PROJECT AMEDEUS
"ACCELERATE MEMBRANE DEVELOPMENT FOR URBAN SEWAGE PURIFICATION"

FINAL ACTIVITY REPORT

SIXTH FRAMEWORK PROGRAMME
Priority 1.1.6.3
"GLOBAL CHANGE AND ECOSYSTEMS"

SPECIFIC TARGETED RESEARCH PROJECT

Executive summary

Project objectives and consortium

Over the past decade, membrane bioreactors have been increasingly implemented to purify municipal wastewater. However, even with submerged modules which offer the lowest costs, the membrane bioreactor (MBR) technology remains in most cases more expensive than conventional activated sludge 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.

In 2005, the European Commission decided to finance four projects dedicated to further technological development of MBR process: the four projects AMEDEUS, EUROMBRA, MBR-TRAIN and PURATREAT were implemented from October 2005 up to December 2009 and joined their efforts within the coalition "MBR-Network" (www.mbr-network.eu).

The present report synthesises the major outcomes of the project AMEDEUS, conducted from October 2005 up to May 2009. The AMEDEUS research project aimed at tackling both issues of 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 targets the two market segments for MBR technology in Europe: the construction of small plants (semi-central, 50 to 2,000 population equivalent or p.e., standardized and autonomous), and the medium-size plants (central, up to 100.000 p.e.) for plant upgrade.

Table 1. List of participants in the AMEDEUS project.

Partner Name	Acronym	Country
R&D centers		
Coordination: Berlin Centre of Competence for Water	KWB	Germany
Flemish Institute for Technological Research	VITO	Belgium
Tecnotessile	TTX	Italy
Universities		
Berlin University of Technology, TU Berlin	TUB	Germany
University of New South Wales	UNSW	Australia
End-Users		
Anjou Recherche (Veolia Water)	AR	France
Aquafin	AQF	Belgium
Small and medium enterprises (SMEs)		
A3 water solution	A3	Germany
Polymem	POLY	France
Inge	INGE	Germany
Envi-Pur	ENVI	Czech Republic

Technological development of new MBR systems was fostered by a consortium composed of 11 partners (Table 1), of which four are small and medium enterprises (SMEs) proposing novel concepts of low-cost and high-performance filtration systems. Two end-users, three non-profit research institutions and two universities, all of them well versed in research and development (R&D) in the MBR field, investigated solutions to reduce operational costs such as fouling control, membrane cleaning optimisation and aeration decrease, or to optimise capital costs through improved implementation of the membrane bioreactor process. Furthermore, an analysis of the potential for standardisation was performed, and a technology transfer towards Southern, Central and Eastern Europe was organised in order to facilitate the penetration of these new markets. AMEDEUS aimed to achieve concrete and realistic technological breakthroughs for the MBR technology, and to improve the current process engineering and operation practices. It contributed to increasing the competitiveness of the European MBR industry and increased the acceptance in the municipal wastewater sector towards this rather high-tech process.

Progress towards objectives

The AMEDEUS project was completed according to the work programme, and all objectives identified in the scope of the project could be matched. The main outcomes of the project are presented for each original objective in this report.

The progress towards objectives is summarized below.

Objective 1. Minimisation of membrane fouling with chemical additive

30 different chemicals were screened with regards to their potential for flux enhancement and / or fouling control in MBR. Their impact on SMP removal, particle size distribution and fouling propensity of the sludge was investigated in jar and bench tests, but also their biotoxic impact and optimum concentrations were studied. The most promising chemicals (2 synthetic cationic polymers and one biopolymer) were investigated in long term trials in two identical MBR pilot units (1.6m^3 and 22m^2 membrane module each), operated side by side and fed by real municipal sewage. While flocculants were dosed into one system, the other served as a reference. While the biopolymer did not improve the filtration performances, the two cationic polymers proved to retard the TMP jump and to decrease the requirements for chemical cleaning. The related additional operation costs were in the range of 0.6 – 2.5 € per cubic meter of withdrawn excess sludge. For a typical SRT of about 20 d, 1-3 €cent per cubic meter treated wastewater would be incurred by the use of polymers, which would increase the operational costs by less than 10 % for larger MBR plants like Varsseveld or Nordkanal.

Objective 2. Development of on-line sensors for fouling propensity of MBR sludge

Two on-line analysers were developed to monitor potential fouling causing substances or fouling propensity of MBR sludge. The first approach was based on a physical test (assessment of sludge filterability fingerprint, VITO Fouling Measurement) and another approach was based on chemical analyses of the potential organic fouling substances – proteins and polysaccharides– in the sludge interstitial water after particle retention (Photometrical EPS SIA sensor). Due to the strong complementarities of both approaches, their simultaneous implementation as inputs for an advanced control system could be highly interesting.

Objective 3. Improving membrane cleaning

Investigations were performed at lab scale and pilot scale to identify chemical reagents alternative to chlorine with 3 different membrane types supplied by the project partners A3 Water Solutions, Polymem and inge. The results highlight that the composition of the internal fouling could vary according to the used membrane and the operating conditions. In addition, it appears that the cleaning products do not always have the same effectiveness on all types of membranes and the cleaning protocols have to be adapted following the cleaning reagent. Chlorine was efficient on all the membranes but its effectiveness as for the other cleaning reagents was affected when sludge was accumulated into or at the membrane surface. Following the results, it seems that hydrogen peroxide could be a best alternative to chlorine but must be preferentially used with a backwash step, so that the cleaning product comes directly in contact with the internal fouling inside the membrane pores, without dealing with the external fouling at the surface of the membrane.

Objective 4. Modelling of biological process
The MBR process was calibrated on a large range of wastewater types (1mm screened *vs.* primary settled wastewater) and operation conditions (15 d *vs.* 40 d sludge age). The ASM1 model was able to predict correctly the MBR performances at 15 day sludge age for two different influents with the same calibration kinetic parameters. In comparison with a CAS process, the nitrification and denitrification oxygen half saturation constants are different because of a better oxygen transfer improved by the smaller floc morphology. In conditions of higher sludge age (40 days), the ASM1 model was however not able to fully reproduce all biological patterns, and further development would be required. Finally the permeate COD prediction was independent of the operating conditions and mainly related to the membrane cut-off.

Objective 5. Evaluation of the impact of primary sedimentation
The model calibrated at 15 day sludge age was used to assess the impact of primary sedimentation in plant design and operation. The results highlighted that the presence of a settler would result in a total sludge production increase of +19%, biological oxygen demand decrease by 15% and a reactor volume decrease by 30%. Moreover, if a sludge treatment by anaerobic digestion is considered, the production of methane would increase by 28%. Lastly, it seems that the large particles (like sand) not retained by the screen can damage the membranes. The presence of a settler (or an advanced sand trap) would therefore increase the membrane life. Although no full-scale MBR plant was purposely designed in Europe with primary settler and anaerobic digestion, it seems therefore that this option should be considered for the larger plants (typically above 50,000 pe).

Objective 6. Cost-effective positioning of submerged modules
Submerged MBR modules can be implemented in two different ways. In the integrated system, the membrane modules are set up directly in the aerated biological tank, whereas in the separate system, they are submerged in a separate tank which is dedicated to filtration only. An extensive review of the current practices and the pros and cons of the two configurations was performed. In brief, if the integrated system option seems to lead to lower investment and operation costs, the separate system option enables more operation flexibility and control. A decision tree between the two systems is proposed depending on local project conditions.

Objective 7. On-line data acquisition and advanced filtration control system
An operational advanced control system (ACS) was developed which was validated on a MBR pilot unit with a gradual increase in complexity of selected input and output parameters. The ACS had an understandable interface and allowed for clear logging of changes in operational conditions. A first series of demonstration tests was performed on a MBR pilot unit. This showed that the MBR-VFM measurements correlated well with on-line permeability and are thus a suitable input parameter for the ACS. The tests also showed that an average 20% reduction in membrane aeration requirements could be achieved, although this sometimes went at the expense of a stronger permeability decline, and could thus result in a higher cleaning frequency.

Objective 8. Optimised integration and control of MBR system in case of plant refurbishment
Dual configurations, combining conventional activated sludge (CAS) technology and MBR-technology are a means to increase the cost-effectiveness of the refurbishment. During the project, the technical feasibility and the market potential of 2 schemes integrating this idea were investigated. An advanced control system for the flow repartition between the MBR and the CAS line was developed with desk-top analysis, before full-scale demonstration. The design and operation guidelines, as well as the performances of a second CAS-MBR configuration were assessed at pilot scale. Finally, a study on market potential targeting EU

Accession and Associated Countries, was complemented by an engineering study performed for the renovation of a real full-scale plant of 120,000 pe in Bulgaria.

Objective 9. Standardisation of MBR technology
Based on an extensive survey of the MBR industry, a comprehensive analysis was performed on the market interests/expectations and technical potential of going through a standardisation process of MBR technology in Europe. The report of this study, the White Paper was discussed and endorsed by the European MBR industry and is considered as a public discussion document on MBR standardisation in Europe. It increased awareness and interest in the subject and, according to the outcomes and in agreement with the European MBR industry, initiated a formal procedure of standardisation together with the Centre Européen de Normalisation (CEN).

Objective 10. Development of novel concepts of MBR filtration modules and systems
One of the key project objectives was to develop novel concepts of MBR filtration systems. Three different design approaches were proposed by the project partners A3 Water Solutions, Polymem and inge and were then evaluated at Anjou Recherche under typical biological operating conditions.
The flat sheet technology of the company A3 Water Solutions was the more mature technology at the start of the project. The pilot tests showed that this MBR filtration technology was well adapted for operation in MBR application. The implementation of a double-deck configuration does not impact the fouling behaviour and enables to decrease substantially the air demand per membrane surface unit (SADm). In addition, satisfying and reliable fouling control was achieved with this system when operating at a net flux of 25 $L.h^{-1}.m^{-2}$ (20 °C) with backwashes and maintenance cleanings for a relatively low SADm value of 0.2 $Nm^3.h^{-1}.m^{-2}$ (corresponding to 8 $Nm^3/m^3_{permeate}$, competitive with current commercial MBR systems).
The MBR technologies developed in the project by the companies Polymem and Inge were completely new MBR filtration concepts, respectively a carterised hollow fibre module and a Fibre Sheet module, and would require further developments before possible commercialisation. With regards to the Polymem technology, the first tested fibres were subject to breakages leading to permate contamination. The second fibres (with a larger diameter) supplied by Polymem were more resistant and therefore more adapted to MBR applications but longer tests are still required to validate their use. The Polymem module configuration was also not optimal to achieve good fouling control: the packing density of the tested bundles was too high, leading to irreversible entrapment of the sludge into the bundles. With regards to the inge technology, membrane breakage was also problematic on the different tested modules. Clogging was avoided with this technology design but it appeared that the membrane surface was too rough leading to some sludge deposit.

Objective 11. Development of MBR modules with textile filtration media
The project team undertook the development of MBR filtration systems using non woven textile as filtration media. The characterisation of standard nonwovens showed that they have limitations for application in MBR: larger pore sizes (> 10 µm) with a large pore distribution. In order to easily solve the limits of the textile filtration media electrospinning combined with plasma treatment seems to be a promising option. The coating of nanoweb and the functionalisation by means of plasma treatments allows reducing some critical points, such as porosity and roughness mainly responsible for the low filtration performances. Furthermore, plasma is able to enhance the permeability of treated nonwovens because of the reduction of the superficial tension. Concerning the critical flux measurements it was found that a combination of flocculants and textile shows promising results if large flocs can be sustained. The overlapping between floc size and pore size seems to be detrimental for the operation of textile bioreactors (TBR). During long term operation with TBR the nanocoated material showed better results than the coarse nonwoven. The filtration performance with flocculant was however not as good as during the

test cell trials, which indicated that fluxes up to 150 L/(m²h) might be possible. Production cost analysis at industrial scale performed for nanocomposite membranes showed that the overall cost would be 5 €/m² to be compared with about 14 €/m² for conventional microfiltration membranes.

Objective 12. Development of turn-key standardised MBR plants and filtration units
A range of turn-key containerised MBR units was engineered for small communities of 50 up to 2,000 pe. In addition, in case of larger plants or when retrofitting is an option, an engineering study for the production of the filtration units only was performed. Cost estimations for the renovation of a real full-scale plant of 1,000 pe in the Czech Republic were performed.

Objective 13. Results integration
A dedicated objective was to prepare and facilitate the commercialisation or exploitation of the project technologies and developments while enhancing the penetration of the MBR technologies in new European markets. Several initiatives were conducted to address this objective: (i) an analysis of the European MBR market at the start and the end of the project was performed, with a focus on the largest plants (the greater share of the market); (ii) results were "integrated" within AMEDEUS, and also with the project EUROMBRA and the other projects of the coalition of European projects MBR-Network through six "Liaison Groups" (LG) addressing selected topics; and (iii) the project developments were regularly reviewed and compared with current patent: 11 items of exploitable knowledge were identified and at least 4 patents were filed.

Objective 14. Dissemination
The MBR-Network projects performed extensive communication of the project results and supported the construction of a network of expertise on the MBR technology within Europe. The various initiatives undertaken (in particular the common visual identity, the joint press-releases, the numerous workshops and the web-platform) were very efficient in touching a broad public of water and membrane professionals. Nine public workshops were organised at the occasion of international conferences, as well as one final workshop gathering more than 220 water professionals. More than 100 communications, manuscripts and conference talks were presented, among which more than 20 scientific papers. The web-site www.mbr-network.eu has proven to be a powerful and sustainable communication tool and source of information for the international MBR community, and will be maintained to play this role after termination of the projects.

Project information
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