Bij Europees MBR-onderzoek vervagen de grenzen

Arjen van Nieuwenhuijzen

dr.ir. A.F. van Nieuwenhuijzen
TU Delft/ Witteveen+Bos

1. Inleiding

Sinds oktober 2005 wordt in Europees verband intensief onderzoek verricht naar de verdere ontwikkeling en toepassing van MembraanBioReactor (MBR)-technologie voor de behandeling van communaal afvalwater. Versterking van de Europese marktpositie ten opzichte van Japan, Canada en de VS op het gebied van MBR is daarbij de leidraad. Hiervoor worden binnen twee onderzoeksprogramma's drie projecten door de EU gefinancierd, te weten: EUROMBRA, AMEDEUS en MBR-Train (daarnaast wordt tevens onderzoek verricht binnen PURATREAT). Overkoepelend wordt samengewerkt binnen het zogenaamde MBR-network. Binnen dit netwerk zijn ongeveer 50 Europese en Internationale instituten en bedrijven intensief aan het samenwerken. Met een totaal budget van ca. € 15 miljoen vertegenwoordigen de projecten momenteel de grootste gecoördineerde onderzoeksinspanning naar MBR-technologie ter wereld.

Dit uitgebreide onderzoeksnetwerk is tot stand gekomen doordat in de tender binnen het Special Targeted Research Program (STREP) naar MBR de twee onderzoeksconsortia EUROMBRA en AMEDEUS gelijkwaardig hoog scoorden. De EU besloot met verdubbeling van het totale budget om beide consortia te financieren onder voorwaarde dat zij samen zouden werken via zogenaamde Liaison Groups. Parallel aan de STREP procedure liep de selectie van een Marie Curie Fellowship Program waaruit MBR-Train als winnaar naar voren kwam. MBR-train is ondertussen opgenomen in het MBR-network of zo efficiënt mogelijk met de onderzoeksfaciliteiten en geldstromen om te springen.

De gezamenlijke onderzoekslijnen binnen het MBR-network richten zich op belangrijke technologische doorbraken, procesverbetering, kennis- en capaciteitsuitwisseling, ontwerp en realisatie op het gebied van MBR-technologie. Doel is uiteindelijk om te komen tot een bredere toepasbaarheid van de MBR en een verbeterde concurrentiepositie van het Europese bedrijfsleven op MBR-gebied.

Nederland is in het MBR-Network via EUROMBRA vertegenwoordigd door de Technische Universiteit Delft, UNESCO-IHE en het Waterschap Hollandse Delta. In MBR-Train participeren UNESCO-IHE en de TUDelft met ieder drie onderzoeksprogramma's. De Nederlandse bijdrage wordt internationaal zeer gewaardeerd. "Nederland heeft een belangrijke bijdrage geleverd bij de ontwikkeling en toepassing van de MBR-technologie voor de huishoudelijke afvalwaterbehandeling. De pionierende promotie- en onderzoeksinspanningen in STOWA-verband door o.a. DHV, Hoogheemraadschap Hollands Noorderkwartier en Waterschap Rijn en IJssel heeft zijn vruchten afgeworpen." Het is echter niet zo dat we er nu zijn. In vergelijking met de ontwikkeling van het actief-slibproces leven we nu misschien in de jaren 50 van de vorig eeuw. Toepassing wordt overwogen maar nog niet grootschalig toegepast. We hebben dus nog veel te leren. Hoogwaardig onderzoek, zowel fundamenteel als praktijkgerelateerd, is daarbij onontbeerlijk. Ook moet in Nederland niet de gedachte (blijven) heersen dat we het hier allemaal weten. Want wat met name een belangrijk resultaat van het MBR-network is, is dat over de grenzen heen gekeken kan worden. Zowel op het niveau van onderzoekers als ook van de eindgebruikers. Onderlinge kennis- en informatieuitwisseling heeft reeds diverse operationele knelpunten bij ontwerp, opstart en bedrijf van verschillende MBR's opgelost.

Om de internationale informatieuitwisseling ook vanuit de vakantiecursus 2007 zo optimaal mogelijk te maken is het vervolg van deze kennismaking met het onderzoeksconsortium MBR-network verder in het Engels opgesteld. Mogelijk dat hierdoor ook de vakantiecursus in de toekomst internationaliserend werkt en begin 2008 de eerste International TUDelft Winter Water Conference (ITWWC 2008) kan worden georganiseerd.

So, I continue in English……

2. MBR Technology

The technology of membrane separation of activated sludge, commonly referred to as "membrane bioreactor" (MBR), is the combination of activated sludge treatment together with a separation of the biological sludge by micro- or ultra-filtration membranes with pore size of typically 10 nm to 0.5 µm to produce the particle-free effluent. The latter step replaces the final clarifiers used in conventional activated sludge treatment which achieve solid separation by gravity only. The physical barrier imposed by the membrane system provides complete disinfection of the treated effluent. It also enables operation at higher sludge concentrations (typically up to 20 g/L instead of max. 6 g/L with conventional systems), and therefore permits to reduce the required footprint and/or sludge production. However, for municipal applications, the MBR technology is usually related to a higher total life cost, due to the high energy cost. In addition, the perceived risk related to the fouling and the replacement costs of the membrane remains an important limiting factor to its broad application.

2.1. Short history of MBR filtration systems

After initial development started in the late 60s, the MBR technology for wastewater treatment experienced rapid development from the early 1990's onwards. The first systems commercialised in the 70's and 80's were based on what have come to be known as sidestream configurations, i.e. the membrane separation step was employed in an external sludge recirculation loop, mainly with in-to-out flow through organic or ceramic tubular membranes. Due to the high energy demand, these technologies targeted only small and niche market applications such as treatment of ship-board sewage, landfill leachate or industrial effluents.

In the early 90's, the Japanese Government launched an ambitious 6-year R&D project which led to a major technological and industrial breakthrough of the MBR process: the conception of submerged membrane modules, working with low negative pressure (out-to-in permeate suction) and membrane aeration to reduce fouling. This paved the way towards a significant reduction of capital and operation costs, due to the reduction and simplification of equipment and the abandonment of the energy demanding sludge recirculation loop.

Nowadays, two types of technologies of submerged membrane modules are predominant on the MBR market. Both feature out-to-in permeate filtration and comprise the flat-sheet (or plate & frame) membrane module and the hollow fibre membrane module. Novel and alternative MBR filtration systems have recently appeared in the market and we can expect that the most innovative products will raise commercial interest in the coming years.

The commercialisation of the submerged MBR system precipitated rapid and extensive market penetration. The first pilot-scale European submerged MBR plant for municipal wastewater was built in 1996 (in Kingston Seymour, UK), soon followed by the construction of the full-scale Porlock WWTP (UK, commissioned in 1998, 3,800 p.e.), Büchel and Rödingen WWTPs (Germany, 1999, resp. 1,000 and 3,000 p.e.), and Perthes-en-Gâtinais WWTP (France, 1999, 4,500 p.e.). A few years later only, in 2004, the largest MBR plant worldwide was commissioned to serve a population of 80,000 p.e. (in Kaarst, Germany). In 2005 MBR Varsseveld (18.000 p.e.) was the first fully operational MBR in the Netherlands followed by the MBR Heenvliet (9.000 p.e.) in 2006 and later on the MBR Ootmarsum. The size of installations has thus grown from few thousand to hundreds of thousands population equivalent in only a few years.

2.2. Industrial and Municipal MBRs in Europe

By 2006, around 100 municipal full-scale plants with a capacity >500 p.e. were in operation in Europe, and around 250 large industrial plants with a capacity >20 m^3/d. The development and successful commercialisation of the technology in the past few years has led to significant decrease in capital and operating costs. However, the delineation between municipal and industrial systems shows that the technology remains especially competitive for industrial applications. In the municipal sector, it is now considered that for a green field and for a given treatment quality the capital cost of MBR plants is comparable to a conventional scheme. However, the energy costs remain 30 to 50% higher. Should this discrepancy be reduced in the coming years, the MBR technology would become a State-of-the-Art process for the municipal sector.

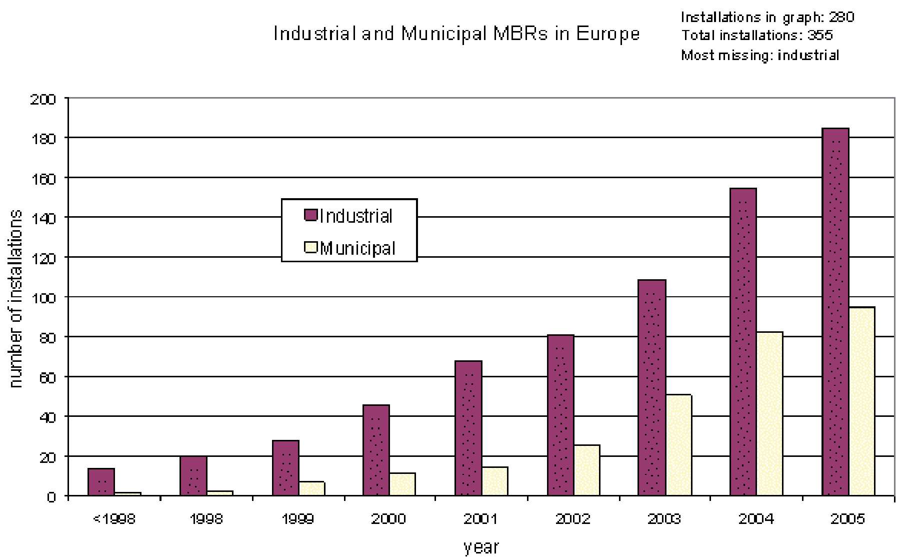


Figure 1 - MBR installations in Europe anno 2006

3. MBR-Network: the cluster of EU projects dedicated to the MBR technology

The European Commission has decided to promote the development of the MBR technology while funding four projects entirely dedicated to research, development, capacity building and technological transfer in regards to this promising wastewater treatment process. The four projects, namely AMEDEUS, EUROMBRA, MBR-TRAIN and PURATREAT are supported by three different financial instruments set up by the European Commission within the sixth Framework Program, and will be implemented in parallel from October 2005 up to December 2009.

Around 50 European and international companies and institutions are actively involved in these four projects and will join their efforts and co-ordinate their actions within the cluster "MBR-Network". The four projects amount to a total budget of ca. EUR 15 Million, for which ca. EUR 9 Million will be financed by the European Commission. They represent the largest co-ordinated research initiative world-wide dedicated to MBR technology since the first developments of this treatment process in the early 90's.

Important technological breakthroughs, process improvement, knowledge and capacity transfer and building are expected, which will lead to better acceptance, competitiveness and broader implementation of the technology in both municipal and industrial fields.

3.1. EUROMBRA

EUROMBRA's subtitle is Membrane bioreactor technology for advanced municipal wastewater treatment strategies. EUROMBRA is a Specific Targeted Research Project supported by the European Commission under the Sixth Framework Programme (Priority "Global Change and Ecosystems") with a project duration of 3 years, between 01/10/2005 - 30/09/2008. The total budget is €4.2 Million (incl. €3.0 Million EU subvention and €0.2 Million from the Australian government).

<u>Project description</u>

The World is running out of clean, safe, fresh water. By 2025 one third of humanity (ca. 3 billion people) will face severe water scarcity. This has been described as the "single greatest threat to health, the environment and global food security". Water is essential and preservation of its safety in quantity and in quality is critical to the sustainable development of any society. The goal of this project is to make a contribution to meet this challenge. The protection of water in the European Union has been encouraged through the Water Framework Directive (WFD). The intention of WFD is to protect water resources (quality and quantity) through an integrated water resource management policy. Wastewater treatment is an important aspect of water management. Efficient, cost effective treatment processes are needed for transforming wastewater into water free from contamination which can be returned to the hydrological cycle without detrimental effects. The development and application of MBR for full scale municipal wastewater treatment is the most important recent technical advance in terms of biological wastewater treatment. It represents a decisive step further concerning effluent quality by delivering a hygienically pure effluent and by exhibiting a very high operational reliability.

The overall objective of EUROMBRA is to develop a cost-effective, sustainable solution for new, efficient and advanced municipal wastewater treatment based on MBR technology. This will be achieved through a multi-faceted, concerted and cohesive research programme explicitly linking key limiting phenomena (fouling, clogging) observed and quantified on the micro-, meso-, and macro-scale. Key to the success of the programme is the harnessing of specialist knowledge, conducting of dedicated yet interlinked experiments and incorporating key aspects of both system design and operational facets, the latter encompassing hydrodynamics and mass transfer, foulant speciation and dynamic impacts.

Strategic objectives

The overall project objectives are to develop sustainable solutions for new, efficient and cost-effective advanced wastewater treatment technologies for municipal wastewater based on membrane bioreactor technology. The specific objectives of the programme are:

- Assessment and comparison of different configurations of membranes and membrane modules
- Development of new methods for qualitative and quantitative analysis of foulants, both short and long term
- Assessment of the impact of identified foulants under a range of conditions representative of those encountered in practice
- Study of the use of novel single-filament or other dedicated test cells for optimisation and predicting behaviour at larger a scales
- Appraisal of antifouling strategies, both for short and long-term fouling, with specific reference to key adjustable operational parameters such as imposed flux, aeration and cleaning
- Assessment of the impact of dynamic effects, such as sudden increases in hydraulic and organic loading
- Examination of possible impacts of and on microbial speciation and diversity
- Examination of removal of specific contaminants through appropriate integration within process treatment scheme
- Assessment of residuals management
- Overall cost benefit analysis
- Dissemination of results

Partners

The following partners are involved within EUROMBRA:

- Norwegian University of Science and Technology (NTNU), Norway - Trondheim
- Cranfield University (CRAN), United Kingdom - Bedford
- Department of Chemical Engineering (IVT), RWTH Aachen University (RWTH), Germany - Aachen
- Instituto de Biologia Experimental e Biológica , Lisboa (IBET), Portugal - Lisboa

- Institut National des Sciences Appliquées (INSA), France - Toulouse
- University of Montpellier II (UM II), France - Montpellier
- Delft University of Technology (DUT), Netherlands - Delft
- Università degli Studi di Trento (UNITN), Italy - Trento
- Polymem (POLYM), France - Toulouse
- University of KwaZulu-Natal (UKZN),South Africa - Durban,
- University of Technology of Sydney (UTS), Australia - Sydney
- Institute for Water Education (UNESCO-IHE), Netherlands - Delft
- Swiss Federal Institute for Environmental Science and Technology (EAWAG), Switzerland - Dübendorf
- Water board Hollandse Delta (WHD), Netherlands - Dordrecht
- Erftverband (EV), Germany - Bergheim / Erft
- Millenniumpore Limited (MILL), United Kingdom - Washington, Tyne & Wear
- KOCH Membrane Systems (KMS), Germany - Aachen
- FlowConcept (FLCO), Germany – Hannover

Workpackages

The EUROMBRA project is structured in 10 Workpackages as illustrated in Figure 2. Although MBR technology is currently available on a commercial level as an optional solution for treating municipal wastewater the development of the technology and industry is still in its infancy. In comparison with other membrane based technologies and applications, i.e. nanofiltration and reverse osmosis, there has been a very little degree of standardization within the MBR industry. MBR solutions that are available on the market today differ in many aspects related to choice of membrane material, module design, recommended operating modes and ranges, strategies to maintain a sustainable and economic opera-

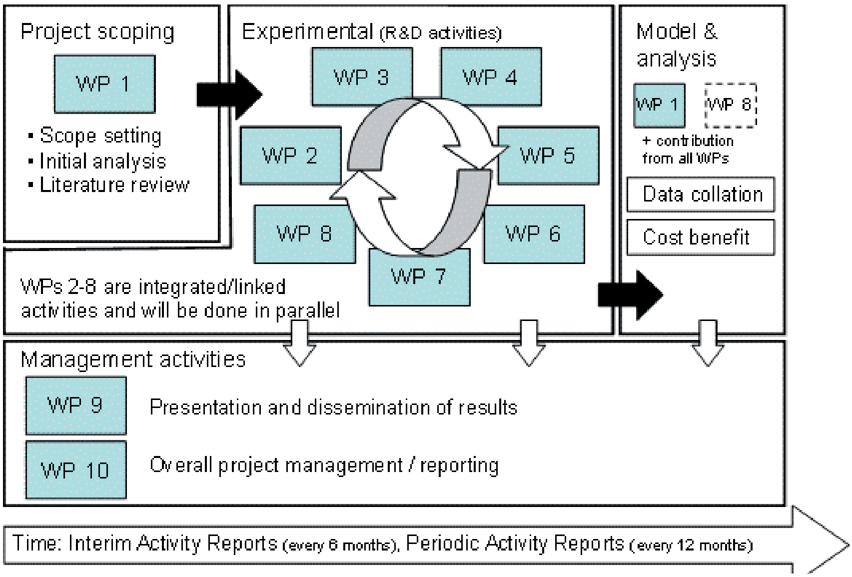


Figure 2 - Project scope of EUROMBRA

tion, and footprint. The reason for this diversity is due to attempts in overcoming the challenges and bottlenecks found in MBR processes while making sustainable and economically sound process solutions. A key to the further development and standardization of the technology is having a better understanding of the challenges specific to the technology and finding efficient ways to overcome the bottlenecks. An overall goal of the EUROMBRA project is to improve the basis of MBR technology by integrating fundamental research and implementation of the new technology in the steps towards an established and standardised industry:

- WP1 Project scoping
- WP2 Membrane module
- WP3 Aeration and membrane operation (TUDelft involved)
- WP4 Process configuration (TUDelft involved
- WP5 Feedwater characterisation and MBR monitoring (TUDelft main research)
- WP6 Cleaning protocols
- WP7 Concentrate / sludge handling
- WP8 MBR case studies (TUDelft project leader, WSHD main contributor)
- WP9 Presentation and dissemination of results
- WP10 Overall and scientific coordination

3.2. AMEDEUS

AMEDEUS stands for Accelerate Membrane Development for Urban Sewage Purification and is part of the Specific Targeted Research Project supported by the European Commission under the Sixth Framework Programme (Priority "Global Change and Ecosystems") with a project duration of 3 years, between 01/10/2005 - 30/09/2008. The total budget is €5.9 Million (incl. €3.0 Million EU subvention and €0.2 m from Australian government).

<u>Project description</u>

Over the past decade, membrane bioreactors have been increasingly implemented to purify municipal wastewater. However, even with submerged membranes which offer the lowest costs, the MBR technology remains in most cases more expensive than conventional processes. In addition, the European municipal MBR market is to date a duopoly of two non-European producers, despite many initiatives to develop local MBR filtration systems.

The AMEDEUS research project aims at tackling both issues, accelerating the development of competitive European MBR filtration technologies, as well as increasing acceptance of the MBR process through decreased capital and operation costs. The project will target the two markets for MBR technology in Europe: the construction of small plants (semi-central, 50 to 2,000 pe, standardized and autonomous), and the medium-size plants (central, up to 100.000 pe) for plant upgrade. Technological development of new MBR systems will be fostered by a consortium composed of 12 partners, of which five SMEs proposing novel concepts of low-cost and high-performance filtration systems. Two end-users, three non-profit institutions and two universities, all of them well versed in R&D in the MBR field, will investigate solutions to reduce operation costs such as fouling control, membrane cleaning optimisation, aeration decrease, or optimise capital costs through improved implementation of membrane bioreactor process. Furthermore, an analysis of the potential for standardisation will be performed, and a technology transfer towards Southern and Eastern Europe will be organised in order to facilitate the penetration of these new markets.

AMEDEUS will achieve concrete and realistic technological breakthroughs for the MBR technology, and improve the current process engineering and operation practices. It will improve the competitiveness of the MBR European market and render common this high-tech process for municipal wastewater treatment.

Strategic objectives

The project objectives are:

- To reduce both capital and operation costs of the MBR technology in Europe, and to minimise its environmental impact, in order to increase its competitiveness with respect to conventional technologies;
- To increase the share of the European companies in the market of MBR plants, in EU as well as worldwide, while strengthening the MBR European market;
- To facilitate the implementation of the European directives on the treatment of wastewater for discharge or bathing waters, as well as increase the potentials for non potable reuse of treated effluent.

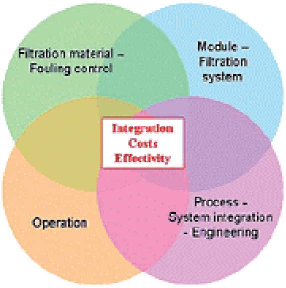
Partners

The following partners are involved within AMEDEUS:

- Berlin Centre of Competence for Water (KWB), Germany - Berlin
- University of Technology Berlin (TUB), Germany - Berlin
- Tecnotessile (TTX), Italy - Prato
- Flemish Institute for Technological Research (VITO), Belgium - Mol
- inge AG (INGE), Germany - Greifenberg
- Millenniumpore Limited (MILL), United Kingdom - Washington, Tyne & Wear,
- Anjou Recherche / Veolia Water (AR), France - Maisons-Laffitte
- Aquafin (AQF), Belgium - Aartselaar
- Polymem (POLYM), France - Toulouse
- A3 water solutions GmbH (A3), Germany - Gelsenkirchen
- Envi-Pur (ENVI), Czech Republic - Tabor
- University of New South Wales (UNSW), Australia – Sydney

Workpackages

The AMEDEUS project is structured in 11 Work Packages which will address the 4 technological fields of MBR process to achieve overall improvement and increased acceptance of the technology: (1) Filtration material and fouling control, (2)



Module and filtration system, (3) Process, system integration and engineering, (4) Operation (see Figure 3):

- WP1 Textile material for MBR filtration
- WP2 Fouling control strategies and on-line sensors of fouling indicators
- WP3 Development of 4 innovative MBR technologies and optimised cleanings
- WP4 Analysis on standardisation of MBR
- WP5 Biological modelling of MBR and impact of primary sedimentation
- WP6 Implementation of submerged module inside or outside of reactor
- WP7 Design of a range of containerised and standardised MBR plants
- WP8 Advanced data acquisition, supervision and control system for MBR
- WP9 Design and control of dual MBR configurations for plant refurbishment
- WP10 Results integration, dissemination and clustering activities
- WP11 Management and reporting

3.3. MBR-TRAIN

The working title of MBR-Train is Process optimisation and fouling control in membrane bioreactors for wastewater and drinking water treatment. MBR-Train is part of the Marie Curie Host Fellowship for Early Stage Research Training supported by the European Commission in the Sixth Framework Programme (Structuring the European Research Area; "Marie Curie Actions") with a total project duration of four years, between 01/01/2006 - 31/12/2009. The total budget is €2.05 Million

Project description

The research project MBR-TRAIN provides an Early Stage Research Training on process optimisation and fouling control in membrane bioreactors for water treatment. Membrane bioreactors (MBRs) which combine biological treatment with a membrane separation step are among the most promising emerging technologies in the water treatment sector.

As membrane fouling has been identified as a major barrier to sustainable MBR application, MBR-TRAIN undertakes dedicated efforts to characterise and investigate both biological and physico-technical aspects of this phenomenon and to develop strategies to control it. The overall aim is to optimise the operation of MBRs taking into account inter alia membrane types, materials and configuration, operational settings as well as economic aspect. The findings shall be used to advance the modelling of MBR processes in order to improve the prediction of plant performance. The scope of the offered research projects ranges from laboratory scale experimental set-ups to pilot- and full-scale operational plants.

Developing MBR technology is an interdisciplinary task. Understanding the mutual interactions between biological system and membrane separation requires knowledge in a combination of fields as diverse as analytical chemistry, microbiology, polymer and surface science, fluid dynamics, systems technology, civil and chemical engineering. Hence the consortium of MBR TRAIN comprises 10 partners from the water-industry, research institutes and universities across Europe representing a cross-section of relevant disciplines, sectors and regions. Due to its consortium composition, the MBR-TRAIN project provides an ideal framework for young researchers to prepare for future assignments in intersectorial tasks pursuing a research career in both academic institutions and industrial enterprises.

MBR-TRAIN offers the young researchers a well organised and structured training programme in a technology field of growing relevance. They will benefit from a tutored PhD thesis work with additional scientific training offered in short-courses or workshops. The exchange of personnel between the participating institutions will train adapting to work in different research structures. In order to bring benefit to the researchers' careers beyond a merely scientific formation, MBR-TRAIN will provide training on complementary skills such as presentation techniques, communication skills, intellectual property rights or research project management.

Strategic objectives

The strategic objectives of MBR-Train are:

- To enhance the intersectorial collaboration in an interdisciplinary field that is considered crucial for sustainable development, the field of water technologies,
- To contribute to overcoming the fragmentation within European research hence strengthening the European Research Area.

Partners

The following partners are involved within MBR-Train:

- Department of Chemical Engineeing RWTH (IVT), Aachen University (RWTH), Germany – Aachen
- Istituto di Ricerca Sulle Acque Consiglio Nazionale delle Ricerche (IRSA-CNR), Italy - Roma
- Aquafin (AQF), Belgium - Aartselaar
- Cranfield University (CRAN), United Kingdom - Bedford
- Berlin Centre of Competence for Water (KWB), Germany - Berlin
- Ghent University (UGent), Belgium - Ghent
- Brno University of Technology (BUT), Czech Republic - Brno
- Politecnico di Milano (POLIM), Italy - Milan
- RWE Thames Water (RWE), United Kingdom - Reading
- Delft University of Technology (DUT), Netherlands - Delft

Workpackages

MBR-TRAIN focuses its efforts on the open questions of viable MBR technology application while utilising different approaches and methodologies pursued in the participating institutions.

MBR-TRAIN concentrates its efforts on the open questions of viable MBR technology application while utilising different approaches and methodologies pursued in the participating institutions.

The research addresses the following topics and aspects (see Figure 4):

1. Membrane types, materials and configuration
2. Foulants and fouling characterisation
3. Biological processes, sludge interactions
4. Fluid dynamics
5. Operational cost
6. General process performance

One particular aspect of all projects is their training character and the formation they shall provide to the young researchers.

In total, MBR-TRAIN offers 19 individual research projects of different duration, which will be investigated by a single fellow, but always in close co-operation and exchange with the other project partners, which is expressed in mandatory exchanges of personnel throughout the training duration.

- WP1 MBR data acquisition, instrumentation and control
- WP2 Modelling of enhanced biological phosphorus removal (EBPR) in MBR
- WP3 Comparison of the performance of hollow fibre and flat sheet immersed MBR processes operating at full
- WP4 Optimisation of operational costs in a full-scale MBR
- WP5 Application of MBR models in full-scale plants
- WP6 Characterisation and determination of filterability within MBRs (TUDelft topic)
- WP7 Impact of chemical cleaning agents on membrane material
- WP8 Optimisation of full scale MBR operation for decentralised treatment

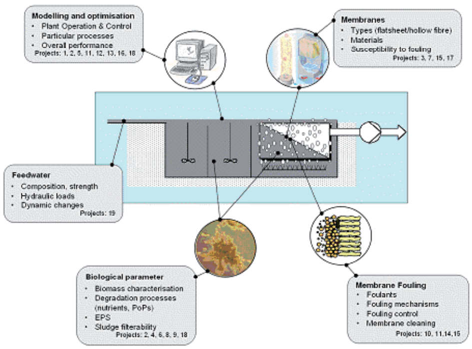


Figure 4 - Project scope of MBR-Train

- WP9 Comparison of operational processes of three full-scale MBRs (TUDelft topic)
- WP10 Investigation of MBR fouling by particles, colloidal and soluble organic matter
- WP11 Experimental and theoretical investigations on the influence of permeate back-flushing on fouling
- WP12 Computational fluid dynamics applied on MBR systems
- WP13 Process optimisation and biomass characterisations
- WP14 Fouling control in a household MBR plant
- WP15 Influence of membrane material properties on fouling in MBRs
- WP16 The fate of persistent organic pollutants (POPs) in MBR for drinking water use
- WP17 High-shear ceramic air-lift MBR for sludge treatment
- WP18 Mathematical modelling and process control of MBRs
- WP19 Effect of dynamic changes of feedwater on operational parameters within MBRs (TUDelft topic)

4. *MBR-network focus: The Hybrid MBR concept*

Within the EUROMBRA consortium the Hybrid MBR Heenvliet of Waterboard Hollandse Delta plays an essential role. MBR Heenvliet is the first fully operational Hybrid MBR of its kind in the World. The Heenvliet Hybrid MBR provides a good opportunity to study the system behaviour under typical Dutch circumstances (high rwf/dwf-ratio's) 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 Hybrid 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 series and in parallel. MBR Heenvliet is thé European Full Scale Test MBR for communal wastewater within the EUROMBRA project. Several artners from the MBR-network focus momentarily on MBR Heenvliet to learn and conduct essential research.

From an operational point of view, the hybrid MBR concept 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 concept, where the membranes will have to be designed at storm weather flows.

The Heenvliet Hybird MBR consists of the following parts (see Figure 5):

Screening. The influent will be treated in screens with plates 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 membrane system. Flat sheet membranes are expected to be less sensitive for pollution than hollow fiber membranes.

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

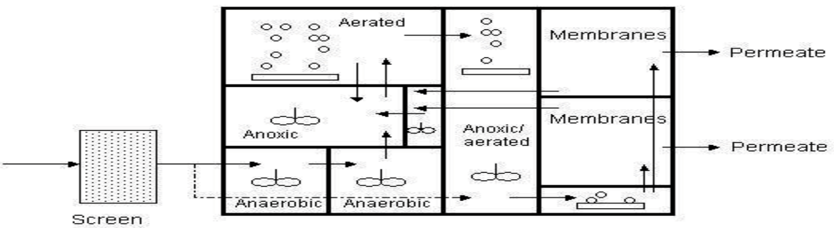


Figure 5 - Flow sheet of the MBR

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 P-removal, $FeCl_3$ can be dosed in order to reach the required very low effluent concentrations.

Membrane tank. The 2 parallel membrane tanks are equipped with Toray flat sheet membranes. With a pore size of 0,08 µm this can be classified as ultrafiltration. By having 2 membrane tanks there will be flexibility in the hydraulic membrane load, because the flow can be distributed in different proportions over the two tanks.

The Heenvliet Hybrid MBR concept can be operated in two ways:

1. MBR in parallel with the conventional lane
   During dry weather flow, the MBR will be treating relatively more wastewater than 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 (flow control). This type of operation is referred to as parallel hybrid operation.

2. 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 6).

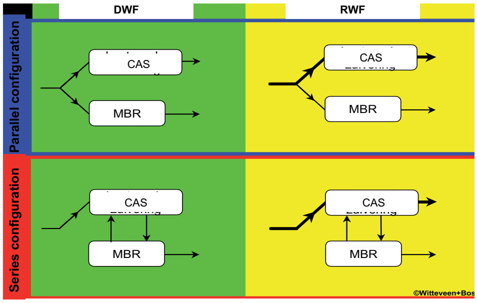


Figure 7 - Flow sheet of the parallel and in-series-hybrid configuration of the Heenvliet Hybrid MBR concept (dwf = dry weather flow, wwf = wet weather flow)

In this so called 'in series hybrid configuration' the clarifier also functions 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 (flow control, sludge concentration control). In this way the conventional clarifier is producing effluent discontinuously, increasing the overall effluent quality compared to parallel hybrid configuration.

During parallel hybrid operation, the influent will always be distributed over both systems in the same ratio and the sludge loading rate will be equal. This enables a direct comparison between performance of both systems of a very low loaded conventional system and an MBR system.

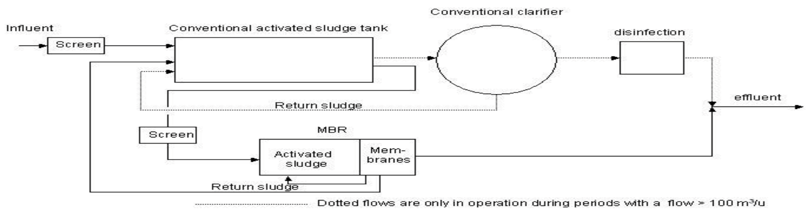


Figure 6 - Flow sheet of the in-series-hybrid configuration

With the in series hybrid configuration the membrane filtration step can be optimised without the risk of overloading the conventional plant during wet or storm weather. This provides the opportunity to upgrade the plant with a minimum loss of overall effluent quality.

5. *Filtration characterisation of feedwater and sludge for MBR optimisation*

Another Dutch input in EUROMBRA is the Delft Filtration Charactersation Installation (DFcITM). This innovative and unique testing equipment to determine the filtration characteristics of activated sludge and feedwater of MBR's is being used in several workpackages within EUROMBRA and MBR-Train. By supplying research facilities and knowledge on this topic Delft University of Technology is one of the central and leading research partners within MBR-network.
For research into membrane fouling Delft University of Technology, within the PhD-research of Herman Evenblij, has developed a small-scale Filtration Characterisation Installation (FCI) and an accompanying measuring protocol. The DFcITM is represented schematically in Figure 8. The FCI is not intended as a lab-scale MBR installation aiming at imitating the MBR process on a long term, but is a measuring tool for short-term assessment of the fouling properties of a given MBR activated sludge sample. The heart of the installation is formed by a single sidestream ultrafiltration membrane tube (X-flow, diameter 8 mm, nominal pore size 0.03 μm). A peristaltic pump is used to recirculate the sludge; cross-flow velocity is adjustable. Permeate is extracted with another adjustable peristaltic pump, so the flux can be regulated. With the DFcITM it is possible to filtrate MBR activated sludge samples collected under different circumstances or from different MBR installations under identical circumstances.

In order to obtain unequivocal results a standard measuring protocol was formulated, consisting of three steps:

1. Clean Water Resistance determination.
   Demineralised water is recirculated with a cross-flow velocity of 1.0 m/s and filtrated with a flux of 80 l/m^2*h to verify whether the membrane is clean prior to sludge filtration. Clean water resistance should be around $0.5*10^{12}$ m^{-1}.
2. Sludge filtration, the actual experiment.
   A sample of about 30L is poured into the activated sludge vessel en kept in suspension by stirring and/or aeration. The sample is recirculated with a cross flow velocity. Permeate can be extracted with any desired flux (0-160 L/m^2*h).
3. Membrane cleaning.

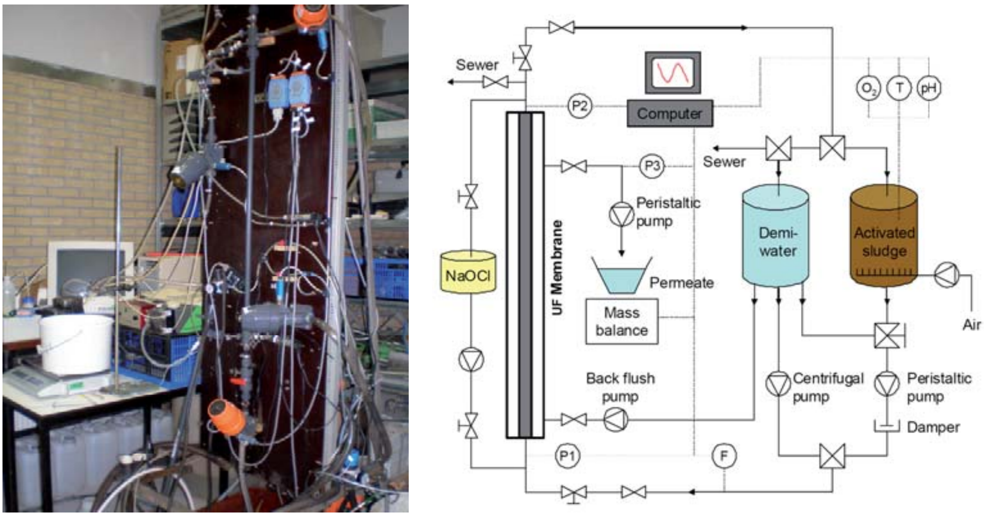


Figure 8 - Schematically representation of the Delft Filtration Characterisation Installation (DFcITM)

After sludge filtration the membrane has to be cleaned. For this (a combination of) three methods can be used:

- Forward flush with demineralised water (crossflow velocity about 4 m/s, 30 seconds)
- Back flush with demineralised water (TMP about -0.6 bar, 30 seconds)
- Chemical cleaning, soaking with NaOCl (500 ppm, 20 minutes)

After the membrane cleaning the clean water resistance is determined again to verify whether the membrane has been cleaned properly. If not supplementary more intensive chemical cleaning (NaOCl, 1500 ppm) can be applied.

The Mobile version of the DFcI as it is developed by Delft University of Technology is a tool which characterises sludge fouling tendencies. Filtration tests of different full scale MBR sludges with the test Unit enable a database formation. This database can be used as a comparison starting point.

The Mobile DFcI Unit can also be combined with batch tests. Dynamic changes can be investigated by manipulating the sludge (30L sample) and by monitoring differences in sludge fouling behaviour. Impacts of substrate, pH, aeration, dilution factor were already examined.
The Mobile DFcI Unit can also be useful during starting up or optimisation of full-scale MBR plants. Indeed monitoring the sludge characteristics during a long-term period can provide information about the sludge behaviour and evolution. Then actions can be taken quickly.
There is not any specific requirement depending on the location of the MBRs (pilots or full scale plants). The Mobile DFcI Unit only needs some 220V power supply and a sewage discharge.
However, water analysis facilities should be supplied by the host / partner university (EPS, MLSS, SVI, turbidity).

As an example of results of a measuring campaign with the DFcI Figure 9 represents the filterability (DRv=20 is the value of the membrane total resistance after 20L/m^2 of permeate extraction) depending on the suspended solid concentration.

6. *Results, Progress and Planning*

At time of preparation of the manuscript of this article the yearly reports per workpackage were in the final phase of delivery for the EUROMBRA and AMEDEUS projects. Due to the MBR-network broad Confidentiality Agreement the results presented in these reports are not yet open for public. However, the first results of specific workpackages will be presented during the Vakantiecursus. Recently the presentations and abstracts of the First EUROMBRA MembranBioReactor Conference held in Trondheim in July 2006 are available on www.mbr-network.eu. Also the White Paper on Standardisation of MBR-technology as discussed within MBR-network in co-operation with DIN and

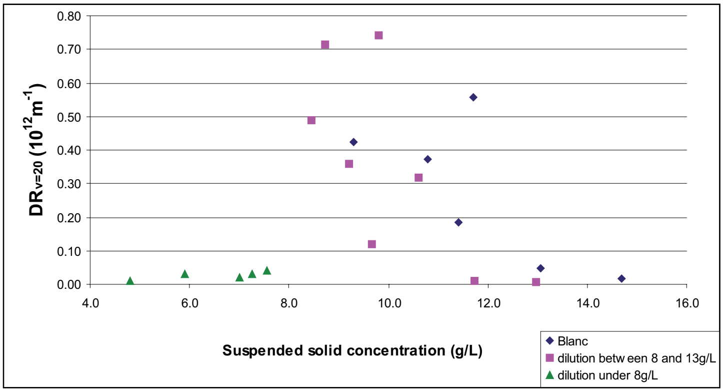


Figure 9 - Filterability versus sludge content

EC are available on this site. Another future podium for presentation of research results from all MBR-network projects will be the 4th International IWA Membrane Conference in Harrogate, in May 2007 (www.iwamembranes.info). This conference is also host of the Mid-term meeting of the EUROMBRA and AMEDEUS projects.

7. Conclusions

The MBR-network represent the largest co-ordinated research initiative world-wide dedicated to MBR technology since the first developments of this treatment process. Important technological breakthroughs, process improvement, knowledge and capacity transfer and building are expected, which will lead to better acceptance, competitiveness and broader implementation of the technology in both municipal and industrial fields. Within the MBR-network Dutch research institutes, companies and end-users are developing valuable information to optimise MBR-technology, making it a more competitive technology in Europe and in the Netherlands. Joint research not only produces advanced technology but also results in important and constructive knowledge exchange. All involved parties will get richer from this, on technology, knowledge and open minds.

Joint European research into MBR-technology opens boarders!

8. Acknowledgements

This piece of work is the product of international co-operation. So, many thanks to Stefan Geilvoet, Adrien Moreau, Maria Concecao Ferreira, Jaap de Koning, Jaap van der Graaf and all MBR-network participants.

More information on the MBR-network is available on www.mbr-network.eu