Design and Operation of Membrane Bioreactors in Europe

Johannes Pinnekamp, Hiroki Itokawa, Christoph Thiemig, Aachen

1 Introduction

For decades membrane processes have been used successfully in industry, for leachate treatment or for drinking water purification. The combination of biological waste water treatment by activated biomass and subsequent phase separation by membranes was described in 1969 for the first time /Stephenson, 2000/. With further development of the low-pressure technology using immersed membranes, the technology of the so-called membrane bioreactor (MBR) has now arrived in municipal waste water treatment, too. With this process, the conventional final clarification for the separation of treated waste water and activated sludge is replaced by a membrane separation stage. The nearly germ-free effluent quality and the smaller footprint are regarded as the most important advantages, compared to conventional technology. As first German installation of this type for the treatment of municipal waste water, the Titz-Rödingen waste water treatment plant was commissioned in 1999. High demands on the treated waste water were the background for the application of this technology. These demands could be met with the filtrate of the MBR which did not contain solids and was nearly free of germs. The positive experience acquired during operation but also extensive promotion of this technology by environmental politics led to the construction of more installations, such as the Nordkanal waste water treatment plant, at present the largest municipal MBR in Europe with a daily waste water throughput of 16,000 m³, which was commissioned in July 2004 /Engelhardt, 2005/. Since then the installation is a reference object for MBR technology in municipal waste water treatment and serves national and international experts as model. The development of the number of installations, their capacities and the installed membrane surface areas in Germany since 1999 is presented in the following diagram.

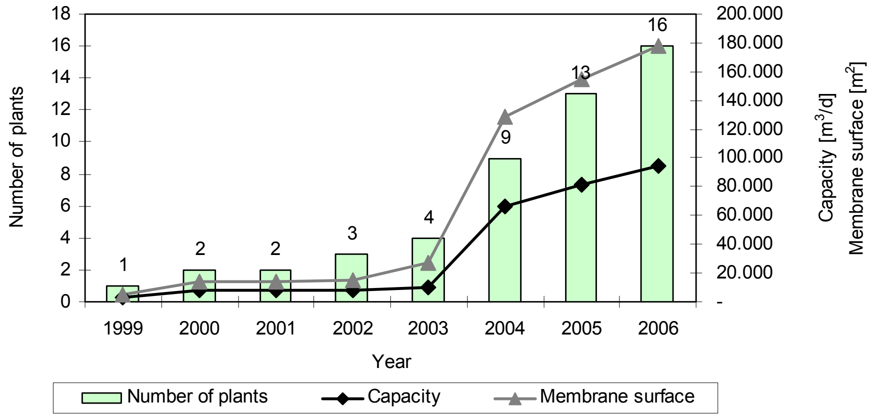


Figure 1: Development of the number of installations, their capacities and installed membrane surface areas in Germany since 1999 (exept pilot plants)

Besides complete substitution of the final clarification by a membrane stage, today the use of a MBR in a hybrid solution in parallel to a conventional waste water treatment plant is discussed, the largest part of the annual waste water quantity being treated in the MBR. This process presents the advantage that the cost-intensive membrane stage is economically exploited. However, in the case of storm-water flow, a partial waste water flow still gets into the receiving water via the conventional plant. The suitability of this process variant in practice is being tested in The Netherlands /Mulder, 2005/.

This report summarizes the results of a Europe-wide survey of the operators of municipal MBR. For this purpose an extensive questionnaire was sent to a large number of installations in different European countries. The data collected were recorded in a database and evaluated with view to technical equipment, operational conditions, purification goals and success as well as operational problems recognized up to now and approaches for their solution.

At the press date of the proceedings of this conference, not all of the questionnaires sent were available for evaluation. Therefore mainly the results collected up to that time are presented in the following. At present, the DWA committee of experts KA-7 is also collecting detailed data on the utilization of membrane technology for waste water treatment in Germany. The publication of this data is to be expected in the near future /DWA, 2006/.

2 Development of membrane technology in municipal waste water treatment

In 2000, more than 500 commercial aerobic MBR were in operation worldwide /Stephenson, 2000/. More than 3/4 of the installations serve for industrial applications, are in-building installations or small plants for the treatment of waste water from single households. Additional 9 % of the plants are used for the treatment of landfill leachate. Only 12 % of them treat municipal waste water.

In non-European countries, membrane technology is planned and demanded in the meantime also for large waste water treatment plants as best available technology to improve the water quality and to protect the drinking water resources. This is the case e.g. on the Arabian Peninsula and in the U.S.A., where some MBR are planned or already under construction which will exceed the design capacity of the Nordkanal waste water treatment plant /Engelhardt, 2005/. But in our direct neighbourhood, The Netherlands, too, a MBR for the treatment of the waste water from 91,000 inhabitants (1,400 m^3/h) is under construction. The following diagram presents the numerical distribution of municipal MBR and the waste water volume treated daily in Europe.

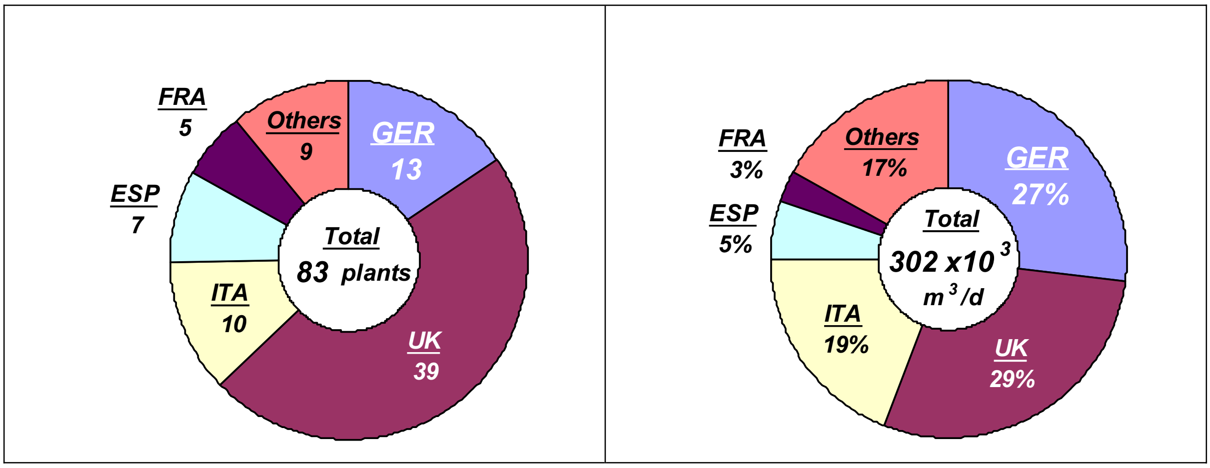


Figure 2: **Numbers of MBR for the treatment of municipal waste water (left and waste water volumes treated daily (right) in Europe**

Germany and Great Britain take the leading role in Europe concerning the utilization of MBR for the treatment of municipal waste water. Meanwhile 13 municipal MBR (except pilot plants) with a total capacity of approx. 80,000 m³/d are working in Germany. These figures are exceeded only by Great Britain where MBR have been applied since the middle of the nineties for the treatment of municipal waste water. In 2003, already 22 installations with a total waste water throughput of approx. 88,000 m³/d were under construction or in operation in this country /Cranfield Univ., 2006/.

3 Europe-wide survey with operators of municipal MBR

3.1 Description and way of proceeding

The project started with an investigation in the different European countries in order to collect the contact data of the relevant installations. For the collected data, no claim for completeness is made. In parallel with the investigation, a questionnaire in English language was developed. It contained 51 questions to collect information on technical equipment, operation and operating problems recognized up to now. Since it was asked partly for sensitive data, the operators were assured of anonymous treatment of the data collected. For this reason no names of installations are mentioned in the following text. The subject areas recorded by the questionnaire are compiled in Table 1.

Since the aim was an inventory of large-scale application of MBR in municipal waste water treatment, only installations with a daily waste water volume of at least 1,000 m³ and a minimum period of operation of one year were considered. On this basis, 25 MBR operators from seven countries in total were contacted. Some German and a Dutch plant could be visited directly which made it easier to collect data. 14 operators completed the questionnaire and sent it back. Unfortunately it was not possible to move the operators of the remaining plants to co-operate. Therefore data from the operation of three additional plants, although with less details, were taken from literature as an alternative. Thus data from 17 large-scale MBR for the treatment of municipal waste water were available on the whole.

Table 1: Contents of the questionnaire

	Basic data	Design data
Subject areas	Address/contact data Drainage system Connected inhabitants Date of commissioning	Reason for the choice of the MBR process Number of lines, design flows, part of industrial waste water Pretreatment, configuration of the biological stage, type and total surface area of the membranes, design flows, sludge treatment

	Operational data	General information
Subject areas	Water quantities treated, influent and effluent concentrations, operating conditions of the biological stage and the membrane stage, membrane cleaning, measuring technology, operational problems and solutions (sieving, silting, sticking of fibrous material, floating sludge, etc)	Investment and operating costs Energy consumption Potential for optimization General satisfaction with the process Perspectives according to the operators

3.2 Results of the survey

Within the scope of the survey concerning installations with a capacity of at least 1,000 m³/d, the ratios of the numbers of installations and capacities are similar to the total numbers in Europe (see Figure 2). Figure 3 shows on the left side the number of plants divided up into size classes. On the right side, the cumulated frequency is presented using the connection size. Again it becomes clear that Great Britain and Germany play the leading roles in Europe. The majority of the installations are in the range between 1,000 PE and 50,000 PE. The three largest installations of Europe are in Germany, Italy and Great Britain.

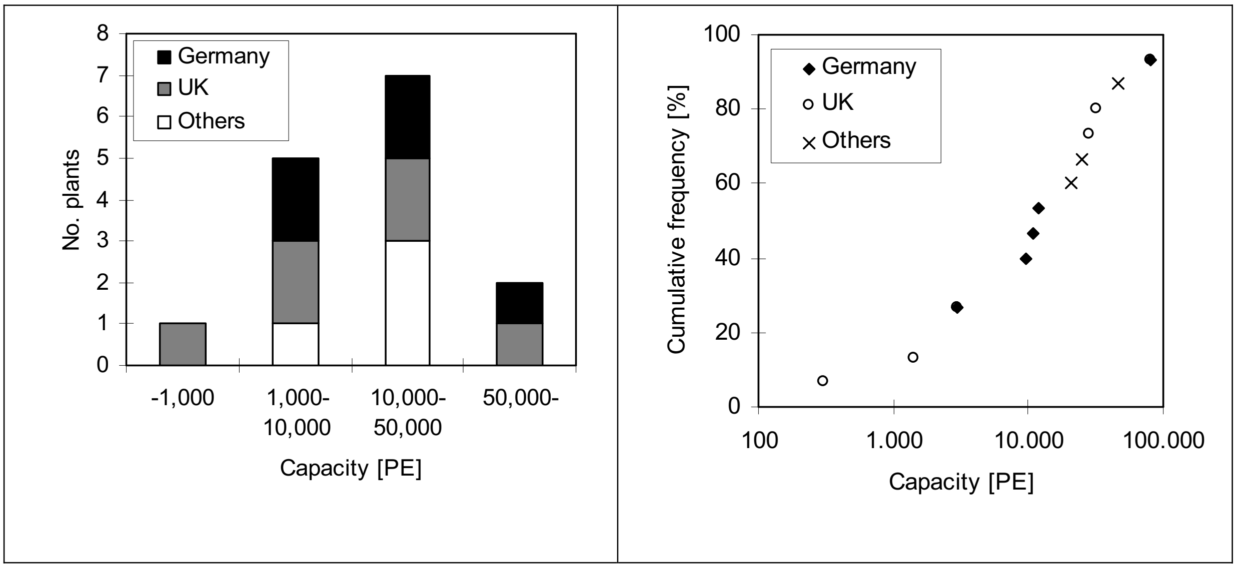


Figure 3: **Plant capacities in different size classes according to population equivalents (PE) (left) and cumulated frequencies depending on the connection size (right)**

For most operators, the reason for the choice of the MBR process was the smaller footprint, followed by the improved effluent quality. In some cases the plants served as demonstration object in the respective country in order to acquire first experience with the technology or to make the introduction of MBR technology to the market easier.

3.2.1 Inflow conditions

The ratio of the maximum dry weather flow per hour or the maximum storm-water flow related to the mean dry weather flow respectively is an important factor for the design of a MBR because the necessary membrane surface area has to be calculated according to the maximum inflow water quantity. The higher this ratio, the more unfavourable is the capacity utilization of the membranes which are a considerable part of the investment costs. These rations are represented in Figure 4. For four installations, the ration is nearly 1, thus optimal for MBR operation. In the most unfavourable case, the inflow during storm-water flow is higher by the factor 7 than the mean dry weather inflow.

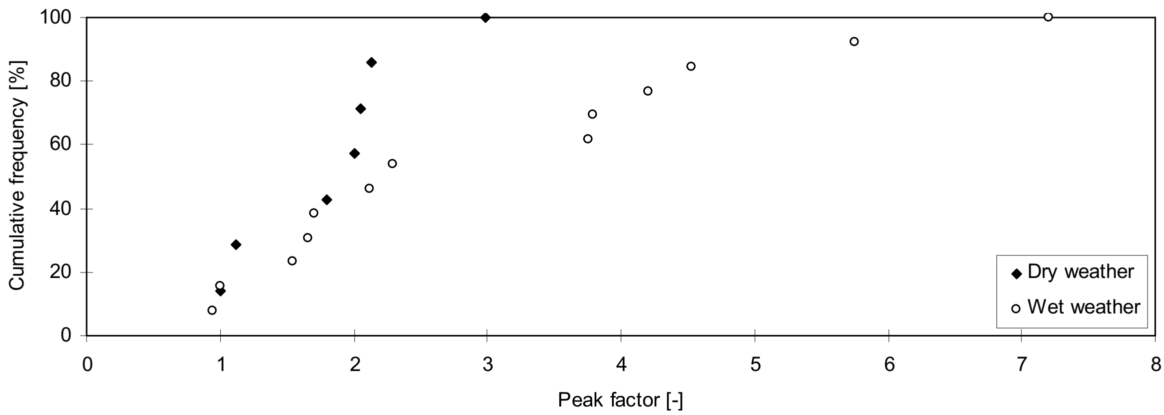


Figure 4: Ratio of dry weather peak or storm-water peak respectively and mean dry weather flow

3.2.2 Pretreatment

Pretreatment measures are essential for MBR operation, since the membrane modules, depending on the type, are susceptible to silting or sticking of fibrous waste water contents. The following diagrams in Figure 5 show the „conventional“ pretreatment measures such as coarse screen, grit chamber/grease trap and primary clarification (left) as well as the slot widths of fine sieves for waste depending on the membrane type used (right).

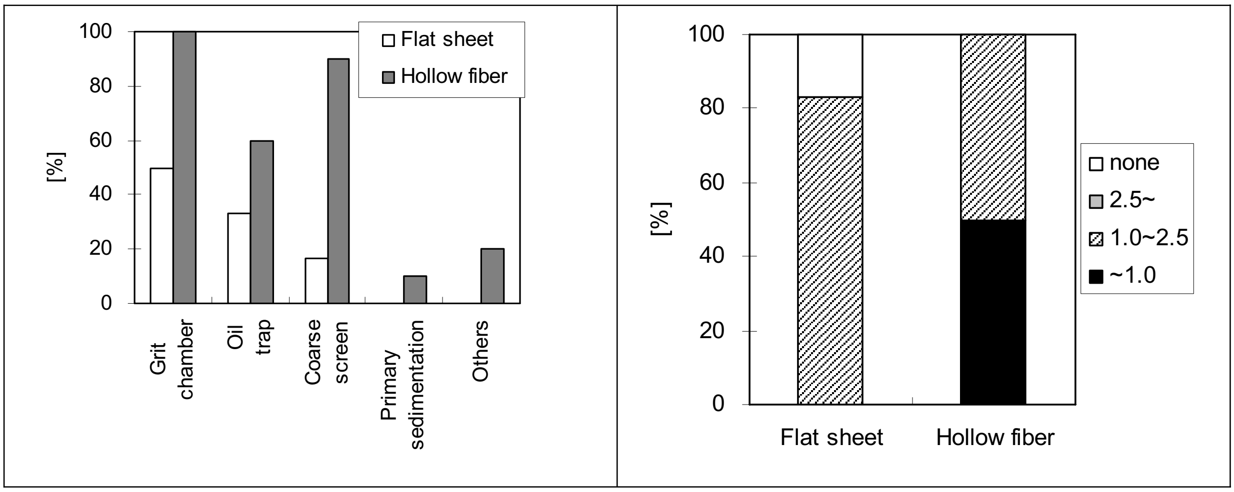


Figure 5: Conventional pretreatment measures (left) and fine sieving of the waste water depending on the membrane type used (right)

It can be seen clearly that smaller slot widths are normally used in plants equipped with hollow-fibre modules because these modules are more susceptible to sticking and clogging of fibrous material.

Besides the pretreatment steps presented, some operators of hollow-fibre modules additionally use a so-called bypass sieving of the activated sludge. This means that a partial flow of the recycled sludge is submitted to sieving with slot widths of $\geq$ 0.5 mm in order to remove more inhibiting substances from the bioreactor.

3.2.3 Operation of the activated sludge stage

The process of upstream denitrification predominates when choosing the operating mode of the plants with view to carbon and nitrogen removal. In Great Britain, most plants are continuously aerated, since in this country no demands are usually made on the effluent values for nitrogen and phosphorus (Figure 6, left). Only one of the plants was designed for increased biological phosphorus removal. In the plants where the phosphorus effluent values are controlled by precipitation, no special precipitant is used (Figure 6, right).

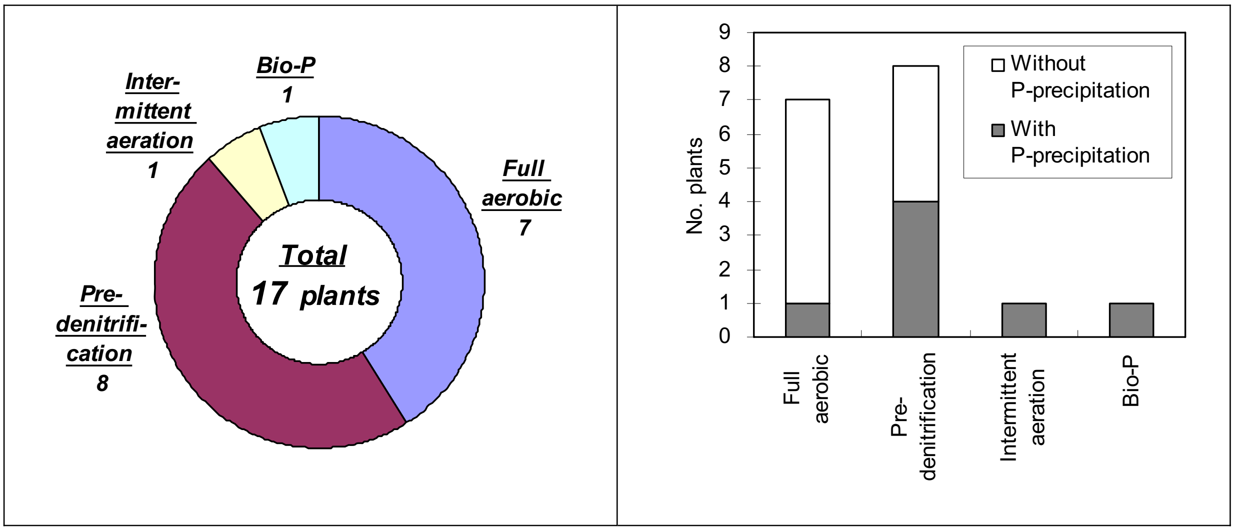


Figure 6: **Operating mode of the plants: total numbers (left) and with/without P precipitation (right)**

The solid matter concentrations in the activated sludge tank of the plants on the European continent are predominantly between 10 and 12 g/l. In Great Britain, these values are between 7 and 15 g/l. Concerning the hydraulic retention time which is frequently used in the design of a MBR /MUNLV, 2003/, the data vary significantly. Related to dry weather flow, they are between 2.8 and 16 hours (Figure 7, left). But these retention times not always coincide inevitably with the critical design case.

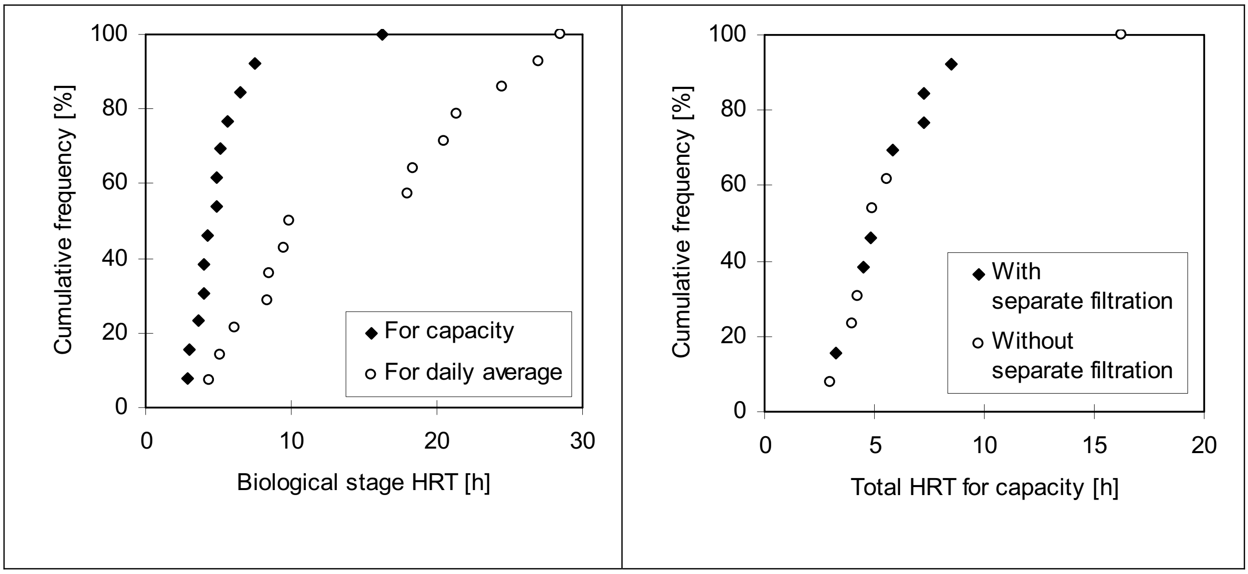


Figure 7: **Hydraulic retention times: activated sludge tank only (left) and including filtration stage (right)**

In Figure 7 (right), the retention times including the volumes of separate filtration tanks are presented. It is striking that the plants equipped with a separate tank for the membrane modules (55 % of all plants) not inevitably require a larger total tank volume (resulting in a longer retention time).

3.2.4 Operation of the membrane stage

The flow rates which can be attained on average are another important factor for the assessment of the cost-effectiveness of a MBR. In Figure 8 (left), the average flow rates determined by calculation and the maximum flow rates attained briefly under wet weather conditions are presented. The broad range of these values shows here, too, significant site-specific differences (cf. chapter 3.2.1 Inflow conditions). On the right side, the specific air requirement for the control of the covering layer is represented. The higher air requirement of the plate modules becomes clear. However, the manufacturers currently develop modules to reduce these values because this co-called cross-flow aeration has a decisive share in the overall energy costs.

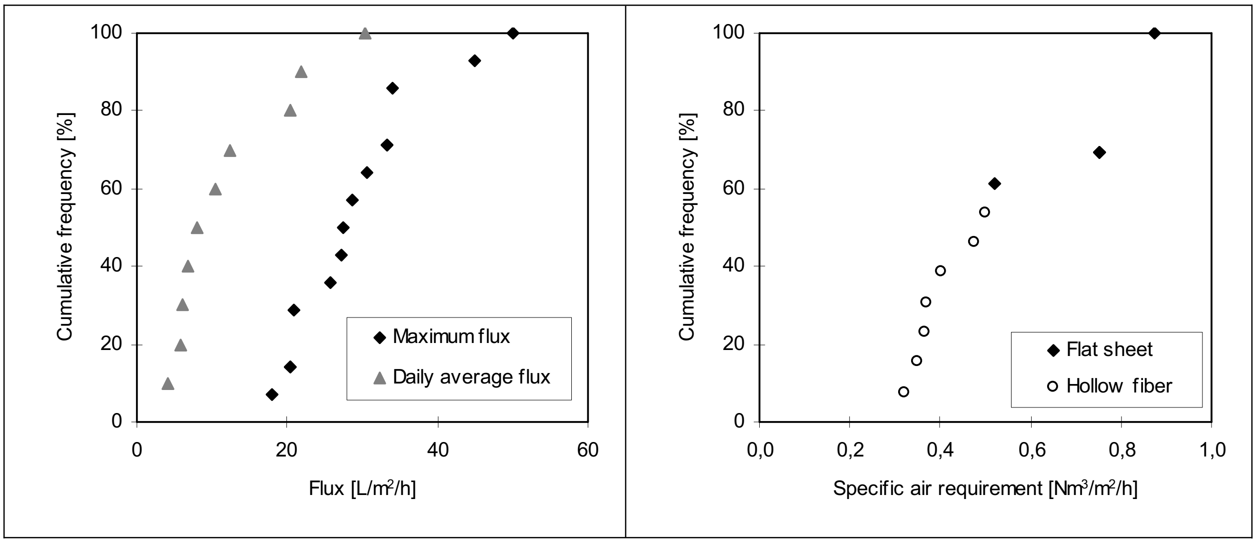


Figure 8: Flow rates (left) and air requirement for covering layer control (right) depending on the membrane system used

Concerning membrane cleaning, one distinguishes **two strategies**. The so-called m**aintenance cleaning** is carried out in intervals of one or two weeks in order to maintain the permeability, i.e. the filtration capacity of the membrane. An oxidative cleaning solution (mostly NaOCl) is introduced into the membrane from the permeate side. Most of the operators carry out an acid cleaning as second step.

In most of the plants, a so-called **recovery cleaning** is carried out once up to four times a year to counteract the inevitably progressing reduction of the permeability. This is done in nearly the same way as the maintenance cleaning described above, but with cleaning agents in higher concentrations.

Irrespective of the strategy, cleaning can be carried out in different ways. With in-situ cleaning, the membranes remain immersed in the activated sludge. Better cleaning results are attained with the so-called on-air cleaning. For this purpose, the modules remain in the tank and the sludge level is lowered to the bottom edge of the module. This procedure requires separation of the tank zones (activation zone – filtration zone). The best cleaning results are attained with the so-called soaking. This means that the modules are immersed completely for several hours into a cleaning solution.

However, either the activated sludge has to be removed and the cleaning solution has to be filled into the membrane chamber, which requires a corresponding arrangement of the tanks like in on-air cleaning. Or the modules are lifted from the activated sludge tank into a separate washing cell where the cleaning takes place. Since this is the most expensive cleaning method, it is only used for recovery cleaning.

Two of the 17 plant operators questioned told us that they carry out the cleanings described with H_2O_2 instead of NaOCl. This proceeding has the advantage that the effluent is not charged with organic halogenated compounds. However, the other operators still prefer NaOCl as cleaning agent because of better cleaning results in their plants.

Concerning membrane cleaning, there are clear differences depending on the membrane system used. Hollow-fibre membranes are usually cleaned by a combination of maintenance and recovery cleaning, while it is done without maintenance cleaning for plate membranes. Table 2 presents the cleaning methods, chemicals and their concentrations depending on the membrane system as well as data on the operating cycles of the membranes of eleven different plants.

Table 2: Cleaning strategies depending on the membrane system

	Kläranlage	1	2	3	4	5	6	7	8	9	10	11
	Membrantyp	Platte	Hohlfaser	Hohlfaser	Hohlfaser	Hohlfaser	Hohlfaser	Hohlfaser	Hohlfaser	Hohlfaser	Hohlfaser	Hohlfaser
Betriebs-zyklen	Filtrationszeit [s]	540	400	200	500	k.A.	k.A.	300	k.A.	k.A.	360	300
	Pause [s]	60 (+30s)	0	0	1	k.A.	k.A.	0	k.A.	k.A.	0	5
	Rückspülung [s]	-	50	15	50	k.A.	k.A.	30	k.A.	k.A.	20	25
Maintenance cleaning	Methode	nie	On air + In-situ	On air	On air	In-situ	In-situ	In-situ	In-situ	In-situ	On air	On air
	Frequenz	-	1/Woche	0.5-1/Woche	0.5/Woche	1/Woche	k.A.	1/Woche	k.A.	1/Woche	1/Woche (Winter) 0.5/Woche (Sommer)	1/Woche
	Erstes Reinigungsmittel	-	Zitronen-säure (+HCl)	NaOCl	H_2O_2	NaOCl (1+2. Woche) Zitronen-säure (3. Woche)	H_2O_2	NaOCl	NaOH	NaOCl	NaOCl	NaOCl
	Konzentration [ppm]	-	pH=2	250-500	300	700 (NaOCl) 30000 (Zitronen-säure)	k.A.	200	k.A.	500	800	250
	Zweites Reinigungsmittel	-	NaOCl	Zitronen-säure	Zitronen-säure (+HNO_3)	k.A.	Zitronen-säure	Zitronen-säure	k.A.	k.A.	Zitronen-säure	HCl
	Konzentration [ppm]	-	500	jeweils berechnet	300	k.A.	k.A.	k.A.	k.A.	k.A.	3200	675
Recovery cleaning	Methode	Soaking (in situ)	Soaking (sep.Tank)	-	Soaking (in situ)	Soaking (sep.Tank)	-	Soaking (in situ)	Soaking (sep.Tank)	k.A.	-	Soaking (in situ)
	Frequenz	4-5/Jahr	1/Jahr	nie	2/Jahr	1/Jahr	nie	1/Jahr	k.A.	2/Jahr	nie	1-2/Jahr
	Erstes Reinigungsmittel	NaOCl	Zitronen-säure (+HCl)	-	H_2O_2	NaOCl	-	NaOCl	k.A.	NaOCl	-	NaOCl
	Zweites Reinigungsmittel	Oxalsäure ($C_2O_4H_2$)	NaOCl	-	Zitronen-säure (+HNO_3)	Zitronen-säure	-	Zitronen-säure	k.A.	k.A.	-	Zitronen-säure
Grund für RC	TMP	1	0	0	0	0	k.A.	0	1	k.A.	0	1
	fester Zeitpunkt	0	0	0	1	1	k.A.	0	0	k.A.	0	0
	Andere	1	1	0	0	0	k.A.	1	0	k.A.	1	0

3.2.5 Purification capacity

Figure 9 (left) presents the ratio of the maximum inflow concentration and the mean values. The inflow concentrations in part vary significantly. The average COD inflow concentrations are in a range between 232 mg/l and 700 mg/l. The COD peak load also shows a broad range (from 508 mg/l to 2140 mg/l). This also applies for the nitrogen and phosphorus concentrations. Nevertheless, all MBR are able to efficiently remove organic substances and nutrients. Nearly all plants attain average COD removal rates of > 90%. Figure 9 (right) presents the removal rates for COD, total nitrogen and total phosphorus as cumulated frequencies.

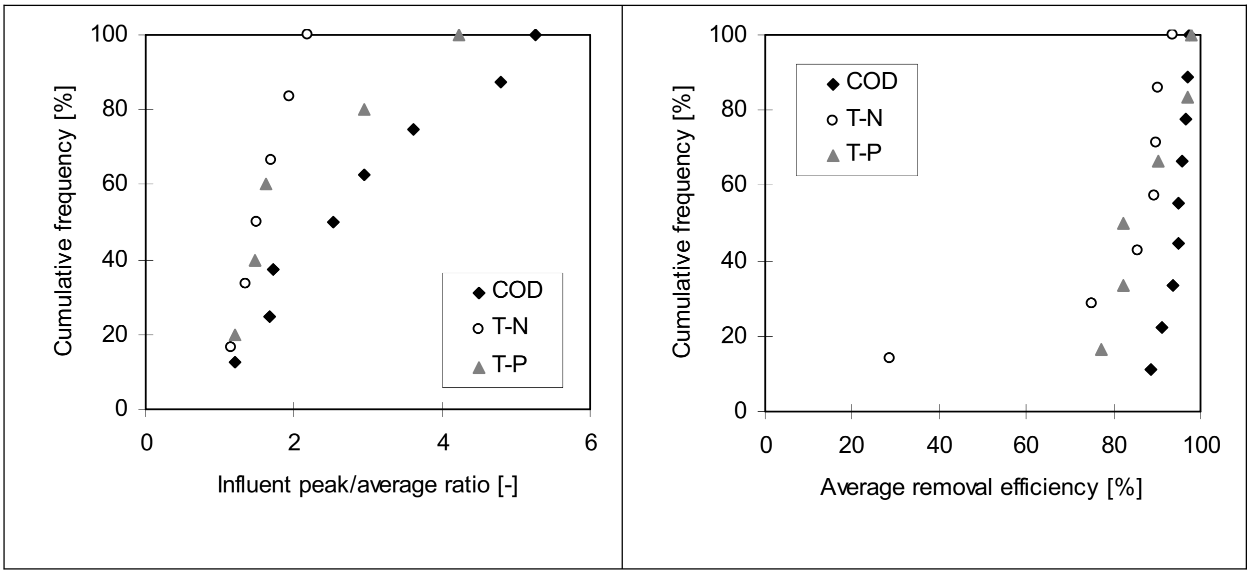


Figure 9: **Ratio of inflow concentrations (left) and removal capacity (right)**

3.2.6 Operating problems, approaches for solutions and need for optimization

When introducing a new technology, most different operating problems usually occur during the first years which cannot be foreseen or only to a limited extent when designing the plants. In the case of MBR, the following “classical” operating problems with possible approaches for solutions can be identified:

- Problems with fine sieving of the waste water ➔ to be optimized by the screen manufacturers (in cooperation with the operators)
- Problems with the membranes due to insufficient fine sieving of the waste water (sticking of fibrous material) ➔ change of the type of sieve, reduction of the slot widths, sieving of partial sludge flows
- Problems with the membranes by insufficient aeration (silting) ➔ optimization of module aeration or to be optimized by the module manufacturer
- Damages at the membrane modules ➔ to be optimized by the module manufacturer, more careful handling of the modules during operation and cleaning

- Strong development of floating sludge ➔ skimming, spraying, utilization of polymers, “ignoring“
- Air in the permeate pipe ➔ constructing the permeate pipes ascending to the pump, vacuum pump
- Problems with the control software ➔ to be optimized by the software producer in cooperation with the operators

Besides these general operating problems, some special proposals and remarks of the operators should be considered when planning MBRs:

- The membrane modules should be arranged in separate tanks. The advantages of cleaning compensate the disadvantages from operation
- The permeate pipes should be designed as short as possible in order to reduce the periods of backwashing.
- The number of racks per unit should be small, and the permeate pipes to the units should have uniform lengths. This ensures homogeneous feeding of the membranes with the cleaning solution.
- The permeate pipes should be made of plastic. This helps to avoid corrosion due to cleaning agents.

From the operators’ point of view, there is still general need for optimization of the plant operation. The above problems and remarks were the most frequently mentioned ones and, with this, at the same time an appeal to the researchers:

- To lower the energy demand
- To optimize the pretreatment in order to ensure stable MBR operation
- To make chlorine-free cleaning possible

4 Summary and outlook

Within a few years, the MBR technology has become a promising alternative for conventional technology. At present, more than 80 large-scale MBRs are in operation in Europe. Some more large-scale plants are in planning stage or already under construction.

The survey carried out had for result that most of the operators are quite satisfied with the efficiency of their plants. The operating problems mentioned are understandable, since the technology is still new, but they seem solvable. For this purpose, however, plant operators, membrane manufacturers, consulting engineers and research institutions have to cooperate closely. In Germany, approaches in this field already exist. Within the framework of conferences and workshops, organized by university institutes, water boards or DWA, engineers and scientists get the opportunity to exchange and discuss their experience. First publications give instructions for design and operation of MBRs. The book “Membrane Technology for Waste Water Treatment”, edited by MUNLV NRW /MUNLV, 2006/ and the work reports of the committee of experts KA 7 of DWA /DWA, 2005/ are to be mentioned here. The development of an internet-based data base for the collection of all relevant data in this field would be a possibility to improve cooperation in Europe. These data might serve as ideal basis for coordination and planning of additional research activities.

With the construction of the Nordkanal WWTP, it was demonstrated that the MBR technology can be mastered on a large scale and can be used efficiently. The question is now: Which perspectives has this process concept in Europe? The political and legal boundary conditions concerning the demands on the effluent quality will surely influence the membrane market in a positive way. Within these bounds, the IVU and the Water Framework Directive have to be mentioned. Thus it can be expected that the number of membrane installations in Europe will increase significantly from 2010 on within the scope of the implementation of water protection measures. The reasons are not only the high capacity for nutrient removal and the nearly germ-free effluent quality of MBRs. Since it is aimed at reducing priority substances in surface waters, the solid-free effluent, ensured by the membranes, offers ideal prerequisites for the use of downstream treatment steps such as ozonation or active carbon filtration.

The market research institute „Frost & Sullivan“ has found out that the biggest challenge for the membrane manufacturers is to persuade the decision-maker in the market of the possibilities of the MBR process and to show them which benefit the customer may derive from them /Frost & Sullivan, 2005/.

Integration of the MBR into the conventional technology, as it is the case with the hybrid solution, or complete replacement of the final clarification by the MBR – from European legislation concerning purification requirements, but also from the purely technical advantages of the process it can be expected that the market for MBR in municipal waste water treatment in future will increase.

Acknowledgements:
We express our thanks the participants of the survey who have compiled all necessary data for the extensive questionnaire and who have given information in a patient way during long conversations, and the Federal Ministry of Education and Research for the promotion of the project.

References:

/Cranfield Univ., 2006/ Cranfield University, UK: http://www.cranfield.ac.uk/sims/water/mem-net/uk_membrane_municipal_plant.html, Last access: January 2006

/DWA, 2005/ Deutsche Vereinigung für Wasser, Abwasser und Abfall e.V., DWA: 2. Arbeitsbericht des Fachausschusses KA-7 "Membranbelebungsanlagen, KA – Abwasser, Abfall 2005 (52) Nr. 3; ISSN 1616-430X, (2005)

/DWA, 2006/ Deutsche Vereinigung für Wasser, Abwasser und Abfall e.V., DWA: Auskunft des Fachausschusses KA-7, (2006).

/Dohmann, 2005/ Dohmann, M: Perspektiven für den Einsatz der Membrantechnik in der Abwasserbehandlung, Beitrag zur 6. Aachener Tagung Siedlungswasserwirtschaft und Membrantechnik (2005)

/Engelhardt, 2005/ Engelhardt, N: Das Gruppenklärwerk Nordkanal nach einem Jahr Betrieb – eine Perspektive für große Membranbelebungsanlagen, Beitrag zur 6. Aachener Tagung Siedlungswasserwirtschaft und Membrantechnik (2005)

/Frost&Sullivan, 2005/ Frost & Sullivan Research Report: Strategic Analysis of the European Membrane Bioreactor Markets (2005), http://www.frost.com

/Mulder, 2005/ Mulder, J. W., v. d. Berkmortel, H., Kramer, F.: Hybrid-MBR – Ein neues konzept für die Abwasserbehandlung, Beitrag zur 6. Aachener Tagung Siedlungswasserwirtschaft und Membrantechnik (2005)

/MUNLV NRW, 2006/ Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz des Landes Nordrhein-Westfalen: Membrantechnik für die Abwasserreinigung, Erschienen im FiW-Verlag, ISBN 3-939377-00-7 (2006)

/Stephenson, 2000/ Stephenson, T., Judd, S. J., Jefferson, B., Brindle, K.: Membrane Bioreactors for Wastewater Treatment. IWA Publishing, London (2000)

/Stephenson, 2003/ Stephenson, T.: Membrane Technology for Wastewater Treatment and Reuse - State of the Art and future Prospectives, Beitrag zur 5. Aachener Tagung Siedlungswasserwirtschaft und Membrantechnik (2003)

Environmental Engineering RWTH Aachen University

Design and Operation of Membrane Bioreactors in Europe

Univ.-Prof. Dr.-Ing. Johannes Pinnekamp
Dr.-Eng. Hiroki Itokawa
Dipl.-Ing. Christoph Thiemig

Institute of Environmental Engineering
RWTH Aachen University

Environmental Engineering RWTH Aachen University

Performance data of membrane bioreactor plants compared to conventional activated sludge plants

Parameter		Conventional activated sludge plant	Membrane Bioreactor
Suspended Solids	mg/L	10 – 15	0
COD	mg/L	40 – 50	< 30
N_{tot}	mg/L	< 13	< 13
P_{tot} (with simultaneous precipitation)	mg/L	0.8 – 1.0	< 0.3
Microbiological quality		No bathing water quality	bathing water quality
MLSS	g/L	< 5	< 20
Specific energy consumption	kWh/m³	0.2 – 0.4	0.7 – 1.5

Environmental Engineering RWTH Aachen University

MBR application in Germany

Municipal WWT

- First application in 1999 (Rödingen WWTP, 3,000 PE)
- Presently, 12 plants are operated, 4 plants are under construction/design
- Principal reasons for application are to meet the effluent quality regulation and to reduce tank volume

Industrial WWT

- Far more applications in a range of industries (*e.g.* textile, brewery, food...)
- Typically applied in conjunction with water reuse

Environmental Engineering RWTH Aachen University

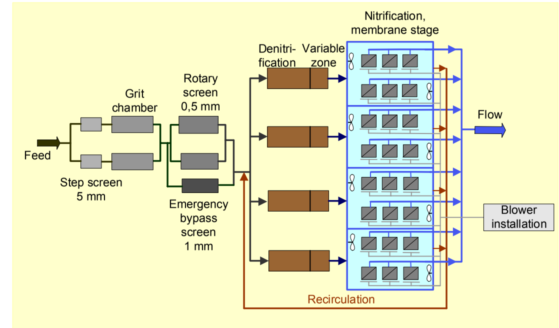
Existing municipal MBR plants in Germany

Name	Start-up	Capacity [PE]	Reactor volume [m³]	Membrane supplier
Rödingen	1999	3,000	480	ZENON
Büchel	1999	1,000	190	Kubota
Markranstädt	2000	8,000	1,800	ZENON
Knautnaundorf	2001	900	68	Martin Systems
Monheim	2003	9,700	1,640	ZENON
Simmerath	2003	700	136	PURON
Nordkanal	2003	80,000	9,200	ZENON
Schramberg	2004	2,600	730	ZENON
Seelscheid	2004	10,500	2,310	Kubota

Driving forces for MBR application in Germany

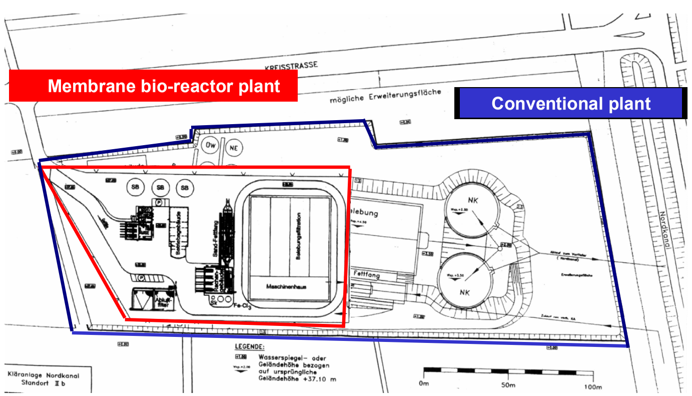
- Increased requirements for the effluent quality
  - EU Water Framework Directive
  - EU Directive on Bathing Water
  - Sensitive receiving water bodies
  - WWTP effluent in drinking water protection zones
- Local situation (space requirement)
- Introduction of new technology
- Financial support by local governments
- Technical improvement of immersed membrane modules
- Increased knowledge & experience from existing plans

Example of municipal MBR application (Nordkanal)



- Largest in Europe (80,000 PE = approx.10,000 m³/d, 84.000 m² membrane surface)
- Operated since December 2003

Example of municipal MBR application (Nordkanal)



Source: Erftverband 2002

Example of municipal MBR application (Nordkanal)

Minimum requirements and discharge consent of the Nordkanal WWTP

Parameter	Unit	Minimum requirements	Discharge consent (at T<10° C)
COD	mg/l	90	< 25
BOD_5	mg/l	20	< 5
NH_4-N	mg/l	10	< 2
N_{tot}	mg/l	18	?
P_{tot}	mg/l	2	< 0,5

- An energy demand approx. 60 % (0.8 kWh/m³) higher than for conventional plants (0.51 kWh/m³) can be expected
- The investment was 21.5 million €.
- Approx. 6.6 million € of this amount had been taken over by the federal state North-Rhine Westphalia.

Source: Erftverband 2002

Environmental Engineering RWTH Aachen University

WWTP Kaarst/Nordkanal

Design and Operation of Membrane Bioreactors in Europe

Environmental Engineering RWTH Aachen University

Membrane installation at the WWTP Nordkanal

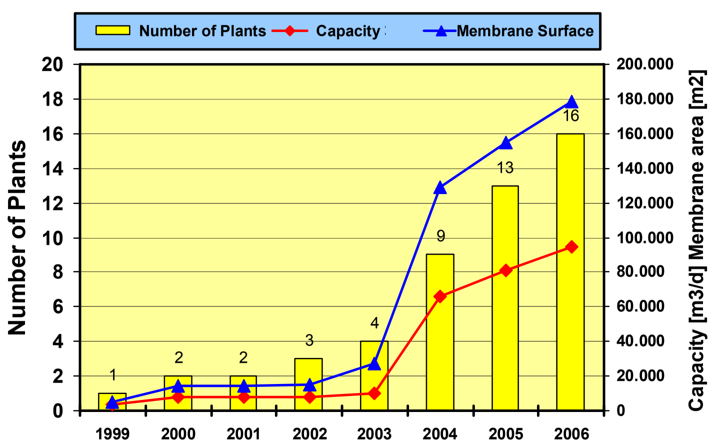
Source: Erftverband 2002

10

Design and Operation of Membrane Bioreactors in Europe

Environmental Engineering RWTH Aachen University

Development of Plant Number in Germany



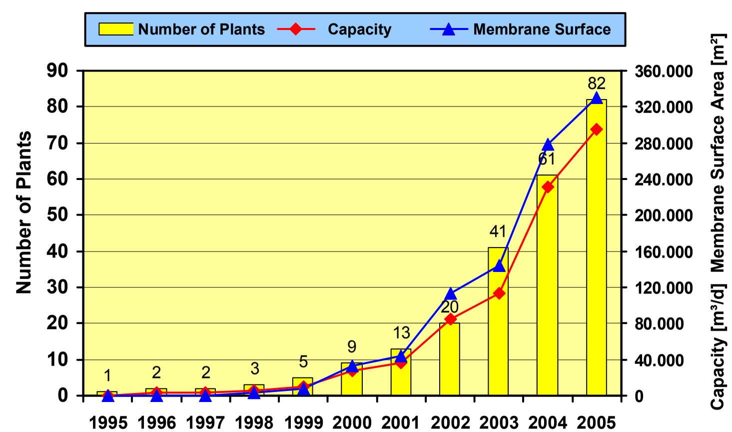
(Without pilote plants)

11

Design and Operation of Membrane Bioreactors in Europe

Environmental Engineering RWTH Aachen University

Development of Plant Number in Europe



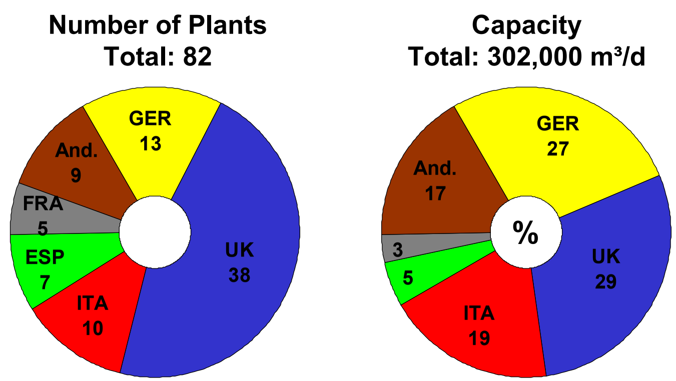
Without Pilote Plants

12

Design and Operation of Membrane Bioreactors in Europe

Environmental Engineering RWTH Aachen University

Plant Number and Capacity



(Without pilote plants)

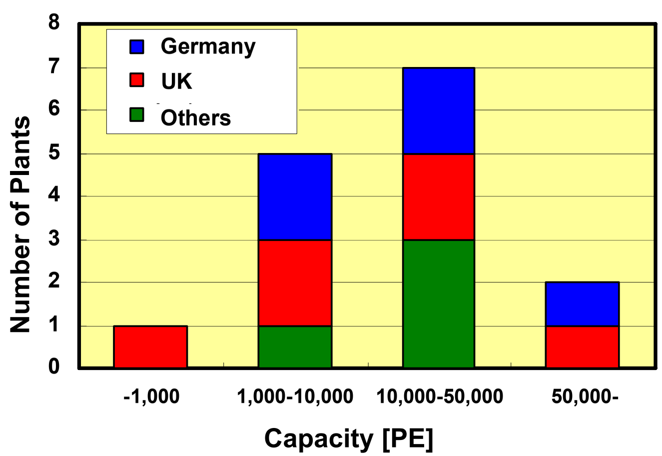
Environmental Engineering RWTH Aachen University

Content of Questionnaire

- **Basic Data**
  - Address/Contact Data
  - Sewerage System
  - Capacity
  - Start of Operation
- **Design Data**
  - Reason for MBR
  - Design Flow
  - Industrial WW Flow
  - Number of Lines
  - Pretreatment
  - Configuration of Biol. Reactor
  - Type and Design of Membranes
  - Sludge Treatment
- **Operation Data**
  - Flow
  - In- and Outflow Concentrations
  - Operational Conditions
    - Biological Reactor
    - Membranes
  - Membrane Cleaning
  - Measuring
  - Operational Problems
  - Lessons Learned
- **General Information**
  - Costs
  - Optimization Potentials
  - Contentedness
  - Perspectives

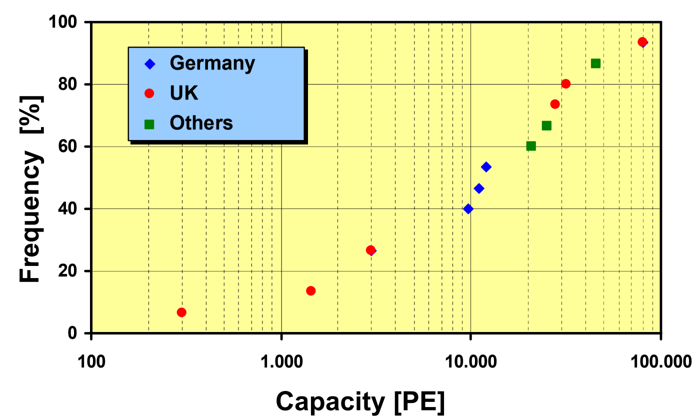
Environmental Engineering RWTH Aachen University

Size Distribution

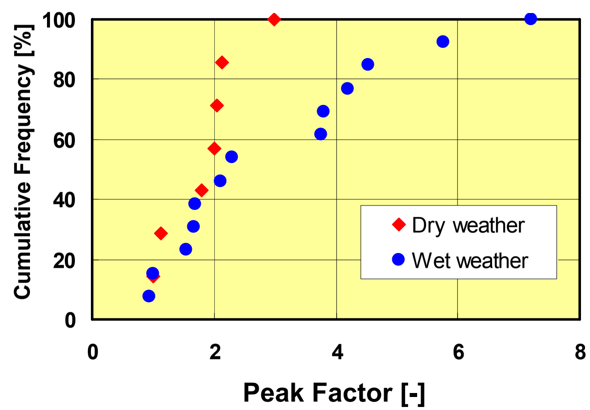


Environmental Engineering RWTH Aachen University

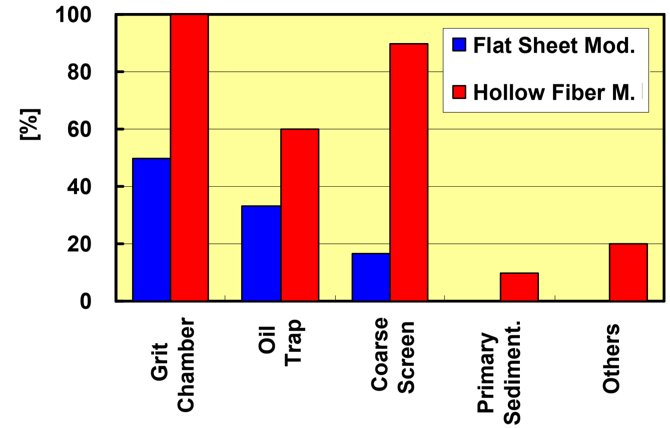
Participants in the Survey



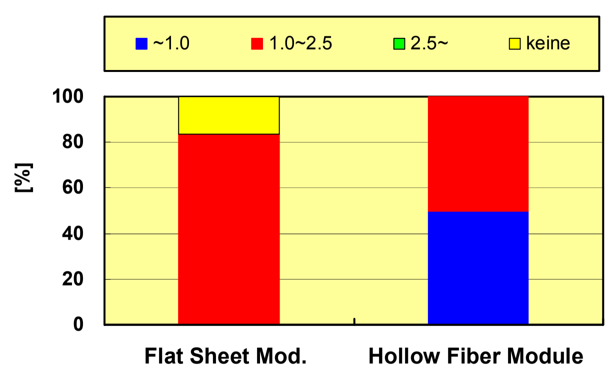
Influent Variation



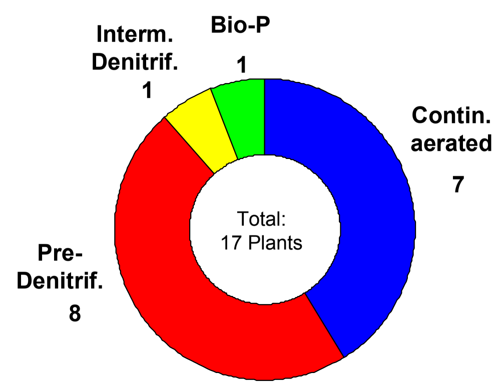
Pre-Treatment Technologies



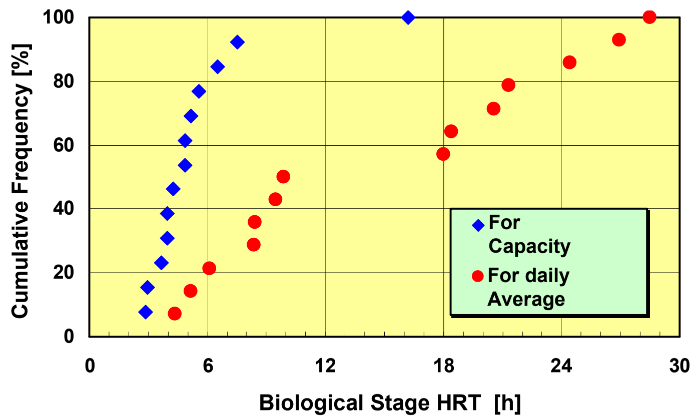
Fine Screen as Pre-Treatment



Operation of Biological Stage



Biological Stage HRT [h]

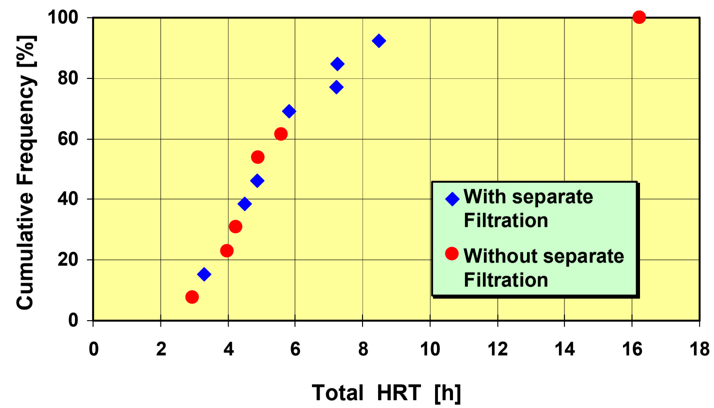


Environmental Engineering RWTH Aachen University

Design and Operation of Membrane Bioreactors in Europe

21

Total HRT [h]

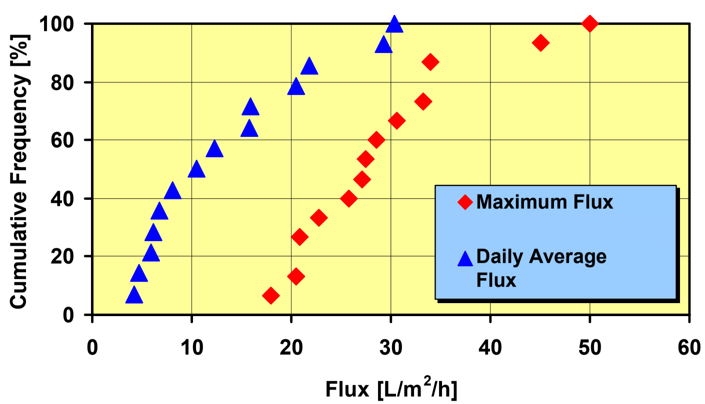


Environmental Engineering RWTH Aachen University

Design and Operation of Membrane Bioreactors in Europe

22

Maximum and Average Flux Rates

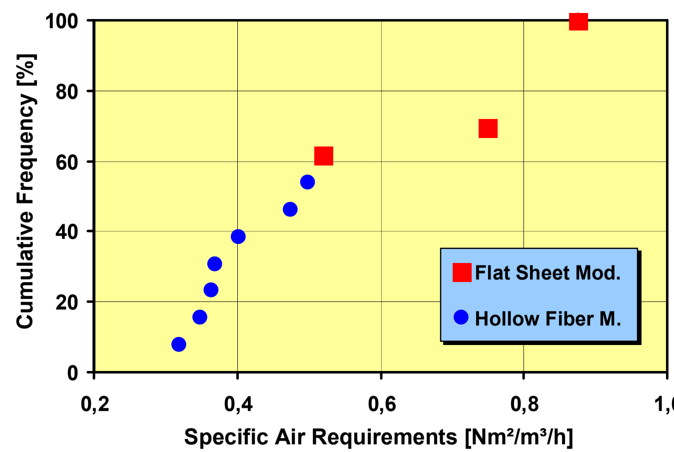


Environmental Engineering RWTH Aachen University

Design and Operation of Membrane Bioreactors in Europe

23

Air Requirements for Covering Layer Control

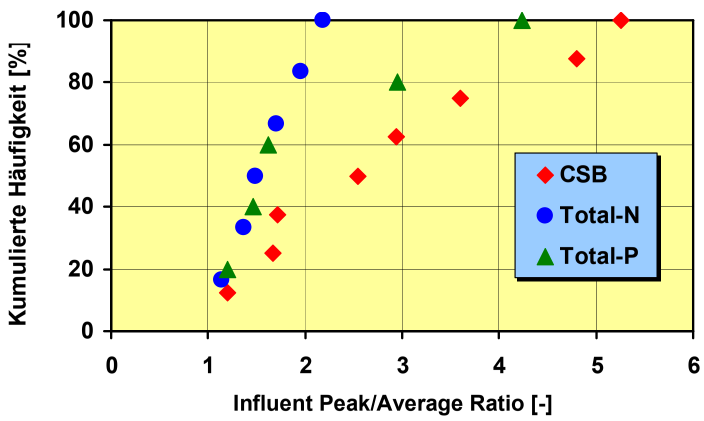


Environmental Engineering RWTH Aachen University

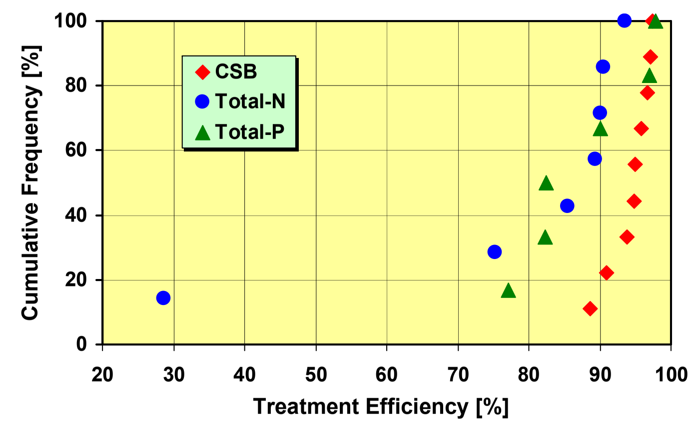
Design and Operation of Membrane Bioreactors in Europe

24

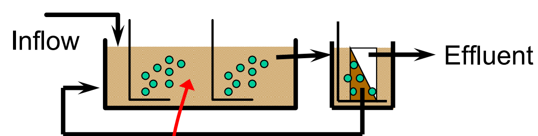
Variation of Inflow Concentrations



Treatment Efficiency [%]

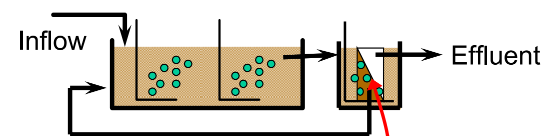


Research Topics



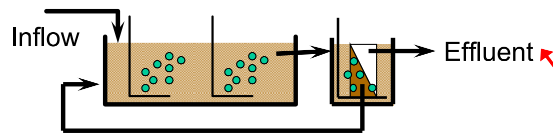
1. Biological Process
   - Pretreatment
   - Optimal MLSS-conc.
   - Excess sludge production
   - Sludge properties
   - Aeration efficiency (α-value)
   - Hydraulic behaviour
   - (Min. hydr. retention time)
   - Floc structure, Foaming
   - Pretreatment
   - etc.…

Research Topics



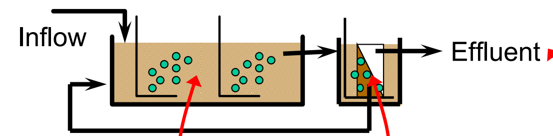
2. Membrane
   - Material
   - Pore size
   - Flow, permeability
   - Fouling, scaling
   - Cleaning
   - Costs
   - Life span
   - etc.…

Research Topics



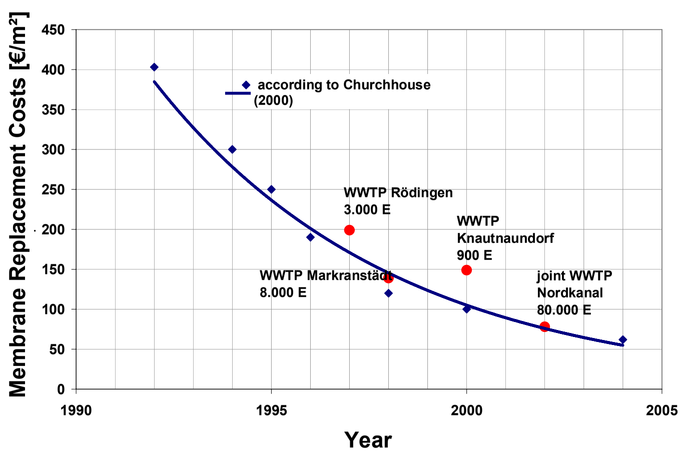
3. Treatment Efficiency
   - Conventional parameters
   - Hygienic quality
   - Organic trace pollutants
   - Mechanisms
     - Degradation
     - Transformation
     - Adsorption
     - Filtration
   - Post-treatment
   - etc.…

Research Topics



4. Whole Process
   - Energy Demand
   - Costs
   - Life Cycle Analysis
   - Automation and Control
   - ……….

Cost Development



Vielen Dank für
Ihre Aufmerksamkeit.

ご清聴ありがとうございました。