappelijk zijn in te passen met een minimum aan geuremissie, bepalend. Bij het internationale vliegveld Ben Gurion (casestudie 2) ligt de motivatie in de compactheid en de goede effluentkwaliteit. Het opgewerkte water zal zowel worden toegepast voor irrigatie als voor industriële toepassingen.




Dutch MBR development: reminiscing the past five years

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Chris Ruiken, DWR
Dennis Piron, Water board Rivierenland
Ferdinand Kiestra, Royal Haskoning
Ruud Schemen, Water board Hollands Noorderkwartier

The MBR research that has taken place at WWTP Beverwijk since 2000 has yielded positive insights into the applicability of the MBR technology for the specific character of Dutch municipal wastewater. The research has been innovative and has proven inspirational to the development of the MBR technology worldwide. The research has fundamentally revolutionised the technology, particularly in the areas of chemical cleaning and process control and automation. In 2002 other initiatives came to light via the WWTPs Hilversum and Maasbommel studies, where the pilot research programmes were specifically aimed at MTR effluent quality. Through Beverwijk, Hilversum and Maasbommel, the first phase of the Dutch MBR development programme has been fulfilled.

In 2000 and 2001 large-scale pilot research at WWTP Beverwijk was carried out under the supervision and coordination of DHV, commissioned initially by the Water board Hollands Noorderkwartier, and followed through by the STOWA. The goal of the pilot research was to confirm the technical feasibility, to further develop the technology, to eliminate uncertainties, and finally to compare the MBR-technology with the conventional activated sludge technology.

In co-operation with four membrane suppliers (Kubota, Mitsubishi, X-flow & Zenon) various MBR pilot systems with a capacity up to 10 m³/h were commissioned. An important aspect of the first phase of the pilot research was to integrate the knowledge of membrane technology and the activated sludge process. From 2002 until mid 2004 the research at WWTP Beverwijk was extended with various other membrane suppliers (Memfis, Seghers-Keppel, & Huber-VRM).

In 2002 other initiatives were taken to give a better insight into the first phase of the MBR development programme. In co-operation between Water board Rivierenland and Royal Haskoning, a Zenon MBR pilot installation with a maximum hydraulic capacity of 20 m³/h was commissioned in April 2002 at WWTP Maasbommel. This research was primarily directed towards the feasibility of MTR quality, and a comparison was made with classical secondary effluent sand filtration. The research received a participation allowance from the STOWA and traversed a two-year duration. Co-operation with the Beverwijk research team occurred regularly with an in depth evaluation of membrane fouling and cleaning.

The end of 2002 saw the start-up of a Kubota MBR pilot with a maximum hydraulic capacity of 5 m³/h on WWTP Hilversum under supervision of the Water Authority DWR. The research was also directed primarily to the feasibility of MTR quality. Much effort has been directed to the design and automation of the pilot so that a better insight could be made regarding the N- and P-removal. This research also received a participation allowance from the STOWA.

All knowledge and experience from the three pilot research programmes was brought together in the Dutch MBR-committee, which was organised via the STOWA. Furthermore, in an effort to disseminate the knowledge, an MBR website has been opened in co-operation with the STOWA at Waterforum Online.

MBR Beverwijk

Beverwijk stands synonymous for MBR since the Water board Hollands Noorder-kwartier, STOWA and DHV began the large-scale pilot research in 2000. In a short time, the four pilots of Kubota, Mitsubishi, X-Flow and Zenon were commissioned and more than two years of broad research carried out. This was reported in 2002 via STOWA and via the IWA[1)] for the worldwide audience. However, the MBR research was not finished and remained active till mid 2004. Other MBR pilots, from Memfis, Seghers-Keppel and Huber-VRM were tested alongside some of the original four MBR systems[2)].

The foundation blocks of the MBR knowledge were born out of twelve pilot configurations from seven membrane suppliers, over a period from March 2000 to July 2004, as summarised in table 1.

Table 1: Overview of the Beverwijk pilot research project.

system	speciality	type	pore size (μm)	surface area (m²)	design capacity (m³/h)	research period
Zenon	ZW500a-c-d	hollow fibre	0.035	184-60-95	8	03/2000-10/2003
Kubota	SD / DD	flat sheet	0.4	240	10	05/2000-07/2002
Mitsubishi	3-layer	hollow fibre	0.4	314	7	05/2000-03/2002
X-Flow	AirFlush	tubular	0.03	220	9	05/2000-04/2002
Memfis	MTR	flat sheet	0.035	112	5	05/2002-06/2003
Toray	DD	hollow fibre	0.08	137	5	02/2003-02/2004
Huber	E	rotated flat sheet	0.035	360	15	10/2003-07/2004

The technical advisory committee of the Beverwijk research project.

In 2000 and 2001 the research stood in the realm of development and applicability to the specific Dutch wastewater characteristics, i.e. low process temperatures and variable flow conditions[3)]. The continuous comparison between the four systems made very efficient research possible, where the process operation of the MBR systems could be improved in a very short timespan. The research in 2002 and 2003 directed more to the optimisation of the chemical cleaning of the membranes, and on several pilots various techniques were intensively tested for better cleaning methodologies.

Feed conditioning

From the seven MBR suppliers mentioned two suggested that extensive feed screening was overdone and could be carried out on a more cost effective base with far less stringent final filtration of the nominal 0.8 mm punched holes. Eventually, both pilots were refitted with slightly more extreme final filtration, this was due to the fact that the membranes were relatively free of debris, but the auxiliary membrane equipment was prone to contamination, e.g., the aeration system, module sides and distribution points. Eventually all MBR systems tested at the Beverwijk were fitted with some form of final feed stream filtration between 0.8 mm to 1 mm punched holes. Wedge wire and square mesh was tested on several occasions but proved less efficient at hair removal than the selected punched hole screens. Due to the extra measures required to condition the feed stream to an MBR innovative new ideas have come to light to achieve the required MBR feed stream quality in one simple step.

Biological conditioning

In Holland we are conscious of the fact that the biology and not the membrane does the work in the MBR. The membrane is a simple reliable tool able to achieve a solids free effluent and nothing more. The goal has therefore been set to condition the MBR sludge in such a way that the membrane only sees water and predominantly inert suspended solids. The latter promotes low trans-membrane pressures and high sustainable permeability.

But how do we achieve the optimal biology? This has been a study item ever since aerobic biological treatment systems were first envisaged, the rules of thumb that apply to an operationally perfect conventional treatment works also applies to the MBR, only the speed of events occurs three times faster due to the lower hydraulic retention time. The MBR knowledge base is present, but is often overlooked as the technology has been dominated by the MBR suppliers, who, by trial and error, have generated viable marketable products. Many of these products differ from what would be considered as a 'normal' biological solution - the membranes have dictated the configuration rather than the biological configuration dictating where and how the membranes should be utilised.

Most pilots at Beverwijk where designed for a total nitrogen of < 10 mg N/l with a simple biological process, as the knowledge base increased the discharge levels were forced down to < 5 mg N/l and the biological configurations and automation increased in complexity. The step to MTR quality required advanced biological treatment in the form of Racetrack bioreactors, extended plug-flow design, or plug-flow and racetrack in combination; the latter are displayed in the pilots of Varsseveld, Maasbommel and Hilversum respectively. Key similarities of all the pilots are the energy input devices. Where energy is directly put into the sludge via mixing, pumping or aeration, the device is such that the sludge flock structure is least mechanically affected. Low energy input relates to better sludge quality and better sludge characterisation, and ultimately higher alpha-factors and better membrane performance. As the configurations become more complex, the dissolved oxygen profile becomes more critical throughout the biological reactor. This is a major area of R&D and is detrimentally affected by the air input via the membranes.

Membrane cleaning

In the beginning of the research, the cleaning methodology of that time was applied; this allowed the membranes to foul to a certain point before a recovery clean was necessary. This technique was deemed a large risk to full-scale installations, as at the point when the full hydraulic capacity was necessary, for instance during RWF, the fouled membrane capacity would be insufficient to treat the required throughput. This required a new membrane cleaning philosophy. The solution was simple - don't let the membranes foul. For most membrane types, this standpoint yielded a new cleaning methodology based on 'Maintenance Cleaning in Air'.

This MC in Air is carried out once a week or two weeks with considerably less chemicals compared to the classical recovery cleaning techniques. Overall the MC in Air procedures has lead to a more stable process operation. Further optimisation of the procedures at Beverwijk yielded even better results with intermittent MC in Air back flushing with warm water/permeate, by some 10 to 15°C above the normal process temperature.

The year 2002 also saw the beginning of advanced automation of several pilots, both for the membranes and the process control, the latter was in foresight of larger practical installations. The dynamics of the MBR system varies tremendously from that of a conventional installation and little was known about the performance of high-tech measurement devices in the higher sludge concentrations. In co-operation with Endress+Hauser, Dr. Lange and Danfoss various measurement devices were tested for reliability, reproducibility and accuracy and numerous processes were automated.

The new membrane tank at Hilversum (photo: Solis).

MBR Hilversum

At the Hilversum STP, an MBR pilot was envisaged to help the design process for the full-scale installation Hilversum, and several goals were specified. Firstly, to see if the pilot could generate knowledge directly related to an improved full-scale design, to establish if the required effluent discharge criteria of MTR for nitrogen and phosphorus could be achieved and to give an idea of the chemicals needed, and finally, to gain the practical experience of running an MBR for at that time an unknown technique within DWR.

In essence the pilot system is as follows. A Huber pretreatment on raw influent via a 0.5 mm fine screen, a plug flow biology and a sludge water separation via a separate Kubota membrane filtration tank. The company Solis supplied the membrane system with 150 flat sheets with a surface area of 0.8 m^2 and a maximum RWF of 5 m^3/h.

The pilot installation was commissioned in November 2002 and is expected to remain in operation on location WWTP Hilversum until July 2007. Unfortunately, start-up problems forced a rebuild in 2003, and by the end of 2004 the system had undergone further rebuilds to optimize to smaller membrane tanks. The coming months will see changes in the cleaning of the fine-screens and a methanol dosing system will be installed. Eventually, a small man-made lake will be installed after the system to further investigate the effects of permeate on surface waters, in relation to algae growth and ground water infiltration characteristics.

Reflecting on the results so far, a number of items spring out. The pretreatment with fine screens is most problematic. Blockage through fat, hair and toilet paper causes the necessity for intensive and frequent cleaning. The future design takes into account these factors and is foreseen with hot water and high pressure cleaning facilities. An interesting fact is that the screenings (paper), makes up approximately 25% of the sludge production that can be further dewatered to some 35% DS.

The achievement of MTR quality effluent (TN < 2.2 mg N/l and TP < 0.15 mg P/l) is not easy, even with sodium acetate dosing the discharge criteria remained difficult. At the same time it was seen that due to the release of biologically bound P in the post denitrification it was not possible to achieve the P discharge criteria, but is believed with the future use of methanol as C-source for denitrification the P release shall no longer occur. A complicated factor for MTR discharge is the presences of humic acid in permeate and the relevant bound phosphorus and nitrogen. For this reason alone is the MTR discharge criterion almost impossible to reach.

One item that stood out was the effortless functionality of the Kubota membrane system, this has built up trust within the DWR organisation for membranes and has increased the knowledge of the operational aspects of membrane technology.

The sludge production of the pilot installation, including the 'paper production' was much lower than in conventional systems. It is believed that due to the relatively large membrane tank with continuous aeration, mineralisation of the sludge occurred. The reduction in the membrane tank size from 12 m^3 to 3 m^3 at the end of 2004 confirmed this observation. The sludge production without chemical addition rose considerably and proved advantageous for the phosphorus removal and for the formation of humic acid.

Through the decrease in size of the membrane tank the Kubota principle of circulation of sludge in the membrane tank has been abandoned. Sludge and air, required for the dynamic scouring of the membrane however, remains turbulent as in the old situation.

MBR Maasbommel

In 2002 the Water Board Rivierenland, together with Royal Haskoning and STOWA, started a two-year research project concerning the applicability of MBR and continuous sand filtration for the treatment of municipal wastewater[4)].

On the wastewater treatment plant Maasbommel, a MBR with an organic loading of 650 p.e. (136 g TOD) and a hydraulic capacity of 20 m^3/h was operated parallel to the existing WWTP. Two full-scale continuous sand filters were installed downstream of the secondary clarifiers to polish the effluent of the existing WWTP at a total hydraulic capacity of 120 m^3/h. The performance of the two alternatives was compared on the following aspects.

MTR quality

The results of the research project concluded that for both configurations it was difficult to comply with the yearly average MTR effluent standards for nitrogen and phosphate[5)]. During conditions of RWF, the contact time of the MBR was reduced and process conditions deteriorated (especially for denitrification). As for the removal of heavy metals, compared to conventional treatment both configurations displayed no advantage.

The same applied to the removal of herbicides and pesticides. For the purpose of desinfection (as determined using the bacterial level and *E. coli*) performance of the MBR was superior. Based on the chemical analyses of several endocrine disruptors, the conventional system with sand filters and the MBR yielded comparable effluent qualities. Both systems achieved removal efficiencies of 95% for bisfenol A, estron and ß-oestradiol. The oestrogene potential of the effluent (determined using a bioassay) was about 60% lower for the MBR as compared to the sand filter effluent.

Performance

Technical process stability was comparable for the two alternatives. Achieving a stable effluent quality for nitrogen and phosphate was easier for the sand filters than for the MBR. Especially under rainwater flow conditions the effluent quality of the sand filters was stable while that of the MBR is more vulnerable to influent flow variations. Optimisation of the process configuration and process control would lead to improvements in this respect. When membrane cleaning was completely automated, required operator attention was equal for both configurations. Another problematic aspect was the process measurement and control in low concentration ranges around the MTR effluent standards. Current instrumentation is too inaccurate in these ranges to be reliably used as input for process control. For future design purposes this will require additional attention.

Epilogue

Looking back at the last five years we must assess our current position and consolidate the knowledge we have acquired. 'MBR Beverwijk' as a trigger still lingers on in the thoughts of many foreign and domestic end users, and the Dutch contribution to the successful

Module types of Kubota, Mitsubishi, X-Flow and Zenon.

development of the MBR-technology has been widely recognised and applauded.

The MBR hype associated with Beverwijk has found a solid form in the realisation of the demonstration plant MBR Varsseveld; many aspects of numerous Beverwijk pilots have been combined into this demonstration system. The possibility to interchange membranes has been addressed, removal of cassettes has been eliminated, cleaning procedures have been made totally flexible and integrated, the biological system has been fine tuned to the membrane configuration, and the pre-treatment has been exhaustive and final in the removal of unwanted debris able to hinder the performance of the membranes. Understandably, all these items are being addressed in the research and development programme.

At the time of writing this article MBR Varsseveld has been in operation for some four months. Already the fruits of the MBR Beverwijk experience are being harvested: the flexibility in the chemical cleaning procedure was essential as the wastewater feed from Varsseveld contains substantially more fat than at Beverwijk, the biological configuration is already yielding MTR values for total nitrogen, and total phosphorus will follow. The pre-treatment has been intensively tested to yield better quality influent suitable for the membranes, here, off the shelf technologies have proved inadequate and the devices have required serious modification to achieve a debris free feed stream. The membranes have been made maintenance friendly with easy inspection and overall accessibility.

From the pilot research project described in this article, much knowledge has been gained. Knowledge however, only becomes 'real' once it has been proven under various conditions, on several systems, and lastly has been scaled up to a viable full-scale installation. The lessons of the first phase experiences will have to be tested in full-scale, with Varsseveld the next phase has been entered. ¶

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Samenvatting

Het MBR-onderzoek dat sinds 2000 plaatsvond op de rioolwaterzuivering Beverwijk, heeft tot positieve inzichten geleid over de toepasbaarheid van de MBR-technologie voor het Nederlandse afvalwater. Het onderzoek stimuleerde de ontwikkeling van de MBR-technologie wereldwijd. Het onderzoek leidde bovendien tot fundamentele wijzigingen in de procesvoering van een mebraanbioreactor, in het bijzonder op het gebied van chemische reiniging en procesbesturing en automatisering. In 2002 zijn pilotonderzoeken gestart op de rioolwaterzuiveringen Hilversum en Maasbommel. Hierbij was de aandacht met name gericht op de haalbaarheid van de MTR-norm voor het effluent. Met het onderzoek op de rwzi's van Beverwijk, Hilversum en Maasbommel is hiermee de eerste fase van de ontwikkeling van de membraanbioreactor in Nederland afgerond.






Dutch MBR grows to maturity

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Coert Petri, Water board Rijn en IJssel
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The MBR development in the Netherlands enters the next phase after five years of pilot investigation. MBRs will be constructed at three wastewater treatment plants. The first, in Varsseveld, treats the total influent flow of this town, and has been in operation since December 2004. The MBRs in Ootmarsum and Heenvliet will be hybrid systems that are integrated into the existing conventional treatment plants. At all three plants the effluent quality is a major criterion. Extensive research programmes, under supervision of STOWA, will shed light on the scale up effects, the achievable effluent quality and the operational aspects of MBR. The three water boards involved have chosen for three fundamentally different membrane types (hollow fibre, flat sheets and tubular membranes) that maintains open MBR development in all directions. After the first phase of Beverwijk, Hilversum and Maasbommel, during which all aspects of the membrane and their interactions were investigated, the Dutch MBR has now grown to maturity.

After five years of pilot research at different locations in the Netherlands, the second phase of MBR development has begun. This second phase projection of three demonstration installations shall shed light on the technical aspects of the scale up and on the achievable effluent quality of MBR plants. The first operational years of all three MBRs shall be dedicated to broad based research programmes, which will address all aspects of the MBR technique: pretreatment, biological treatment, and membrane filtration. The projects are supported by STOWA via the innovation fund. Through these demonstration installations and the research programmes, much knowledge and experience will be gathered which can be relayed to future systems with larger capacities. The first demonstration installation was started up at the end of 2004 at Varsseveld WWTP. The Varsseveld MBR is a full-scale application in which all wastewater is treated with this new technology. Two other demonstration plants, at Ootmarsum WWTP and Heenvliet WWTP, will start up in 2006, and will be hybrid installations where the MBR is integrated in a conventional activated sludge system.

Table 1: Effluent requirements and targets.

parameter	unit	Varsseveld[3] required	Varsseveld[3] target	Ootmarsum required	Ootmarsum target	Heenvliet required	Heenvliet target
year	-	2015		2005	2018	2006	2010
season*	-	S	W	S W	A	S W	S W
BOD_5	mg/l	10		5	2	-	-
NH_4-N	mg/l	-		1 2	0.8	1 -	1 -
N_{total}	mg/l	10	5	10	4	5	2.2
P_{total}	mg/l	1	0.15	1	0.15	0.3	0.15
SS	mg/l	10	5	5	2	-	-
E-coli	-/ml	-		-	-	20	20
ecology	-	-		-	+	-	-

* S = summer, W = winter, A = all year

MBR technology has great potential in the Netherlands, where almost all wastewater treatment plants are activated sludge based, where space is often limited and where the quality of the local surface waters must be improved. The latter was confirmed through an MBR market research programme commissioned via STOWA[1]. The most important driver for the applicability of the MBR technology was the effluent quality. In regard to the effluent guidelines with respect to nitrogen en phosphorus, the treatment efficiency for these substances is an important research item. The effluent requirements for the three MBRs are listed in table 1.

The results of a STOWA pilot research project at Maasbommel WWTP [2] showed that a stable MTR quality (N_{total} < 2.2 mg/l, P_{total} < 0.15 mg/l) is difficult to achieve, with both MBR and effluent filtration. The full-scale research at the demonstration plants will give more insight in the effluent quality that can be actually achieved.

Membrane type

In the past decade the number of membrane suppliers and membrane types has increased drastically. As a result of this, the competition between the membrane suppliers is tough. Each membrane type has its own specific characteristics, which may or may not be beneficial for the application in municipal wastewater treatment. For the future of MBR the competition is good as it inspires the membrane suppliers to produce the best membranes at the lowest costs. In other countries it is shown that if one supplier controls the market, like Kubota in England and Zenon in Germany, prices remain high and the market penetration of MBR remains limited. In the Netherlands this situation does not occur as three water boards have selected three fundamentally different membrane types (hollow fibres, flat sheets and tubes), as shown in table 2. In this way experience will be gained with all types of membranes, and all paths for future development remain open.

Compared to other countries, the applied design fluxes are relatively high. In Germany the advised net flux rate is approximately 25 $l/(m^2.h)$. The higher flux rates in the Netherlands are based on the positive experiences of the pilot research. As the

RWF/DWF ratio is relatively high, the average flux rate of the membranes is much lower.

Complete versus hybrid MBR

The MBR at the Varsseveld WWTP is a complete system, in which the existing conventional WWTP is taken out of operation and all the wastewater is treated in the MBR. In general, the complete MBR configuration will be applied in the case of very strict effluent criteria, for instance at the Hilversum WWTP, or at locations where space is limited or valuable. Based on the current projects and the results of the STOWA market research, it is expected that in most cases MBR will be applied for the extension of existing treatment plants. In such cases the application of a hybrid configuration is a serious option. In a hybrid configuration the MBR is connected parallel to or even in series (DWF) with the existing conventional WWTP. The hydraulic capacity of the MBR is limited, during DWF all (Heenvliet) or most of (Ootmarsum) the wastewater is treated in the MBR. During RWF the surplus of rainwater is treated in the conventional activated sludge system with secondary clarification. In this manner the required membrane surface can be reduced compared to a complete MBR installation and the membranes can be continuously used at an optimum level. The costs of such a hybrid installation can be lower whereas the effluent will have the desired quality to comply with the guidelines, most of the time.

The hybrid MBR system can be applied in several configurations but none of them have been tested so far. For two locations, Heenvliet (Water Board Hollandse Delta) and Ootmarsum (Water Board Regge en Dinkel), the hybrid configuration has been chosen as the best solution. In 2005 the construction of both installations will commence and in the design and research phase, a close corporation between both water boards has been established which will lead to better design considerations and optimal performance. The hybrid MBR plant at Heenvliet and Ootmarsum will, just like the Varsseveld MBR, be a role model for the Dutch MBR development. The two installations will have to prove the applicability of the hybrid concept for the Dutch circumstances.

parameter	unit	Varsseveld[4)]	Ootmarsum	Heenvliet
type	-	complete	hybrid	hybrid
biological capacity MBR	p.e.	23,150	7,000	3,300
average daily flow MBR	m^3/d	5,000	1,400	2,400
maximum flow at RWF	m^3/h	755	150	100
average flow at DWF	m^3/h	250-300	75	50-100
membrane type	-	hollow fibre	tubular	flat sheet
membrane supplier	-	Zenon	Norit/X-Flow	Toray/SKG
product specification	-	ZW500d	LPCF	unibrane
pore size	µ m	0.035	0.03	0.08
design net flux at RWF	$l/(m^2.h)$	37.5	54	24.3
maximum net flux at RWF	$l/(m^2.h)$	50	54	45
average net flux at DWF	$l/(m^2.h)$	12-15	26-40	12.2-24.3
membrane surface installed	m^2	20,160	2,784	4,110
number of lanes	-	4	6	2

Table 2: Membrane type and design specifications.

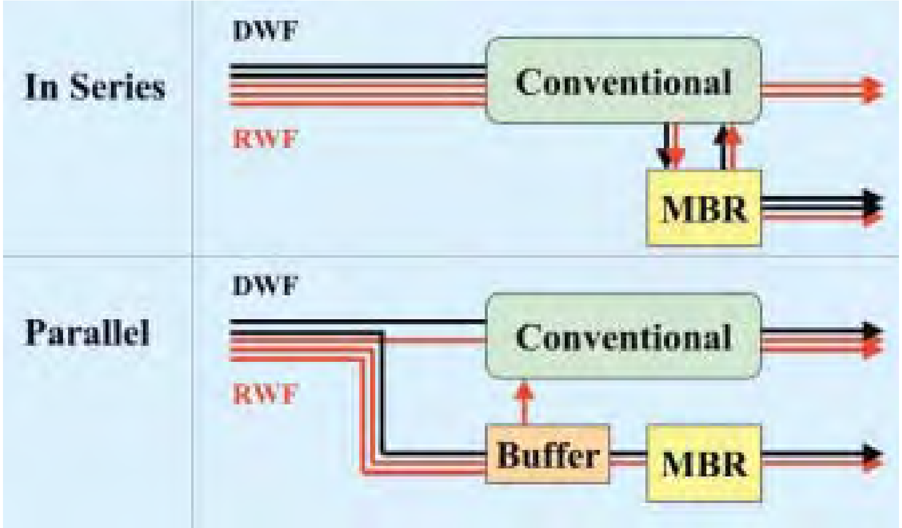

Figure 1: Two hybrid configurations during dry weather flow and storm weather flow.

Two different ways of operation of the Hybrid MBR are possible (figure 1);

- Parallel hybrid operation, the influent is always distributed over both systems. The distribution ratio and the sludge loading of both systems can vary, depending on the flow conditions. At Ootmarsum a buffer tank is used to split the hydraulic and biological loading during RWF. At Heenvliet the conditions are equal during parallel operation, which enables a direct comparison between the performance of the conventional system and the MBR;
- In series hybrid configuration, the preferred option at Heenvliet. The membrane filtration step can be optimised without the risk of overloading the conventional plant during storm weather. This provides the opportunity to upgrade the plant with a minimum loss of overall effluent quality.

Research

For a successful introduction of MBR in the Netherlands, and to improve the knowledge and performance of MBR systems in different configurations and set-ups, the technical aspects of scale up are of great importance. Initiated by the STOWA innovation fund, the start-up and operation of the three MBRs will be accompanied by extensive research programmes. Also Europe supports the Dutch MBR research activities. For the Varsseveld project, a subsidy is received from the LIFE programme. For the Heenvliet project the European commission is requested for a subsidy for the EUROMBRA research programme as a specific targeted research project (STREP). The Ootmarsum project is subsidised by the European Interreg IIIb-programme (UWC project).

MBR Varsseveld

The main goals of the research programme at the Varsseveld MBR are to demonstrate the technical feasibility of the MBR scale-up and to evaluate the design. The following study items were selected:

- pretreatment: effectiveness and redundancy
- general aspects: overall performance and operational requirements
- MTR effluent quality: heavy metals, micro pollutants, hormones and hygienic quality
- oxygen input and hydraulics of both the

aeration tank and the membrane tanks
- sludge quality, its relation with the influent characteristics and its effect on the membrane performance
- process control: an evaluation and optimisation based on dynamic simulation
- membrane filtration: optimisation of the operation and cleaning.

For each study item a separate project team has been formed, in which, besides WRIJ, STOWA and DHV, some of the top research institutes in the Netherlands participate, which are TNO, Wetsus, Delft University of Technology and BRCC.

Pilot plant

The worldwide experience with the MBR technology has shown that the use of a pilot plant can significantly speed up and simplify the start-up of a full-scale MBR installation. It was therefore decided that a pilotplant should be installed at the Varsseveld WWTP before and during the startup period of this plant. The pilot plant is a reflection of the full-scale installation, with a scaling down factor of approximately 200. The most important advantage of the pilot plant was the fact that the operating software was a copy of that from the full-scale installation. This meant that all software problems and other control items were dealt with in the pilot plant. The pilot plant was commissioned in May 2004, and until the startup of the full-scale plant the operators MBR knowledge and skills were refreshed and deepened. This improved the start up and minimized the risk of mismanagement of the full-scale plant[5]. Besides that, the use of the pilot plant increased the efficiency of the research

The symmetric membrane tank concept requires an inflow pipe (bottom right) and an outflow gutter (top left) over the full tank length.

activities, especially regarding the membrane operation and cleaning.

Energy savings

Membrane development occurs quickly and new module configurations are designed with energy consumption in mind. More surface area is built into a smaller footprint and the modules can be sequentially aerated. Larger systems, like Varsseveld, contain multiple trains. In the train that is not required for operation the air can be drastically reduced and actually stopped for long periods of time. All these options are being tested intensively in the pilot plant and the full-scale installation at Varsseveld. From the pilot plant tests it can be concluded that the aeration capacity in the membrane tank can, under specific circumstances, be reduced by 40%. The research on energy savings will be continued in the full-scale plant and will focus on the membrane aeration in both process and relaxation mode.

Membrane tank symmetry

An important design aspect of the Varsseveld MBR is associated with the typical Dutch condition of much rain that is transported in the sewers, here, the maximum hydraulic loading of the MBR is some three times larger than the average flow. The design net flux of the membranes is 37.5 l/(m².h) at maximum influent flow. To be able to maintain a good functionality of the membranes it is important to achieve symmetrical loading of the membranes. Therefore special attention has been given towards the design of the sludge supply and discharge to and from the membranes. The performance of this 'symmetric' membrane tank design will be investigated in more detail and will include the following items:
- the hydraulic profile in the membrane tank,
- the distribution of the cleaning chemicals in the membrane tanks, modules and cassettes,
- the filtration balance: the permeability variations in all membrane modules in time,
- the oxygen input in the membrane tank under different circumstances.

MBR Ootmarsum

The Ootmarsum MBR is a hybrid configuration that can be operated in parallel mode, as illustrated in figure 1. The existing conventional activated sludge system will be low-loaded and extended with a sand filtration step to improve the effluent quality. The effluent of both plants will be discharged via an ecological filter system. The typical design feature of the whole system is that the flow is distributed in different proportions under DWF and RWF conditions and that an influent buffer tank is used to equalize the biological loading of both systems. At RWF the buffer tank will be working as sort of primary clarifier of which the overflow is treated in the conventional system and the underflow in the MBR. Due to this configuration, special attention will be required for the large hydraulic variations on the conventional system.

The ecological filter (or ecological activation system) uses water and marsh plants as an environment in which an aquatic ecosystem will develop (with zooplankton, phytoplankton, macro fauna, fish, birds, amphibians and insects). This should transform the 'sterile' effluent into 'living' water with equal characteristics as the receiving surface water.

The main objective of the research programme is to gain practical experience with, and optimise the operation of, the hybrid MBR system. The achievement of the MBR system will be compared with the conventional system with sand filtration. After startup when the plant is in stable operation, the following research objectives are defined:
- comparison of the effluent quality of both systems,
- investigation of the synergy effects between the sand filtration, the MBR and the 'ecological filter', to achieve an optimal overall performance,
- the development of a universal operational concept for the (hybrid) MBR,
- monitoring the effect of the ecological filter, as switch between the WWTP and the receiving water.

The Water Board Regge en Dinkel and Norit Process Technology, the membrane supplier for Ootmarsum, intend to carry out a pilot research programme, prior to the startup of the full-scale plant. The main goals are to speed up, simplify and improve the startup procedure of the plant, especially regarding the control system.

MBR Heenvliet

The Heenvliet MBR is a hybrid configuration that can be operated both in series and parallel mode, as illustrated in figure 1. The pretreatment of the MBR is a 3 mm micro screen with perforated holes. It is possible to adjust this 2 mm, if necessary. The design philosophy was to keep it simple but flexible.

The Heenvliet MBR research programme will focus on the achievable effluent quality for the MBR as a sole technology as well as in series Hybrid MBR operation. Besides that, the operational aspects (process stability and maintenance), the minimisation of operational cost and the maximum achievable flux will be investigated. Because of the unique activated sludge configuration during the in series Hybrid MBR operation special attention will be given to sludge filtration characteristics and sludge morphology.

A three-year research programme is foreseen;
- first year, parallel, non-hybrid configuration: to compare the effluent quality of the conventional plant and the MBR;
- second year, in series configuration: to investigate the feasibility of this system;
- third year: parallel, non-hybrid configuration: the load of the MBR as a sole technology will be reduced in order to achieve effluent concentrations as low as possible, with MTR values as target.

Epilogue

The development of MBR technology in the Netherlands has reached a crucial stage. After a decade of laboratory and pilot research the first full-scale installations are coming into being. In the coming years the essential experience and required knowledge to judge the MBR on its merits, will be acquired. The Varsseveld MBR will have to demonstrate the feasibility of the scaling up of the application under typical Dutch flow conditions. The hybrid MBR configuration is an obvious extension to the Beverwijk research programme and the Varsseveld demonstration plant. The Heenvliet and Ootmarsum MBRs will have to show that MBR can be a serious alternative for the extension of WWTP's where effluent quality has priority and one seeks an optimum between costs and performance.

The research programmes are essential for the MBR development and are supported and supervised by STOWA and numerous Water Boards. The national co-operation, supervised by the STOWA, leads to an increased nestling and acceptation of this new technology. Learning by doing, and learning from each other is the basis of success.

With the Hilversum MBR, the third phase will already be entered in the very near future. This installation is characterized by its universal membrane tank design, in which all available membrane types can be applied. The second phase of MBR development supplies the required experience on all types available; hollow fibres, flat sheets and tubular membranes. The Dutch MBR development strategy works out well and promises a prosperous future for the MBR.

The Water board Regge & Dinkel visits Beverwijk to compare the hollow fibre, flat sheet and tubular membranes.

Samenvatting

De MBR-ontwikkeling in Nederland is na vijf jaar pilotonderzoek toe aan de volgende fase. Op drie rioolwaterzuiveringsinstallaties worden MBR-installaties gebouwd. De eerste installatie, in Varsseveld, behandelt de gehele influentstroom en is sinds december 2004 in bedrijf. De MBRs in Ootmarsum en Heenvliet zullen als hybride systemen, geïntegreerd in de bestaande conventionele installatie, worden uitgevoerd. Bij alledrie de installaties is de effluentkwaliteit een belangrijk criterium. Uitgebreide onderzoeksprogramma's, onder supervisie van de STOWA, zullen de komende jaren meer inzicht moeten geven in de opschalingeffecten, de haalbare effluentkwaliteit en de operationele aspecten van MBR. De drie betrokken waterschappen hebben gekozen voor drie principieel verschillende membraantypen (holle vezels, plaat- en buismembranen) waardoor de MBR-ontwikkeling in Nederland in de volle breedte wordt voortgezet. Na de eerste stappen door Beverwijk, Hilversum en Maasbommel, waarbij alle aspecten van het membraan en zijn omgeving zijn verkend, wordt de MBR in Nederland volwassen.

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ZENON wil Waterschap Rijn en IJssel hierbij graag feliciteren met de succesvolle opstart van het MBR demonstratieproject in Varsseveld

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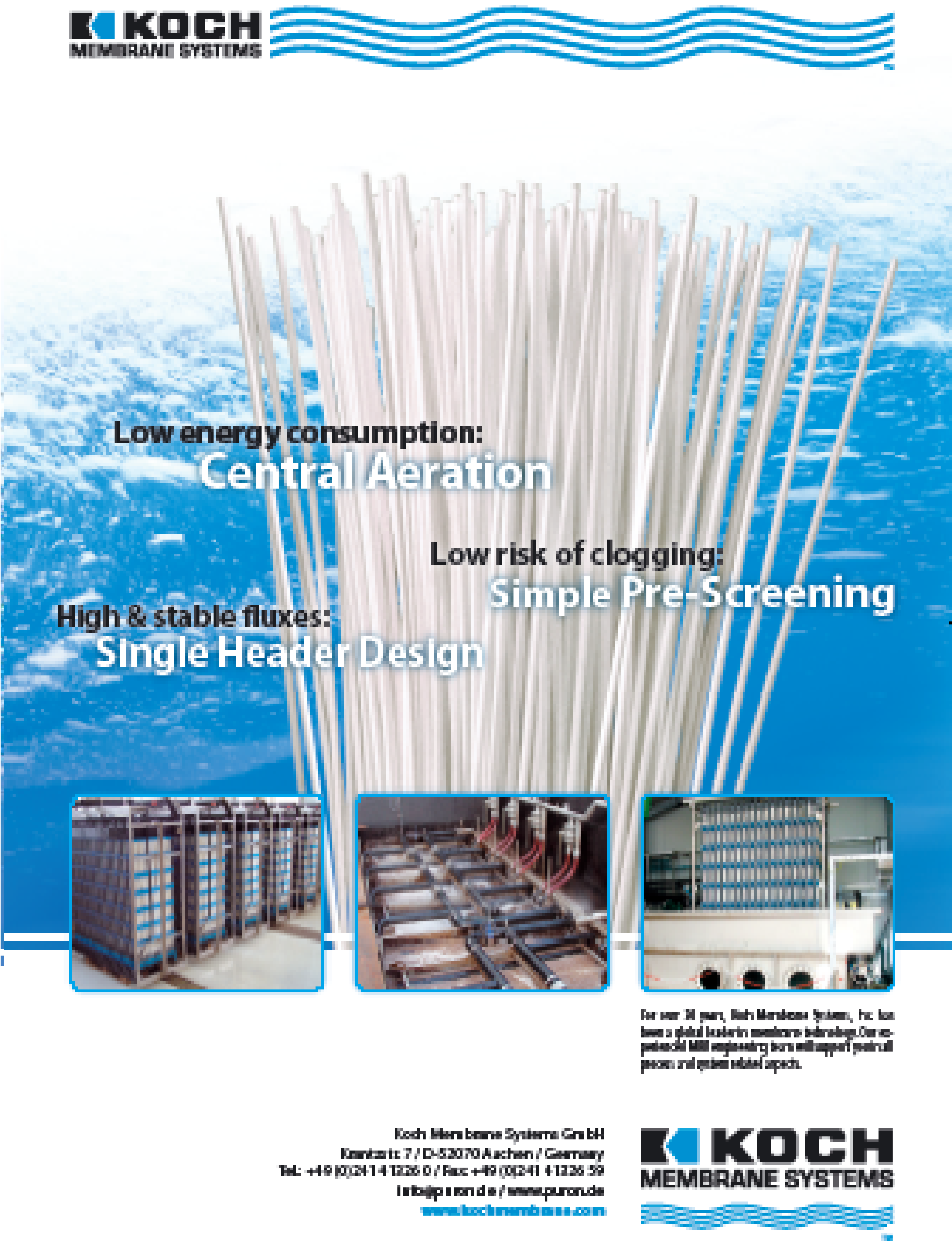
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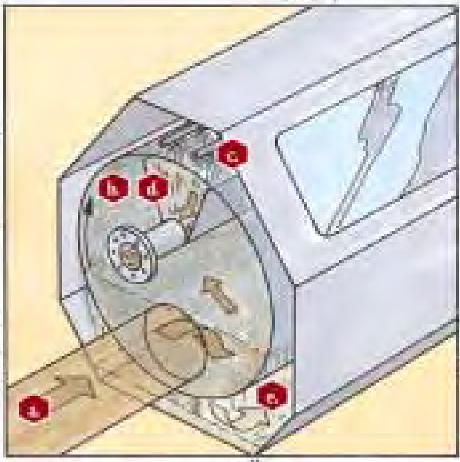
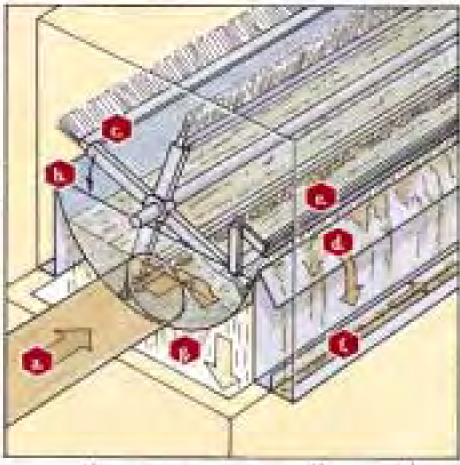
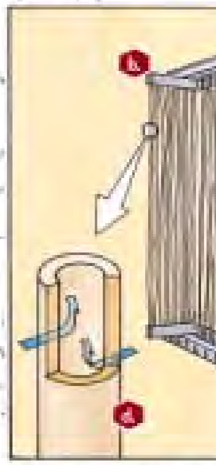


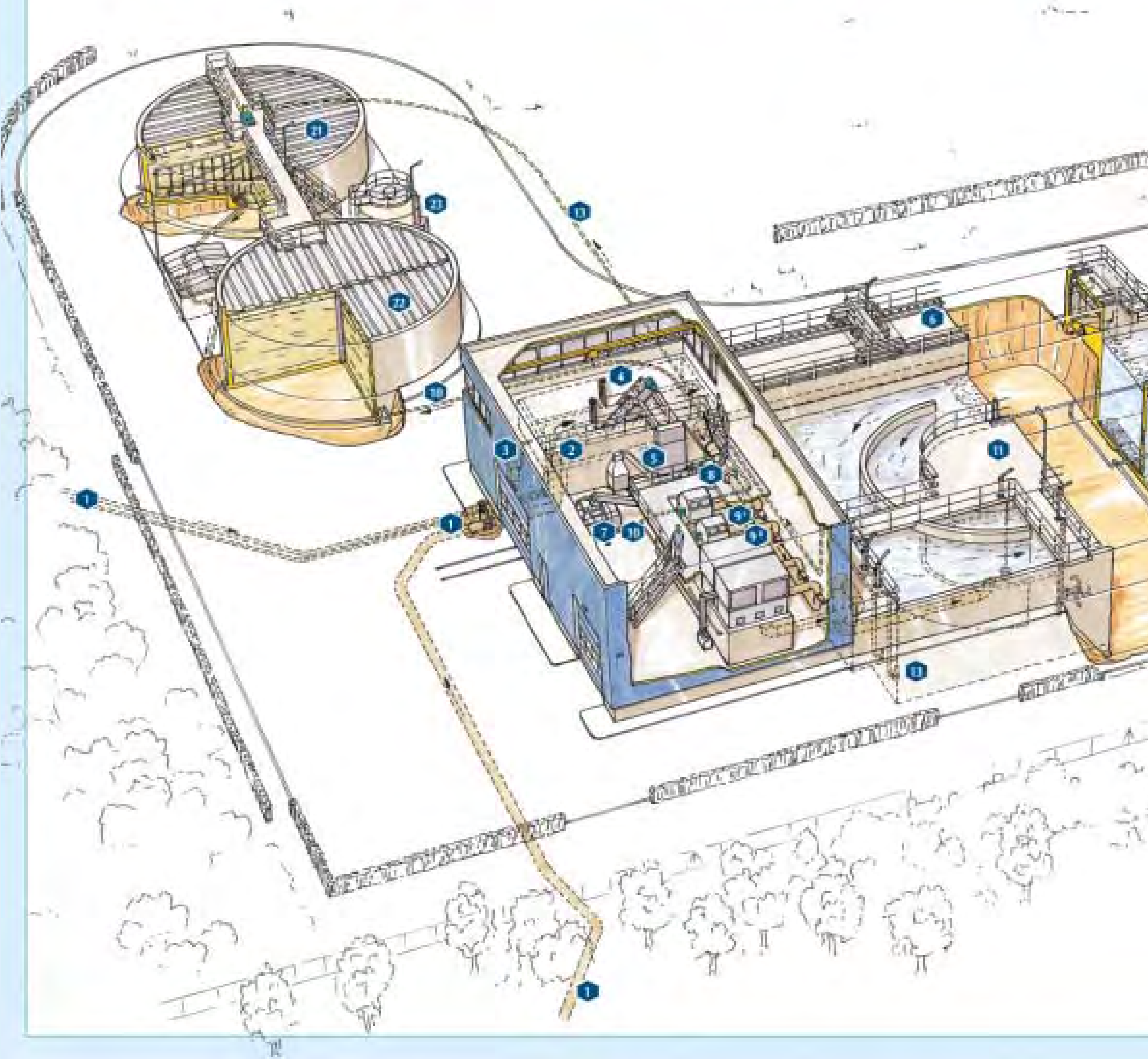
Detail 9' **MICROSIEVE TYPE I**



Detail 9'' **MICROSIEVE TYPE II**



Detail 15 **MEMBR**



VARSSEVELD SEWAGE TREATMENT PLANT
with membrane bioreactor

Waterschap Rijn en IJssel · stowa · DHV · Life

1. Sewage water supply (high-pressure pipes)
2. Sewage water collection
3. Sewage water sampling
4. Extraction of large pieces of refuse
5. Removal of large pieces of refuse
6. Sand and oil trap
7. Sand cleaner and sand removal
8. Water volume monitoring point
9[I]. Microsieve type I
9[II]. Microsieve type II
10. Removal of sieved particles
11. Oxygen-poor section
12. Purification by bacteria with oxygen
13. Removal of excess sludge
14. Membrane supply pump
15. Membrane tanks
16. Pump room
17. Blower room for aeration
18. Purified water inspection point
19. Removal of purified water
20. Plant management building
21. Sludge thickener
22. Sludge storage
23. Iron salt storage tank (for removal of phosphate)
24. Air treatment

DETAIL 9 [I] - MICROSIEVE TYPE I
a. sewage supply
b. rotating microsieve
c. sprayers for cleaning sieve
d. collection/removal of sieved particles
e. collection/removal of sieved water

DETAIL 9 [II] - MICROSIEVE TYPE II
a. sewage supply
b. stationary sieve
c. rotating sieve cleaning brushes
d. sieved particles overflow
e. brush cleaning scraper
f. collection/removal of sieved particles
g. collection/removal of sieved water

DETAIL 15 - MEMBRANES
a. frame with membrane modules
b. subframe with discharge channel for purified water
c. collection pipe
d. detail of membrane fiber

START OF SECOND PHASE DEVELOPMENT PROGRAMME

MBR Varsseveld, first Dutch full scale experience

The first Dutch full scale MBR for municipal wastewater is now operational, supported by all Dutch water boards, STOWA and financial contributions from the European Life programme and Dutch Ministries. The first results indicate that an excellent permeate quality is reached but that special attention is required to maintain the membrane permeability at a constant high level. An intensive research programme, including pilot plant studies, has been carried out from May 2004 and will continue until December 2005.

Water board Rijn en IJssel (WRIJ) had to upgrade Varsseveld STP due to more stringent effluent requirements, to expand the biological capacity, to reduce odour and noise emissions and for a complete revision of the technical installation.

Improving the effluent quality was necessary as Varsseveld STP discharges to a very small vulnerable waterway called the Boven Slinge, which serves as a regional ecological stepping stone. Before the MBR option was selected, WRIJ considered to upgrade the STP in a conventional way, with continuous floc filtration in sand filters as a final treatment step. WRIJ recently upgraded two comparable STP's with this post-treatment step and obtained good results.

In 2000, the co-operation within the Dutch wastewater sector regarding MBR development started and it soon was evident that the location, size and situation at Varsseveld were perfect for a first full scale demonstration plant using MBR for municipal wastewater treatment. The MBR Varsseveld was commissioned at the end of 2004 and has been fully operational since January 2005.

The MBR Varsseveld has been designed by DHV Water BV in co-operation with WRIJ and Zenon. The design loading of the Varsseveld MBR amounts to 23,150 p.e. (1 p.e. = 54 g BOD/day) and 755 m^3/h. The design and engineering aspects of the Varsseveld MBR have been described in the second edition of the H_2O MBR special in April 2003.

The pages 48-49 of this MBR edition shows an artist view of the MBR Varsseveld, including some details of the micro-screens and the membranes. This artist view gives a good impression of the main installation parts of this MBR.

Pilot plant research

The worldwide experience with the MBR technology has shown that the use of a pilot plant can significantly speed up and simplify the start-up of a full-scale MBR installation. It was therefore decided to install a pilot-plant at the Varsseveld STP before and during the start-up period of the plant. The pilot plant is a reflection of the full-scale installation, with a scaling down factor of approximately 200. The pilot plant was commissioned in May 2004. The tests offered great value on the chemical membrane cleaning, the potential for reduction in energy consumption and the optimisation of the process operation and start-up.

Effluent concentrations of 2.2 mg N_{total}/l and 0.15 mg P_{total}/l have been accomplished for several weeks. The so called MTR (maximum tolerable risk) concentration in surface water was reached. This is very important in view of the emerge of more stringent European legislation (EU Directive Water) coming up, requiring substantial improvements of the effluent quality by 2015.

A cleaning procedure including NaOH and temperatures of 35-40°C turned out to be more effective than with hydrogen peroxide. The full-scale MBR has been refitted to cope with the dosing of NaOH, in addition to other cleaning chemicals.

The testing of the full-scale software in the pilot plant proved to be very useful. Almost all software bugs have been tackled during the studies with the pilot plant, lowering the risks during operation of the full scale plant. Another main advantage was the training of the WRIJ personnel and researchers during use of the pilot plant, for optimal preparation for working with the full scale MBR. The filtration unit of the pilot plant has now been connected to the full scale biology, offering possibilities to perform tests with the pilot membranes before 'jeopardizing' the full-scale membranes.

The Boven Slinge.

Startup

The startup of the full scale MBR was relatively prosperous (H_2O 38 (2005), no. 5, pp 27-29). In about a month time the sludge concentration grew from 2.4 to 10 kg mlss/m³ and after this month the full hydraulic load could be handled in the MBR. Scum or foam did not appear during startup.

Pretreatment

The pretreatment in a MBR is considered to be very important to avoid damage to the membrances induced by hair, fat, sand and other physical pollutions. By-passing the pre-treatment, for instance during maintenance, is not acceptable. It was therefore decided to double the installed capacity of the bar screens and the micro-screens.

There are two types of 0.8 mm micro-screens, due to the European tendering and the demonstration character of the plant. One type is a fixed 'half drum' with rotating sieve cleaning brushes. The other type is a rotating drum with sprayers for sieve cleaning. It was necessary to adapt the spraying system for the rotating drum micro-screens, therefore some sprayers are placed now directly within the gutters. Both types of micro-screens show a complete removal of hairs, but were not consistently capable to handle rapid changes from dry weather flow (DWF) to rain weather flow (RWF). These problems are probably caused by material that settles down in the mains during low flow periods. To cope with this problem all the micro-screens can work in parallel (at double capacity) during about 10 minutes at the start of RWF.

Table 1: Average concentrations MBR Varsseveld from 1 February until 31 March 2005.

parameter	influent mg/l	permeate mg/l	efficiency %
COD	950	26	97
NH_4-N	29	0,5	-
NO_3-N	-	1,8	-
N_{total}	67	3,0	96
P_{total}	17	3,3	81

Membrane compartment feed/recirculation pumps.

Figure 1: Development of MBR permeability over time.

Biological treatment

Although the MBR was started up in a relatively cold period (average water temperature of 12°C), nitrification was complete from the start. The permeate ammonia concentration mostly is about 0.1 mg NH_4-N/l. After one month the sludge concentration reached the design value of 10 kg MLSS/m³ and the MBR was fully loaded. From that time, also denitrification and biological phosphorus removal rapidly improved. The nitrate concentration in the permeate is about 1-2 mg NO_3-N/l, which means that the overall nitrogen removal is about 96%. The average influent and permeate data are presented in Table 1.

The data shows that the phosphorous permeate concentration still is relatively high, compared to the design value of 0.15 mg/l. Considering the high influent concentration and the fact that until now no iron salt has been dosed, it can be concluded that the biological phosphorous removal capacity is significant. It is expected that the required ferric dosing amount, to reach the required permeate quality, will be relatively low.

The nitrogen removal is stable, although the aeration control was unstable during the first two months due to software and start-up problems. As a consequence, the aeration capacity was insufficient, which had a negative effect on the sludge characteristics. Besides that, there was a rapid temperature decrease in February.

Both factors were responsible for the induction of a scum/foam layer on both the denitrification tank and aeration tank. The specially designed scum/foam collector had to be switched on to avoid that the scum/foam-layer would become too thick.

Membrane filtration

The four parallel membrane tanks are equipped with Zenon ZW500d hollow fibre membranes. Each membrane compartment contains four membrane cassettes, with a membrane surface of 1,260 m² each. The total membrane surface amounts to 20.160 m². The maximum capacity of each membrane tank is 250 m³/h, the biomass recirculation flow into the membrane compartments is supplied by the feed pumps, which have a maximum capacity of 800 m³/h.

Figure 1 displays the permeability trend of one of the membrane compartments. The permeability start value and trend are as expected, until the permeability decreased to a level of about 300 l/(m².h.bar), which started mid February this year.

Mid February, after a rainy period of four days, a membrane guarantee test was executed in one of the compartments. In this membrane compartment the following test procedure was executed:

- 64 hours at a 37.5 l/(m².h) net flux, followed by
- 8 hours at a 50 l/(m².h) net flux.

The 64-hour test obtained satisfactory results, while the 8-hour test resulted in high suction pressures, and had to be interrupted. After this test the membranes were inspected visually. It proved to be of great advantage that the compartments could be drained completely, for the maintenance cleaning in air procedures. Close inspection showed that part of the membranes were sticking together with a slimy/glue-like substance, which was probably caused by a combination of anaerobic sludge conditions and the discharge of polymeric substances by a local industry.

Slimy sludge was also discovered on the compartment walls and the membrane aerator tubes. As the membrane fibres were sticking together, the available membrane surface had decreased dramatically, which resulted in high suction pressures during the peak test. Under normal conditions, the available membranes were working optimally and could process the required flow without problems, at a permeability above 300 l/(m².h.bar). Only at maximum flow conditions, the required suction pressure was near the upper limit, which requires special attention.

Currently, the oxygen control is being improved, and, in co-operation with the local industry, the polymer discharge will be stopped for a specified period. Both options are further investigated, including the cleaning method to cope with the specific fouling. As figure 3 shows, a mild cleaning on April 10 already recovered the permeability up to 350 l/(m².h.bar). After an intensive cleaning of all the membranes and removal of the fouling, the peak capacity test will be repeated.

Operation

During the first months of operation the operators were very busy, which is also the case after commissioning a conventional STP. Nevertheless, starting up and operating a MBR requires special attention, as there are several additional and new installation parts to cope with. The data collection and interpretation requires special attention from the operators. Fortunately, the operators had followed an extensive MBR training in 2001 in Beverwijk, and renewed their knowledge and experience during operation of the pilot plant starting from May 2004.

Costs

The investment costs of the MBR installation were about 11 million euro (table 2), which is about 475 euro per p.e. No parts of the old STP were re-used. The investment and running costs are higher than for a conventional STP. However, the difference with a completely new conventional STP with sand filtration for effluent polishing, is relatively small.

Table 2: Construction costs of the MBR Varsseveld (in euro).

civil parts	2,800,000
mechanical parts	1,700,000
electrotechnical parts	1,100,000
membrane parts*	2,400,000
subtotal	8,000,000
indirect construction costs**	3,000,000
total	11,000,000

* including permeate pumps, piping, and others.

** including engineering, personnel, overhead, taxes and others.

The project is financially supported by the STOWA (Innovation Fund), the European Commission (LIFE subsidy), and by the Dutch Ministry of Economic Affairs. Thanks to those contributions, the additional costs and risks could be covered, and this innovative project could be initiated.

The major running costs are considered to be the additional costs for maintenance, energy and chemicals. However, as mainly standard and quite diluted chemicals (citric acid, NaOH and NaOCl) are used, the costs for the chemicals are limited. The extra energy consumption however is quite large. A 100% increase was expected, and the first measurements seem to confirm this (1,600 MWh/year instead of 800 MWh/year). Therefore, energy saving is a main issue in the further research programme on the pilot and full-scale MBR. The membrane aeration requires approximately 40% of the total energy consumption of the whole plant.

Consequently, large energy savings can be obtained by decreasing the membrane aeration. At low influent flows, two or three membrane compartments are not in operation (no permeate extraction). In this so-called relaxation mode, the aeration capacity of the membranes can be reduced significantly. This could lead to considerable energy savings in the future.

The costs for maintenance will turn out to be somewhat higher than for a conventional STP as the number of mechanical and electrical parts in a MBR is larger. A main uncertainty is the lifetime of the membranes, which of course are still relatively expensive. ¶

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MBR VARSSEVELD

Wat heb ik met het waterschap te maken?

We kunnen ons voorstellen dat u er niet elke dag bij stilstaat, maar toch werken wij ook in uw belang. Met ruim 375 enthousiaste medewerkers verzorgt Waterschap Rijn en IJssel het waterbeheer in Oost-Gelderland, het zuiden van Overijssel en het zuidoosten van de Veluwe. In dit gebied zorgen we voor veilige dijken en kaden, het zuiveren van afvalwater van inwoners en bedrijven, voldoende en kwalitatief goed oppervlaktewater en het bevaarbaar houden van de Oude IJssel. In ons dagelijks werk komen wij in aanraking met de mooie en de minder mooie kanten van water. Te veel of te weinig. Schoon of juist vervuild.

Het is onze taak om te zorgen voor een juiste balans tussen wat de mens wil, wat het water doet en wat nodig is. Daarbij hebben we oog voor de belangen van recreatie, burgers, boeren, bedrijven, natuur en milieu. Om onze doelen te bereiken en waar mogelijk maatwerk te leveren, werken we dan ook samen met andere organisaties en overheden. Want water is nu eenmaal een verantwoordelijkheid van ons allemaal.

Meer weten? Kijk op www.wrij.nl

■ MBR in Nederland is samenwerking met hoofdletters. Als we praten over de MBR bioreactor Varsseveld hebben we het over de STOWA, Waterschap Rijn en IJssel en DHV.
De officiële opening van de installatie Varsseveld op 3 mei 2005 door Kroonprins Willem Alexander, is het sluitstuk van datgene dat de kroonprins en ons als samenwerkende partners aansprak, namelijk een innovatieve opstelling en het delen van kennis.

We spreken de wens uit dat de resultaten van de installatie Varsseveld de opmaat mogen zijn van de opschaling van de MBR-technologie voor grotere installaties. De samenwerking in de Nederlandse afvalwaterbranche moeten we koesteren en benutten, ook voor andere ontwikkelingen binnen het waterbeheer.

Meer weten? Kijk op:
www.mbrvarsseveld.nl

Waterschap Rijn en IJssel

WATERBEHEER: VEILIG EN OP MAAT

DESKUNDIG - KLANTGERICHT - INNOVATIEF - TRANSPARANT

A clean balance between economy, technology and ecology

It's increasingly clearer that economic progress and safeguarding the environment, raw materials and nature go hand in hand. Sustainable development means recycling and dealing carefully with scarce raw materials. Purification technologies are necessary to provide clean water and energy saving, non polluting production and recycling processes.

NORIT The Purification Company has been present in the field of realising purification solutions for more than 80 years. The business group NORIT Pure Solutions offers integrated purification solutions. This business group has developed into a valuable partner for utility companies and the business world in general. We are operating on the basis of standard solutions developed using our in-house know how. NORIT primarily supplies services to the water industry and food and drink producers. Depending on the type of problem various NORIT companies may be involved in a project. With Food & Beverage, our clients can employ the specialist know how provided by Haffmans and the SÜDMO companies. In the Water sector these include NORIT Process Technology, NORIT Membrane Technology, X-Flow and NORIT Activated Carbon.

OPERATIONAL IN 2008, COSTS WILL BE 35,500,000 EURO

Wastewater treatment plant Hilversum: ambition and challenge

Infiltration of effluent of the wastewater treatment plant Hilversum requires almost total removal of nutrients. The level of ambition is high: the wastewater treatment plant must produce effluent of superior quality with MBR technology on a limited area and will have a beautiful architectonic design that fits well in the landscape. The biological treatment is a system of 18 tanks in series; anaerobic, anoxic, aerobic and anoxic respectively. The pilotplant results demonstrated the need to use chemicals to produce low phosphorus and nitrogen concentrations. The design of the membrane tanks is based on the principle of the 'universal' membrane tank.

The existing wastewater treatment plant Hilversum is located in the eastern part of the municipality of Hilversum in an area known as Anna's Hoeve. This area lies about 4 - 5 meters above sea level at the foot of the eastern slopes of the Gooise Heuvelrug. Just across the municipal border in the municipality of Laren a nature reserve is situated. In this nature reserve a number of lakes (Laarder Wasmeren) is present. Originally the area was composed of sandy deposits formed some 300,000 years ago by glaciers.

Nowadays the whole area is strongly influenced by human activities. Being the lowest area and outside the city limits, this area has been used to dump solid waste as well as for discharging wastewater.

The dumping of solid waste started before 1885. Since 1920 - 1930 the solid waste was distributed from a transfer station by a narrow-gauge railway. Nearby an incinerator was in operation for dead animal bodies. Combustible industrial waste and waste from public gardens was incinerated in the open air to reduce the amount of waste to be dumped. Ash has been used for filling up low lying recreational areas nearby. The landfill was closed in 1959 but illegal incineration of industrial waste has been practised longer.

Consequently the soil in Anna's Hoeve is heavily contaminated with heavy metals, PAH etc. The discharge of wastewater started as early as 1875, when an open storage area was constructed. From the storage the wastewater was distributed in the surrounding heath land and infiltrated in the soil. In 1940 the discharge of raw sewage was upgraded by the introduction of trickling filters. As a consequence the Laarder Wasmeren and the subsoil in these areas are heavily polluted with e.g. heavy metals.

The present wastewater treatment plant Hilversum was constructed in 1975 and the effluent is discharged in the Gooyergracht, some 5 km to the North. From there the effluent flows into the Eemmeer and finally into the North Sea. (The photo shows the area in its present state).

Anna's Hoeve, view to the north; the new wastewater treatment plant Hilversum will be located exactly in the centre of the photo, just east of the present plant.

For Anna's Hoeve and Laarder Wasmeren a masterplan was developed. This plan includes as main items:

- Removing of the deposits in the Laarder Wasmeren
- Soil sanitation of large areas of Anna's Hoeve
- Storage of contaminated soils in a new 24 m high hill in Anna's Hoeve
- Realisation of new ponds and ditches
- Building of some 700 houses
- Construction of a new wastewater treatment plant Hilversum.

These different projects are realised by the municipality of Hilversum or the water board Amstel Gooi and Vecht (AGV). Other important stakeholders are the province of Noord-Holland and the owner of the nature reserve Goois Natuur Reservaat. As a result of the limited areas available, the different interests and the strong interactions it took many years to co-operate, but with an integrated design master plan as a result to be proud of.

Wastewater and surface water systems

The present situation is indicated in the upper part of figure 1. About 50% of the sewersystem is combined. Because no surface water is available, all stormwater is stored and discharged after treatment in the wastewater treatment plant. The stormwater from the separated sewersystem is discharged in the local ponds and the Laarder Wasmeren. The effluent of the wastewater treatment plant is discharged with a pipe in the Gooyergracht.

One of the important changes in the future situation is that 2/3 of the effluent of the wastewater treatment plant will be infiltrated in the soil in order to reinforce the natural groundwater flows from the

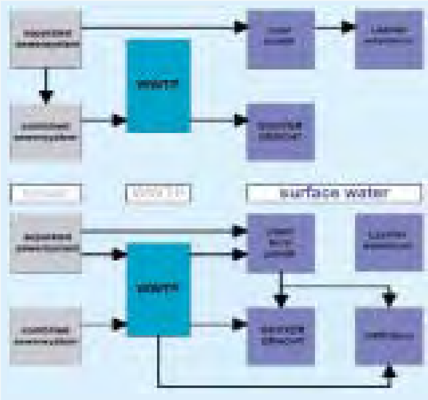


Figure 1: *Sewer system, wastewater treatment plant and surface water at present and in future.*

Gooise Heuvelrug to the west, where some natural lakes suffer from a lack of water. In order to facilitate this reinforcement, the choice was made to apply the best technical means for the wastewater treatment; the effluent standards for nutrients will be as low as 0.15 mg/l total-P and 2.2 mg/l total-N. The wastewater treatment plant is designed as Membrane Bio Reactor (MBR).

In the future situation the system will change as indicated in the lower part of figure 1.

After the cleaning of the Laarder Wasmeren it is no longer allowed to discharge any water in these lakes. New local ponds will be made to replace the storage capacity of the Laarder Wasmeren. Most effluent (2/3) will be discharged to the infiltration area directly by pipe or indirectly via the local pond system. The remaining effluent will be discharged to the Gooyergracht like nowadays. The effluent pipe may be used for discharging the excess stormwater from the local ponds as well. The concentrated wastewater from the separated system will be introduced as a separate flow in the wastewater treatment plant at all times. The other inflow is from the combined sewer and/or the stormwater storage (not indicated in figure 1).

All opportunities to cooperate and to design sewerage, wastewater treatment and the surface water as an integrated system were fully utilized.

Design

The level of ambition is high: the wastewater treatment plant must produce effluent of superior quality with MBR technology on a limited area and have a beautiful architectonic design that fits well in the landscape.

Many aspects of the design result from the knowledge and experience of the pilotplant, in operation since November 2001 and still an indispensable source of knowledge and experience.

Design characteristics MBR Hilversum.

capacity	91,000 p.e.
hydraulic capacity	1,500 m^3/h
DWF (dry weather flow)	450 m^3/h average, 618 m^3/h max
SWF (storm weather flow)	882 m^3/h
effluent quality	P = 0.15 mg/l N = 2.2 mg/l
phosphate removal	biological
F/M ratio	0.044 g BOD/ (kg MLSS.day)
MLSS	7.8 g/l
design temperature	10°C
biological treatment	1 lane concept
biological sludge production	3,000 kg/d solids
sludge treatment	mech. thickening and transport to central facility
redundancy of equipment	based on risk analysis
odour and noise	zero nuisance

The plant will be operational in 2008 and the costs will be 35,500,000 euro.

The separation in the sewer system between the separated and combined system is continued as much as possible in the wastewater treatment plant (Figure 2).

Except for the influentbuffer in the DWF-line both the DWF and SWF lines have the same scheme for pre-treatment: screening (3-4 mm), sand removal and sieving (0.50 - 0.75 mm). The influent buffer in the DWF line has multiple functions: equalize flow and concentration of DWF, reduce flow through aeration tanks and membranes with 11%, removal of floating material and extra anaerobic retention time (assisted by adding some activated sludge).

The DWF line is connected to the anaerobic tank whereas the SWF line bypasses the anaerobic tank and is connected to the predenitrification (Figure 4). This prevents a reduced retention time in the anaerobic tank by the (more diluted) SWF. Moreover the possible introduction of oxygen with stormwater in the anaerobic tank is eliminated.

The biological treatment is a cascade/plugflow system of 18 tanks of about equal size and dimensions in series. The oxygen conditions are anaerobic, anoxic, aerobic and anoxic respectively. The flexibility in the design is demonstrated by the possibility to recycle a low nitrate flow from tank 6 to tank 1 as well as from tank 18 to the anaerobic tank 1. Optional recirculation from tank 18 to 7 results in changing the cascade/plugflow into a recirculation character. Additional flexibility is introduced by the possibility to convert the tanks 5, 6, 13, 14 and 18 into aerated tanks. The pilotplant results showed that it was not possible to produce low P and N concentrations without the use of chemicals. In Figure 3 the use of acetic acid and methanol is indicated, but it is also possible to use ferric chloride and another carbon source e.g. a waste product.

Tank 19 is the last tank ahead of the separate membrane tank. The tank is aerated to prevent EPS to enter the

Figure 2: *Sewersystem and pre-treatment.*

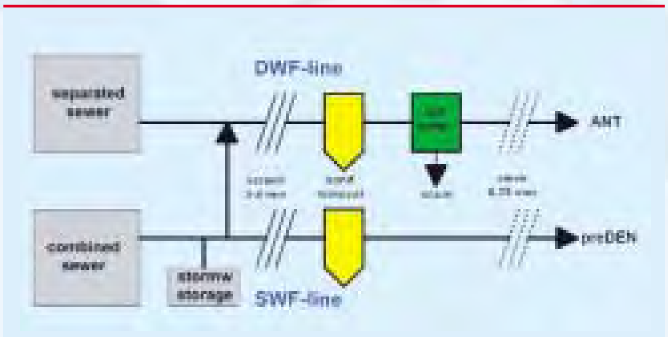
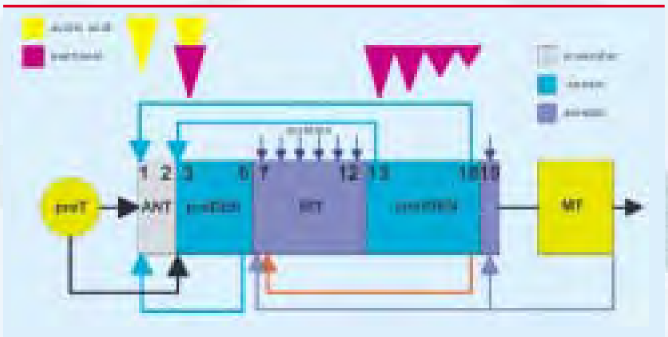


Figure 3: *Biological treatment and membranes. preT = pre-treatment, ANT = anaerobic tank, preDEN = predenitrification, NIT = nitrification, postDEN = postdenitrification, MT = membrane tank.*



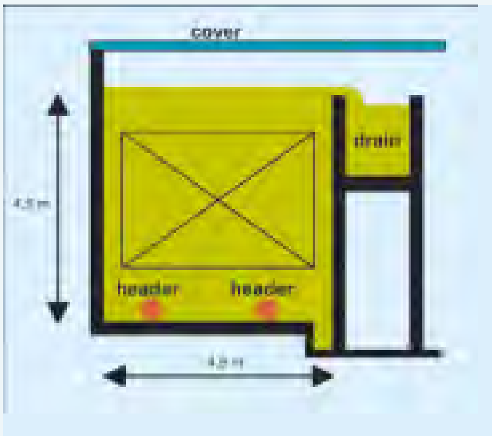


Figure 4: *Cross section of the 'universal' membrane tank.*

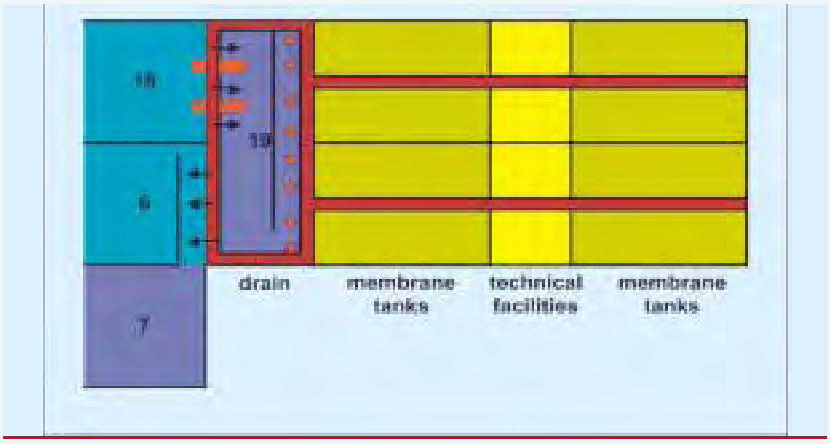


Figure 5: *Layout of membrane tanks.*

membrane tank and also contains the submersible pumps for feeding the membrane tanks. The recycling from the membrane tanks can be divided in any proportion between tank 7 (effect: introducing the oxygen in the nitrification but decreasing the retention time in the tanks 7 - 18) and tank 19 (no effect).

The design of the membrane tanks is based on the principle of the 'universal' membrane tank. This tank can accommodate membrane systems of all major suppliers, submersed and dry systems, eventually with small adjustments ('one size, fits all'). This prevents that dependence on one specific supplier arises during commissioning or in the future, when the membranes have to be replaced. The cross section of the membrane tank is presented in Figure 4. The sludge is distributed in the membrane tank by two headers with a number of restricted openings pointing 45° down.

Figure 5 presents the lay-out of the 8 membrane tanks, the centrally located technical facilities and the drain system for the recycle of activated sludge with the overflow to the tanks 7 and/or 19.

The process control of the wastewater treatment plant Hilversum will reflect the flexibility of the design. This control system will be designed based on a model of the processes of the wastewater treatment plant. The results of the pilot plant will be used for calibration and validation of the process parameters. This enables to design the control system on a trial and error basis while testing the control system for response to different dynamic loading conditions. Once the control system of the model meets the objectives it will be used for source code generation of the plants SCADA system. The method for 'model based design' has been chosen because:

- the design of a good control system without 'seeing what it does' is not considered possible for complicated systems like this wastewater treatment plant with its stringent effluent standards;
- reprogramming the control system of the model for SCADA application is not only expensive, but also a source of errors;
- testing and adjusting under operational conditions is not possible because of the high effluent quality required.

The control system will optimize both effluent quality and costs for energy and chemicals during DWF (89% of the time) and mainly effluent quality during SWF (11% of the time).

Landscape and architecture

An important aspect of the ambition level is a beautiful architectonic design of the wastewater treatment plant that fits well in the landscape. Initially the plant was designed as a compact but more or less traditional wastewater treatment plant. The large buildings with a typical height of eight meter would have been clearly visible from the adjacent nature reserve. The required area was about two ha.

In February 2004 a landscape study was commissioned by the municipality of Hilversum or the water board AGV. The result of this study by Grontmij was that the main part of the wastewater treatment plant should be situated under the hill of polluted soil (double land utilization). Based on this idea the final architectural design was made by Snelder Compagnons. The result is that all buildings will be 'hidden' under the hill, except the office building. This part is designed as a beautiful 30 m high landmark. The excellent opportunity to discharge the treated process and vent air at this altitude with an invisible stack inside the landmark was immediately recognized and will be a major advantage to fulfil the zero nuisance objective. The required footprint was reduced to about one ha.

All logistics (trucking of solid waste, sludge and chemicals) will take place from an incision in the hill, accessible from two sides. Figure 6 shows the outlines of the hill and the situation of the wastewater treatment plant and Figure 7 an artist impression of the office building.

In such a wastewater treatment plant health and safety are extremely important. From the start of the design, health and safety, especially during maintenance and repair, was carefully taken into consideration. Special sessions were organised to check the results and/or improve the standards. ¶

Figure 6: *Artist impression of the office building as a landmark.*

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Coupling 'old' and new system

The Ootmarsum hybrid MBR project

The Ootmarsum wastewater treatment plant, one of the 22 WWTP's managed by the water authority Regge en Dinkel, is situated in the municipality of Dinkelland. The plant is outdated and must be modernised. Renovation must be combined with more effective treatment of the sewage. The Ootmarsum WWTP discharges the treated wastewater into a water system with considerable ecological potential. A restructuring plan includes measures concerning both the sewer network and the WWTP. An innovative approach to the urban water chain/cycle in a region of significant natural value requires a co-ordinated effort. Therefore also participation in the European Interreg IIIB programme was sought. The choice fell on the option, referred to as a hybrid system. A configuration in which the conventional active sludge system and final settling tank are provided with a sand filter. Alongside the conventional treatment system a membrane bioreactor is installed.

This MBR has a limited hydraulic capacity. The necessary synergy can be achieved by coupling both systems. With a hybrid MBR, the costs can be reduced compared to a complete MBR plant, without making many concessions in terms of effluent quality. In order to arrive at a form of water management conducive to nature, an ecological filter will be provided downstream of the treatment systems described above. The construction work on the Ootmarsum WWTP will start in mid 2005 and will be completed by late 2006 or early 2007.

Outdated

The Ootmarsum wastewater treatment plant processes sewage from Lattrop, Tilligte and Ootmarsum and was constructed in 1974. The plant consists of an intake unit with bar screens and a grit collector, a carrousel oxidation ditch and a secondary settling tank. The Ootmarsum WWTP is outdated and must be modernised. In view of the water flow requirement in the area, the WWTP will remain at the current location.

Not only does the plant need to be renovated, but the biological treatment capacity must also be expanded from a population equivalent (PE) of 11,500 to 14,000. This must be combined with more effective treatment of the sewage. The Ootmarsum WWTP discharges the treated wastewater into a water system with considerable ecological potential. The receiving surface water is in the catchment area of a 'water pearl' - a water system in which, by 2018, under the water management plan of the water authority, the quality of the surface water must be such that the associated risk is negligible. In such situations, WWTPs must not have any negative impact on the water system. In order to give practical form to this ecological potential, the water authority and the municipality of Dinkelland have drawn up a restructuring plan. This includes measures concerning both the sewer network and the WWTP. An innovative approach to the urban water chain/cycle in a region of significant natural value requires a co-ordinated effort. This is why participation in the European Interreg IIIB programme (North Sea area) was sought. A number of participants in the Urban Water Cycle project (Hamburg, Bradford, Karlebo, Province of Fryslân, Regge en Dinkel water authority) are working on solutions for urban water problems and are comparing notes about a variety of associated subjects. The core message is: 'improving the urban environment by improving the urban water cycle'.

The restructuring plan drawn up with the municipality of Dinkelland does not provide for an expansion of the hydraulic capacity of the Ootmarsum WWTP. Instead, additional measures will be taken in the sewer network.

As well as the standard effluent limits that now apply to surface waters with a high nature value, a maximum limit of 5 mg/l applies to undissolved components. This is in line with another measure deriving from the water authority's water management plan, namely the status of the Ootmarsum WWTP as a pilot plant for the application of a more comprehensive treatment technique based on filtration. This approach takes account, as far as possible, of more detailed target values for the long term. Effluent limits and target values are summarised in the table below.

Table 1. Effluent limits and target values (mg/l).

Component	Limit (2005)	Target value
BOD	5	2
NH_4-N	1/2 (summer/ winter)	0,8 (90 perc.; temp >10°C)
N_{total}	10	4
P_{total}	1	0,15
Undissolved components	5	2

Choice of configuration

In order to arrive at a responsible choice of configuration with regard to the measures at the WWTP, Grontmij engineering consultants carried out several studies. The WWTP was modelled in SIMBA, and the model was used to study a number of possible wastewater treatment configurations. A feasibility study was also carried out for the purpose of validating the choice of the filtration technique. The choice was between the comprehensive application of downstream sand filtration, and a configuration in which the conventional activated sludge system and final settling tank are provided with a sand filter and a

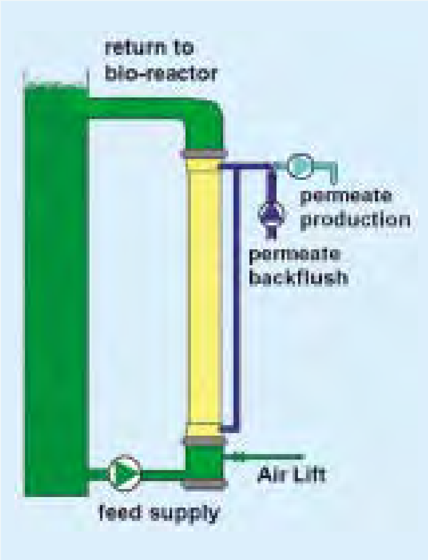


Figure 1: Basic principle of the NORIT AquaFlex MBR with 8" X-Flow COMPACT membrane module and continuous aeration.

membrane bioreactor is installed alongside the existing treatment system. The choice fell on the second option, referred to as a hybrid system. The feasibility study showed that the hybrid system entails higher investment costs, but the predicted effluent quality is significantly better. It is possible that a considerable step can already be made in the direction of the target values. This is partly due to the possibility of achieving the necessary synergy between both systems (conventional and MBR) by coupling them together by means of an intermediate buffer.

The additional costs of the hybrid system must be weighed against the experience that can be gained with the new MBR technology in the coming years, which may result in future cost savings and a smaller risk of failure.

The hybrid system consists of a MBR alongside a conventional system. The MBR has a limited hydraulic capacity. The idea is that a relatively large part of the dry weather flow (DWF) will be treated with the membranes. During periods of storm weather flow (SWF) the excess rainwater will be channelled via the intermediate buffer to the conventional activated sludge system and final settling tank. In this way, the surface area of the membranes can be considerably reduced in comparison with a complete MBR plant, and the membranes can be used to the maximum. With a hybrid MBR, the costs can be reduced relative to those of a complete MBR plant, without making many concessions in terms of effluent quality. There is a number of possible hybrid solutions. No experience has yet been gained with any of these options in the Dutch situation.

The MBR at the Ootmarsum WWTP will treat 50% of the total amount of sewage in periods of DWF, while the hydraulic capacity is only 23% of the SWF. The maximum hydraulic capacity of the MBR will be 150 m^3/h, while the total sewage inflow to the WWTP under SWF conditions is 650 m^3/h. The intermediate buffer will serve the function of a primary settling tank. During prolonged periods of SWF the buffer will have insufficient capacity and therefore overflow. The overflow water (max. 175 m^3/h) will be treated in the conventional system. In this situation, the conventional system will have to treat a maximum of 500 m^3/h.

A notable aspect of this configuration is the large variation in the hydraulic load of the conventional system. The table below shows the distribution of the wastewater under DWF and SWF conditions.

In order to arrive at a form of water management conducive to nature, with the WWTP exerting no disruptive influence on the receiving water system, an ecological filter will be provided downstream of the treatment systems described above. This downstream ecological filter, also referred to as an 'ecological activation system' or 'ecologising step', consists of a unit which is ecological, integrated into the landscape, and in which the 'sterile effluent' is transformed to make it ecologically compatible with the surface water into which it is discharged. During the time it spends in the system, the treated wastewater is transformed into more natural water. This can be achieved by means of a system of varying depth, in which water plants and marsh plants can grow as a basis for an aquatic ecosystem that can accommodate a variety of vital links (zooplankton, phytoplankton, macro fauna, fish, birds, amphibians and insects).

Choice of membrane

For the purpose of selecting a membrane supplier, a procedure was followed whereby, on the basis of a schedule of requirements, suppliers were invited to submit bids for designing, supplying and constructing a membrane extraction unit. The process of selection took place on the basis of the operating costs and a number of quality criteria. This yielded two suppliers with a similar price/quality ratio. The two suppliers then participated in the following phase, in which the definitive design was drawn up, and ultimately NORIT Membrane Technology (NMT) was selected. The final design was then modified to accommodate the findings of a joint risk analysis carried out by Norit, the Regge en Dinkel water authority and Grontmij.

The NORIT AquaFlex MBR system consists of a loop with membranes positioned outside the bioreactor tank (Figure 1), rather than having the membranes in the bioreactor or a separate part of the bioreactor, as in the submerged concepts. The membrane modules are arranged vertically and are aerated continuously at the bottom. This continuous aeration is the main driving force for the circulation of the activated sludge, while the feed pump is only used to overcome the hydraulic losses. Permeation is achieved by a suction pump, as in the submerged concept. A combination of forward flushing and periodic back-flushing and/or relaxation intervals is used to control the cake layer formation inside the membrane tubes and to extend the intervals between maintenance cleaning. The continuous aeration also takes care of the fouling control inside the individual membrane tubes. The side-stream placement of the membranes means that almost all the options for individual optimisation of bioreactor and the membrane system are available. Moreover, a much lower volume of activated sludge is aerated additionally outside the bioreactor than in a submerged system, so that the biological processes are influenced as little as possible.

Design

The Ootmarsum WWTP is designed for a biological capacity of 14,000 PE (at 54 g BOD)

Table 2. Flow through the two systems (m^3/h).

	conventional	buffer	MBR	total
DWF conditions	75	-	75	150
SWF conditions while buffer fills	325	175	150	650
long-term SWF conditions	500		150	650

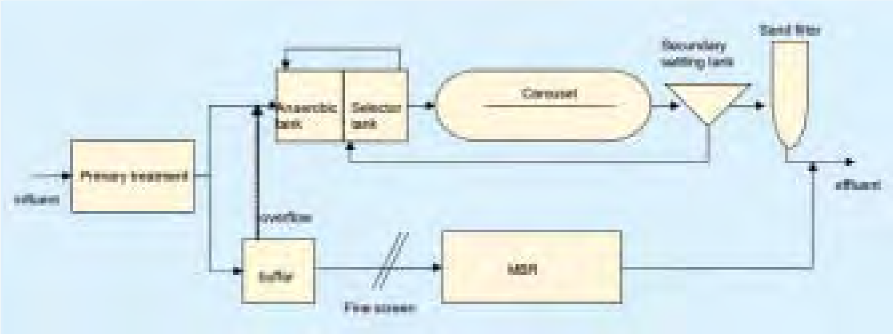


Figure 2: *Schematic presentation of the Ootmarsum hybrid configuration.*

Figure 3: *Schematic presentation of the MBR configuration.*

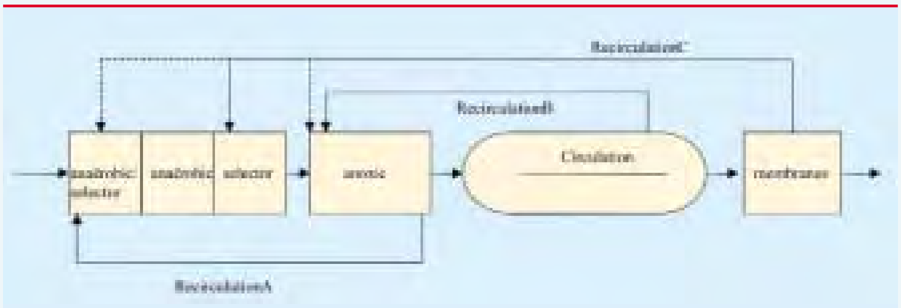
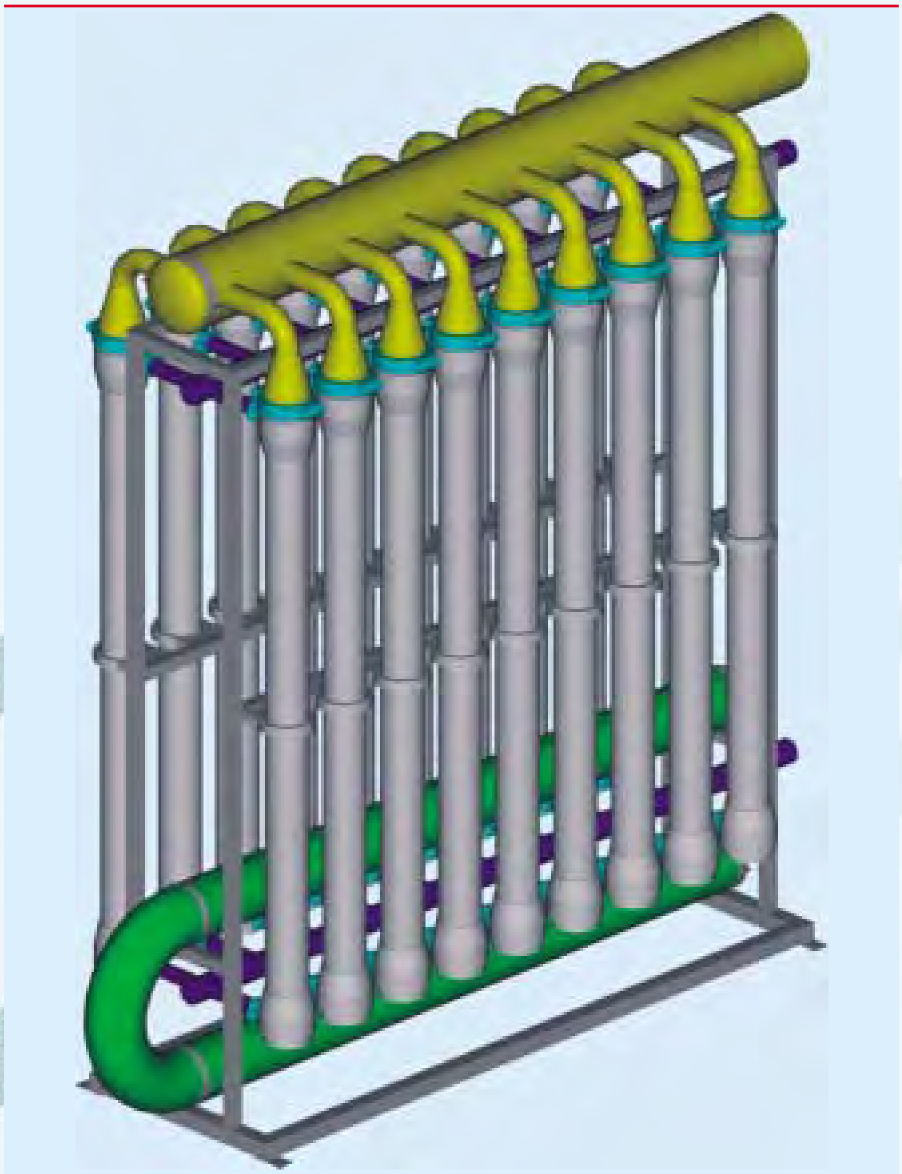


Figure 4: *Artist's impression of one of the AquaFlex MBR stacks for the upgrading of WWTP Ootmarsum.*



under winter conditions (7.5°C) and a capacity of 18,500 PE (at 54 g BOD) under summer conditions (17.5°C). The total hydraulic capacity is 650 m^3/h, and the DWF is calculated to be 150 m^3/h.

The wastewater from Ootmarsum flows through gravity sewers and is collected at the inlet chamber of the WWTP. The wastewater from Lattrop and Tilligte passes through pressure pipelines. It arrives downstream of the screw pumps and is subjected to preliminary treatment together with the wastewater from Ootmarsum. The preliminary treatment is carried out with a bar screen (bar separation 6 mm) and a grit collector. The screenings are passed through a washer and a press. The grit extracted from the grit collector is also washed. The screenings and the grit are then disposed of. The conventional activated sludge system, consisting of the carrousel, will be replaced and expanded by an upstream selector tank/anaerobic tank and a downstream discontinuous sand filter, which can handle a maximum of 250 m^3/h. If the flow exceeds this maximum, the excess is diverted through a bypass. The decision to replace the conventional activated sludge system was taken to simplify the connection to the MBR, and above all to ensure better continuity of treatment during the construction phase. All the wastewater treated in the MBR will first be passed through a micro screen (perforation size 0.75 mm).

The membranes will consist of 6 membrane stacks in parallel, each of them equipped with 14 modules, which can be extended to 18 modules (Figure 4). No pilot studies have been carried out at the Ootmarsum WWTP, so the design of the membrane installation is based on experience with the sidestream concept at other locations, where the design base for Ootmarsum has proved itself over a period of several years (Harry Futselaar, e.a. The side-stream MBR-system for municipal wastewater treatment. In 'Proceedings of membranes in drinking and industrial water production', 15-17 November 2004, L'Aquila (Italy)).

The selector tank/anaerobic tank of both the conventional activated sludge system and the MBR can be operated in a number of ways in order to facilitate the selection of phosphate accumulating bacteria in practice and to optimise the generation of readily settleable activated sludge.

The necessary steps have now been taken to facilitate the design of the ecological filter. The design is, however, not yet complete.

Costs

When the above mentioned feasibility study was carried out, the hybrid system was compared with the conventional system including sand filtration. The complete MBR plant option was taken as a reference. The study looked at the investment costs and the operating costs. The result is summarised in the table below as a factor of the conventional configuration. The relative investment costs and annual costs do not include the costs of the ecological filter.

Table 3: Relative investment and annual costs. (Conventional is 1.0)

	investment costs	annual costs
conventional	1.0	1.0
MBR	2.0	2.5
hybrid	1.4	1.6

Subsidies are provided from two sources, namely the STOWA innovation fund and the European Interreg IIIb programme, under the project name Urban Water Cycle. The activities carried out in the context of the Interreg IIIb programme make an important contribution to the goals of the Ootmarsum project, but, for reasons of transparency, are kept strictly separate from the described activities in the context of the innovation fund. Therefore there is no overlap. The contribution from the innovation fund has its origins in the fact that the Ootmarsum project, together with the Heenvliet project, has the status of a demonstration project for the hybrid MBR, which can yield useful information alongside that from the Varsseveld project. On the basis of the MBR market analysis, which was commissioned by STOWA, it can be assumed that a MBR will usually be considered in the context of the expansion of an existing WWTP. The number of new MBR sites in the Netherlands is expected to be much lower. A hybrid concept will be a genuine alternative in an expansion scenario, provided it can adequately be demonstrated that it functions properly.

Final remarks

Grontmij recently completed the specifications. The construction work on the Ootmarsum WWTP will start in mid-2005 and will be completed by late 2006 or early 2007. Measurements of guaranteed values will then be carried out, and an extensive research programme will also be pursued, which will yield more knowledge of MBR plants in general and hybrid MBR systems in particular. Synergy effects will be a particular area of interest. The research programme will also have to provide insights into the achievement of certain ecological values, and must lead to a plant management concept which focuses on continuity and the management of energy and chemical consumption. ¶

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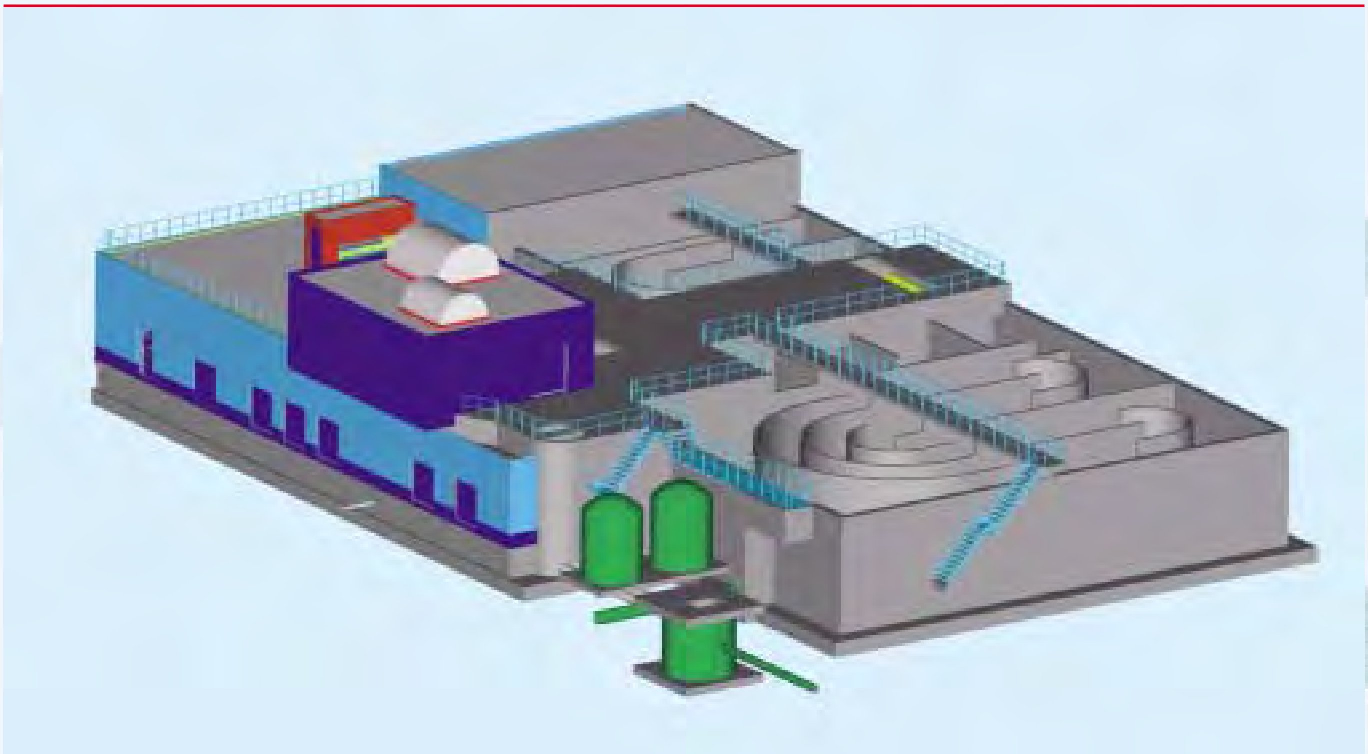
Artist impression of the Ootmarsum MBR.



RESEARCH TO ESTABLISH OPTIMAL PROCESS PARAMETERS AND MINIMUM COSTS FOR FUTURE MBR INSTALLATIONS

Hybrid MBR - the perfect upgrade for Heenvliet

The Heenvliet WWTP consists of a low-loaded activated sludge system, type carrousel, with one secondary clarifier and disinfection of the effluent by means of sodium hypochlorite. The WWTP will be expanded to a hybrid MBR system in which the MBR will treat 25% of the hydraulic load and will operate in parallel to the existing conventional activated sludge system. Flat sheet membrane modules have been chosen as most suitable for the Heenvliet situation. The conventional activated sludge system will be modified in order to improve the current treatment efficiency. In the initial research phase the MBR and the modified conventional lines will be run in parallel and the treatment efficiency of the MBR will be directly compared to the efficiency of the conventional plant. In the following research phase the MBR and carrousel will be operated in series, where as much water as possible will be treated in the membrane units (at DWF conditions) and as little as possible in the existing secondary clarifier (only under SWF conditions). The full-scale MBR research aims to achieve optimal effluent quality. In addition the research aims to establish optimal process parameters and the minimum required costs for future MBR installations. The research will run for a period of three years.

The MBR technique offers unique opportunities for upgrading existing wastewater treatment plants. With the European Water Framework Directive coming into effect by 2006, water boards have to consider new technologies to extend the treatment capacity and efficiency of existing wwtp's. The Heenvliet wwtp is a typical example of such a case and will serve as a demonstration project to gather experience with the relatively new application of hybrid MBR.

The wastewater treatment plant of the city Heenvliet (the Netherlands) is currently treating 8,950 p.e. of domestic wastewater. The hydraulic capacity will increase to 390 m^3/hr when the Abbenbroek WWTP (capacity 1,650 pe) will be closed and will be connected to the Heenvliet WWTP. The produced effluent is disinfected with sodiumhypochlorite before being discharged to a local surface water which is also used as bathing water in the summer time.

The Heenvliet WWTP will be upgraded to a hybrid membrane bioreactor system. The new MBR will treat approximately 25% of the total hydraulic capacity, which is equal to the dry weather flow; during storm weather events the remaining influent will be treated by the conventional part of the system. This hybrid system allows for optimisation of both sub-systems in terms of hydraulics and biological loading rate.

Process scheme

Heenvliet WWTP consists of a screen, a selector, a carrousel type aeration tank, a clarifier and a disinfection tank (see Figure 1). Sludge treatment consists of thickening and storage in a lagoon, followed by transportation for further treatment. The design sludge loading rate amounts to 0.054 g BOD/(g MLSSxday). Two surface aerators are installed and aeration is controlled by oxygen measurement only.

Objectives of the MBR project

The current capacity of Heenvliet WWTP is too small to treat the future increased influent flow, therefore the plant will be upgraded to a hybrid MBR system. The main reason for applying the MBR technique is the expected improved effluent quality in terms of nutrients. Nitrogen and phosphorus for example will have to be removed to lower concentrations, possibly down to the Maximum Tolerable Risk (MTR) level, 2.2 mg N_{total}/L and 0.15 mg P_{total}/L, when the European Water Framework Directive becomes effective.

Furthermore, other components may be reduced in a MBR system, especially those that can be adsorbed to the biomass such as micro pollutants. In combination with the absolute barrier provided by the membrane these substances, as well as bacteria and viruses, will be removed completely, making disinfection with NaOCl superfluous.

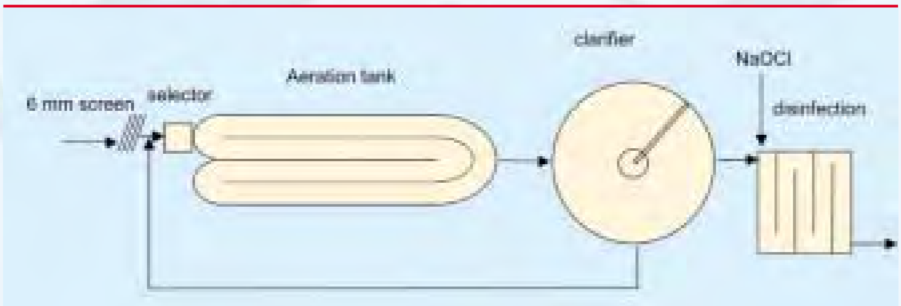
The Heenvliet case provides a good opportunity to study the system behaviour under typical Dutch circumstances and the effects of up-scaling MBR technology. In this way the development of MBR technology is supported and its potentials can be explored to the full. Since the Heenvliet MBR is designed as a hybrid system it is perfectly suited as a research case, since the two sub systems (conventional and MBR) can be tested and evaluated in parallel.

From an operational point of view, the hybrid MBR system is advantageous because the hydraulic capacity of the membranes will be utilised to the maximum during dry weather flow. This results in a more economic use of the installed membrane surface compared to an exclusively MBR system, where the membranes will have to be designed at storm weather flows.

Extension of the plant

The Heenvliet wwtp will be upgraded with a MBR, which will be operated in parallel to the existing plant. The influent will be divided over the MBR and the

Figure 1: Flow sheet of the current situation at Heenvliet WWTP.



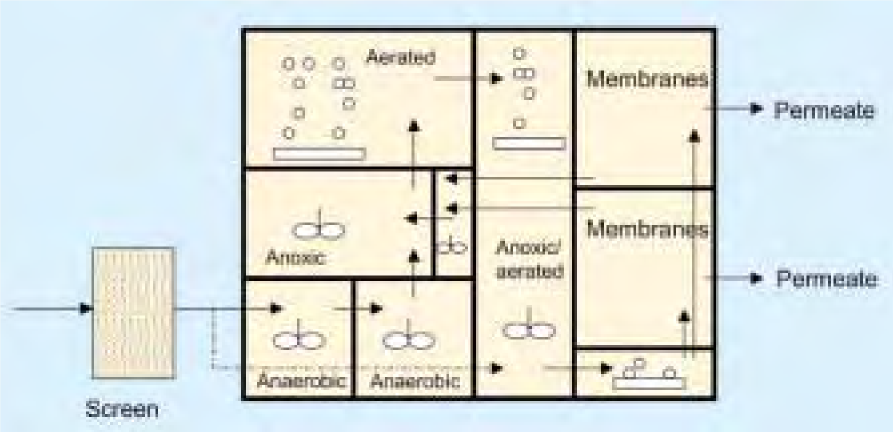


Figure 2: Flow sheet of the MBR.

conventional plant and the influent quality will be equal for both systems. The MBR consists of the following parts (figure 2):

Screening

The influent will be treated in screens with flat sheets with 3 mm perforations, because perforations are more effective than screens with bars. The selection of the size of the perforation is related to the selected flat sheet membrane system. Flat sheet membranes are expected to be less sensitive for pollution than hollow fibre membranes. Besides flat sheet membranes can be cleaned more easily than hollow fibres in case of pollution.

Figure 3:. Two Hybrid configurations during dry weather flow and storm weather flow.

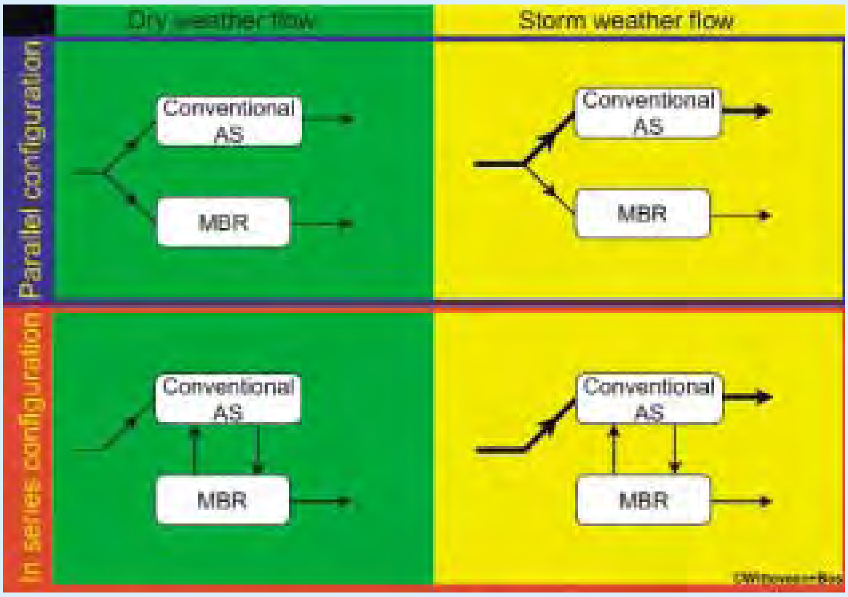


Table 1: Specifications of the plant.

		conventional	MBR
screens	mm	6 (bars)	3 (pores)
maximum hydraulic load	m³/h	290	100
biological capacity	p.e. (136 gr BOD/p.e/day)	9,660	3,330
F/M ratio	g BOD/g MLSS x d	0.045	0.045
sludge concentration	kg MLSS/m³	4.7	10
surface load clarifier	m³/m²xh	0.51	-
net membrane flux	l/m²xh (at 100 m³/h)	-	24.3
maximum possible flux	l/m²xh	-	56.3
disinfection	-	NaOCl	ultrafiltration

Activated sludge tank

The activated sludge tank is divided into different compartments for P-release, denitrification, nitrification and P-uptake. The sludge passes a continuously aerated tank before entering the membrane tanks. This is expected to be favourable for the sludge quality, resulting in a better membrane performance. The return sludge from the membrane tanks passes an anoxic tank to limit the oxygen concentration before entering the denitrification tank.

Phosphorus will be removed biologically as much as possible. To support the biological removal, $FeCl_3$ can be added in order to reach the required very low effluent concentrations.

Membrane tank

The two parallel membrane tanks are equipped with Toray flat sheet membranes, provided by Seghers-Keppel. With a pore size of 0.08 μm this can be classified as ultra-filtration. By having two membrane tanks there will be flexibility in the hydraulic membrane load, because the flow can be distributed in different proportions over the two tanks.

Modifications of the existing plant

The sludge loading rate of the conventional plant will decrease because of the planned extension. This effect will be more pronounced due to the increased sludge concentration available, which is needed to ensure identical F/M ratios in both the conventional plant and the MBR. A mixer will be installed in the carrousel to increase flexibility of aerobic and anoxic zones and to avoid sludge settling in the aeration tank. The existing activated sludge tank is not provided with an anaerobic tank. Therefore, biological P-removal is expected to play a limited role, so $FeCl_3$ is added for phosphorus removal.

The hydraulic load will decrease compared to the present situation, resulting in an improved separation of solids, even at the higher sludge concentration in the activated sludge tank.

In table 1 some specifications are given for both systems in the future situation.

Two configurations of the hybrid system

The new hybrid system can be operated in two ways (figure 3).

MBR in parallel with the conventional lane

During dry weather flow, the MBR will be treating relatively more wastewater than

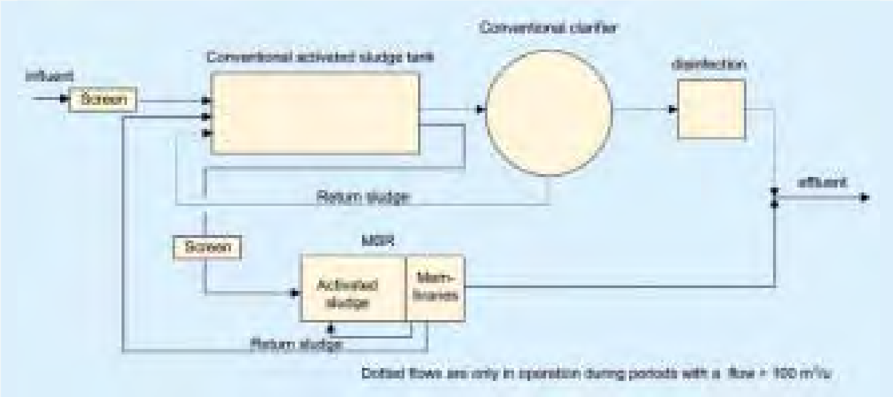


Figure 4: *Flow sheet of the in-series-hybrid configuration.*

the conventional lane. In this way the membrane capacity is utilised as much as possible. If the flow increases, e.g. during storm weather, the hydraulic loading rate of the conventional plant will increase more than proportional. The sludge loading rate of the conventional plant will also increase but the sludge loading rate of the MBR will decrease under these circumstances. This type of operation is referred to as parallel operation.

MBR in series with the conventional lane

In this configuration the activated sludge tanks of the conventional plant and the MBR are connected in series. This results in one biological system, with a possibility to separate solids both with the membranes and in the conventional clarifier (figure 4).

In this so called 'in series hybrid configuration' the clarifier also acts as a hydraulic buffer. If the flow is lower than the membrane capacity, the water level in the clarifiers decreases and effluent is only produced by the MBR. When the flow exceeds the membrane capacity the water level in the clarifier will increase again until the level of the overflow weirs, and the clarifiers will be used for effluent production again. In this way the overall effluent quality is increased compared to parallel configuration.

Research programme

The hybrid MBR project at Heenvliet WWTP will serve as a demonstration case for hybrid MBR systems in the Netherlands. To facilitate the further development and application of this concept an extended research programme has been designed. Part of this research programme is incorporated in a Europe-wide scientific research project in close co-operation with universities from all over Europe. Water board Hollandse Delta, Delft University of Technology and UNESCO-IHW are Dutch representatives in this project. The project proposal was submitted to the EU for a subsidy as a specific tartgeted research project within the sixth framework research programme and will start summer 2005.

The Heenvliet MBR research programme will focus on the achievable effluent quality, and minimisation of operational cost. For a MBR system, both investment and operating costs are higher at the moment compared to conventional activated sludge treatment. To accurately study and optimise the system with respect to energy requirements and other sustainability related aspects, a full-scale installation is a prerequisite.

The first year parallel operation will be investigated. The influent will always be distributed over both systems with a constant ratio and the sludge loading rate will be equal for both systems. This enables a direct comparison between performance of both systems of a very low loaded conventional system and a MBR system.

The last two years will be used to test the serial hybrid configuration. With this type of operation the membrane filtration step can be optimised without the risk of overloading the conventional plant during storm weather. This provides the opportunity to upgrade the plant with a minimum loss of overall effluent quality.

The research programme will start at the end of 2005 and continue until 2009. Research topics include:

- maximum achievable effluent quality to comply with the EWFD; in terms of
  - nutrients: nitrogen and phosphorus; and
  - micro pollutants, such as heavy metals, herbicides, pesticides, medicine residuals;
- effects of in series and parallel configuration in terms of membrane operation, activated sludge settleability, floc structure etc.;
- minimisation of energy input for aeration of the membranes and oxygen transfer;
- influent and recirculation screening requirements and efficiency;
- comparison of ultra low loaded conventional activated sludge system and MBR in terms of effluent quality;
- optimisation of the membrane separation step. Since the membrane compartment consists of two sections that can be operated separately, alternating operation can be applied to increase membrane lifetime. This feature also allows for critical flux determination tests with a part of the membrane while ensuring treatment capacity.

At this moment the MBR is under construction and is expected to be commissioned in October 2005 (an artist impression is presented in figure 5). ¶

Figure 5: *Impression of the Heenvliet MBR.*

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DIFFICULT TO REACH MAXIMUM TOLERABLE RISK QUALITY FOR NITROGEN AND PHOSPHATE

Comparison of the MBR with continuous sand filtration at the Maasbommel WWTP

Recently, a two-year research period in which the membrane bioreactor and conventional wastewater treatment with continuous sand filtration as polishing step were compared has been concluded. The aim for both was to reach Dutch Maximum Tolerable Risk Quality. The research was carried out by Water board Rivierenland, Royal Haskoning and STOWA (Foundation of Applied Water Research) at the Maasbommel wastewater treatment plant. Results showed that it was difficult to attain yearly mean MTR quality for nitrogen and phosphate applying either technology.

Around 2010 the Dutch Water board Rivierenland expects stricter demands on effluent quality of ten wastewater treatment plants (WWTP's) within rural areas. Until concrete legislation comes in effect, the Dutch Maximum Tolarable Risk (MTR) is set as standard for receiving surface water. For nitrogen and phosphate concentrations of 2.2 mg N/l and 0.15 mg P/l, respectively, have been set. With the current WWTP's such levels cannot be reached. Consequently, together with Royal Haskoning and STOWA, the Water board Rivierenland started a research programme on the applicability of the membrane bioreactor and continuous sand filtration for treatment of municipal wastewater. The research was located at Maasbommel WWTP and started in March 2002. The main goals were to determine the feasibility of MBR technology or end-of-pipe continuous sand filtration to reach MTR quality for WWTP effluent and a comparison of MBR and continuous sand filtration technology performance.

Table 1: Influent composition.

Parameter	Value	Unit
BOD influent	50 - 350	mg/l
N_{kj} influent	15 - 110	mg/l
P_{total} influent	3 - 15	mg/l
DWF	50	m³/h
RWF	150	m³/h

Figure 1 shows a schematic presentation of the configuration used at Maasbommel. It included a MBR pilot plant (capacity 16 m³/h) with submerged hollow fibre membranes (440 m²) and two full-scale upflow continuous sand filters (capacity 110 m³/h, surface load 15 m/h).

Effluent quality

The research showed that for both technologies it is difficult to maintain MTR quality for nitrogen and phosphate throughout the year. MBR shows better phosphate removal (minimum values of 0.05 mg P/l) than sand filtration (minimum values of 0.12 mg P/l). This was mainly due to the wash-out of ferric sludge from the sand filters. Better nitrogen removal was

Sand filtration at the Maasbommel WWTP.

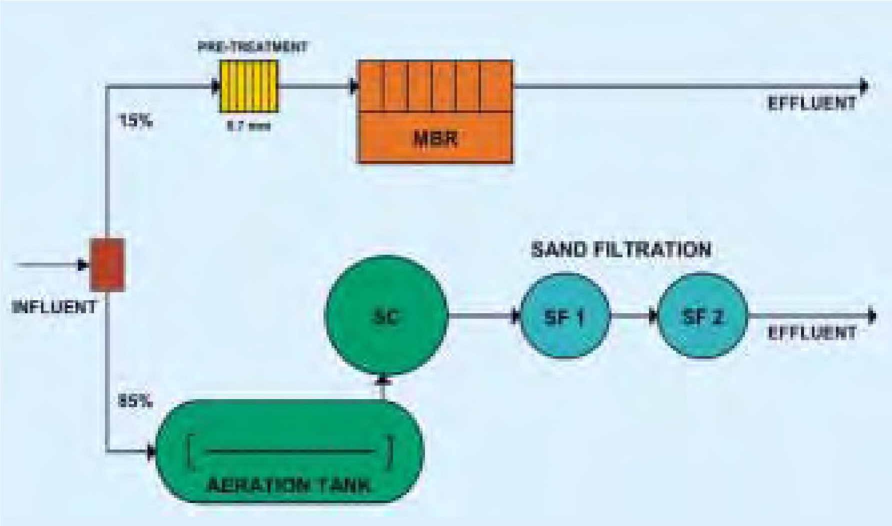

Figure 1: *Schematical representation of the Maasbommel WWTP installation and basic data of the influent. SC = secondary clarifier, SF = sand filter.*

Figure 2: *MBR and WWTP effluent concentrations of total nitrogen and total phosphorus. From July 1, 2003 WWTP effluent was polished using continuous sand filtration.*

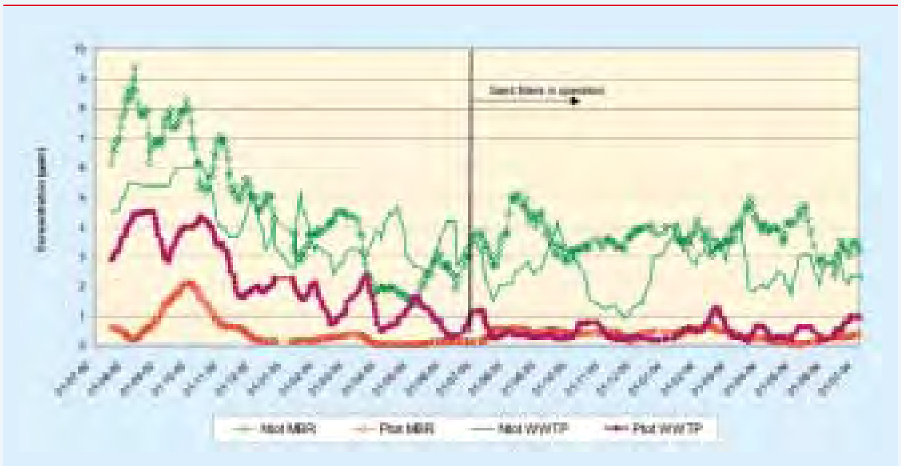

Table 2: *Average effluent concentrations of secondary settler, sand filters and MBR (during periods without disturbances) in 2003-2004.*

parameter	unit	effluent secondary settler	effluent sand filters	effluent MBR	MTR demand
nutrients					
total nitrogen	ppm	6.0	2.5	3.0	2.2
total phosphorus	ppm	2.5	0.5	0.3	0.15
metals					
copper	ppb	6.8	5.2	6.5	3.8
zinc	ppb	27	23	28	9.4
pesticides/herbicides					
glyphosphate	ppb	7.5	3.5	4.5	-
diuron	ppb	0.11	0.18	0.15	0.43
linuron	ppb	1.35	0.9	0.5	0.25
diazinon	ppb	0.1	0.08	0.09	0.037
E.coli	cfu/ml	200	130	< 1	20
estrogens					
bisphenol a	ng/l	28	33	20	-
estron	ng/l	4.75	6.9	3.3	-
β-estradiol	ng/l	1.05	0.85	1	-
EEQ (er-calux)	nm	0.014	0.011	0.004	-

achieved with sand filtration, however. Residual nitrate concentrations are easily lowered to average values of 0.5 mg/l when additional carbon source (acetol) is dosed. It proved to be difficult to attain such values with the MBR by adjusting recycle flows and carbon source dosing. Furthermore, MBR was more sensitive to RWF than sand filtration. Under RWF conditions contact times and process conditions dramatically change. The process configuration used (a highly divided cascade system) enhanced this effect. Application of an M-UCT or BCFS process may partially neutralise this negative effect. Overall, however, both MBR and sand filtration clearly show better nitrogen and phosphate removal than the conventional Maasbommel WWTP without sand filtration (figure 2).

When heavy metals are considered (table 2), only the zinc and copper demands are exceeded by both systems. Other metals are eliminated to concentrations well below the MTR demands. The difference in removal efficiency between MBR and sand filtration is minimal. The added value concerning heavy metal removal when compared with the conventional WWTP is limited as well.

Comparable removal efficiencies of pesticides and herbicides are obtained with both MBR and sand filtration. For most compounds concentrations were below the detection limit. Of the compounds in the higher concentration range, only linuron and diazinon exceeded the MTR quality demands. No additional removal of pesticides and herbicides was achieved with MBR or sand filtration compared to conventional wastewater treatment. Only glyphosphate (herbicide, active compound in Roundup) is about 50% more efficiently removed than in the conventional Maasbommel WWTP.

MBR appeared to be more efficient for disinfection purposes than sand filtration or conventional treatment. Disinfection was quantified through viability and *E. coli* counts. Because of the pore size of 0.04 µm practically no *E. coli* can pass the membrane. *E. coli* counts are lowered down to less than 1 per ml. This is appreciably lower than MTR or swimming water quality demands (20 per ml).

Based on wet chemical analyses, the MBR and conventional WWTP with sand filtration as polishing step show comparable removal of estrogenic compounds. Both systems showed a removal efficiency of 95%

for bisphenol A, estron and b-estradiol. The estrogenic potential expressed in b-estradiol equivalents (EEQ) was determined as well through a bio-assay (ER-Calux). Sand filtration shows a 20% lower potential than conventional treatment alone. Estrogenic potential after MBR treatment is 60% lower than after conventional treatment with sand filtration. An explanation may be the increased removal of suspended solids due to the ultrafiltration membranes applied in the MBR. It is known that the main removal mechanism for phthalates, poly-bromine-diphenyl-ethers (PBDE's) and alkyl-phenols is adsorption to suspended solids (STOWA (2004). Vergelijkend onderzoek MBR en zandfiltratie rwzi Maasbommel. Rapport 2004-28 (in Dutch)).

Process sensitivity and stability

During the whole research period, the MBR was more prone to process disruptions than sand filtration. This was expected, since sand filtration is a proven technology. Furthermore, it was installed as a full-scale plant. After several optimization steps the MBR ran relatively stable. The pre-filtration step before the MBR system ran without any difficulty throughout the testing period. With sand filtration, the on-line measurements, sand velocity meters and chemical dosing demanded increased attention. With increased attention stable operation of the sand filtration was achieved.

It appeared to be less cumbersome to maintain a stable effluent quality with sand filtration than with the MBR. This was especially the case for nitrogen and phosphate. Even at RWF Sand filtration delivered stable effluent quality, while the MBR effluent quality started to fluctuate. MBR effluent stability may be improved, however, through process configuration and control optimization.

If MBR cleaning is fully automated, then it is expected that MBR operation will require as much operator attention as a conventional WWTP with sand filtration as polishing step. It may be roughly stated that membrane filtration requires as much attention as sand filtration.

Membrane tank MBR pilot plant.

Process measurements and control were difficult within the MTR quality range. Current analysis techniques are too inaccurate within this range for good process control. For future design, measuring and control devices require increased attention.

Conclusions

Reaching MTR quality is difficult for both MBR and sand filtration. Nevertheless, it may be stated that there is a slight preference for sand filtration for WWTP expansion or green field WWTP's due to stricter nitrogen and phosphate demands. Sand filtration delivers a more stable effluent quality for these nutrients. It must be said, though, that effluent concentration for N_{total} and P_{total} of 3 and 0.5 mg/l may be reached with MBR under proper operation. Table 3 shows a qualitative comparison of MBR with sand filtration.

When disinfection is the main demand for WWTP expansion or newly built ones, e.g. due to discharge into swimming water, MBR is preferred. Also for hormone removal, an important parameter for future effluent criteria, the estrogenic activity after MBR treatment is considerably lower than after sand filtration.

Compared to conventional treatment, water quality is not significantly improved with either MBR or sand filtration when speaking about heavy metals, herbicides or pesticides. To reach MTR quality and lower concentrations in general, additional techniques need to be applied.

Additional water treatment techniques are necessary to eliminate priority compounds and to comply with expected stricter demands due to the Water Framework Directive. Possible treatment technologies are activated carbon, denitrifying activated carbon, ozonisation, selective resins for metal removal, UV irradiation, nanofiltration or reversed osmosis systems. Specific demands on effluent quality due to the surface water quality wanted will eventually determine which technology will be implemented. ¶

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Table 3: Comparison of MBR with conventional WWTP with sand filtration as polishing step.

parameter	membrane bioreactor	conventional + sand filtration
nitrogen removal	+	++
phosphate removal	++	+
E. coli removal	+	0
heavy metal removal	0	0
pesticide/herbicide removal	0	0
hormone removal	+	0
operational aspects	0	0

GOOD REMOVAL CAPACITIES FOR HORMONES AND MEDICINE RESIDUES

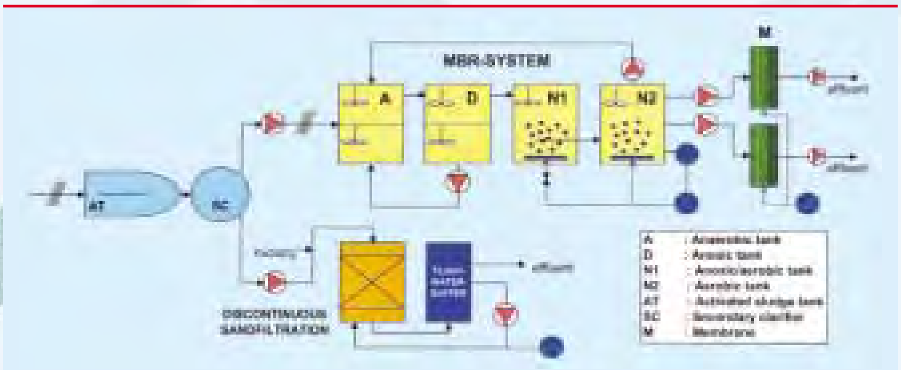
MBR-research at WWTP Leeuwarden for the post treatment of effluent

The Frisian capital Leeuwarden wants to make the city canals more attractive and wants the water in the centre to be separated from the surrounding (nutrient rich) surface water by means of a special water separation construction. These constructions allow the boats and canoes to pass but will minimize the flow of surface water to the centre. To improve the water quality of the canals in Leeuwarden, it is the intention to transport treated effluent of the WWTP Leeuwarden to the canals of the city centre of Leeuwarden. The intention is to make the canals suitable for recreation and to develop ecological areas.

The WWTP has been renovated entirely in 2001, but the effluent still contains too many contaminants to be able to use it as recreation water. Also there was a concern for micro-contaminants. In the middle of 2003 the three-year study on WWTP Leeuwarden into the post treatment of the effluent of WWTP has started. Two systems for treating the effluent, sand filtration (SF) and membrane bioreactor (MBR), have been examined more closely. The research of the MBR is carried out by Wetterskip Fryslân and Vitens at the WWTP of Leeuwarden. Two subjects for research are the specific biological population, which may develop in the MBR and the removal of organic micro-contaminants. This article focuses on the MBR research project.

MBR-pilot at WWTP Leeuwarden.

Figure 1: Lay out MBR for post treatment effluent of WWTP Leeuwarden.



System description

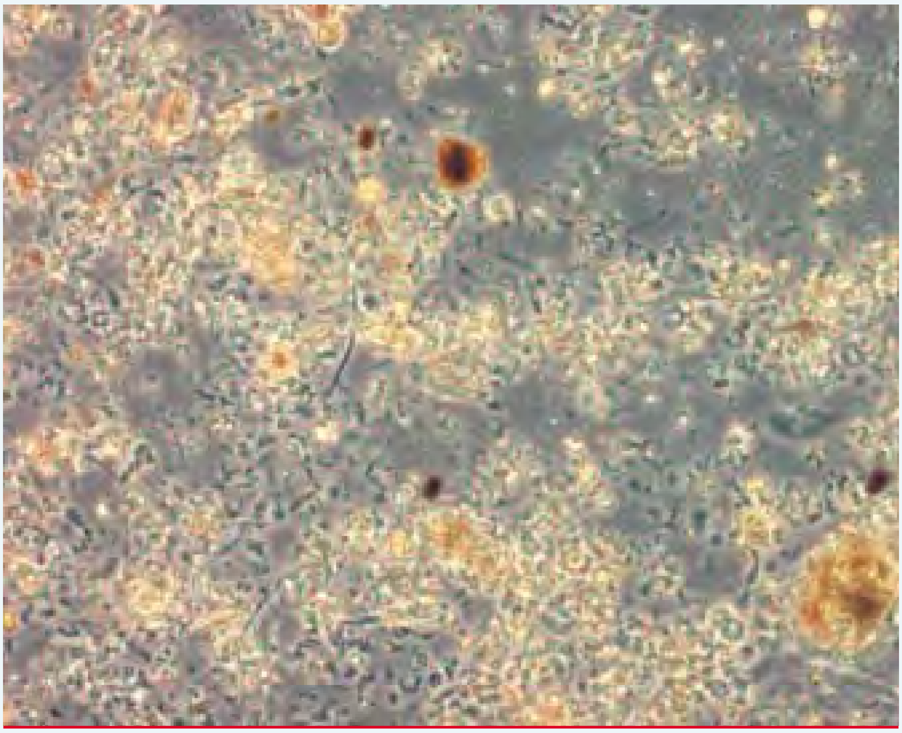
Normally MBR is applied as an integral purification technique, meaning treatment of WWTP influent. At the WWTP site of Leeuwarden however the MBR is used for effluent treatment. The MBR system (see figure 1) is equipped with X-Flow ultra filtration side-stream membranes (0.03 µm pore size) and has a capacity of 8 m^3/h.

The MBR was designed with respectively an anaerobic, anoxic and aerobic compartment. However, the very low BOD content in the effluent of the WWTP and the cleaning of the membranes with air, in combination with the recirculation flows, ensured aerobic conditions in all compartments. Consequently the MBR is not capable to remove phosphate and nitrogen biologically at this time.

Unique micro-organisms

The research workers expect that treating the WWTP-effluent in a MBR, enables the development of a unique bacterial population due to extreme high sludge ages. Microscopic analyses (see photograph) show a typical picture of this type of sludge.

The sludge quantity increases very slowly. In 1.5 year time, sludge concentration has increased from 2 to 4.5 g SS/l. Still no sludge has been withdrawn from the system and sludge age is at this point infinite. From the determination of the ash content of the sludge it appears that the non-organic part has increased to 50%, while normal activated sludge shows values between 30 and 40%. It is very likely that the sludge is mineralising itself as a consequence of the low BOD load and therefore the sludge shows a relative low activity and slow growth.



MBR sludge Leeuwarden with high sludge age.

Table 1: Analyse methods and detected compounds of micro-contaminants in influent and effluent of MBR at WWTP Leeuwarden.

analyses	analysing method	detected compounds	laboratory
79 non-volatile compounds	GC-MS	benzylbutylphtalate, bi-sethylhexylphtalate, di-butylphtalate, di-ethyl-phtalate, di-isobutylphtalate, di-n-octylphtalate	Wetterskip Fryslân
phenols en alcohols	GC-MS	- not detected -	Wetterskip Fryslân
organosulfides	GC-MS	CS_2 and di-methylsulfide	Wetterskip Fryslân
steroids, nitrogen compounds	GC-MS	indole, nicotine, caffeine, cholesterol, di-hydrocholesterol	Wetterskip Fryslân
chloorphenol	GC-MS	- not detected -	Omegam
50 volatile compounds*	GC-MS	chloroform, tetra-chloorethene	Wetterskip Fryslân
fenylureum-herbicides	HPLC	diuron	Wetterskip Fryslân
41 pesticides (watersoluble)	LC-MS	di-azinon, carbendazim, furalaxyl, imidacloprid, simazine, propoxur, metzachloor	Wetterskip Fryslân
organophosphor, organonitrogen pesticides	GC-MS	di-azinon	Wetterskip Fryslân
heavy metals	ICP	e.g. chromium, copper, lead, nickel, zinc, iron, aluminium, arsenic	Wetterskip Fryslân
medicines	LC-MS	carbamazepine, coffeine, di-clofenac, erythromycine, gemfibrozil, metoprolol, naproxen, sotalol, sulfamethoxazol	Omegam
oestrogenic compounds	ER-Calux	bisphenol A, estron, EEQ**	Aquasense***
toxicity research	bio-essays	(not applicable)	RIZA

* volatile organohalogens, volatile aromates (eg. BTEX) and chlorinated benzenes
** EEQ = 17ß-oestradiol equivalents
*** analysed by Biodetection Systems, Amsterdam and Waterlaboratorium, Haarlem

Membrane performance

Since the start-up of the pilot MBR in September 2003, the permeability has shown a continuous decrease from 400 l/m²/h/bar at the start to 100 l/m²/h/bar in December 2004 (Figure 2). Chemical cleaning with hypochlorite and citric acid of the membranes to improve the membrane performance, only shows a positive effect for a short period of time. In September 2004 the air supply unit of the membrane tank, which ensures a continuous cleaning of the membranes, was also cleaned. This cleaning has improved the performance of the membranes for a much longer period and the permeability was 'stabilized' to a value around 100 l/m²/h/bar.

Sampling and analysing methods of micro-cantaminants

In 2004 influent and effluent of the MBR have been analysed for micro-contaminants at the laboratory of Wetterskip Fryslân and Omegam for determination of micro-contaminants. Specific analyses of hormones were performed by AquaSense and RIZA determined the ecotoxicity of the samples. In Table 1 an overview is given of the analysis techniques and the detected compounds of each method.

As shown, several persistent micro-contaminants were detected. The Dutch government has made a list of Maximum Tolerable Risk (MTR) values for the most abundant micro contaminants. This list is used to determine the minimal quality level of surface water. These MTR values are also used as a guideline for the determination of the quality level of the WWTP effluent. In general most of these compounds are already below the MTR values, except for simazine, cholesterol, diisobutylphtalate and di-n-octylphtalate.

Although the amount of measurements is limited, so far removal efficiencies tend to be low for the measured herbicides pesticides and phtalates. However steroids and nitrogen compounds appear to be effectively removed.

Furthermore it has to be noted that a lot of pesticide compounds could not be measured since their detection limit is relative high. Since the detection limits of some compounds are higher then the MTR values it still may be that individual compounds are exceeding the MTR value, but have not been detected. For example p,p-DDT has an MTR value of 0.9 ng/l, but its detection limit is 0.1 µg/l, so about 100 times higher.

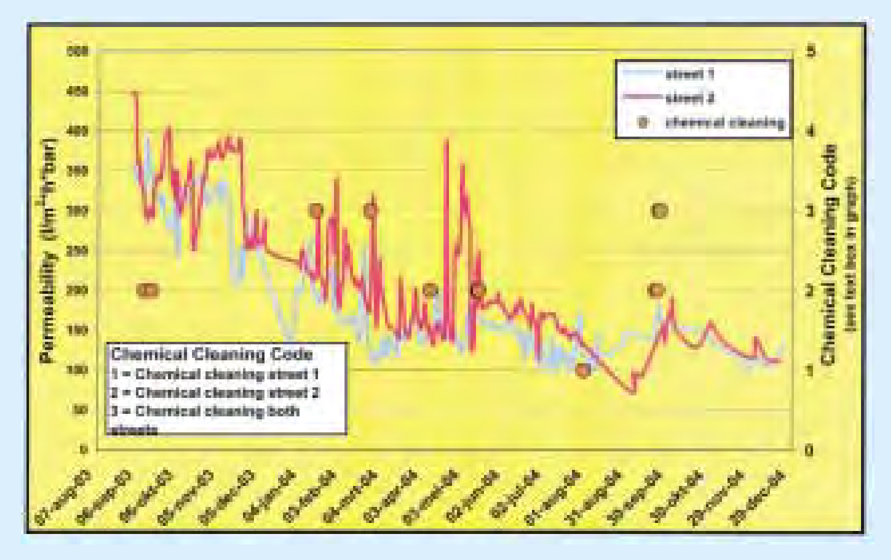


Figure 2: *Permeability of membranes in street 1 and 2 of the MBR Leeuwarden.*

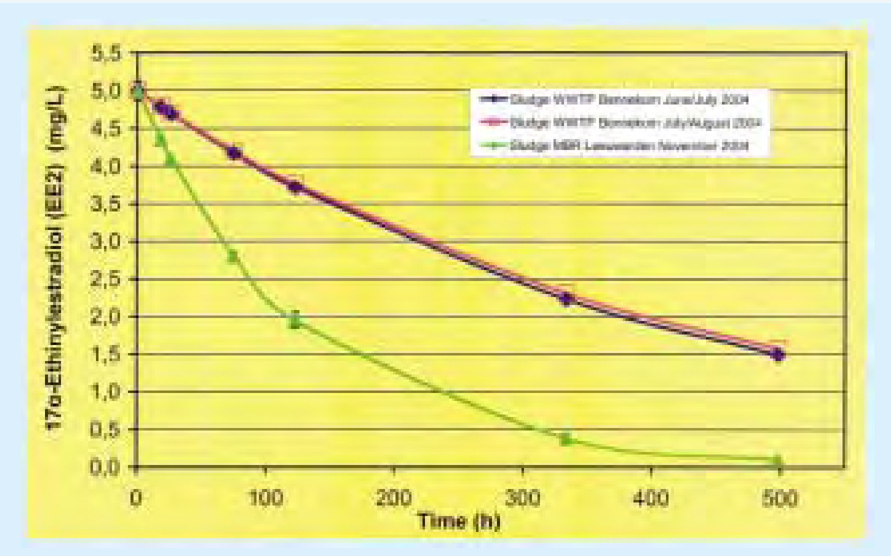


Figure 3: *Degradation activity of EE2 by MBR sludge (WWTP Leeuwarden) in comparison to activated sludge (WWTP Bennekom).*

The single measurement by Omegam so far showed similar medicine compounds as observed in a research by RIZA, such as analgetics (e.g. naproxen), ß-blockers (e.g. sotalol), cholestorol reducing medicines (gemfibrozil) and anti-epileptica (carbamazepine). Most of these detected medicine compounds show a reasonable removal, except for carbamazepine.

Hormone removal

Aquasense has reported that the absolute hormone WWTP effluent concentrations in the effluent of WWTP Leeuwarden were already very low compared to other WWTPs. However the post treatment by the MBR ensured even lower concentrations and ensured a high total hormone removal efficiency of on average 90% (ER-Calux method).

An additional hormone degradation activity test figure 3 was performed at the Wageningen University. It was shown that specific degradation activity of EE2 (17α-ethinylestradiol) by the MBR sludge was three times higher than activated sludge from the WWTP of Bennekom, while adsorption characteristics were identical.

Toxicity reduction

Measurements conducted by RIZA showed that the toxicity of the surface water and the effluent of the WWTP in Leeuwarden was relative low. The ECf50 factor is the concentration factor which causes at 50% of the organisms a toxic effect. The higher the number the lower the toxicity. As can be seen in table 2 the WWTP effluent samples should be concentrated at least 70 times to see 50% effect.

The effluent and the canal water have been tested again on two occasions (data between brackets) showing consistent values for the WWTP effluent and fluctuating values for the canals. The MBR effluent was only measured once and it showed on average a decrease of 1.5 times in toxicity in comparison to the MBR influent.

Table 2: *ECf50 values of influent and effluent of MBR at WWTP Leeuwarden compared to canals of the city centre of Leeuwarden (August 9th, 2004).*

	daphnia IQ test	algae test	bacterial test
effluent WWTP (= influent MBR)	216 (219 / 162)	74 (70 / 105)	71 (64 / 104)
effluent MBR	337	81	113
Canal City centre Leeuwarden	190 (841 / 400)	22 (40 / 209)	138 (170 / 333)

Discussion and conclusion

The pilot MBR is now running for 1.5 years on effluent of the WWTP. The preliminary results show a total hormone removal about 90% (ER-Calux method) and a good removal of medicine, steroids and nitrogen compounds. Furthermore it is shown that the high sludge age and low feed conditions have clearly selected a specific biological population with a three times higher hormone (EE2) degradation capacity in comparison to activated sludge.

Removal efficiencies tend to be low for the measured herbicides, pesticides and phtalates. However most of the detected compounds are already below the MTR value.

Looking at the measured data, simazine, diisobutylphtalate and di-n-octylphtalate exceed their MTR value in WWTP effluent and cannot be effectively removed under the present conditions with the MBR. These compounds are therefore of concern and should be monitored more frequently in order to determine if advanced treatment is required. It has to be noted that a lot of pesticide compounds could not be measured since their detection limit are relative high (even higher then MTR values). The low level of toxicity measured by RIZA in the same samples at least confirms that either these compounds were not present or had a very low concentration.

Previous research by RIZA showed that little is known about the environmental risk of the detected medicine compounds. Therefore new research should determine the chronical and specific effects of these medicine compounds on the aquatic environment. The acute toxicity of the detected medicine compounds however seems to be minimal since bio-essays of the same samples showed low toxicity.

In terms of ecotoxicity a reduction (1.5 times) has been observed by the application of a MBR. Then again the toxicity of the WWTP effluent was already very low and in case of Algae and Daphnia toxicity lower than the surface water in the canals of Leeuwarden. Therefore the need for MBR technology to further purify the effluent on this matter will be low.

Nevertheless, since the cultivated MBR sludge shows indeed good removal capacities for hormones and medicine residues, research will be continued and focussed on this specific subject.

Last but not least, in general efforts should be made to realise reliable measurement techniques, especially for pesticide compounds, which should have a detection limit below the MTR value of the specific compound.

Progress

The current situation will be more closely examined and focussed on the removal of hormones and the removal of micro-contaminants. A second EE2 activity test at Wageningen University is yet under investigation. Since the amount of measurements is very limited monitoring should be extended to determine the actual quality of the WWTP effluent and monitoring is required to support the current findings.

In the following research phase the research will be focused at the combined disposal of micro-contaminants and nutrients. For that purpose methanol will be dosed as a carbon source. Because it is the intention to preserve the unique biomass, which has been created up to now, the biomass will be put into a separate vessel in which it will be cultivated and preserved by a continuous feed of WWTP effluent. Also a lab-scale installation will be applied to perform specific micro-contaminant removal tests using the cultivated MBR sludge. ¶

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The growing importance of education for MBR staff, operators and management

The implementation of MBR technology for municipal wastewater treatment is growing fast in the Netherlands. The first MBR (pilot) installations were intensively and closely monitored by scientists, consultants and (senior) process-technologists.

For good operational results of MBR-installations it is essential that operators have sufficient knowledge of the processes and skills. The course 'Membrane Bioreactor' by Wateropleidingen, which examines all aspects of the MBR technology, has proved itself for technicians and operators in the last few years. The course is an interactive and intensive training given by highly qualified, enthusiastic and experienced teachers. The course members experienced a practical course that helped them with designing, building, managing or operating a membrane bioreactor installation.

The membrane bioreactor (MBR) is seen as the most promising wastewater treatment technology for the future. After successful treatment of industrial wastewaters and recent research programmes, the MBR technique has been optimised in the direction of low effluent concentrations and high flows. Unfortunately, the MBR technology and its implementation were growing faster than the related knowledge to design, build, support and operate such a wastewater treatment system. Especially the knowledge and skills of operators had been neglected, which can lead to bad references, high costs, and neglection of MBR technology. Wateropleidingen has therefore organised a number of MBR training programmes to support technologists and operators.

Nowadays the membrane bioreactor is starting to become a more ordinary wastewater treatment plant. Such wastewater treatment plants are controlled by operators, and just followed from a distance by more specialized (and often higher educated) personnel. The knowledge and skills of the operators becomes therefore more important for good and efficient operation of the MBR. Especially in case of some less known problems, like the optimalization of the membrane cleaning process. It is therefore very important to educate operators early in the process!

Development

In 2001 Wateropleidingen started, in co-operation with some experienced MBR specialists in the Netherlands, to develop a course to support technicians and operators. The focus of this course is to get insight of the MBR fundamentals and to help reduce risks in the realisation of full-scale systems. The first course was held in March 2002 and was visited by procestechnicians from the water authorities, some consultants and operators of industrial plants.

In October 2003 three operators of Water board Rijn en IJssel followed the course because they became responsible for the operation of the new pilot membrane bioreactor in Varsseveld. This was the beginning of a new phase in the development of the course.

At the end of 2004 Wateropleidingen organised a special course mainly for operators of Water board Hollandse Delta. They had to operate the new hybrid MBR which will be build at Heenvliet. The regular membrane bioreactor course of Wateropleidingen takes 2.5 days. The in-company course took three days. In those three days extra lessons were given by the senior procestechnologist of the Water board about the case of Heenvliet. A guest lecturer of the membrane supplier also gave a lesson on how to operate the membranes, including the cleaning process.

Course members are visiting the Beverwijk research project.

Regular course description

The MBR course of Wateropleidingen handles all aspects of the technology. The course is an interactive and intensive training given by highly qualified and experienced teachers. You will get an insight look into the working of a MBR and learn on how to evaluate the performance. You will learn how to assess the critical factors involved and how to control them.

The following items are covered during the course:

- principles of the MBR,
- membranes and their characteristics,
- biological processes in de MBR,
- interaction of the biology with the membranes,
- process control,
- operational costs and performance,

The course members experienced a course that helped them with designing, building, managing or operating a membrane bioreactor installation. Especially the practical experiences and enthusiastic contribution of the lecturers were highly appreciated.

Looking forward

In the (nearby) future there will be more wastewater treatment plants working with MBR-technology. The operators of those plants have partly other needs than the (process)technologists related to the design and building process of the plant. Therefore the operational knowledge of MBR plants will gradually be implemented in the wastewater courses like TAZ, about (waste)water treatment techniques and UTAZ about: comprehensive (waste)water treatment techniques of Wateropleidingen. The membrane bioreactor course will probably separate in a part for technicians and a part especially for operators.

Contact

For those who are interested in following this membrane bioreactor course in the Netherlands or in your home country please visit our website (www.wateropleidingen.nl) or e-mail to: info@wateropleidingen.nl. ¶

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Advertorial

NORIT cross-flow MBR: upgrading of process water for a malthouse

Membrane bioreactor applications are being used since the mid 1990s in industrial wastewater treatment. The treated water is free of particles and bacteria enabling the direct discharge to surface water or the reuse as process water. This article describes the benefits of the side stream cross-flow MBR systems for an 80% reuse of wastewater as high-grade process for a malthouse.

Since the 1970's, NORIT Membrane Technology (NMT) is active in the field of total solutions for industrial wastewater applications with the tubular membrane modules produced by her sister company X-Flow. A large variety of applications have been designed, built and commissioned.

The cross-flow mode is used most generally for industrial wastewater treatment applications. The main characteristic of cross-flow is that a part of the feed is withdrawn as permeate, while the other part is forced to flow along the membrane surface (Figure 1a). The pressure pump pressurizes the feed, while the circulation pump recirculates the concentrate; part of the concentrate is purged to the bioreactor. The advantage is a better control of the cake layer build-up resulting in a long time constant flux without any backwashing or cleaning-in-place. Typically, a system consists of several modules in-series (one street) and several streets in-parallel. NORIT CrossFlow MBR systems are available as standardised, modular skids. The modules are placed horizontally resulting in very reliable and compact installations (Figure 1b). Generally, the capacity of a cross-flow system is restricted to 100 m^3/h due to energy consumption limitations.

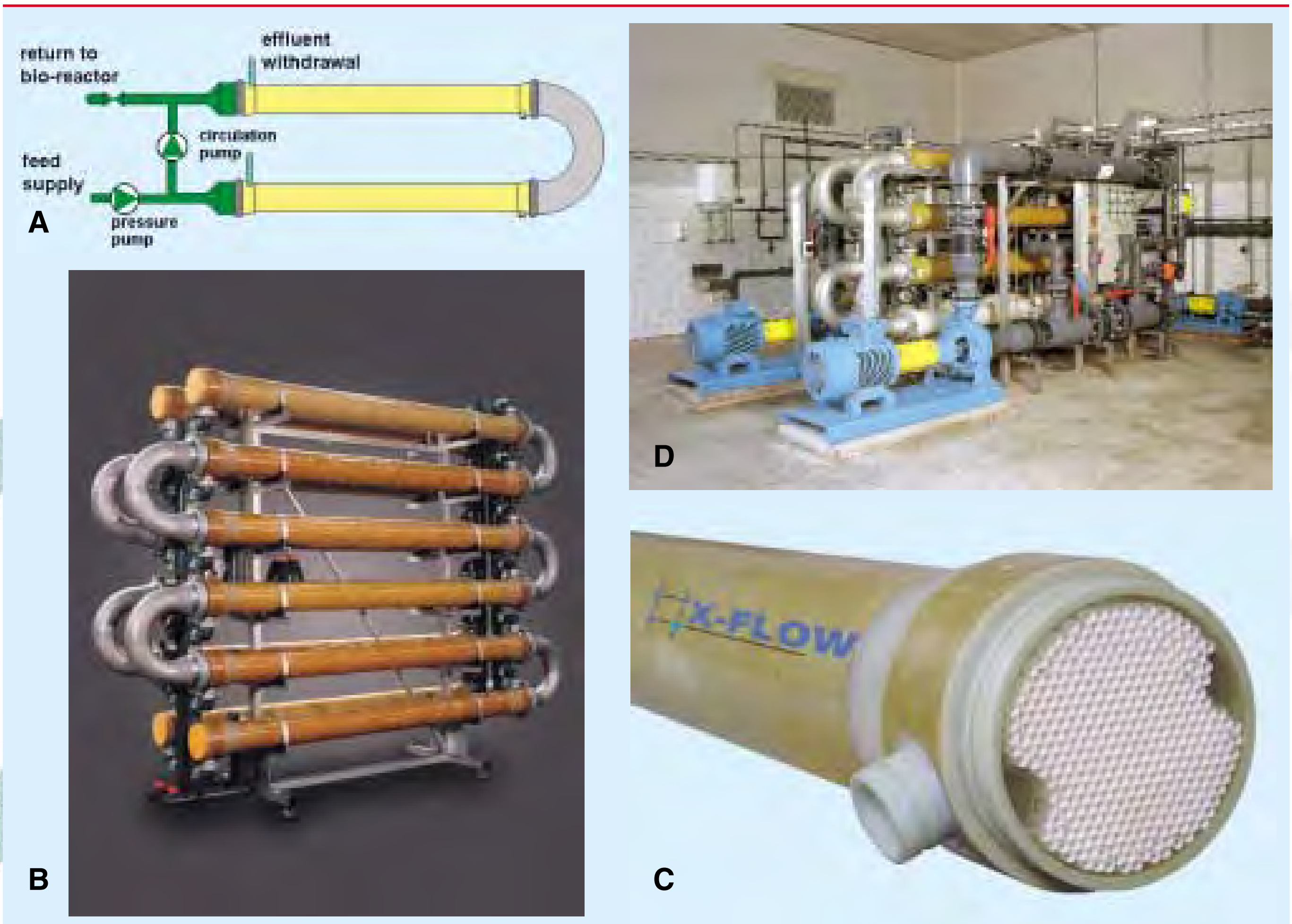
The heart of the cross-flow membrane installations is the 8 inch GPR module with the COMPACT ultrafiltration membranes with an inner diameter of 5 or 8 mm (Figure 1c). NORIT X-Flow has developed the NORIT CrossFlow MBR application high flux membranes with excellent anti-fouling behaviour. Together with an optimal Cleaning-in-Place (CIP) procedure the NORIT CrossFlow MBR process is an efficient solution for industrial wastewater treatment.

Figure 1d shows an example of a full scale cross-flow ultrafiltration installation being part of a MBR at a tank cleaning company. In all the MBR projects NMT can supply everything from the standardised skids to turn-key projects, where dedicated companies are subcontracted for the biological treatment part. Typical references are found in paper and pulp industry, food, beverage and dairy industry, chemical (process) industry, tank cleaning water recycling and leachate water treatment.

Description of the application

Holland Malt B.V. is erecting one of world's largest and most innovative malthouses at Eemshaven (in the Northern province Groningen, the Netherlands) having a malt production capacity of 130,000 metric ton. The feed stock of this plant will be around 165,000 metric ton of barley, which grows at 30,000 hectare of agricultural land. Holland Malt is a joint company of the Dutch brewery Bavaria (Lieshout), the Dutch agricultural co-operation Agrifirm

Figure 1: *Cross-flow system based on 8 inch modules: (a) basic configuration; (b) standard street; (c) 8 inch GFR module; (d) typical full scale installation.*



(Meppel), and around 600 farmers of brewer's barley combining the quality of Dutch barley with the knowledge and expertise of leading producers of malt and beer.

In May 2005, the new malthouse will start up and the wastewater treatment system will be commissioned. One of the main features of this treatment system is the reduction of the wastewater stream with 80% by reusing the treated water in the washing process.

The first steps in the malt process are the intensive washing of the barley followed by a soaking step in large tubs. During these steps the water is polluted with dust particles, sugar and starch. In currently operated malthouses the wastewater is biologically treated in a large bioreactor converting the organic components into carbon dioxide and nitrogen gas. After a rough clarification to remove the insoluble particles the water is discharged on the surface water. This commonly used treatment was not allowed anymore for this new malthouse and better treatment of the wastewater was required by the local authorities.

Description of the process

In order to cope with the strict water discharge requirements Holland Malt has decided to implement an advanced membrane bioreactor/activated carbon and ultraviolet disinfection water recycling plant.

The malt washing water is discharged three times a day and is collected in a large buffer. From this buffer a constant flow of wastewater passes a drum filter and flows into the biological treatment tank. The bioreactor is an intensive activated sludge (aerobic) process converting the organic components into carbondioxide and nitrogen. Next, the activated sludge is pumped to a four stage ultrafiltration system to separate the water from the biomass. The latter is recycled to the bioreactor, while the particle and bacteria free treated water is polished. First, the remaining odour is removed by NORIT Activated Carbon filtration after which the water is disinfected by ultraviolet disinfection before it is reused as process water. The quality of the produced process water is according to the Dutch drinking water requirements. This water recycling plant enables Holland Malt to reduce its effluent sewer volume dramatically to 20% enabling a five times reuse of the potable water. Table 1 summarizes the main process parameters.

Table 1: Process parameters.

parameter	unit	influent	effluent
feed flow rate	m³/h	65	55+10
temperature	°C	12-35	12-35
pH	-	6- 8	6- 8
TSS	mg/l	< 200	< 0.1
COD	mg/l	1,500	< 40
BOD	mg/l	1,350	< 5
N-kj	mg/l	50	< 5

Description of the system

NMT delivers the project turn-key. The construction of the water recycling plant has been finished and will be commissioned as soon as the erection of the malthouse will be ready. Figure 2 gives an impression of the bioreactor and the ultrafiltration cross-flow installation.

Concluding remarks

The installation of the wastewater treatment and water recycling plant has resulted in the following benefits:

- The intake of fresh potable water is reduced with 80%;
- The effluent discharge costs are reduced significantly; both the amount is decreased as well as the quality is improved allowing direct discharge to the local surface water;
- Reduced incoming water as well as discharge costs give double savings increasing return on investment;
- The plant is compact with a small footprint;
- The cross-flow system is robust with a simple process set-up requiring a low chemical use for a stable long term operation;
- The side stream modular built cross-flow membrane system reduces maintenance and gives clean operating conditions;
- Organic load reduction is achieved almost exclusively in the biological stage minimising chemical use in the process;
- The low-fouling tubular membranes have a proven record of a high life time.

The membrane bioreactor will be grafted in May 2005 followed by the commissioning of the water recycling system. Comparable water treatment systems are under investigation for several breweries in Europe. ¶

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Figure 2: Membrane bioreactor system: (left) bioreactor; (right) 4-stage ultrafiltration system.

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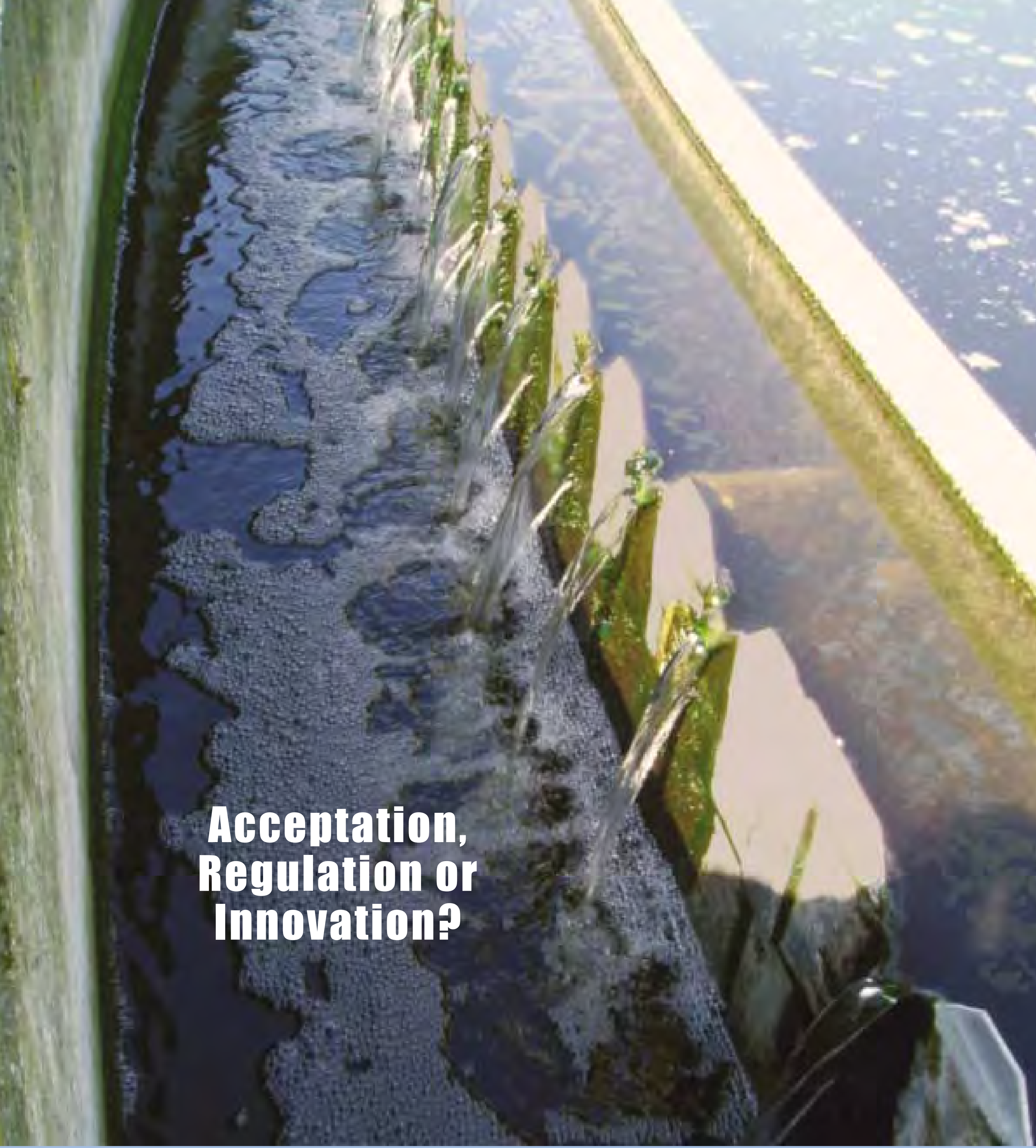
Acceptation,
Regulation or
Innovation?