

Towards standardisation of MBR technology ?

A White Paper analysing market expectations and
technical potential for membrane bioreactor
standardisation in Europe.

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Preamble

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Executive Summary

Approach

Based on an extensive survey of the MBR industry, this White Paper provides a comprehensive overview of the market interests/expectations and technical potential of going through a standardisation process of membrane bioreactor (MBR) technology in Europe.

Today, the European MBR market is very fragmented, and exhibits many membrane characterisation methods and MBR filtration products with diverse dimensions, capacities and operational modes. This situation without standardisation is a bottleneck in the selection of MBR technology and its broad application.

In 2005 the European Commission decided to boost the development and application of MBR processes for municipal wastewater treatment through financing a 3-year research project within the scope of the 6th Framework Program: AMEDEUS (accelerate membrane development for urban sewage purification). Within AMEDEUS an analysis of the potential for MBR standardisation was carried out by Aquafin and Anjou Recherche, in liaison with the *Comité Européen de Normalisation* (CEN). In total, 80 companies and institutions active in all areas of the European MBR market were identified after a thorough market review and individually contacted with an extensive questionnaire. The response rate was spectacular and demonstrated the interest of the industry in this initiative: 45 contacts cooperated to this study.

Due to the predominance of submerged filtration systems in municipal applications, representing 99% of the installed membrane surface of MBR systems in Europe in the period 2002-2005, the study focuses only on this configuration. Two different aspects of standardisation are considered:

- MBR filtration modules (standardisation towards interchangeable modules in MBRs)
- characterisation methods for membrane acceptance, fouling, integrity and ageing (standardisation towards uniform quality assessment methods)

Market interests and expectations

MBR filtration modules

The analysis of market interests and expectations for MBR filtration module standardisation indicates that there is a specific interest in guidelines or standards on interchangeable filtration modules in MBRs from both sides of the market, for small (100-1000 m³/day), medium (1-100 MLD) and large (>100 MLD) capacities. The majority of the MBR operators, constructors, consultants and knowledge institutions are convinced this is the right time to initiate a process of MBR module standardisation. On the other hand, some of the module suppliers are under the impression that initiating a module standardisation process now would be too early and would hamper the technological innovation in the field. Most market players expect that interchangeable MBR filtration modules will increase the willingness of decision makers to invest in MBR technology and will contribute to a growth of the



municipal MBR market - although they do not believe this standardisation process to be one of the top three driving forces.

About twenty potential technological, financial, economical, or environmental advantages/opportunities and disadvantages/threats of MBR filtration module standardisation for suppliers and operators were identified and mapped. It appears that the number of advantages and disadvantages is quite balanced for both sides of the market, the main advantage perceived by the industry being that standardisation should contribute to the growth of the MBR market. Other main advantages/opportunities are the reduction of dependency on one supplier, price decrease and increased trust and acceptance. Main disadvantages/threats for the end-users are over-dimensioning of civil constructions and supplementary works (both at initial project stage and at time of module replacement) and costs to the peripherals for module replacement. Main disadvantages for the module suppliers seem to be the higher competition, lower profit margins and a limitation for innovative module producers to enter the market.

Membrane characterisation methods

The market players mainly agree that it is time to initiate a process of standardisation for membrane characterisation tests. Respondents show a specific interest for membrane characterisation methods standardisation, specifically for small to large size plants (from 100 m³/d to 100 MLD). The majority of the MBR operators, consultants and knowledge institutions, except the plant constructors, believe that harmonisation of membrane acceptance tests at module delivery, will probably have a positive impact on municipal MBR market growth. The majority of the respondents feel that standard acceptance tests during plant commissioning can lead to an increase of MBR market growth. Module suppliers are divided about a possible positive impact of standardised tests either at module delivery or during plant commissioning. The main advantages specified by the respondents are a better comparison between membrane manufacturers, a better understanding and more trust in membrane technology. While several advantages are mentioned, one real concern appears: the difficulty to find the right methods applicable to all types of membranes.

Technical potential

MBR filtration modules

The technical potential for standardisation of MBR filtration modules in Europe was evaluated based on a unique analysis and comparison of nine commercially available MBR filtration modules in Europe, completely different in terms of design and mode of operation. The analysis has shown that a standardisation process common for both flat sheet and hollow fiber membranes/modules is riddled with difficulties and challenges. More than thirty technical factors hampering or interfering with a standardisation process were identified, quantified and compared for the surveyed modules, and their relative potential in affecting the possible outcome was evaluated. Four factors with a high to extremely high capacity for nuisance (module dimensions, filtration tank dimensions, specific permeate production capacity and specific coarse bubble aeration demand) are mainly the result of a totally different geometry and dimensions of the filtration module and discussions for the standardisation of MBR



filtration systems should in essence focus on these factors. Sixteen factors with a moderate to high capacity for nuisance are mainly the result of the fact that either a number of products are still in the early development phase of their life cycle, or because they will (drastically) increase total costs of module replacement due to required adaptation works to the peripherals. Sixteen other factors with a low to moderate capacity for nuisance will only be a minor issue since they are either part of the common knowledge or practice, or because the interchangeable module supplier will resign to the design in force at the moment of membrane replacement. It was also revealed that it would be easier and technically wiser to consider two separate standardisation groups: one for flat sheet modules and one for hollow fiber modules. From this study, it cannot be deduced that a standardisation process would be more straightforward or would go faster for one category as opposed to the other.

Membrane characterisation methods

The main operating and monitoring techniques applied were evaluated, and some parameters were identified for integration in a standardisation process. Simple, well-assessed and well-defined methods to operate membrane filtration systems and to better predict membrane behaviour are necessary. An official and common standard test to check product quality and performances at module delivery and at plant commissioning will probably confirm and extend the position of membrane technology in the wastewater treatment world. This study emphasizes some important parameters for which a common definition and measurement protocol could be helpful, such as monitoring of membrane fouling, integrity and ageing, membrane lifetime, flux and peak hydraulic load. In a second step, the industry would welcome the identification and harmonisation of guidelines and characterisation protocols for membrane acceptance at module delivery, membrane performance at plant commissioning and permeability in water and sludge. Harmonisation of parameters definition and measurement methods should precede, or accompany the harmonisation of the technologies in sight of product interchangeability: this will increase trust in the technology, and will also reduce the risk of lower quality products.

Workshop / Recommendations

The outcomes of this study were presented to and discussed with representatives of the European MBR industry at a workshop organised together with the CEN in Berlin on 24/11/2006. 35 MBR representatives from 9 countries and 29 different companies accepted the White Paper by plebiscite as a reference document to initiate a procedure of standardisation within the MBR industry. A minority of the participants believe normative standards are not needed for submerged MBR filtration systems (25%) or membrane characterisation methods (15%). Instead they favour the development of technical guidelines. A significant amount of the participants (40%) argue that normative standards for both MBR filtration systems and membrane characterisation methods are needed only within a few years. A large majority of the companies argues that their company would be interested one way or another to commit/participate in a process of standardisation of submersed MBR filtration systems (75%) and membrane characterisation methods (90%) in the



coming years. The representatives of the MBR industry present at this workshop decided to initiate a standardisation process on submerged MBR technology through a CEN Workshop Agreement (CWA).



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Glossary of important terms and acronyms

Biofouling	Formation of bio-growth upon membrane surface or into the porous membrane structure.
Broken membrane %	Percentage of broken fibers compared to the total fibers contained in a module
CEN	European Committee for Standardisation
Cleaning rate %	Chemical cleaning efficiency
DIN	Deutsches Institut für Normung
FFD	Filtration flux decay at constant TMP per unit of time
Filter structure	Pore size, morphology, ratings (see "Ratings")
Flow rate	Volume of fluid passing through a filtration system per unit of time
Flux	Volume of permeate produced by a filtration system, typically expressed in volume per membrane area per unit of time
FS	Flat sheet (membranes or module)
HF	Hollow fiber (membranes or module)
Hydraulic resistance	Inverse proportional to membrane permeability. Membrane resistance resulting of the movement of the fluid to be filtered through this membrane.
Integrity test	A physical / technical test informing on the membrane or module integrity and correlating with the quality of the treated water, generally in terms of bacteria breakthrough.
IP	Intellectual Property
Mechanical properties	Thickness, dimensional stability, swelling, tensile strength and hydraulic permeability.
Mineral fouling	Precipitate of soluble salts upon the membrane surface or into the porous membrane structure.
Module	A "building block" in a membrane bioreactor comprising a housing which accommodates 1/ semi-permeable membranes connected to one or more headers which need to be connected to a central manifold for permeate discharge and 2/ a piping system located at the bottom which needs to be connected to another central manifold for air supply.
Molecular weight cut off (MWCO)	The minimal molecular weight of soluble or colloidal compounds which can be retained by a filtration system
Morphology	Pore structure: uniform, foam or bubble like, symmetric, asymmetric, homogeneous, heterogeneous.
Organic fouling	Adsorption of soluble or colloidal organic compounds upon the membrane surface or into the porous membrane structure.



(membrane) Packing density	The amount of square meter of membrane area per unit of volume (e.g. m ³ of filtration module) or surface area (e.g. m ² of filtration module or membrane filtration tank).
Permeability	Or specific flux: flux divided by the trans-membrane pressure
Pore size	Diameter of the particle that can be expected to be retained to some degree of efficiency. Pore sizes are usually stated in micrometer (µm).
Ratings	Membrane ratings refer to the size of a specific particle or organism retained by the filter to a specific degree of efficiency.
Retention and selective permeation	Techniques for the characterisation of micro filtration (MF) or ultra filtration (UF) membranes of molecular weight cut off. They generally implement marker compounds of a known molecular weight (dextran, proteins) to challenge the membrane under controlled conditions of temperature, flow rate and pressure.
Scan electron microscopy (SEM)	Technology used for microscopic observation of membrane surfaces. Scan electron microscopy is performed by scanning a focused probe across the surface of the membrane sample. Secondary electrons emitted from the sample are typically detected by a photomultiplier system, the output of which is used to modulate the brightness of a TV monitor that is rastered in synchronization with the electron beam scan. The more electrons a particular region emits, the brighter the image at that point. SEM images typically contain a good deal of topographical detail.
TMP	Trans-membrane pressure. Driving force provided by the pressure differential occurring across the membrane thickness



1 Introduction

What if...

Imagine your car tires of type A are worn-out and you have just decided to purchase four brand new tires of type B, since apparently these are more durable, safer and in addition to that: cheaper. How would you react if your local garage owner told you the following:

“I’m sorry but I can’t install type B tires in your car because they are manufactured in a larger size than your type A ones. If you want to use these type B tires you’ll have to change both your drive shaft and automatic gear.”

OR

“I just installed your new tires, but let me tell you two things. First of all, I cannot guarantee you this is a type B tire, since all tires look quite similar from the outside. I do not have the equipment to test this, neither can I show you any official certificates, so you will just have to trust me. For the same reason, I cannot tell you if this is a safe tire, but you will notice while driving. Secondly, it is possible we will soon meet again because you might have the sensation that after a 1000 km this tire will already be worn-out. I developed my own method to check this, but I do not really know how reliable it is. Anyway, we can always do a rough visual inspection.”



In both cases, you will probably declare your garage owner insane.

Sadly enough, the situation above is illustrating what we are facing today when talking about filtration modules for membrane bioreactors (MBR).

Ask a few simple questions to any MBR practitioner:

- How sure are you that your original membrane supplier will not have withdrawn from the market when you need to replace your modules ? Will they still have your filtration module series in their product range ? And how will you react if they charge double the original price ?
- Can you prove that the membrane you are operating has exactly the characteristics of the type you ordered ?
- Was the integrity and filtration performance of your filtration modules measured right after installation, was this done in the correct way, and can you show the results?
- Can you ascertain that you have never experienced any membrane integrity problem in your plant ?

It seems the main difference between MBR filtration modules and car tires is their level of standardisation.

Ask these few simple questions to any MBR owner. Many of them will not be able to give you a clear and precise answer.



- What is the filtration performance of your modules in comparison to a year ago ?
- When will you need to replace your filtration modules and how exactly will you determine this moment ?

The truth is that most of the MBR practitioners will not be able to give you a clear and precise answer, if they have any clue at all.

Wayback machine

To understand why it is so difficult to answer these questions, let's step into the Wayback machine and imagine what the situation with MBR modules was like only ten years ago. In 1996, the first MBR treating municipal wastewater in Europe still had to be constructed. Huge knowledge gaps on numerous topics such as pre-treatment requirements, treatment performance, membrane fouling, module clogging, sludge production and membrane lifetime characterized the many uncertainties at that time. Research projects and programs to develop existing MBR modules of the few suppliers on the market had just been launched. Only a dozen of European companies had significant MBR knowledge, mainly based on pilot plant experience.

Ten years later, it is clear that fantastic progress was achieved through devoted R&D efforts and feed-back from full-scale applications: optimised module design, better control of the filtration process and significant reduction of capital, consumables and labour costs. MBR technology has developed into a mature product available for nearly all sizes of application. Together with legal aspects and stringent effluent norms, this paved the way for more projects. Today in Europe, more than ten MBR module suppliers offer their products and almost a hundred MBRs for municipal wastewater treatment have been constructed. Nearly every wastewater related company or research group in Europe possesses MBR knowledge and/or experience to some extent.

Throughout all these years, the MBR industry has produced a remarkable diversity of filtration products. As if this is not yet complex enough, not only the filtration modules themselves, but also the electromechanical equipment surrounding the modules can take many forms and modes of operation. In addition to that, many different methods are used to characterise the integrity, ageing and performance of membranes.

Why is it so difficult to answer the questions above ? Simply because the world of MBR filtration modules and their characterisation methods is one without standardisation.

MBR modules & car tires

To gain a better insight into the impact standardisation can have on an industry, let's take once again car tires as an example. In fact, there are many similarities between MBR modules and car tires. They both form a crucial component in the system they are part of, having an enormous impact on safety, reliability, durability, effectiveness and energy costs of this entire system. While they may seem simple products, developing them is a quite complex process. Inappropriate operation can accelerate



ageing and cause dangerous damage. There is a bewildering amount of information available, from many competing companies and, depending on your needs and expectations, plenty of decisions must be made before purchasing.

It seems the main difference between MBR filtration modules and car tires is their level of standardisation.

Standardisation: often inevitable, and beneficial for the entire market

The thinking in tires has changed since 1968, when the first standards for tires were set. Hearings in the mid-1960s revealed problems with deceptive advertising by sellers, and it was concluded that consumers lacked the information needed to make informed purchasing decisions. Since then, tire manufacturers are required to place standardised information on the sidewall of all tires. This information identifies and describes the fundamental characteristics of the tire and also provides a tire identification number for safety standard certification and for traceability. In order to be branded, a tire must receive laboratory approval, meet confirmation-testing requirements and have the manufacturing facility pass inspection.

If we buy a new tire we expect it is fulfilling certain criteria of dimension, quality and safety. To the average person, “185/55R14 H” is a mystery, but car enthusiasts can explain the meaning of every alphanumeric character of the tire on which this label is affixed: the code stands e.g. for width, height, internal radius, temperature rating, and so on. These are standards agreed by all tire manufacturers. By using standardised ranges of tires, buyers – including car manufacturers – can easily shop around and purchase tires from different vendors, while selecting the range in relation to the criteria of dimension, quality and safety. This leads to competition and reduced prices. If each car manufacturer would decide to use a proprietary standard, both he and the buyers of that car would be restricted to one supplier of tires. This would lead to higher prices because tire manufacturers would be making many small batches of unique tires. Moreover, if one of these tire makers achieved market dominance, they could hurt the car industry by discontinuing a tire size, forcing the car makers to revise the wheels on their car. This market dominance would lead to a deadlock for car makers and buyers.

An organisation of the MBR market can be expected, which may lead to a natural identification of few standards, as decided by market forces. However, a proactive approach between market stakeholders may accelerate this process of standardisation.

Normalisation criteria for MBR module design and characterization methods which are identified and accepted by market stakeholders could benefit the entire sector. By using standard size and interchangeable modules, end-users, manufacturers, suppliers and investors could all benefit due to increased trust and larger market. Standards are generally good for business.

Standardisation does not exclude intellectual property (IP) protection and competition

Although car tires exhibit a high level of standardisation, many manufacturers exist, all offering different tires featuring specific properties and patents. Facing a global market where it is more and more difficult to turn a profit, all of the leading tire

A pro-active approach between market stakeholders may accelerate the natural phenomenon of MBR standardisation.

Standards are generally good for business.



manufacturers regularly announce new technology partnerships and investments to improve the quality, safety and production cost of their product, which in the end is critical for its performance, customer approval and ultimately market share.

A certain level of MBR standardisation, a high competition between membrane and module suppliers and extensive IP production and protection, can co-exist.

Fuel the debate

The same market players that boosted MBR technology into the 21st century, could now start looking at the potential impact standardisation of this technology can bring to the whole wastewater treatment industry. This White Paper wants to initiate and fuel the discussion. It presents the results of a comprehensive study which was not aimed at outlining and defining the ideal MBR standards, but rather at analysing the potential for MBR standardisation in Europe, by focusing on both the market player's expectations and the relevant technical provisions.

So let's start the debate !

The same market players that boosted MBR technology into the 21st century could now start the standardisation of this technology.



2 Background, objectives, scope and approach

2.1 Background

In 2005 the European Commission decided to boost the development and application of European MBR processes for municipal wastewater treatment through financing a 3-year research project within the scope of the 6th Framework Program: AMEDEUS (accelerate membrane development for urban sewage purification). AMEDEUS (www.mbr-network.eu) focuses on the development of competitive MBR filtration technologies and the acceptance of MBR technology for municipal wastewater treatment through decreased capital and operational costs.

Within AMEDEUS an analysis of the potential for MBR standardisation was carried out by Anjou Recherche and Aquafin, in liaison with the European Committee for Standardisation (CEN). This White Paper sets off the results and recommendations of this analysis, providing an overview of the market interest and technical potential of going through a standardisation process of MBR technology in Europe.

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, soon followed by the construction of some full-scale WWTPs of several 1,000 PE. A few years later only, in 2004, the largest MBR plant worldwide was commissioned to serve a population of 80,000 p.e. The size of installations has thus grown from few thousand to hundreds of thousands population equivalent in only a few years. 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 m³/d (Figure 1). The development and successful commercialisation of the technology in the past few years has led to significant decrease in capital and operating costs.

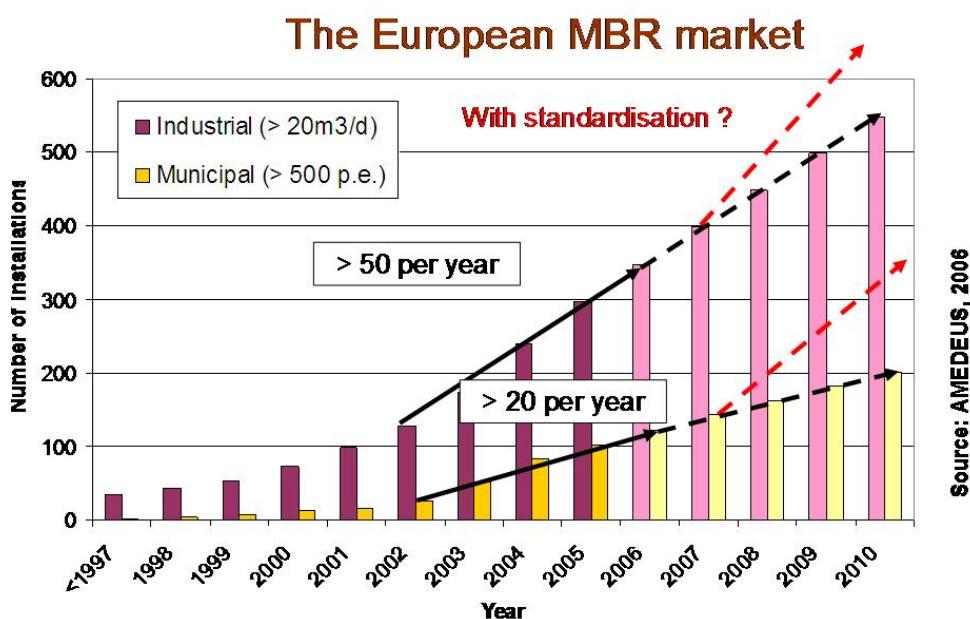


Figure 1 Number of municipal and industrial MBRs in Europe.

This study was carried out within AMEDEUS, a 3-year research project financed by the European Commission

www.mbr-network.eu



Facing a European MBR market that has significantly increased in the last ten years, the MBR industry is now more and more confronted with an emerging market of module replacement (Figure 2).

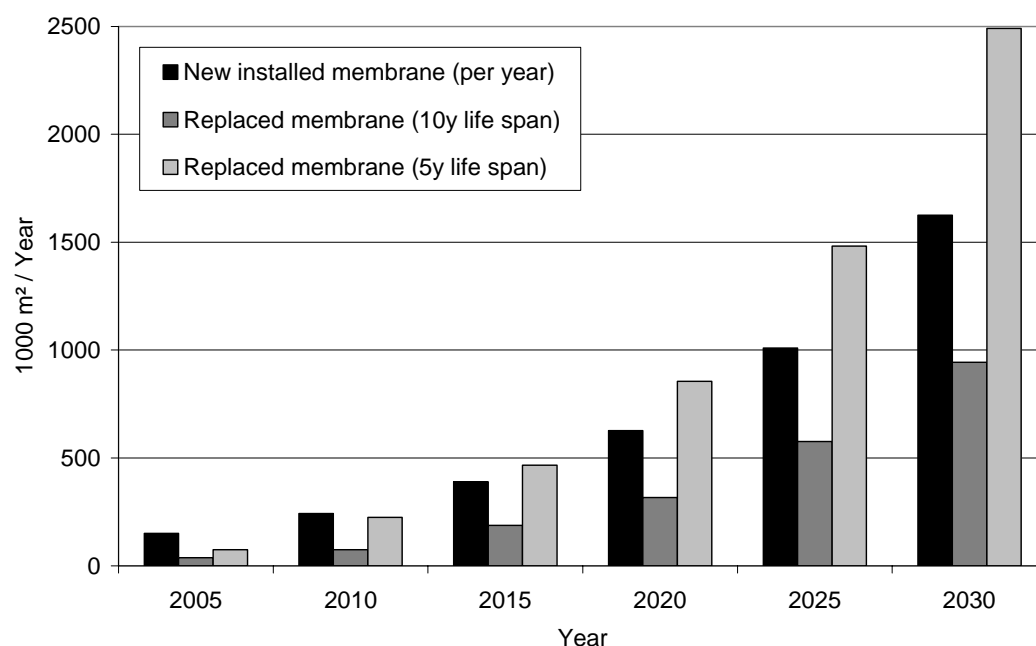


Figure 2 Emerging market of module replacement (hypotheses: 10% annual growth, 5 or 10 year module life span)

2.2 Standardisation: general aspects

Products and services affect the lives of millions of consumers, and standards are almost always involved, although they mostly go unnoticed. Without standards a sheet of paper would not fit the printer, a petrol pump nozzle would not fit the tank of a car, a credit card would not fit the cash point. Standardisation diminishes trade barriers, promotes safety, allows interoperability of products, systems and services, and promotes common technical understanding. Standards provide certainty, references, and benchmarks for designers, engineers and service providers.

CEN, the European Committee for Standardisation (Comité Européen de Normalisation), is the officially recognized standardisation representative for sectors other than electrotechnical (CENELEC) and telecommunications (ETSI). CEN is a private non-profit organization whose mission is to foster the European economy in global trading, the welfare of European citizens and the environment by providing an efficient infrastructure for the development, maintenance and distribution of coherent sets of standards and specifications. Its twenty nine national members work together to develop voluntary European standards (ENs) in various sectors. A European



Standard (EN) is implemented in all 29 countries, this means 1 EN = 29 national standards¹ = access to more than 460 million people.

European standards are consensus-based and will be developed by the interested parties themselves. The implementation of standards is voluntary. Standards are only legally binding if they are part of a contractual agreement between parties, or if legislators stipulate their conformity.

Several CEN deliverables, differing in the levels of consensus and acceptance, offer flexible means to meet market needs for technical requirements and information.

These deliverables are:

- the European Norm (EN): leads to full implementation, as national standard, over the whole of Europe, also serving the European regulatory purposes of the New Approach;
- the Technical Specification (CEN/TS): serves as normative document in areas where the actual state of the art is not sufficiently stable for a European Norm;
- the Technical Report (CEN/TR) :serves as a means of information and transfer of knowledge;
- the CEN Workshop Agreement (CWA): aims at bringing about consensual agreements based on deliberations of open Workshops with unrestricted direct representation of interested parties;
- the Guide (CEN Guide): gives information about standardisation principles and policies and offers guidance to standards writers.

These products are, apart from the CWA which has direct industry representation in Workshops, drawn up by the community of the CEN members, who in turn consult their interested parties, usually via the means of national mirror committees.

The usual procedure to publish a European Standard takes about 3 years (may be 1 to 2 years for a CWA). The development of a European Standard includes a public enquiry, followed by an approval by weighted vote of CEN national members, final ratification and endorsement at national level. Periodic review will be undertaken.

Different kinds of standards exist:

-Open standards:

are documented for all, have been developed and are maintained in public and are characteristically supplier-neutral.

-Proprietary standards:

are in fact not standards at all. They are technical specifications developed, released and maintained by a single entity or a single large corporate that dominates an industry sector. Proprietary "standards" such as these are typically not supported by competitor organisations and almost always remain the property of the issuing

¹ The current CEN Members are: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and the United Kingdom.



organisation. They may require a license to use, and may be incompletely documented.

-De-jure standards:

are those that are defined and published by recognised formal standard organisations. These could be international standards (e.g. ISO) or a country specific standard developed by the national equivalent of the international standard body.

-De-facto standards:

are the result of a collaborative effort by a consortium of interested parties or by a single company or individual. Although not "*de-jure*", they nevertheless carry the credibility of an open and transparent collaborative effort. This standard is so dominant that everybody seems to follow it like an authorized standard. A *de facto* standard is sometimes not formalized and may simply rely on the fact that someone has come up with a good idea which is spontaneously copied.

2.3 Scope & Approach

Due to the predominance of submerged filtration systems in municipal applications, the study focuses only on this configuration. Two different aspects of standardisation are considered:

- standardisation of MBR filtration modules (towards interchangeable modules in MBRs): this analysis was performed by Aquafin and
- standardisation of membrane (performance) characterisation methods for acceptance tests, fouling, integrity and ageing (towards uniform quality assessment methods of MBR filtration systems): this analysis was performed by Anjou Recherche

The approach followed in this analysis was based on two considerations:

- 1/ Hardly any information on MBR standardisation is available. Somehow, new information needs to be collected to bridge this knowledge gap.
- 2/ Standards are mostly the result of a long process in which all interested parties (enterprises, consumers, public authorities,...) can participate. This requires dialogue between the market players.

Therefore, the following step-by-step approach was followed:

Step 1:

Developing an extensive questionnaire on MBR standardisation in order to collect information from various MBR market players (MBR module suppliers, operators, constructors, consultants, universities, research institutes) in Europe

Step 2:

Identification of the companies and institutions in Europe with most relevant MBR know-how and experience useful for this standardisation study

Step 3:

Contacting these companies and institutions by telephone and sending them the questionnaires by e-mail

Step 4:

*New information
needed to be
collected to fill the
knowledge gap on
MBR
standardisation*



Collecting, checking, processing and analysing the replies to the questionnaire

Step 5:

Drafting the White Paper

Step 6:

Organisation of an international workshop on MBR standardisation in order to initiate a debate on standardisation of MBR technology in Europe, using the interim version of the White Paper as a discussion document

Step 7:

Finalising the White Paper with recommendations of the MBR industry representatives issued during the workshop

2.4 Content & Objectives

What you will not find in the content of this White Paper:

- proposition of (best) MBR standards
- direct publication or quotation of a company's reply to the questionnaire
- literature study

What you will find in the content of this White Paper:

- results of a comprehensive impartial analysis on
 - the market expectations and interests on dimensional, quality & performance and test method standards
 - the technical aspects and difficulties/bottlenecks to be considered in a standardisation process
- recommendations for a possible MBR standardisation process in Europe

The goal of this White Paper is not:

- to analyse the market interest and technical potential for MBR terms & symbols standards or codes of MBR practice standards
- to impose the author's own view
- to outline a detailed timing and approach for a possible future standardisation track
- to form an endpoint and final conclusion

The goal of this White Paper is:

- to analyse the market interest and technical potential for dimensional standards, quality & performance standards and test method standards in MBRs
- to provide a groundbreaking publicly available discussion document on MBR standardisation in Europe
- to foster the debate on MBR standardisation with the different stakeholders and to increase the awareness and interest in the subject
- according to the outcomes and in agreement with the European MBR industry, to initiate a formal procedure of standardisation together with the CEN

A comprehensive impartial analysis on MBR standardisation can be found in this paper.





3 Survey: general characteristics

3.1 Introduction

For the purpose of this study, a serious effort was made to establish the most exhaustive sample group of stakeholders in the municipal European MBR market (submerged membrane). Our constant concern was to:

- Obtain a significant number of companies in the technical and economical fields
- Obtain a good geographic representation in Europe.

In order to achieve this, 3 lists were established:

- The existent MBR plants in Europe in order to identify their operators
- All membrane/module suppliers and plant constructors involved in submerged membrane bioreactor design in Europe.
- The list of experienced and specified technical partners: research institutes, consultancy agencies as well as European and non European academic experts.

In total, 80 market participants out of 14 countries were asked to fill in an extensive questionnaire for this study.

3.2 Companies addressed

3.2.1 List of companies addressed

The table below shows the number of companies contacted in each core activity. We can see that each job stream is well represented in number.

Table 1. Number of companies contacted

Core activity of companies and institutions contacted:	
Core activity	Number
Membrane / module suppliers	20
MBR constructors	15
MBR Operators	25
Research centres - consultants	11
Academic experts	9
TOTAL	80

A complete list of the companies contacted for this study is shown in Appendix 1.



3.2.2 Represented countries

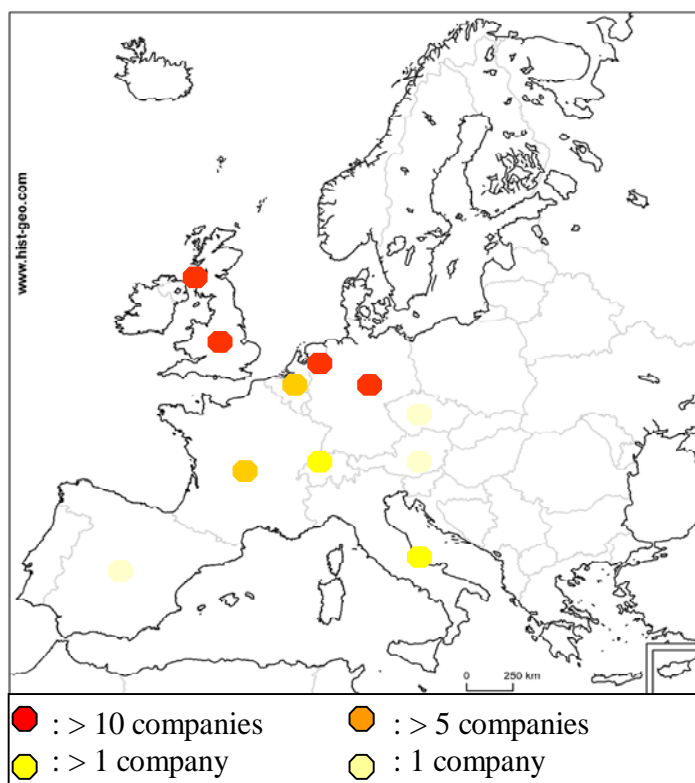
The map below shows the geographic location of the 80 respondents. We can see that the representation rate decreases from north to south of Europe. A study by Frost & Sullivan², showed that the Iberian and Italian market comprises the same number of companies as in Benelux and France. In our study these countries are less represented than France and Belgium: it can be explained by the fact that this study covers only submerged MBRs for municipal wastewater treatment, and most of MBR plants built in South Europe concerned industrial applications with pressure-driven systems.

Origin of companies and institution

▶ The Netherlands	17
▶ UK	16
▶ Germany	15
▶ France	8
▶ Belgium	5
▶ Switzerland	3
▶ Italy	2
▶ Spain	1
▶ Czech Republic	1
▶ Austria	1
▶ Japan	2

Academic experts

▶ France	2
▶ Germany	2
▶ UK	1
▶ Korea	1
▶ Canada	1
▶ Japan	1
▶ Australia	1



² Strategic Analysis of the European Membrane Bioreactor Markets – Frost & Sullivan - 2005



3.3 Respondent characterisation

3.3.1 Number & core activity

Figure 3 shows the percentage of replies obtained within each group of core activities.

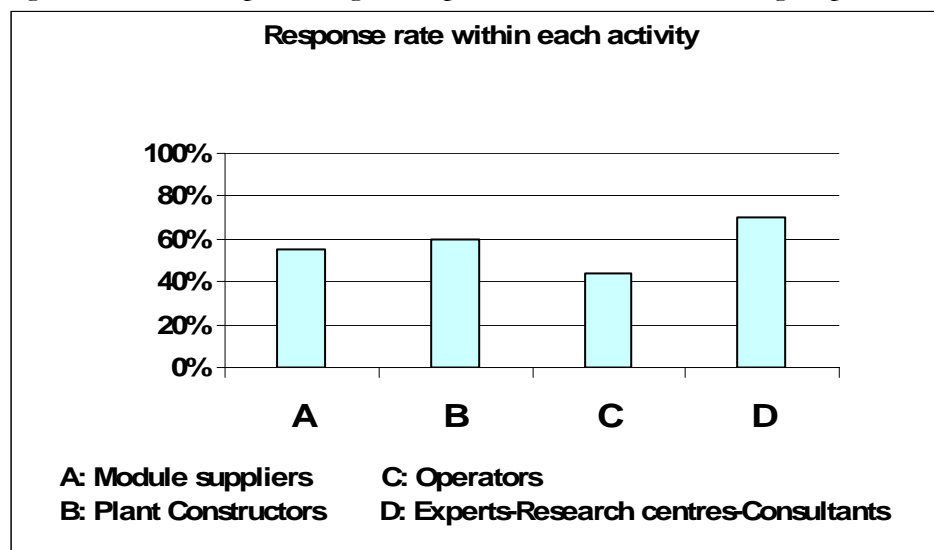


Figure 3. Response rate within each activity

In total, 45 replies were obtained (80 questionnaires sent), which represent a total participation rate of 56 %.

Although it can be assumed MBR operators will be beneficiaries of a standardisation process, this category has the lowest response rate (44 %). This can be caused by various reasons:

- Lack of time / high number of questions
- MBR is not their core activity
- Lack of specialised people skilled enough to provide answers
- Bad comprehension of the aim of the study
- Language barrier

Membrane/module suppliers and plant constructors, replied with a higher rate (respectively 55 and 60 %), which could be attributed to the fact that these kind of companies shall be the first in applying the consequence of such a standardisation. With the same interest, University /Research centres replied with a high rate.



Figure 4 shows the distribution of the answers between the core activities.

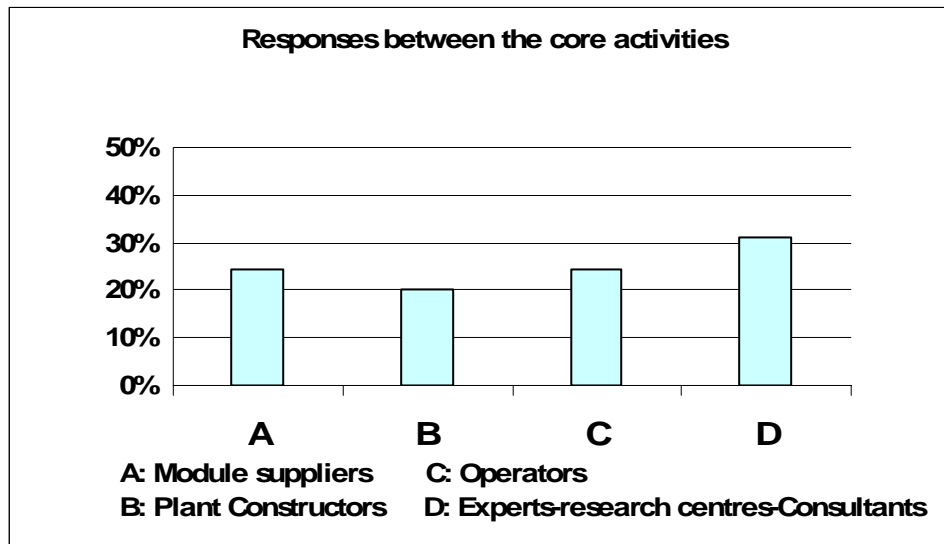


Figure 4. Response rate between the core activities

A good balance was obtained, since each activity represents more than 20% of the total number of replies:

- Membrane module suppliers: 11
- Constructors: 9
- Operators: 11
- Universities – research centres – consultants: 14

We obtained a balanced panel of respondents and this should give us a good indication of each sample group's needs.



3.3.2 MBR experience

Figure 5 shows the replier's experience in MBR technology.

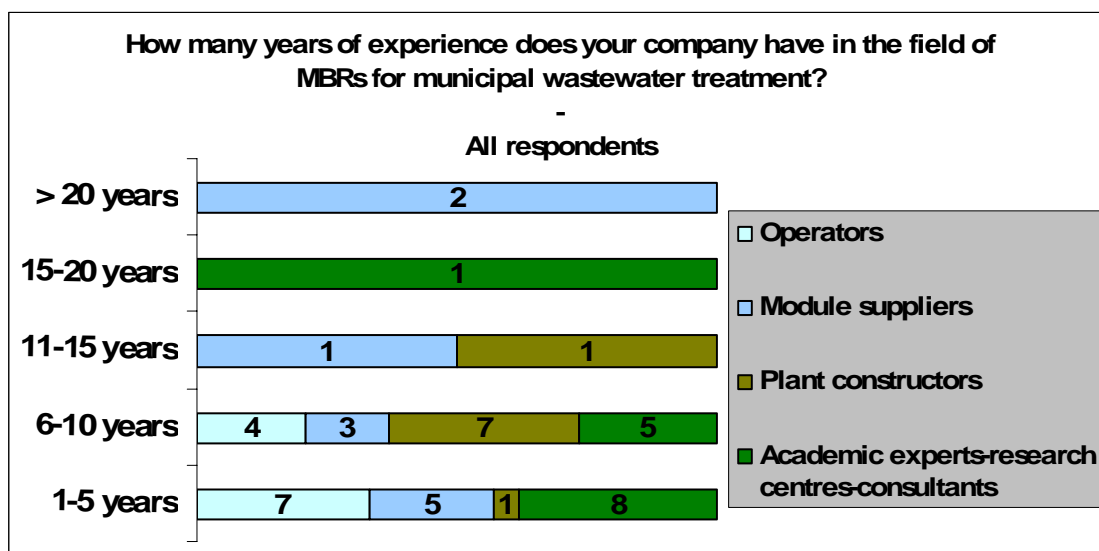


Figure 5. MBR experience of the repliers

Module suppliers and plant constructors have the highest level of experience, which reinforces the reliability of their replies. Among the membrane/module suppliers, the two market leaders in Europe replied to the questionnaire.

End-users are less experienced, which is a logical consequence of the fact they are the last link in the chain after introduction of a new technology.

Figure 6 provides more information on the number of MBRs (and their capacities) operated by the end-users who replied to the questionnaire.

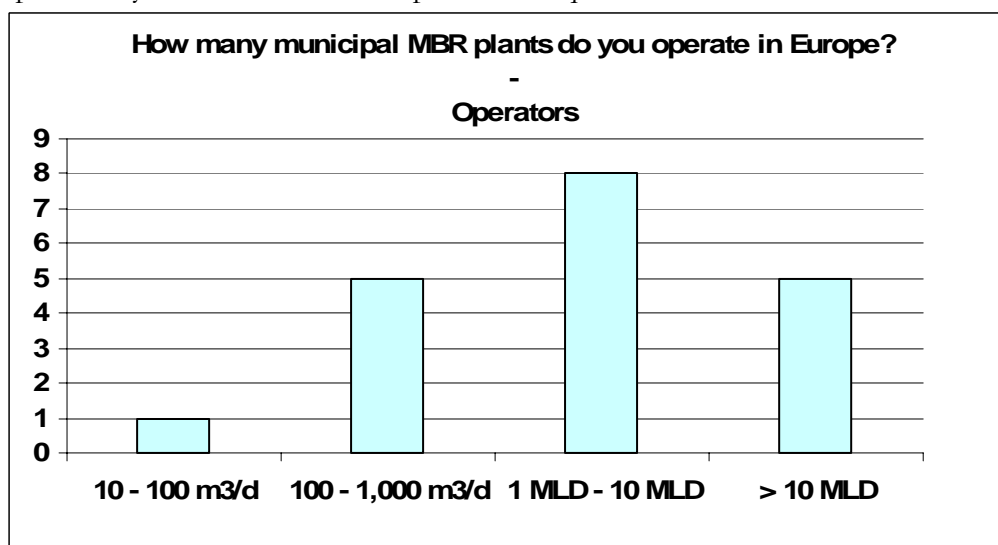


Figure 6. Number of MBR plants operated by the respondents



Figure 6 shows that the most represented capacity range is rather high: 1MLD to 10 MLD capacity.

The number of municipal MBR plants operated in Europe is shown in Figure 7.

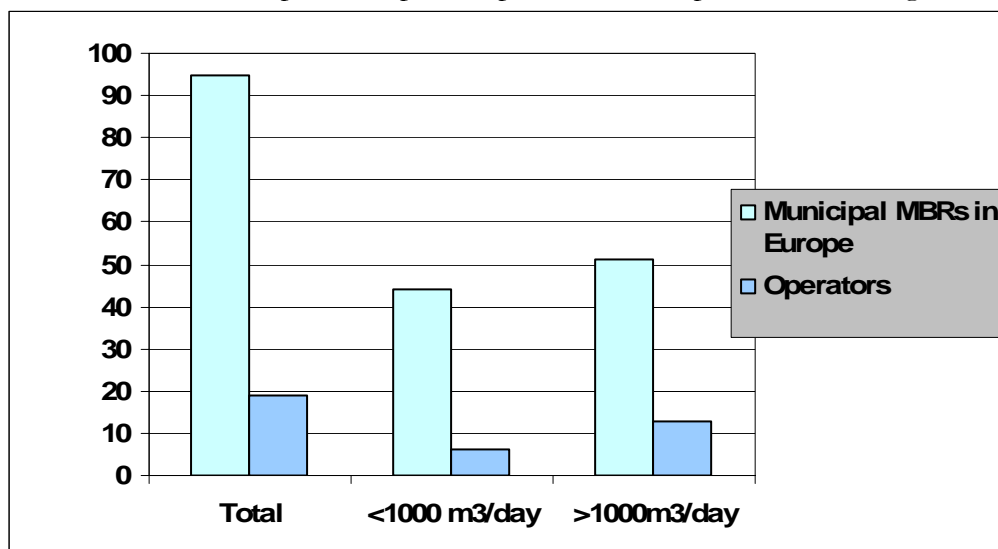


Figure 7. Comparison between the number of municipal MBR plants operated in Europe > 100 m³/day or 500 p.e. (2006) and the number of plants operated by the questionnaire repliers. Source: intern review AMEDEUS consortium.

From this figure, it can be noticed that the repliers operate 19 of the 95 existing submerged MBR municipal plants in operation in Europe in early 2006 with a capacity > 100 m³/d (i.e. 20 % of the plants). 51 plants with a capacity > 1000 m³/d are operated in Europe, and 25% of them are operated by respondents who provided information for this study. In addition, the five largest plants operated in Europe (> 10 MLD) are represented in our study.

For membrane/module suppliers and MBR constructors, it can be noticed that:

- more than 50 % of membrane/module suppliers and plant constructors designed plants of 1 to 10 MLD
- Four plant constructors and one module supplier designed plants > 10 MLD

As the two leading module suppliers in Europe replied to the questionnaire, more than 80% of the European submerged municipal MBR plants with a capacity > 100m³/day are represented. The main outsiders of the remaining 20 %, replied also to the survey.



3.3.3 Conclusion

This is a representative study: a large, significant and representative amount of companies provided information on which this paper is based:

- Total number of replies is high: 45 companies – response rate of 53%
- The core activities (supplier, constructor, operator, other knowledge institutions) are equally represented
- The two leading module producers as well as the principal outsiders on the European market replied
- Ten European countries and four non-European countries are represented
- Repliers have a significant and long MBR experience (e.g. high capacity plants are well represented)
- Each core activity replied with a response rate superior at 50 % except for operators (38 % only).

The low response rate of end-users decreases the representativeness of their group, especially for the small-size plants.





4 Market expectations

4.1 MBR filtration module standardisation

(note: this section was prepared under responsibility of Aquafin)

4.1.1 Introduction

This chapter of the paper can be divided into two non-technical parts.

The first part elaborates on the market interests and expectations on standardisation of MBR filtration modules and related periphery:

- Do people think a standardisation study like this is **relevant** ?
- Is there a **need** for MBR filtration module standards ? By who ? What should be the **scope** of standards/guidelines ? Only limited to the filtration module ? Or extended to the filtration tank, the entire MBR or even operational aspects of MBRs ?
- Is it the right **time** to start this study and discussion on MBR filtration standards in Europe ? Should the standardisation process itself start today ? Or is it too soon yet, or maybe already too late ?
- What is the expected **impact** standardised modules may have on the MBR market size ?

The second part wants to define and map the potential advantages/opportunities and disadvantages/threats of MBR filtration module standards, not by writing out the author's own ideas and opinion, but by clearly synthesising and neatly presenting considerations acquired after consulting the most relevant part of the market.

4.1.2 Results and discussion

4.1.2.1 Timing

When exactly should a business commit itself to standard making ? The time at which a standard is established is absolutely critical to its success. This is illustrated in Figure 8 by "the apocalypse of the two elephants"³. This figure shows the amount of activity surrounding a new subject. When the subject is first discovered, there is a peak of research activity in the form of discussions, papers and meetings. After a while this subsides, corporations discover the subject, and the million-euro wave of investment hits.

It is essential that the standards be written in the trough between the two "elephants".

If standards are written too early, before the research is completed, the subject may still be insufficiently understood, which leads to inadequate standards. If standards are written too late, many companies will already have made major investments, and a large number of users will be locked into proprietary products and standards. If the

³ Based on the figure provided by Andrew S. Tanenbaum, Computer Networks, fourth edition, 2002.

This chapter elaborates on

- *Relevance*
 - *Need*
 - *Scope*
 - *Timing*
 - *Impact*
 - *Advantages*
 - *Disadvantages*
- of/for MBR standards*



interval between the two elephants is very short (because everyone is in a hurry to get started), the people developing standards may get crushed: the investments already start at the time the standard is still under development.

It is essential that standards are written in the trough between the two "elephants".

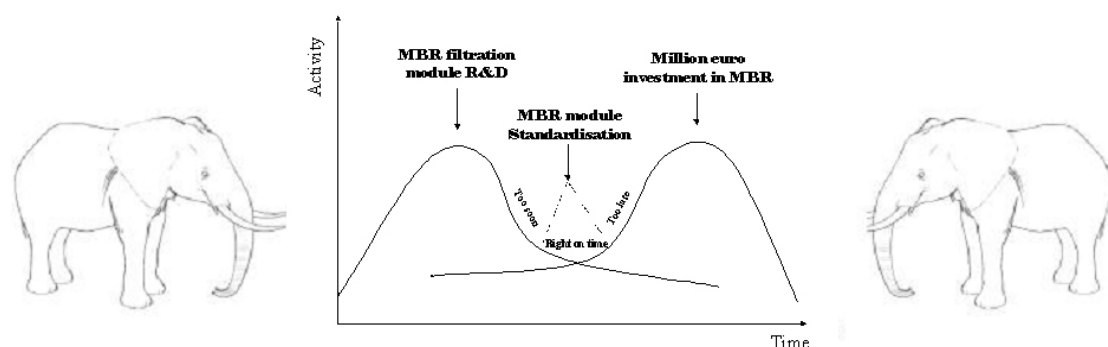


Figure 8. Apocalypse of the two elephants

Figure 9 represents the surveyed companies' opinion on the right timing for standardisation of MBR modules.

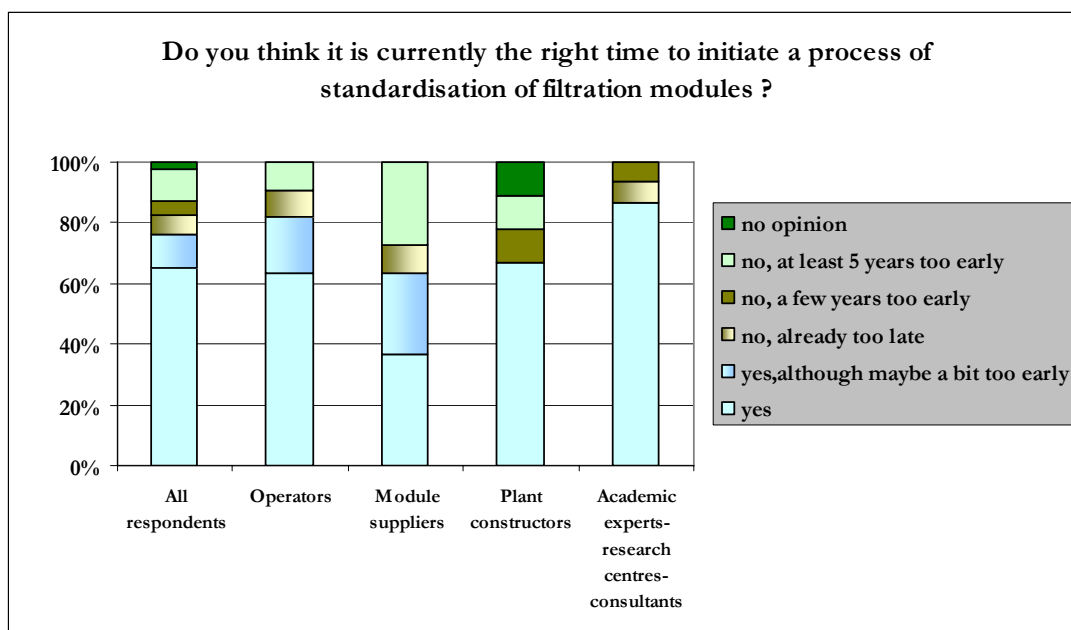


Figure 9. Timing for standardisation of MBR filtration modules

From this graph it is clear that the big majority of the companies think it is the right moment to initiate a process of filtration module standardisation. The difference between operators and modules suppliers is interesting here: while the majority of the operators think it is the right moment, the majority of the module suppliers think it is one or several years too early. They consider that the product is not mature yet and that other innovations will be presented in the coming years.

Most operators think it is the right moment to start a standardisation process of filtration modules. Most suppliers are more reluctant, and think it is one or several years too early.



4.1.2.2 Relevance

Standardisation is a self-regulating process based on consensus amongst different economic actors (industry, vendors, consumers, public authorities,...). Interested parties come together on a voluntary basis to reach an agreement on (technical) matters that will allow them to boost the competitiveness of their economy by implementing policies such as accessibility, security,... Any attempt at standardisation, regardless of the subject, is a complex venture. Discussions surrounding the idea mostly tend to be intense, and inevitably give rise to a number of arguments both in favour and against the process of standardisation. A prerequisite for active participation and contribution in an MBR filtration module standardisation process, is the conviction that an impartial analysis of the topic is relevant, as is also illustrated by Figure 10.

Half of the respondents are convinced an analysis on module standardisation is either "useful" or "very useful", while a quarter thinks it "may be useful".

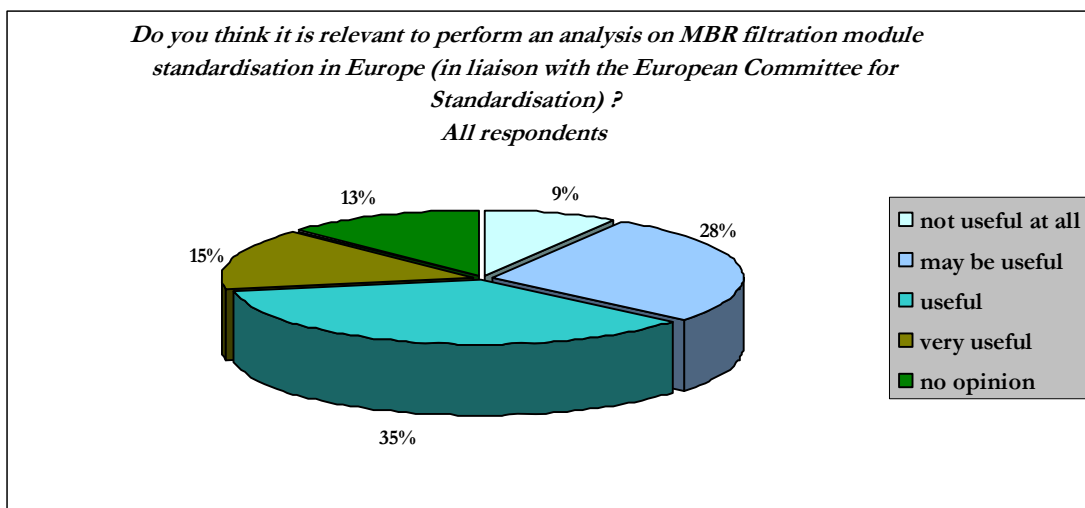


Figure 10. Relevance of an analysis on MBR filtration modules standardisation

Half of the respondents are convinced an analysis on MBR filtration module standardisation in Europe is either "useful" or "very useful". Only 9% claim it is "not useful at all", and 28% argues it "may be useful". The figure for MBR operators and modules is more or less similar, although none of the module suppliers are convinced this study is "very useful".

4.1.2.3 Scope

From Table 2 the following conclusions can be made regarding the scope of standardisation:

- For small (100-1000 m³/day), medium (1-100 MLD) and large (>100 MLD) MBRs, there is a specific interest of every side of the market in guidelines/standards






on interchangeable filtration modules. This interest is most pronounced for small MBRs.

- About half of the surveyed MBR operators also show an interest in standards/guidelines on the design of the entire filtration tank/system and on the operation of small, medium or large size MBR plants. It can be noted that in some countries (e.g. Germany) some working groups have already developed and published technical recommendations on the design and operation of MBR plants.
- For household (< 10 m³/day) and package MBRs (10-100 m³/day) there is a hardly any interest in any guidelines or standards whatsoever (either modules, filtration tank, total MBR design or MBR operation). This outcome could be biased by the fact that mainly representatives from larger systems were surveyed. The only interest comes from module suppliers: about half of them would be interested in standards/guidelines for package MBRs. It could be noted that also here, some national guidelines (e.g. France and Germany) can already exist for household wastewater treatment plants (< 50 PE), covering all technologies, incl. MBR systems.

Table 2. Scope of a standardisation process on MBR filtration modules

		<10m ³ /d (household plants)	10-100 m ³ /d ("package" plants)	100-1000m ³ /d (small size)	1-100MLD (medium to large size)	>100MLD (very large size)
MEMBRANE/ MODULE SUPPLIER	module interchangeability					
	design of filtration tank or system					
	design of entire WWTP system					
	MBR plant operation					
END-USERS	module interchangeability					
	design of filtration tank or system					
	design of entire WWTP system					
	MBR plant operation					
CONSTRUCTORS	module interchangeability					
	design of filtration tank or system					
	design of entire WWTP system					
	MBR plant operation					

Legend

	more than 60 % of the respondents replied "no interest/no opinion"
	50/50 distribution between "no interest/no opinion" and "specific interest"
	more than 60 % of the respondents replied "specific interest"

Module suppliers, operators and constructors have a specific interest in standards or guidelines on interchangeable filtration modules for small, medium and large installations.



4.1.2.4 Potential benefits/strengths

A. Market size

The size of the municipal and industrial Western European membrane bioreactor market in 2005 was estimated to be around €65 million with an annual growth rate of 11 percent⁴. In this estimation the MBR market was defined as the total industry revenues for MBR units excluding costs for all civil engineering structures and associated equipment, such as replacement membranes. The municipal sector accounts for the larger share of European MBR sales with 62 percent of the market. MBR module filtration standards could open the market and thus help avoid end user dependency on a single supplier. Could standardised MBR filtration modules be a force boosting the market growth and development? And to what extent? An answer to these questions is given in Figure 11.

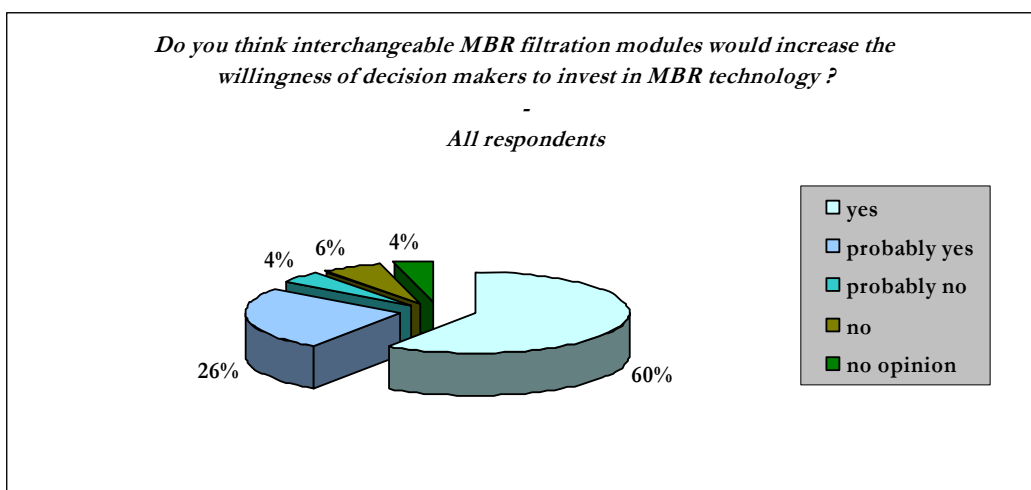


Figure 11. Willingness of decision makers to invest in MBR technology

A large majority of all the respondents is convinced that interchangeable MBR filtration modules will increase the willingness of decision makers to invest in MBR technology and will contribute to a growth of the municipal MBR market. This is confirmed by Figure 12 and Figure 13. Two questions were asked in these figures:

- Suppose you have good experiences with your existing modules, but they need to be replaced because of ageing. Would you choose for interchangeable modules from another module supplier if his offer is 20% cheaper than the offer of you original module supplier?
- Suppose you have bad experiences with your existing modules (e.g. regular fouling problems), but they need to be replaced because of ageing. Would you choose for interchangeable modules from another module supplier if his offer is equally priced to the offer of you original module supplier?

⁴ Analyst briefing Frost and Sullivan - Large municipal projects & industrial penetration drive European MBR market - 2006

Most companies are convinced interchangeable filtration modules will increase the willingness of decision makers to invest in MBR technology.



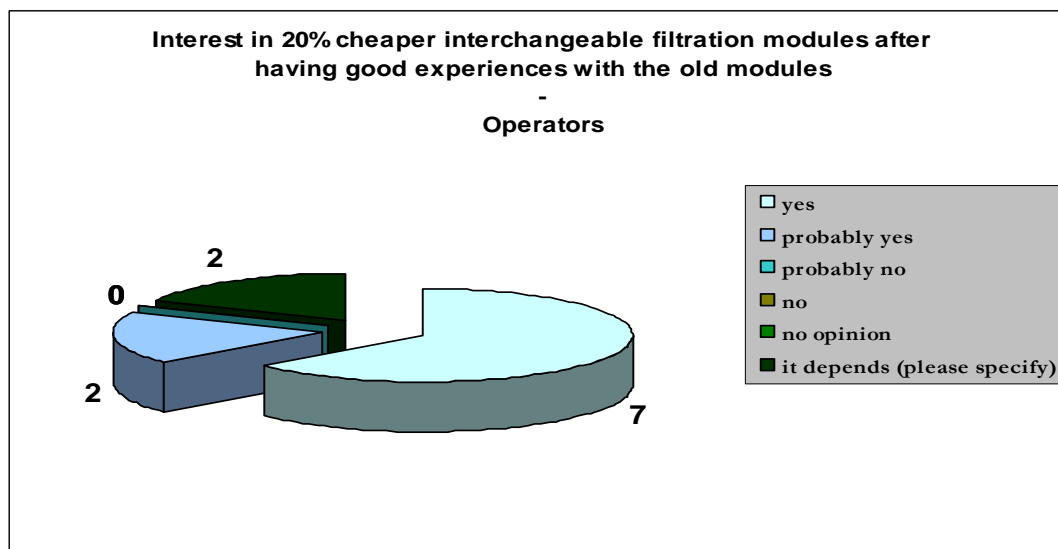


Figure 12. Operator interest in cheap interchangeable filtration modules after having good experiences with old modules

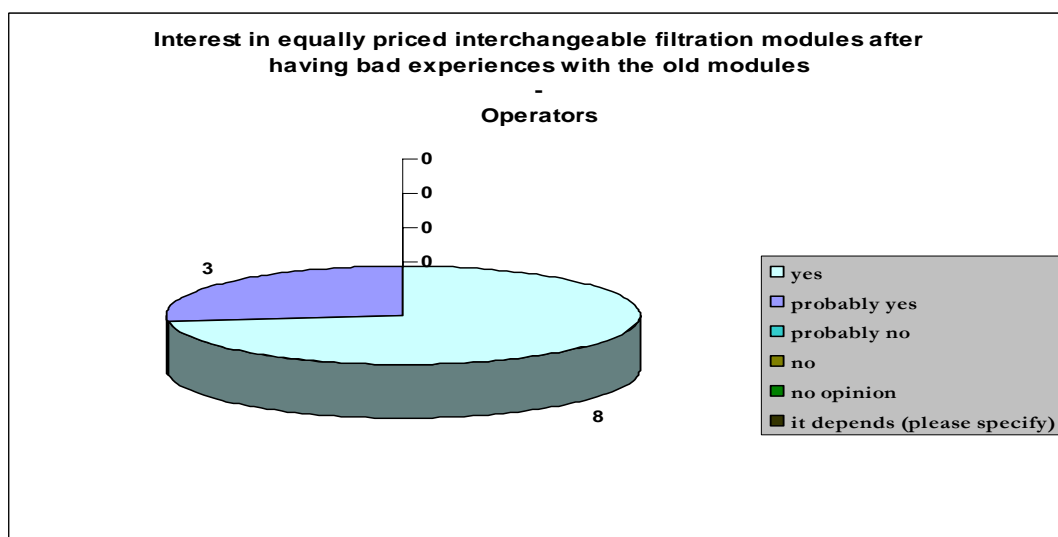


Figure 13. Operator interest in interchangeable filtration modules after having bad experiences with old modules

These figures indicate that operators would be very interested in interchangeable modules in case they are either cheaper or in case they had bad experiences with the old ones.

On the other hand the expected positive impact of possible module interchangeability on the MBR market has to be moderated by the results presented in Figure 14. This figure shows that other driving forces are considered as more preponderant than module compatibility to accelerate MBR applications. Standardisation may contribute to the MBR market growth but is not the primary requirement.



Interchangeable filtration modules are not believed to become one of the top three driving forces boosting the application of MBR technology.

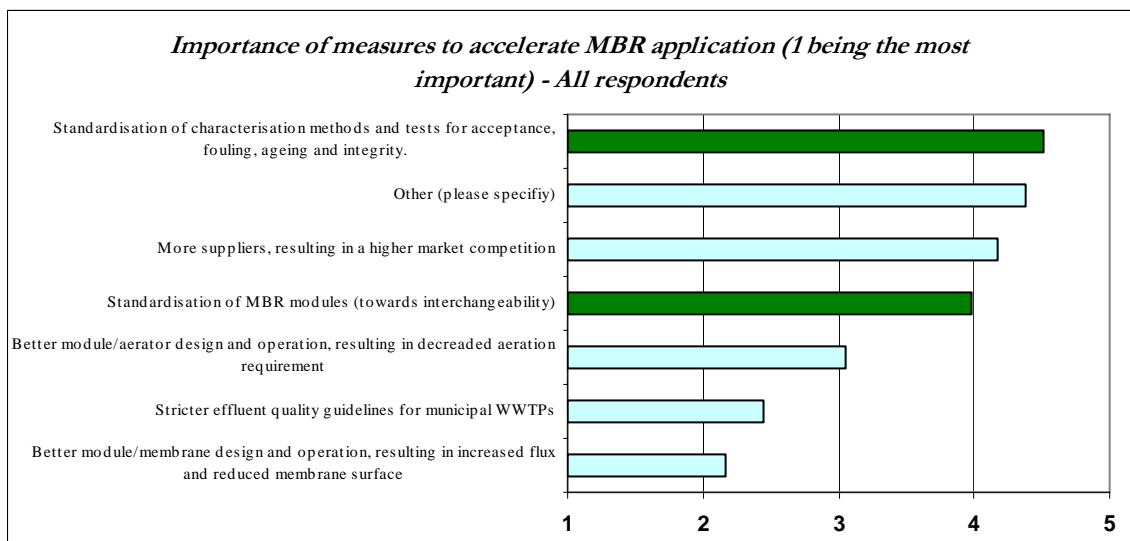


Figure 14. Importance of different measures to accelerate MBR application
 Note: 1 being the most important score

B. Lower investment costs

If certain features of MBR filtration modules are standardised, these product characteristics will be eliminated as a means of competition, leading to another potential economic effect of standardisation: increased price competition. Price cuts can in turn push the diffusion of MBR technology.

Figure 15 represents the surveyed companies' opinion on investment costs.

50% of the module suppliers and 80% of the operators predict a cost decrease as a result of MBR filtration module standards.

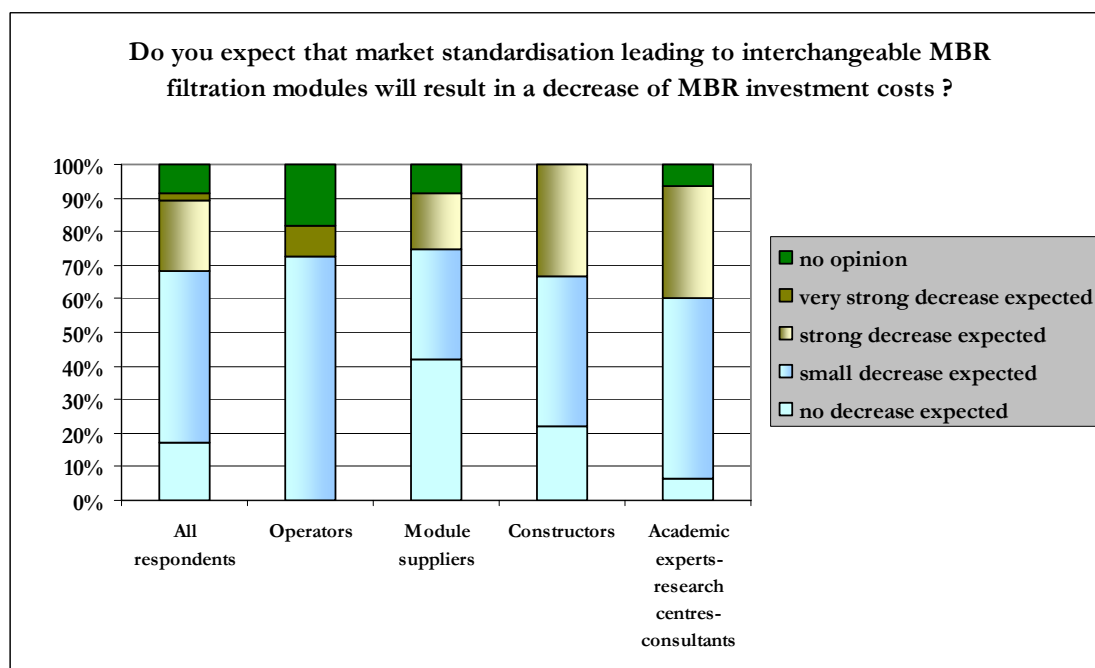


Figure 15. Expectations on investment cost decrease as a result of MBR filtration module standardisation



It is interesting to note the different opinions of suppliers, operators and constructors on this topic. More than 70% of all respondents is convinced a cost decrease (small or strong) can be expected, but it is clear that the large majority of this group are operators, constructors and knowledge institutions: e.g. more than 80% of the operators is convinced interchangeable modules will lead to a decrease (small or strong), while nobody expects no decrease at all. Half of the module suppliers expect a small or strong cost decrease, but they are a bit more reserved: one third of them think no decrease at all is to be expected.

C. Vendor-lock in / sole source contracts avoided

C.1. No technological dead-ends

A dead-end is created when there is no migration path from an established filtration module to a newer model. In fact, current MBR end-users purchase products that could eventually leave them stranded with an incompatible technology. When membrane replacement becomes an issue 5, 10 or 15 years after the original purchase, problems arise: in the fast developing world of MBRs, it will be very difficult, if not impossible, to benefit from the latest progresses and developments already implemented in the succeeding model. Two successive generations of filtration modules from the same supplier can already differ significantly in size, aeration regime and connections, filtration mode,... And even if the whole filtration module product series of a certain vendor is interchangeable, this is still no guarantee the suppliers will not miss an emerging development. The result is that users are forced to either work with outdated technology or switch to completely new and different systems, which will be a very costly exercise.

C.2. Security of supply

If the module supplier abruptly ends a product line to start a complete new one, this endangers the security of supply. How many years can a module supplier support and offer multiple production lines of filtration modules ?

C.3. Competitive market price guaranteed

The lack of bidding processes diminishes opportunities for identifying the best supplier or for getting the best possible price for MBR filtration modules. MBR module standardisation would lead to a reasonably fair market price when existing filtration modules need to be replaced.

D. Others

D.1. Improved comparability/transparency in the selection process

MBR filtration module standardisation would also allow a better comparability of different products. In the selection process of the right filtration modules for a new MBR plant, it can be very difficult and time-consuming to judge different offers on a selection criteria as "overall design". Standards could lead to a better comparability and a reduced decision cycle, i.e. the time required to award contracts.

When membrane replacement becomes an issue 5, 10 or 15 years after the original purchase, problems may arise.



D.2. Applying standardisation in tendering and design

Currently, the content and length of tendering specifications and design documents for MBR plants is highly variable and very author-specific. A potential benefit from MBR filtration module standards could come from the fact that they can be directly integrated into several documents during the tendering and design process. This should clarify areas of potential confusion and reduce the time and the costs during these phases of the project.

D.3. Increased trust

Trust in a certain technology is one of the easiest things to lose and one of the hardest to regain. It can take years of experience with dozens of well-operated MBRs to build up a certain level of trust with end-users, while it may take only one well-designed but poorly operated MBR to forever destroy the faith in this technology. Building up trust requires knowledge. During the last decade, the MBR industry has produced a remarkable diversity of filtration products. It takes months if not years before someone truly understands the design and mode of operation of these products. Transparent, open standards for MBR filtration modules could help in achieving a common understanding and terminology, and in increasing the confidence in MBR technology.

D.4. Standardised training of operators

The level of theoretical and practical training received by operators, reflects on how well they will eventually operate their plant, and this in turn affects the public's confidence in MBR technology. MBR filtration module standards would allow for an easier, quicker and standardised training for MBR operators.

4.1.2.5 Potential drawbacks/weaknesses

A. Affected product quality

The quality of an MBR filtration module is significant in determining its acceptability by the purchaser. The degree to which the module meets the buyer specifications is the most important consideration of satisfaction. Standardisation of filtration modules means that manufacturers have to abandon certain procedures and habits for design and construction of a filtration module. If this means that specific advantages of the filtration module (e.g. compactness) have to be abandoned, there is a high chance that the final product quality will be affected. On the other hand, the use of standardised methods often increases consumer confidence in supplier quality and reliability.

This issue also illustrates the dependency between standardisation of MBR filtration modules and the methods for characterising their performance: to avoid dissatisfied buyers, uniform and accurate testing procedures that can be readily reproduced are desirable for MBR filtration module quality determinations. This is further discussed in paragraph 4.2 and 5.2.

Figure 16 represents the expectations of the MBR community concerning a potential decrease in quality of MBR products and services.

There is a dependency between standardisation of MBR filtration modules and the methods to characterise membrane performance.



Do you expect MBR filtration module standardisation will lower the overall quality of MBR products and services ?

All respondents

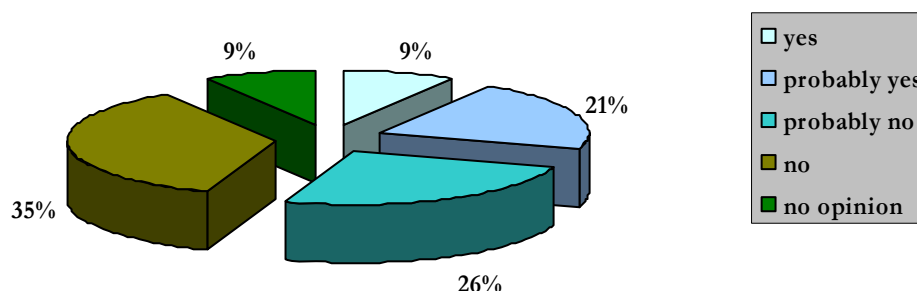


Figure 16. Expectations on quality decrease of MBR products and services as a result of standardisation

More than 60% is convinced that standardised filtration modules will (probably) not lead to a decrease in the quality of products and services, about 30% argue a quality decrease is to be expected. The figures for operators and module suppliers are similar to Figure 16. One can note that the standardisation of the monitoring and quality control methods may reduce this risk: the harmonisation of the methods should therefore precede or accompany any standardisation of product.

B. Less research / product development / innovation / IP protection

Standards development is moving to the centre of the fundamental conflict between the unique and the uniform. Patents are one way to value the unique, standards are a technical society's means to define the uniform. When considering MBR filtration module standardisation, two potential weaknesses or threats arise from this conflict.

- First of all there is a potential threat which occurs when the implementation of the MBR standard necessitates the use of technology protected by one or more patents, for which prior authorisation from the patent holder will be required. Right holders may then push for the adoption of their own patented MBR technology in the framework of the standard, so that they can benefit from royalties. If the patent owner claims unreasonably high royalties or refuses a license, this can even block the implementation of the standard, which would obviously be against the objective of the technical standardisation process.

There are hundreds and hundreds of standards out there in the field of MBR modules, and it is clear that this raises several issues for business, patent holders and standard development organisations. Should an MBR technology protected by IPRs be incorporated in a technical standard ? Do companies willing to adopt a standard need to obtain a license from the patent holder ? If so, under what terms and conditions ? Do companies involved in the MBR standard-setting process have a duty to disclose information about their patent applications, to the other members of the standard-setting committee ? What happens if the patent holder refuses to provide

There are hundreds and hundreds of standards out there in the field of MBR modules, raising several issues for business, patent holders and standard development organisations.



licenses for the use of patented technology ? Mostly, standard setting bodies (like CEN) have special procedures and policies to deal with these conflicts⁵.

- Secondly, the emergence of certain MBR standards can have an impact on research, innovation and product development of a company, thereby forming a potential weakness. To what extent will MBR standardisation halt innovation ? This last issue is addressed in Figure 17.

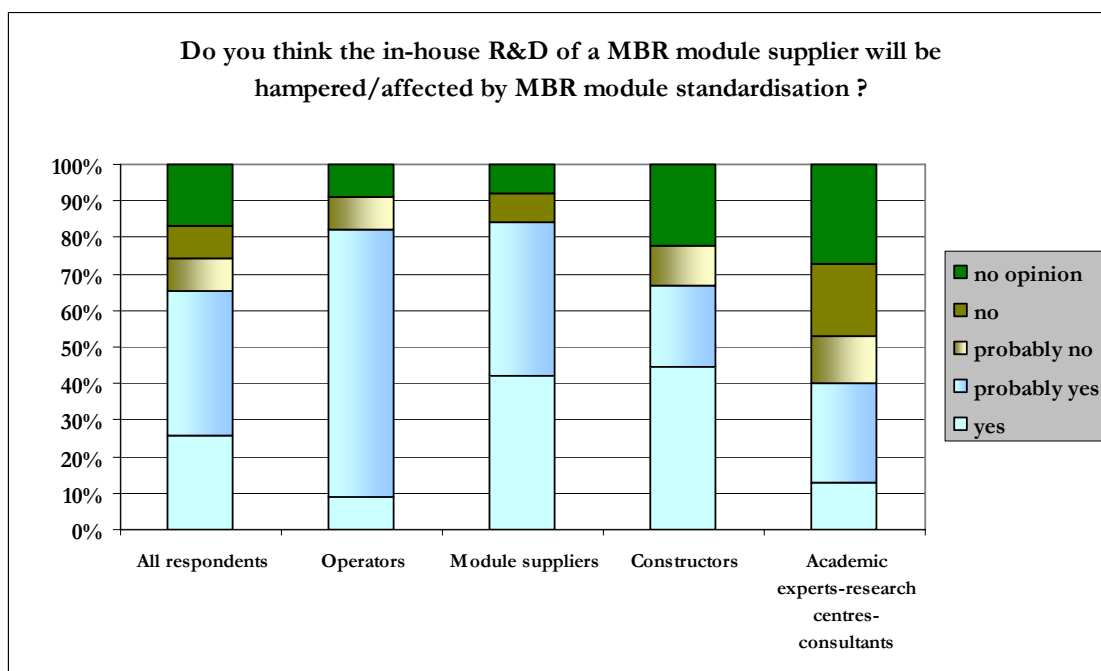


Figure 17. Expectations on the impact of standardization on in-house R&D of a module supplier

It appears that a large majority of respondents fear that standardisation of MBR filtration modules will affect or hamper the in-house R&D of module suppliers. On the other hand, if a norm is accepted by the industry, the innovation will not be performed on the definition of new products, but on the optimisation of the production line: this could further reduce the cost of the product and make it more competitive.

C. Others

C.1. Over-dimensioning

The membrane packing density in an MBR filtration module is highly variable, dependent on the module manufacturer. Modules that treat exactly the same amount of water can vary a factor 2 or 3 in size. The filtration tank will be over-dimensioned in either of these two cases:

⁵ E.g. CEN/CENELEC Guide 8: Standardization and Intellectual Property Rights (IPR)

A majority of the respondents fear that standardisation of MBR filtration modules will affect or hamper in-house R&D of module suppliers.



- the MBR filtration module standard excludes those modules with the highest packing density currently available on the market. In that case the filtration tank could have been designed smaller if no standardisation would exist.
- in case not the modules but the filtration tank (and possibly its surrounding building) is standardised in a way its dimensions allow for easy installation of different module types. In that case, the filtration tank/building will be (over)dimensioned according to the "largest acceptable" modules.

C.2. Supplementary costs and works to peripherals

Not only MBR filtration modules can take many different forms and diverse modes of operation, also the electromechanical peripheral equipment surrounding the modules and filtration tanks exhibits a large diversity: pumps, blowers, manifolds,... If the re-investment in new membrane modules requires adaptation works to the existing peripherals, this could level out the cost savings which were gained as a result of competition between suppliers. This will be further highlighted in part 5.1.2.

Figure 18 illustrates the importance attributed to different criteria for interchangeability of filtration modules.

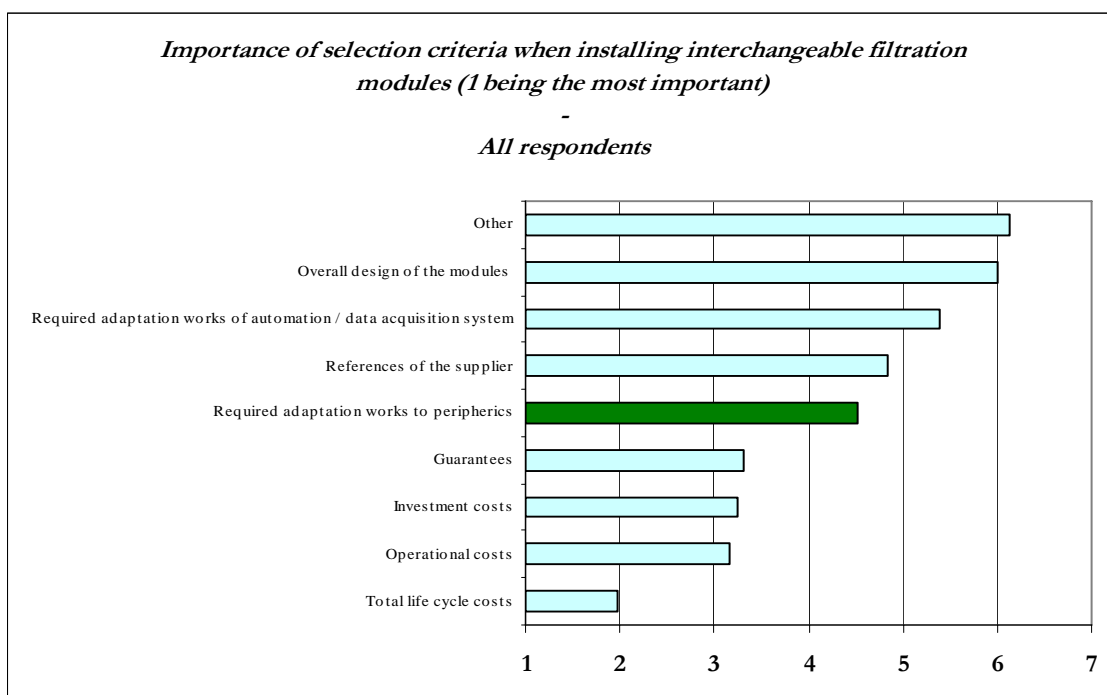


Figure 18. Importance of selection criteria for interchangeable filtration modules

It appears that costs and guarantees are most important, followed by the required adaptation works to the peripherals. The technical aspects which need to be considered in a standardisation process will be studied in part 5.1 of this paper. The graph shows indeed that this is an important and crucial aspect to consider when identifying the norm.



C.3. Lower reliability (process + plant performance may be affected)

The design of a membrane bioreactor plant is a matter of carefully blending and matching the core of the technology - filtration modules - with its surroundings. The type of filtration module determines to a large extent the design of many of the peripherals. A bad design of pumps, blowers, filtration tank, pre-treatment, MLSS concentration,... will have a noticeable impact on the final plant performance. The danger exists that after replacement with another type of membrane module in an existing MBR, the module-peripherals' conformity will not be a 100% match anymore, which will in turn affect the reliability and performance of the plant.

C.4. More complicated legal/guarantee matters/warranty coverage

Installing filtration modules in a system/plant which was not designed by the new module supplier, could complicate legal matters regarding guarantees and warranty coverage. Harmonisation of membrane characterisation methods and definitions (section 4.2 and 5.2) should facilitate the legal issues.

4.1.3 Summary

Following potential advantages/opportunities and disadvantages/threats on MBR filtration module standardisation for end-users and MBR suppliers/constructors can be defined (based on survey results):

Table 3. Summary of potential advantages/opportunities and disadvantages/threats for end-users and module suppliers/constructors as a result of MBR filtration module standardisation

	For end-user	For module supplier/constructor
+ Potential advantages/ opportunities	<ul style="list-style-type: none"> • Avoids vendor lock-in (sole source contracts) <ul style="list-style-type: none"> • No technological dead-ends - BAT at all time • Security of supply • Competitive market price guaranteed during re-investments • Price decrease of module • Increased trust and acceptance • Applying standardisation in tendering • Improved comparability of modules • Easier/standardised training of operators 	<ul style="list-style-type: none"> • Bigger market • Applying standardisation in design and construction - cost savings • Reduction of introduction times for new products and services • SMEs may be able to compete (fairly) with large enterprises
- Potential disadvantages/ threats	<ul style="list-style-type: none"> • Civil constructions may be over-dimensioned • Supplementary costs and works to the peripherals (both initial and at time of module replacement) • Process + plant performance might be affected (smaller reliability) • Perhaps more complex legal/guarantee matters 	<ul style="list-style-type: none"> • Increased competition • Lower profit margins • Limitation for innovative module producers to enter the market • Can restrict innovation or affect internal R&D efforts - makes differentiation more difficult



4.2 MBR characterisation methods standardisation

(note: this section was prepared under responsibility of Anjou Recherche)

4.2.1 Introduction

Membrane modules are central to MBR plants and various techniques are used for their characterisation. Different measured characteristics and information (morphology or performance related parameters) are supplied by membrane manufacturers and module suppliers. Some of these techniques are commonly used while others are not harmonised.

Researchers, manufacturers, constructors or operators may resort to diverse techniques at different occasions and for different reasons.

Testing membrane or module integrity, monitoring membrane performance before and during plant operation, investigating membrane deterioration or loss of performance (membrane fouling or clogging) are actions requiring specific methods and test procedures.

This section presents the market expectations on standardisation of membrane characterisation methods. It is focused on the following methods:

- Acceptance tests: The tests carried out in the presence of the customer's representative at the start of the operation in order to check the quality and the required performance of the membrane/modules.
- Membrane fouling characterisation methods: Any method implemented to directly or indirectly monitor the phenomenon of membrane fouling or module clogging causing a decrease of hydraulic flux (e.g deposition of solid substances on the surface of the membrane).
- Membrane/module integrity characterisation methods: Any method to monitor the membrane or module integrity, i.e. the capacity of the system to retained targeted pollutants, and especially pathogens or bacteria (e.g continuous indirect methods providing information about membrane deterioration).
- Membrane ageing characterisation methods: Any method to monitor the ageing of the membrane in terms of filtration or cleaning performance (e.g a threshold indicating that the membrane has reached its “end-of-life” and should be replaced).

The main question addressed in this section of the report is whether a harmonisation of all these techniques (by a standardisation process) could lead to an increase of the MBR market.



4.2.2 Results and discussion

4.2.2.1 Timing

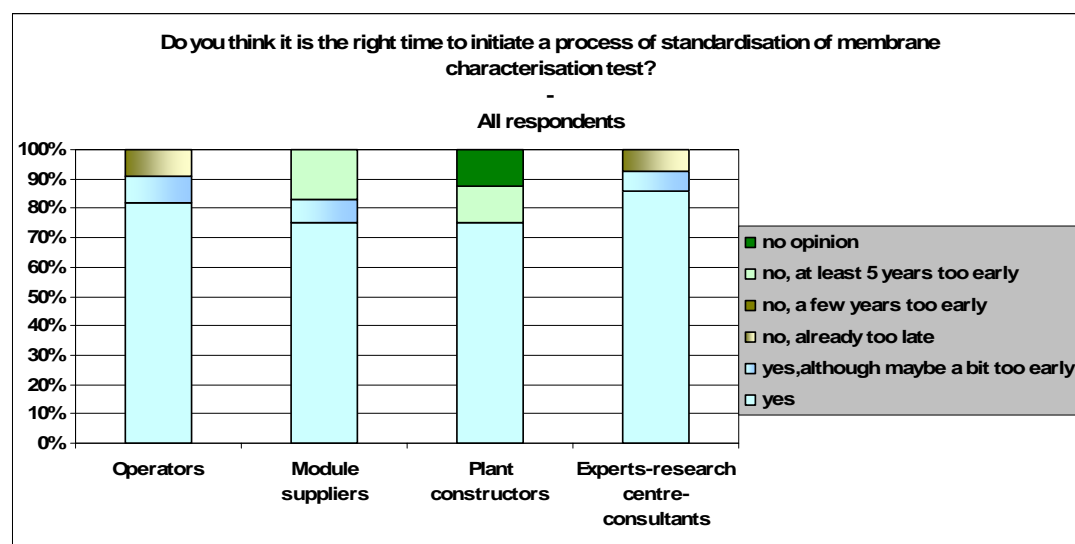


Figure 19. Companies' opinion on timing to initiate a process of standardisation of membrane characterisation methods.

Figure 19 shows that the majority of the respondents, whatever their activity, mainly agree that it is the right time to initiate a process of standardisation of membrane characterisation tests (membrane acceptance, membrane integrity, membrane fouling, membrane end of life determination).

4.2.2.2 Standardisation of membrane acceptance tests

"Membrane acceptance tests" can be defined in two ways:

- At the delivery of new modules during operation: (not during plant construction or plant commissioning) as for any kind of plant equipment, the first step should be the compliance check with standards (when these standards exist), or with the ordered specifications.
- At plant commissioning during plant start-up: filtration systems need to be tested just like the rest of the plant, in order to check the good performance (according to the tender book) and the conformity with the supplier's (membrane or plant supplier) guarantees. These guarantees are among the most important criteria to choose one or another wastewater treatment technology.

Could standardisation of such acceptance tests contribute to increase the size of the MBR market?

A large majority of the respondents think it is the right moment to start a standardisation process of membrane characterisation methods.



A. Acceptance at module delivery:

Is an end-user able to prove that the membranes he is operating have exactly the characteristics of the type he ordered? Simple and clear procedure at membrane delivery could help to positively answer this question.

Figure 20 shows the repliers' expectations on market growth when standardising acceptance test at module delivery.

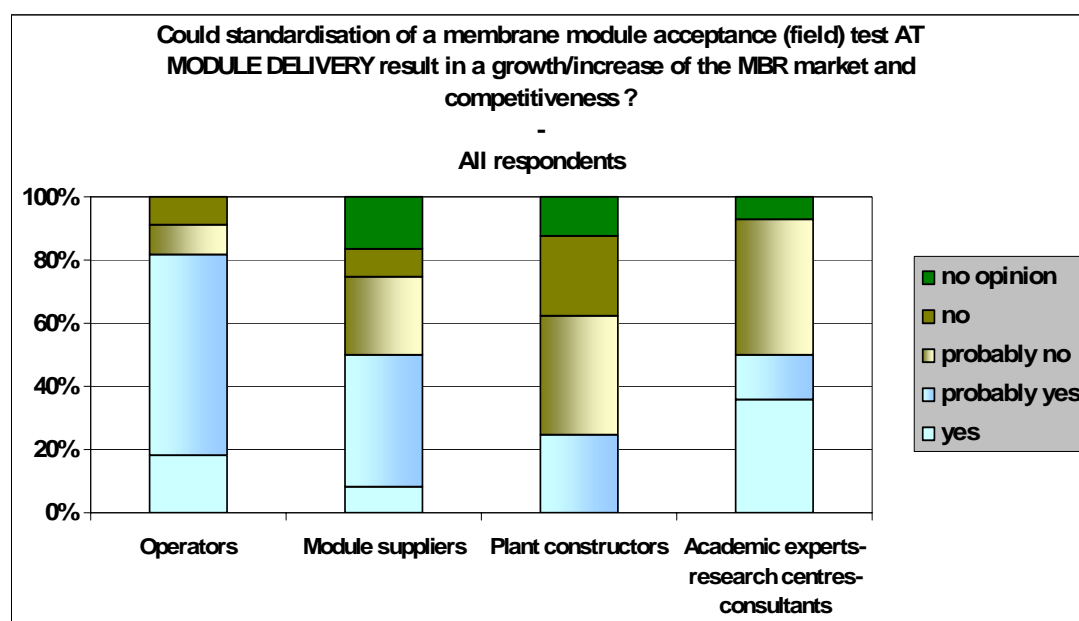


Figure 20. Expectations on market growth when standardising acceptance test at module delivery

It seems that non-commercial institutions (academic experts, research centres and consultants) agree with the idea that it's important to develop some simple tests that can be used for contractual purposes prior to installation.

This idea is broadly shared by end-users but not strongly marked, as 70 % answered "probably yes". Nevertheless, it seems that end-users would be more confident if protocols of acceptance field tests were standardised.

On the other hand, 50 % of module suppliers and only 25 % of plant constructors estimate that standardisation of membrane acceptance tests at module delivery could probably lead to an increase of MBR market growth.



B. Acceptance test at plant commissioning:

A majority of the respondents consider that standard acceptance test during plant commissioning could lead to an increase of MBR market.

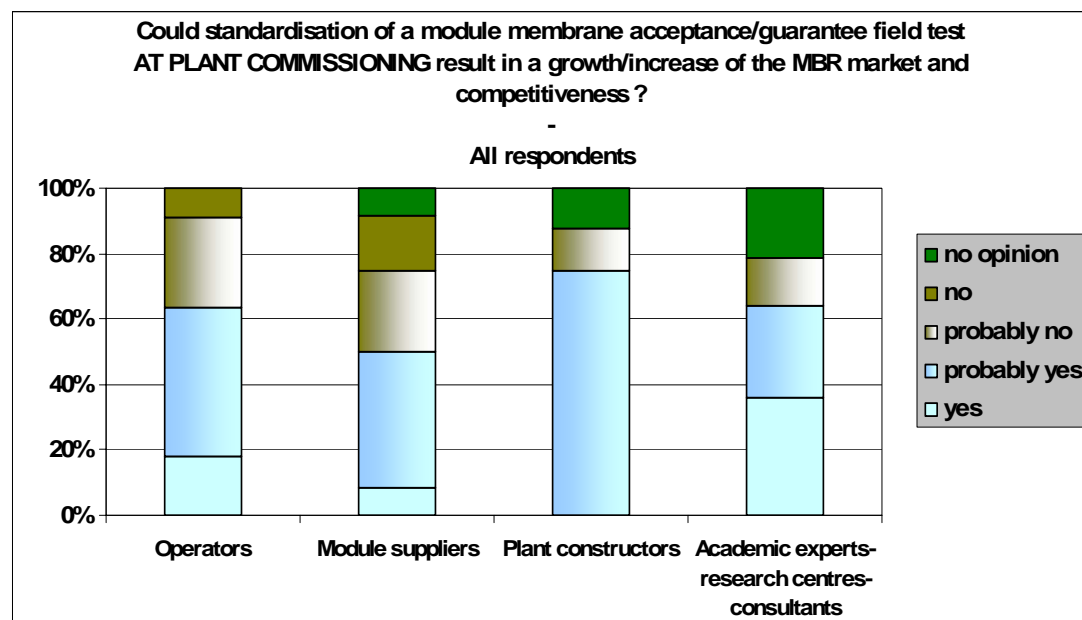


Figure 21. Expectations on market growth when standardising acceptance test at plant commissioning

Acceptance/guarantee testing at plant commissioning seems of prime necessity to increase confidence in MBR technology and to develop competitiveness. For example, we can attribute the important development of fine bubble aeration in plant's bioreactors for a big part due to the development of standardised oxygenation rate tests, usually done at wastewater plant commissioning.

Figure 21 shows that this opinion is shared by plant constructors (75 % answers "probably yes"). Constructors have to make sure that their membrane supplier keeps to its commitments and at the same time, they have to comply with guarantee given to their final client. As a consequence, their opinion is rather logical. They need to be clear and precise at plant commissioning, toward their supplier and their client.

Constructors had a very different opinion towards standardisation of acceptance test at module delivery (25 % answers "probably yes") and at plant commissioning (75 % answers "probably yes"): it can be assumed that they didn't consider membrane module as a piece of equipment such as pumps, impellers, blowers, etc., but as a complete filtration system which need to be checked at plant commissioning and not at delivery.

The operators think that membrane acceptance test standardisation at plant commissioning (63 % answers "yes, probably yes") have less interest for market growth, than at module delivery (82 % yes, probably yes"). Nevertheless, it could be supposed that they should be encouraged by a standard acceptance test, allowing them to check in the correct way and without any doubt, the good performance of their filtration system. Two reasons can probably explain their answers:



- Some operators are not the owner of the plant and in consequence are not concerned by plant commissioning
- There is no clear overview on the possible methods that can be applied to easily check the membrane/module performance.

Module suppliers' answer is similar to the previous question (membrane acceptance test at module delivery): 50 % of them think that standardisation of membrane acceptance tests at plant commissioning could lead to an increase of MBR market growth. In many cases the constructors are contractually responsible for the warranty risk, and therefore they are directly responsible for the plant commissioning. The module suppliers are only in few cases responsible, and may underestimate the significance of standardising acceptance tests for market growth.

Finally for “experts and consultants” an acceptance guarantee field test will provide some confidence to the owners and operators that new systems conform to basic performance requirements. It is also a good tool to make sure that all manufacturers (existing and future) deliver good quality products.

4.2.2.3 Standardisation of membrane characterisation methods

Checking membrane performance (e.g. fouling, ageing- end of life determination, integrity), is necessary for a good plant operation. No common rule (from manufacturers) is currently defined to manage these actions. This could enhance confusion, and further increase the association of membrane technology as a complicated system. Could standardisation (or guidelines) on these kind of characterisation methods be a way to increase the membrane market for municipal wastewater treatment?

A. Membrane fouling methods:

The expectations on market growth when standardising fouling methods are addressed in the Figure 22.

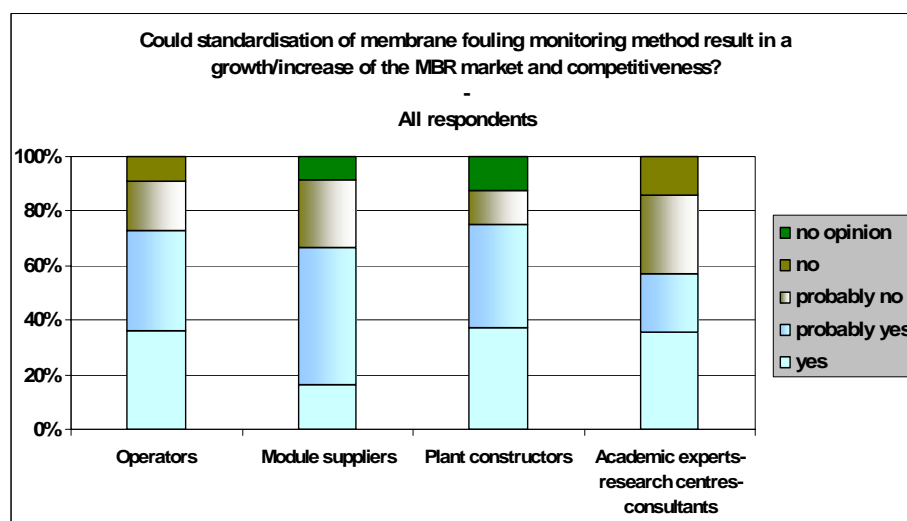


Figure 22. Expectations on market growth when standardising membrane fouling monitoring methods

A majority of the respondents think that standardisation of membrane fouling monitoring methods could lead to an increase of MBR market and competitiveness



Membrane fouling monitoring is essential, as fouling is the major factor determining the operational stability of a membrane bioreactor.

This is probably the reason why the four different groups think that standardisation membrane fouling measurement method could lead to an increase of market growth (60 to 70% “yes” and” probably yes”).

B. Membrane integrity methods:

The expectations on MBR market growth when standardising membrane integrity methods are addressed in the Figure 23.

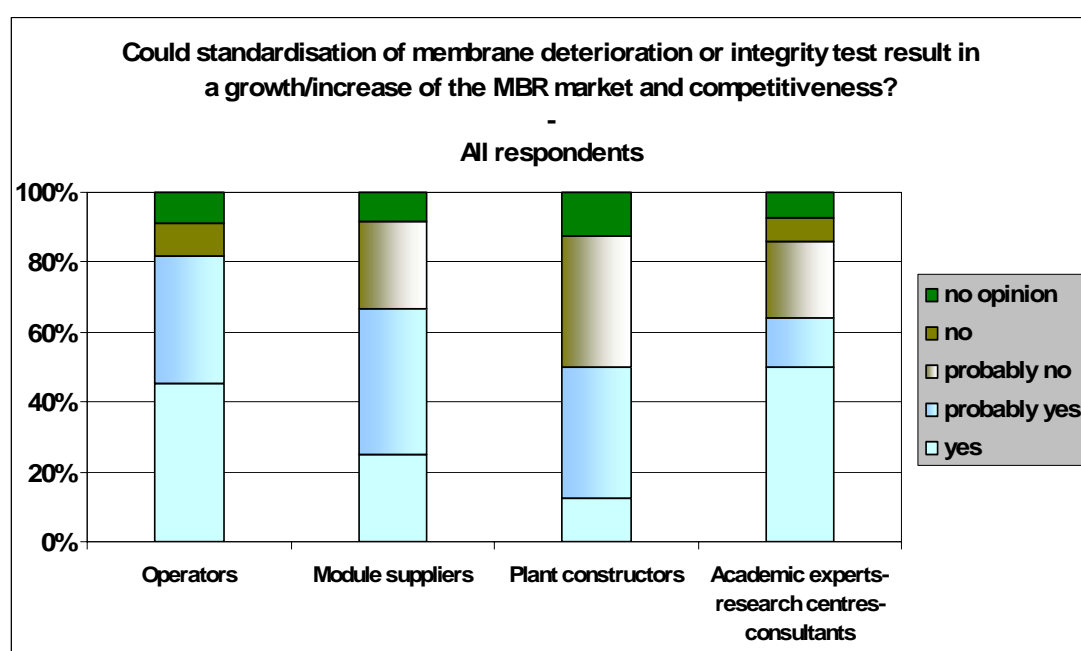


Figure 23. Expectations on market growth when standardising integrity test

Many characterisation techniques are used to control the membrane performance during its use, in order to test membrane integrity in real time. But although many applications are well-assessed, there is no standardisation.

This is a typical issue for end-users (80% asking for a standard against 10% not requiring). Membrane suppliers understand that this may impact the business on the long term, and a majority is favourable to a standard (63% against 27%). Constructors only show a minor majority in favour of standardisation (51% against 38%); this doesn't seem to be their main concern.

C. Membrane ageing methods:

The expectations on MBR market growth when standardising membrane ageing methods are addressed in the Figure 24.



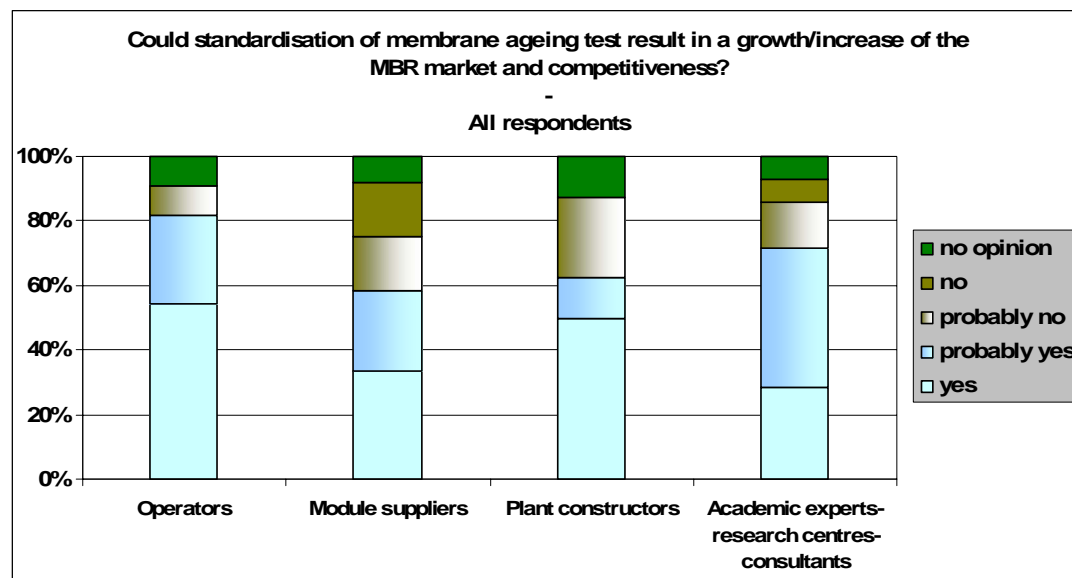


Figure 24. Expectations on market growth when standardising membrane ageing methods

Similar to membrane integrity, operators and constructors are also in favour of a standardised method to monitor membrane ageing (80% of end-users asking for a standard). Academic experts and research centres notify membrane ageing standard methods and definitions as potentially useful.

4.2.2.4 Scope of membrane characterisation methods standardisation

The tables below show an outline of the respondents' current opinion on membrane tests standardisation.

Following statements can be made:

- About half of the membrane suppliers show an interest for a standardisation method for delivery of new modules for package plants to very large plants, while half of end-users and plant constructors show a restricted interest for small plants and for medium to large plants.
- End-users show a specific interest for standardisation of monitoring methods for small to large plant size.
- Module suppliers show a specific interest for standardisation of monitoring methods for small plant size.
- Constructors show a specific interest for standardisation of monitoring methods for large plant size.



Table 4. Scope of membrane characterisation methods standardisation

		<10m ³ /d (household plants)	10-100 m ³ /d ("package" plants)	100-1000m ³ /d (small size)	1-100MLD (medium to large size)	>100MLD (very large size)
MEMBRANE/MODULE SUPPLIER	acceptance method for delivery of new modules					
	membrane fouling characterisation method		specific interest	specific interest		
	membrane deterioration / integrity characterisation method			specific interest		
	membrane ageing / end-of-life characterisation method			specific interest		
END-USER	acceptance method for delivery of new modules					
	membrane fouling characterisation method			specific interest	specific interest	specific interest
	membrane deterioration / integrity characterisation method			specific interest	specific interest	
	membrane ageing / end-of-life characterisation method			specific interest	specific interest	
CONSTRUCTORS	acceptance method for delivery of new modules					
	membrane fouling characterisation method				specific interest	
	membrane deterioration / integrity characterisation method				specific interest	
	membrane ageing / end-of-life characterisation method			specific interest	specific interest	

Legend:




	more than 60 % of "no interest/no opinion" reply
	opinion is divided near 50/50 between no interest/no opinion and specific interest
	specific interest more than 60 % of "specific interest" reply

Table 5 below shows more precisely which kind of interest is mentioned by repliers

Table 5. Respondents who mentioned a specific interest

Scope of	Application size	100-1000m ³ /d (small size)	1-100MLD (medium to large size)
	membrane fouling characterisation method		- 45 % both guidelines & market norms now - 38 % guidelines now - 17 % general interest but in few years
	membrane deterioration / integrity characterisation method		- 41 % both guidelines & market norms now - 37 % guidelines now - 22 % general interest but in few years
	membrane ageing / end-of-life characterisation method	3 equivalent groups : - both guidelines & market norms now - guidelines now - general interest but in few years	- 43 % both guidelines & market norms now - 29 % guidelines now - 29 % general interest but in few years

In a general way, repliers are asking for guidelines, rather than for market norms, as guidelines are mentioned by more than 70% of the repliers, whatever the scope is.

Module suppliers, operators and constructors have a specific interest in guidelines on membrane characterisation for medium and large installations.



More exactly 40 % are asking for both guidelines and norms and 30 % for guidelines only. 17% to 30 % of the repliers have general interests but in a few years only. Guidelines and technical recommendations can be the first step leading to standardisation of the MBR process.

4.2.2.5 Potential advantages

Among the 45 repliers, 40 specified advantages.

The most important advantages as perceived by the respondents were, in decreasing order of importance:

A. Improved comparability in selecting membranes (21 repliers)

Standardisation of membrane characterisation tests make it easier to compare between membrane suppliers. All groups see an advantage from standardization:

- Transparency of the selling points for supplier and for client.
- Clarification of warranty issues
- Reduction of commercial risk and after-sale conflicts.

The selection criteria should be clear and well-assessed in the eyes of all stakeholders. Competition will be more transparent.

B. More trust/transparency/knowledge in MBR technology (13 repliers)

Trust is an essential criterion in the selection process of a wastewater treatment technology. The plant should be able to run continuously for a long time, in a reliable way. For an end-user, it could be difficult to choose a technology which seems to need a highly specialized staff for its operation. Design parameters and operating instructions should be clear and simple. Standardisation of monitoring methods could lead to more transparency and a better understanding of membrane technology. A standardised acceptance test would clarify and help the application of guarantees (thanks to official testing).

C. Easier operation and cost optimization. (12 repliers)

Operational cost is obviously an important criterion in a selection process for wastewater treatment plant technologies. Standardisation of operating methods could lead to easier operation and all the ensuing benefits: mastered operation, saving time, better evaluation and optimization of operational cost.

D. Others

A limited decrease of the module prices and a possible natural selection of the better products are two additional advantages quoted by several repliers.

A majority of the respondents think that standardisation of membrane characterisation tests make it easier to compare between membrane suppliers



4.2.2.6 Potential disadvantages

Among the 45 repliers, 26 specified disadvantages.

The most important disadvantages as perceived by the respondents were, in decreasing order of importance:

A. Less development/innovation of membrane technology (14 repliers)

Some of the respondents seem to be frightened of standardisation. The main fear for operators or membrane/plant manufacturers is to see innovation and technical development too controlled, due to the fact that new products would not satisfy the defined standards. Standardisation would make them suspicious. It must be noted that the study only asked for standardisation of membrane characterisation methods or tests (at delivery or during membrane use) and in no case, a standardisation of the membrane itself.

Improving membrane performance and reducing their costs requires the use of new membranes, better materials, new preparation techniques, etc... Research & development is necessary for economic growth. Standardisation of membrane characterisation methods would not be introduced with the purpose of hampering membrane innovation. A rigorous standardisation process could be obtained with the technical and economical players' contribution. A debate would be necessary in order to clarify the objectives of this standardisation and the means to set up this process.

B. Reliability of the methods? (7 repliers)

Some respondents are suspicious that it will be difficult to find the right methods that could be applied to all types of membranes. It's obvious that this is one of the main challenges for standardisation of membrane characterisation methods.

To be widely accepted by the MBR industry, the characterisation methods should be:

- Universal (adapted / adaptable to all module types)
- Non destructive (No membrane sampling etc)
- Quick (frequent measurement possible, no down-time of operation)
- Simple (no needs of highly trained staff, simple protocol and devices)
- Cost-effective (no costly material or consumables)

C. Others

The other disadvantages mentioned were:

- Standards will be mainly defined by large companies
- Operational cost increase
- Know-how would be published

Each argument was mentioned by only one respondent.

To be mainly accepted, the standard characterisation methods should be simple, universal and cost-effective



4.2.3 Summary

A standardisation process of membrane tests is considered to be useful and profitable for market development.

However, much work has to be done to define the objectives and the methods to be used.

Table 6 below shows a summary of the market expectations on membrane characterisation methods standardisation.

Table 6. Market expectations on standardization of membrane characterization methods

Scope Sampling groups	Percentage of the respondents considering that standardisation process could result in an increase of the MBR market.				
	Acceptance test at module delivery	Acceptance test at plant commissioning	Membrane fouling test	Membrane integrity test	Membrane ageing test
Operators	82 %	63 %	72 %	81 %	82 %
Module suppliers	50 %	50 %	67 %	67 %	58 %
Plant constructors	25 %	75 %	76 %	51 %	63 %
Academic experts- Research centres - consultants	50 %	65 %	57 %	64 %	72 %

Provided that harmonisation of main monitoring tests doesn't stop innovation and can be applied to the large number of different membranes, the process could be initiated from now on, for a real need is revealed in this study. There is a need of transparency between the supplier's products, and a need of more trust in membrane technology.



5 Technical considerations

5.1 MBR filtration module standardisation

(note: this section was prepared under responsibility of Aquafin)

5.1.1 Introduction

An analysis on the technical aspects of MBR filtration module standardisation should not focus on modules alone. While it is true that factors as module size and treatment capacity per module are very important in reflections on standardisation towards interchangeable filtration products, the situation is much more complex than that. Today, MBR filtration modules do not only differ in their membrane characteristics or their physical shape. Each filtration module exhibits its specific requirements towards most of its surrounding peripherals: filtration tank design, influent pre-treatment, maximum sludge concentration, characteristics of pumps and blowers, cleaning,... Therefore, in a technical analysis of standardisation, all these factors need to be considered as well.

In this section a clear overview is presented of the most important technical factors which could eventually play a role in a future standardisation process of MBR filtration modules. The value of this part of the paper does not merely lie in the enumeration of factors, but mainly in the fact that for almost each item data is provided to quantify these factors for the different MBR filtration products currently available. In that way, it is possible to assess to which degree a specific technical item can become an issue or even bottleneck for standardisation. An overview table summarising all this information can be found in the concluding part of this chapter.

Data about 9 completely different MBR filtration modules were analysed after gathering them from the different suppliers and their local partners, distributors or constructors:

Table 7. Overview of the 9 filtration systems and their supplier(s) surveyed in this part of the study

MBR filtration module supplier (or partner, local distributor,...)	MBR filtration module	Configuration	
		Flat sheet (FS)	Hollow fiber (HF)
A3 water solutions GmbH	A3 module	X	
Koch Membrane Systems GmbH	PURON PSH 500		X
Kubota Membrane Europe Ltd (or HERA AMASA S.A., SOLIS Engineering bv, AV Aggerwasser GmbH)	KUBOTA Submerged Membrane Unit	X	
Martin Systems AG	siClaro FM & siClaro DM	X	
Mitsubishi Rayon Engineering Co., Ltd. (or ROTREAT Abwasserreinigung GmbH & CoKg)	Sterapore SADF & Sterapore SUR		X
Microdyn-Nadir GmbH	Bio-Cel BC-100-50 & Bio- Cel BC-100-100	X	

MBR filtration modules do not only differ in terms of their dimensions and configuration, but also towards most of their surrounding peripherals.

The value of this chapter lies in the fact that the relevant technical aspects will not only be defined, but also quantified for 9 different commercially available MBR



MBR filtration module supplier (or partner, local distributor,...)	MBR filtration module	Configuration		
		Flat sheet (FS)	sheet	Hollow fiber (HF)
POLYMEM	IMMEM			X
Toray Industries, Inc. (or Keppel Seghers Belgium)	MEMBRAY	X		
GE - Zenon Membrane Solutions (or DEGREMONT)	ZeeWeed ZW 500			X

A good mix was obtained between:

- flat sheet and hollow fiber membranes/modules
- mature and juvenile products

In what follows, none of the module suppliers will be explicitly named or linked with a specific answer they provided in the questionnaire. Either cake figures or bar graphs will be presented, the latter for which the answers provided by the supplier are ordered from small to large, from large to small, or even just randomly.

In case nine or less filtration modules are presented in a certain graph, this means that from each membrane supplier a maximum of one product is included. In case more than nine products are plotted in a certain graph, this means that from at least one supplier, two different filtration module types are included. Opinions from the local distributors or constructors deviating from those of their mother company/supplier were not integrated into the graphs. For instance, if main module supplier A has opinion X, and their local partner/distributor/constructor has opinion Y, only opinion X is plotted in the graph.

5.1.2 Results and discussion

5.1.2.1 Intensive pre-treatment

Pre-treatment of the influent before it enters the bioreactor, is one of the most important factors to consider in every MBR design. The required pre-treatment will largely depend on the MBR filtration module installed. Not every filtration module (supplier) requires (advises) the same type, degree or redundancy of pre-filtration.

A. Screen type

Different kinds of screen types exist. The most important ones are wedge-wire, square mesh or punched hole screens. The link with standardisation lies in the next question: what if the module supplier delivering the interchangeable modules in an existing MBR advises or requires a totally different screen type than that which was initially installed? It is clear that either the supplier should resign to this situation or the operator will choose another supplier or be confronted with additional re-investment costs.

To each module supplier was asked:

- Whether or not they (minimum) require a certain screen type (and if yes, which type)

What if the interchangeable filtration module requires a totally different pre-screening than the originally installed module? Would we still call it “interchangeable”?



- Whether or not they would advise a certain screen type to their client (and if yes: which type)

For instance, it could happen that a supplier does not want to install their modules if the pre-treatment does not at least includes screen type A. However, at the same time, the supplier could also informally advise their client to install screen type B, because they e.g. have better experiences with it.

This overview can be found in Figure 25.

It can be concluded that:

- more suppliers require or advise a specific screen type than those who do not;
- those who do not require or advise a specific screen type are mostly FS (flat sheet) suppliers (not shown on the figure);
- a punched hole screen is most advised by the suppliers
- none of the three screen types is not required or not advised

In other words: this could be a bottleneck for standardisation towards interchangeable MBR filtration modules, although it is more a problem for HF (hollow fiber) suppliers than for FS suppliers.

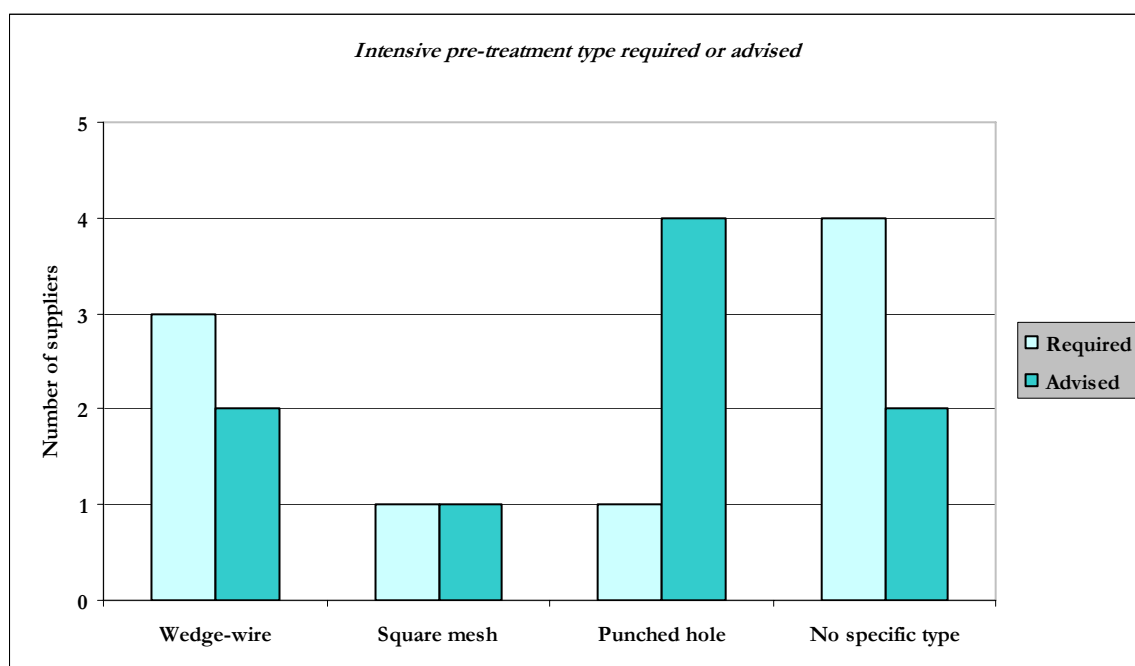


Figure 25. Intensive pre-treatment type required or advised by module suppliers

B. Mesh width

Not only the screen type, but also the mesh width is an important factor. Some suppliers argue they can do the job with a pre-screening of 3 mm or more, others will not give any guarantees unless the screening is 1 mm or less. What if a 3 mm screening is installed, and the new interchangeable module will work only with a 1 mm screening ?



An overview of the recommended mesh width for different screen types can be found in Figure 26.

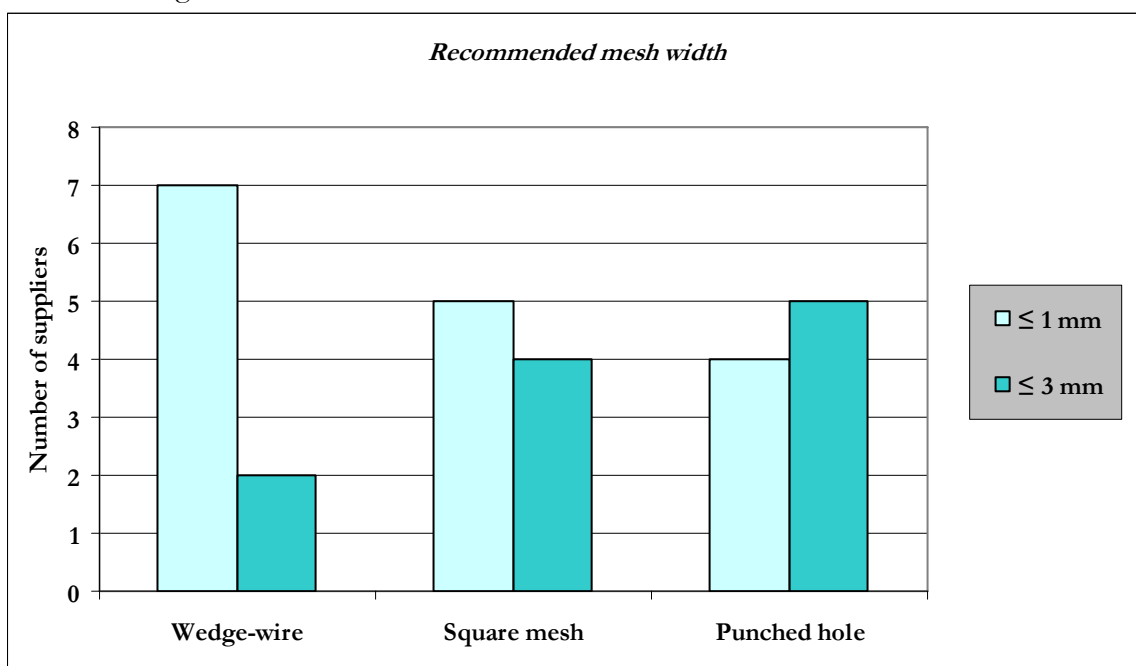


Figure 26. Mesh width recommended by module suppliers

Figure 26 shows that the punched hole screen is most trusted by suppliers: when going from wedge-wire over square mesh to punched hole, less suppliers recommend a 1 mm screen, and more suppliers trust 3 mm screens. Most of the suppliers who advise 3 mm (or more) deliver a FS product (not shown in the figure): eg from the five suppliers who recommend 3 mm for a punched hole screen, four offer FS-modules.

Mesh width is clearly an important discussion point in a standardisation process towards interchangeable MBR modules. HF modules are definitely more demanding here than their FS alternatives. However, if standards could be developed for the FS products on the one hand, and the HF products on the other hand, there would be hardly any problems: 3 mm or less could be used for standardised FS products, 1 mm or less for standardised HF modules.

C. Redundancy

Does the module supplier advise or require that the pre-treatment be designed with some level of redundancy? Does he consider redundancy only as something useful, or as a prerequisite to supply his product? If MBR filtration modules become interchangeable, these are important questions. This is addressed in Figure 27.



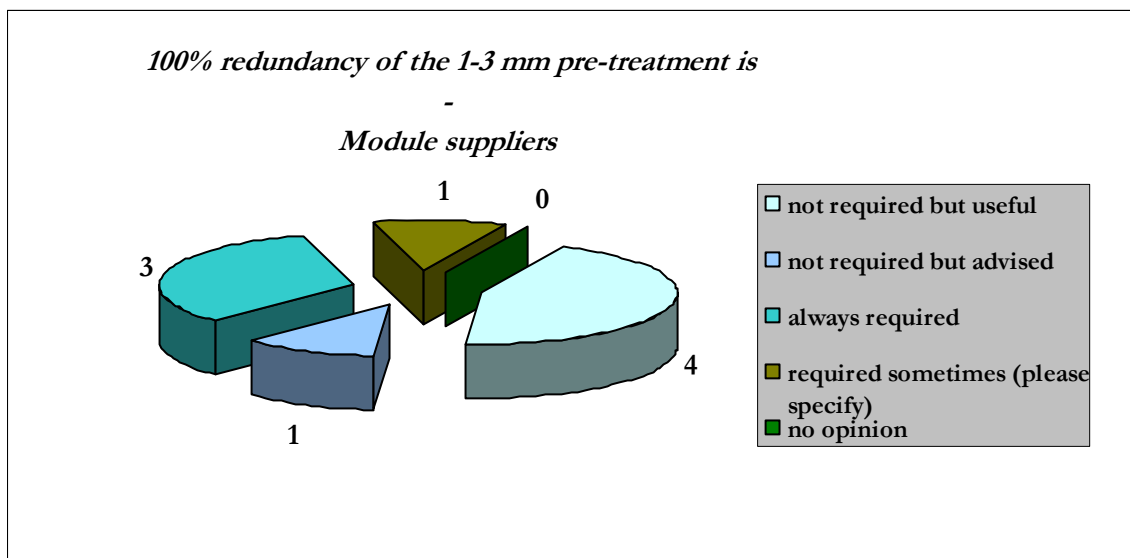


Figure 27. Opinion of module suppliers on the level of redundancy required for the intensive pre-treatment

Figure 27 shows that half of the suppliers indicate some level of redundancy as a requirement. No specific distinction can be made between FS or HF suppliers. It can be concluded that the importance of redundancy is moderate. Redundancy only becomes an issue if a supplier who requires some level of redundancy delivers his interchangeable product for a plant were redundancy in the 1-3 mm pre-treatment was not designed.

D. Bypass

Do module suppliers allow a temporary bypass of untreated influent over the fine pre-screening? A problem could arise in case the opinions on this are divided. This issue is addressed in Figure 28.

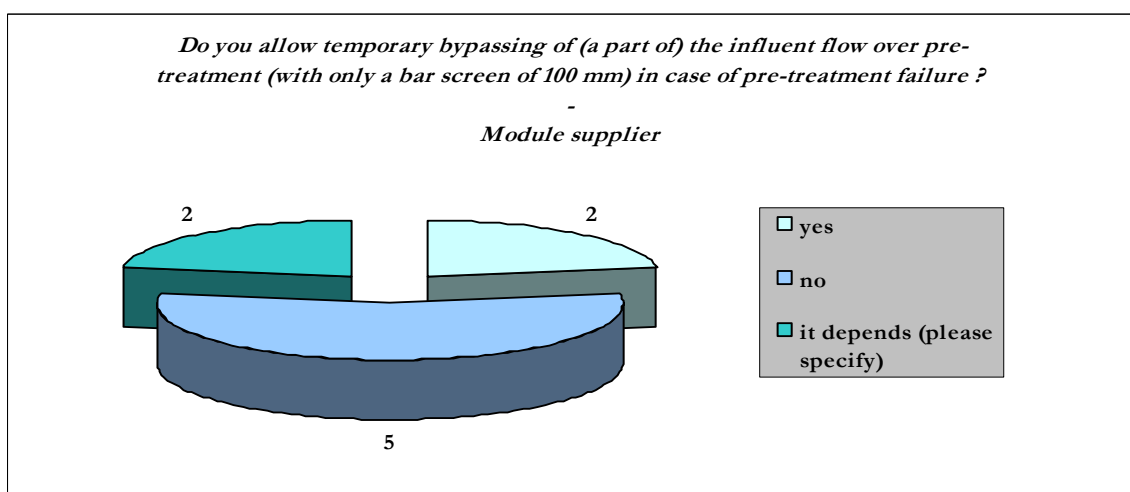


Figure 28. Opinion of module suppliers on bypassing the intensive pre-treatment



This figure indicates that the majority of suppliers do not allow a bypass of untreated influent over the fine screening (the two suppliers answering "it depends" mean that they would only allow it for very short terms and low loads). Therefore, this does not lead to any issues regarding a possible standardisation process, where the MBR industry would easily agree not to accept any by-pass.

5.1.2.2 Filtration module

A. Size

Dimensional standards are among the most obvious prerequisites for interchangeability: all other factors being equal (e.g. permeate filtration capacity), module size must be within certain limits to allow easy installation in the existing tank and connection to the existing peripherals. Numerous shapes of MBR filtration modules have been introduced onto the market over the last decade. The lengths, widths and heights of several commercially available MBR filtration products can be found in Figure 29 and Figure 30.

Module lengths and heights are between 1 and 3 meters, module widths range from 0.5 to more than 1.5 meters. This is clearly one of the main points of attention in a future standardisation process.

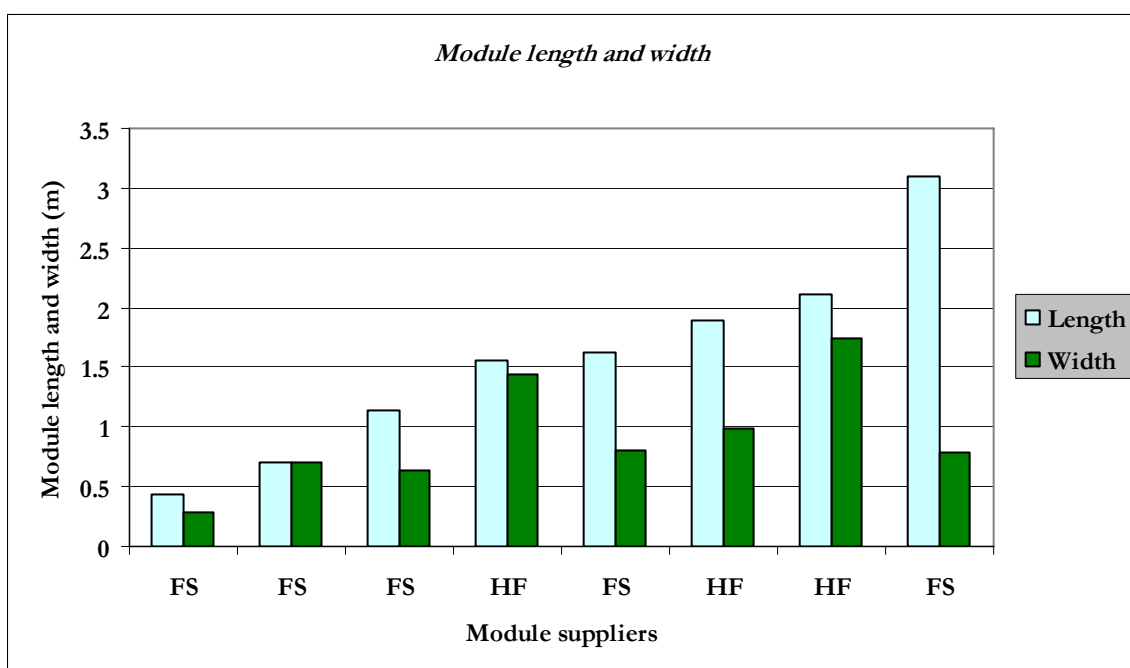


Figure 29. Lengths and widths of the surveyed filtration modules



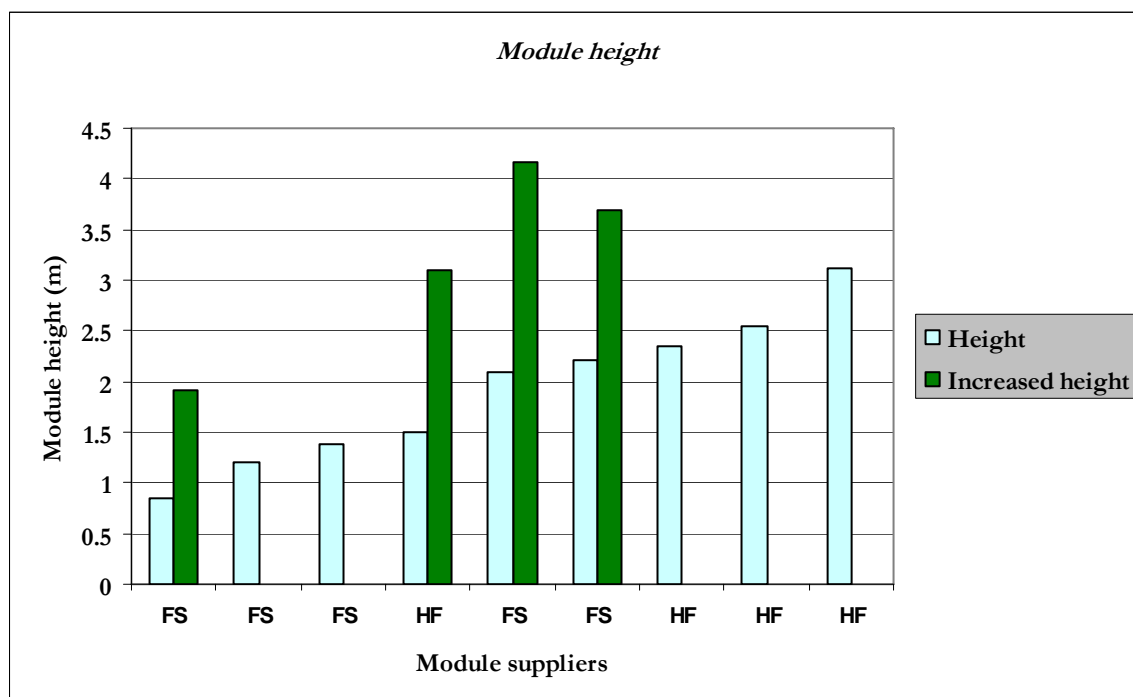


Figure 30. Heights (+ increased heights) of the surveyed filtration modules
 Note: Increased height refers to those modules who have the flexibility to be upgraded in height, e.g. some so-called “double deck” FS modules.

From these figures the large variety in size can be noted: module lengths and heights range from smaller than 1 to larger than 3 meters, widths range from smaller than 0.5 to larger than 1.5 meters. It is clear this is one of the main points of interest in a future standardisation process, but it would be also a difficult issue to agree upon by the MBR industry. Concerning module length and widths, no real distinction can be made between FS and HF modules. As far as the height is concerned, nearly all HF modules are taller than the FS ones, except when the FS modules are used in the so-called double deck configuration.

B. Capacity: packing density and design flux

Module packing density and design flux are interrelated with module size and must be considered simultaneously: two modules with the same size may seem interchangeable, but if the multiplication of their membrane surface area (= packing density x volume of the module) and design flux (l/m².h) is not equal, they will not be able to produce the same flow rate, and will therefore, not be interchangeable.

Membrane packing density can be expressed in 4 different units:

- per volume of the filtration module itself
- per volume of the filtration tank where the modules are suspended
- per surface area of the filtration module itself
- per surface area of the filtration tank where the modules are suspended

Module packing density and design flux must be considered simultaneously in a standardisation study.



An overview of these values for the most important products currently on the market can be found in Figure 31. In the next paragraph, it is established that, concerning standardisation, the most important unit is [m² membrane/m² filtration tank].

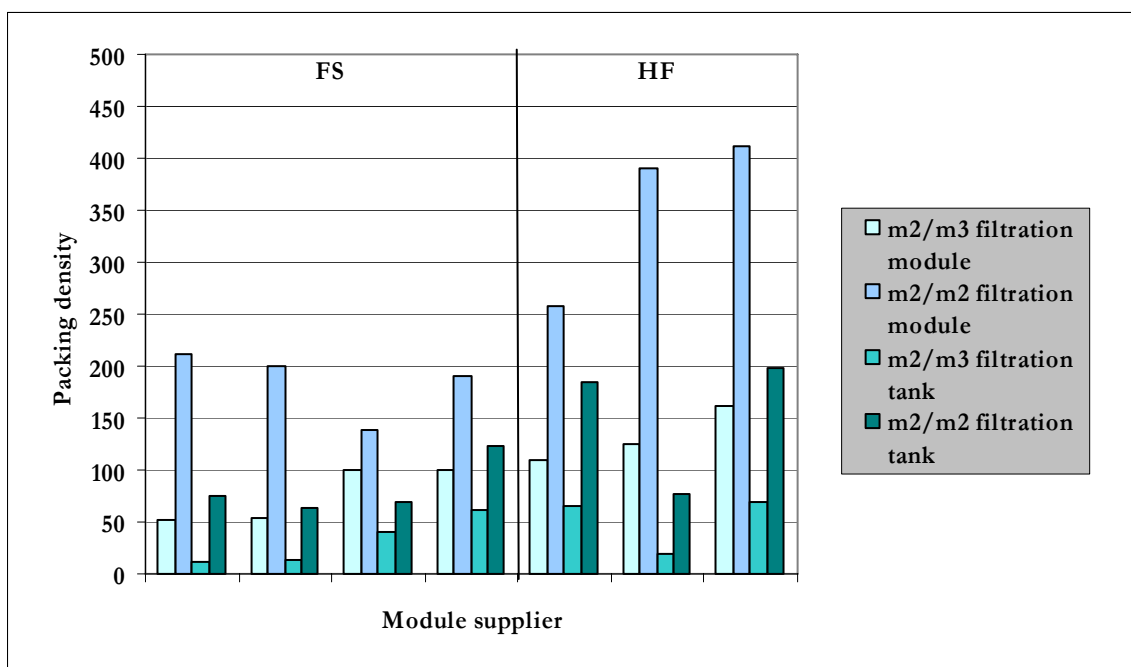


Figure 31. Membrane packing density of the surveyed filtration modules

If one wants to know whether or not a certain filtration capacity can be reached when installing interchangeable modules, studying the values in Figure 31 is not going to provide any answers. Two more pieces of information are needed:

- Design flux (l/m².h)
- Number of modules that can be installed inside a tank with specific dimensions

The design flux in a membrane bioreactor is dependent on many boundary conditions, like temperature, MLSS concentration, low-high flow variation, influent quality,... The last couple of years much attention was paid and money was spent on increasing the membrane flux in membrane bioreactors: higher fluxes mean less membranes and cheaper installations. Depicting the values of design fluxes from different suppliers in a graph would still not provide the information necessary to assess the potential for filtration module standardisation. The design flux needs to be multiplied by the packing density, expressed in [m² membrane/m² filtration tank], and therefore, it is necessary to know how many modules of a certain supplier can be installed.

All the information above was retrieved from the questionnaire, and the results are represented in Figure 32, where the treatable flow (as percentage of the average) in a filtration tank with a given surface area, is provided. Abstraction is made of the height of the filtration tank. It is assumed that the height is not limiting for interchangeability of the module. While this is an unrealistic assumption, it is necessary in order to make a comparison.



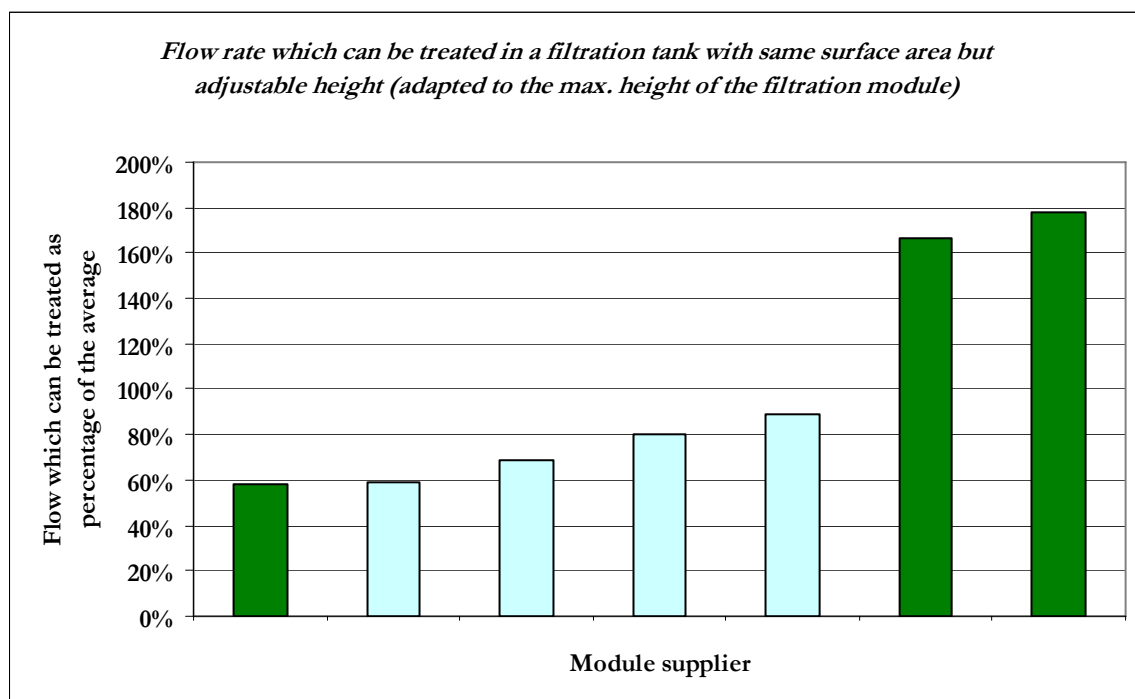


Figure 32. Flow rate which can be treated in a filtration tank with predetermined surface area
Note: blue=FS (single deck or double deck: makes no difference), green=HF

This graph indicates that the two modules with the highest capacity:

- are HF ones;
- produce two to three times more permeate than the FS modules;
- produce three to five times more permeate than their other HF competitors.

The FS module capacities are more in the same range.

Obviously module capacity forms an important point of attention if one wants to develop standards common for both HF and FS modules. Within the group of HF modules, capacity still forms a quite important limiting factor due to the large variations. Within the group of FS modules this factor is far less an issue, although still moderately important.

C. Permeate connections

C1. Number of connections

The number of connections between a filtration module and the central permeate collection manifold to which this module is connected, could obviously be an important factor for standardisation of this technology. In some filtration modules, the permeate is evacuated through only one permeate header (mostly on top of the module), in other modules two permeate headers (either one for the top and one for the bottom, or one for the left and one for the right part) are designed. A module with two connections can never be installed in a filtration tank where the permeate header is designed to allow modules with only one connection, without cost-effective modifications. Figure 33 shows how many modules can be found in each category.

On the same surface area, some HF modules can produce double the permeate capacity of most FS modules.



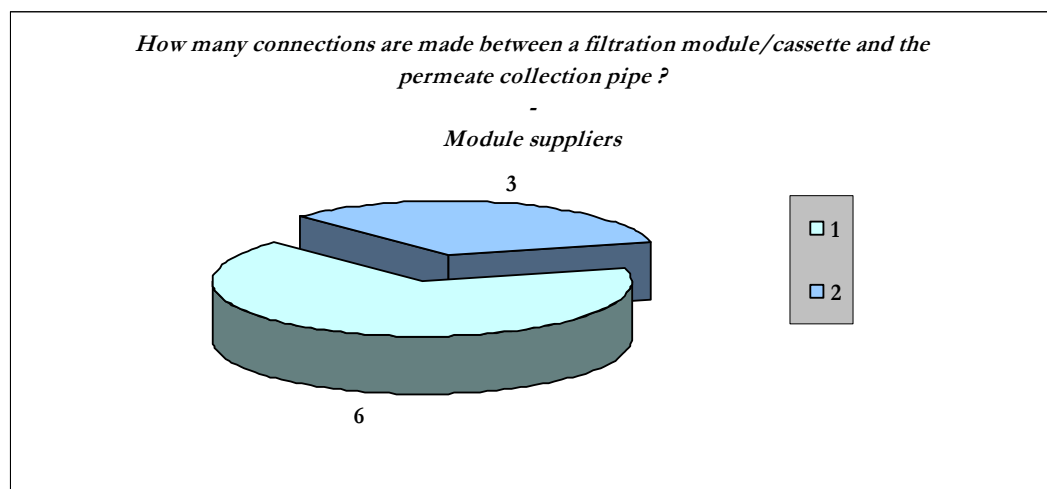


Figure 33. Number of connections between a filtration module and the permeate collection pipe.

This Figure illustrates that the number of connections forms a moderately important factor to consider in the standardisation process, since one third of the modules have two connections, and two thirds have only one connection. No distinctions can be made between HF or FS membranes, in each category there are modules that evacuate the permeate through one or two connections.

C2. Diameter

Not only the number of connections between a module and its permeate manifold is important, but also their diameter. Interchangeable MBR filtration modules would require a standard diameter in which they can be connected to the permeate manifold for evacuation of permeate. In Figure 34 a plot of the diameters currently used in the filtration modules commercially available can be found.

From this graph it is clear that a large range of diameters is currently used (from 20 to 80 mm), therefore forming a moderately important issue in a possible standardisation process. No real pattern within the group of FS or HF modules can be discovered. It can be noted that in a good design, the harmonisation of module capacity should lead automatically to the definition of a standard permeate diameter (minimal head loss).



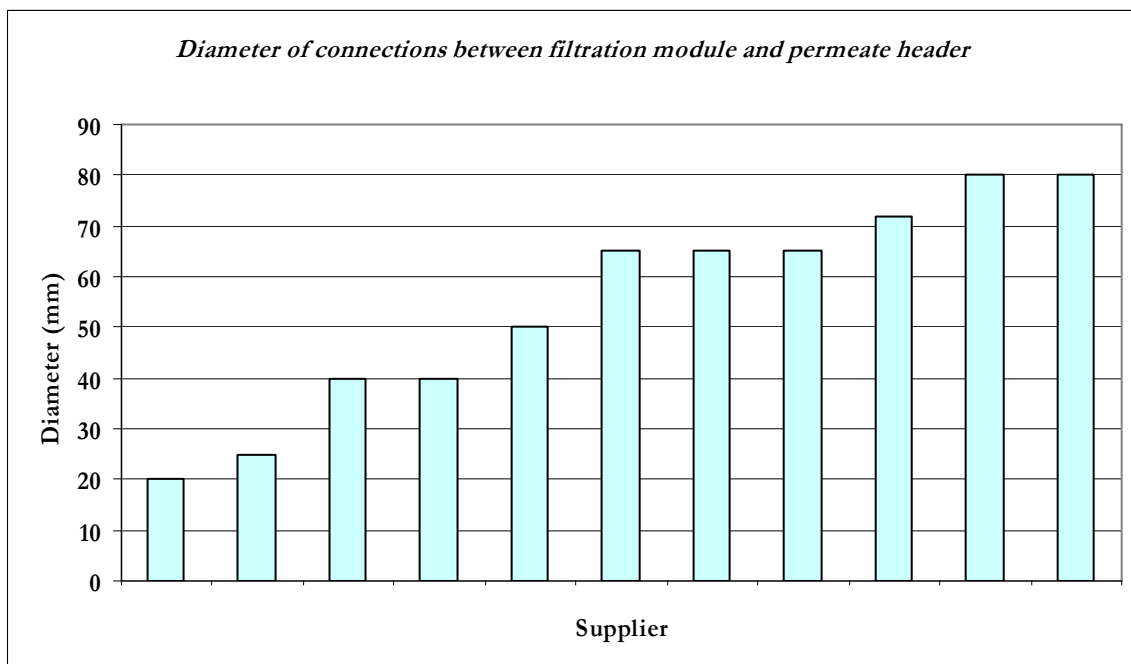


Figure 34. Diameter of the connections between a filtration module and permeate header

C3. Type

Apart from the number and the diameter of the connection between module and permeate evacuation manifold, also the type of this connection is important. If no guidelines or standards exist about the connection type, permeate manifold connections will have to be re-engineered during the replacement process. The type of connection used in MBR filtration modules is illustrated by Figure 35.

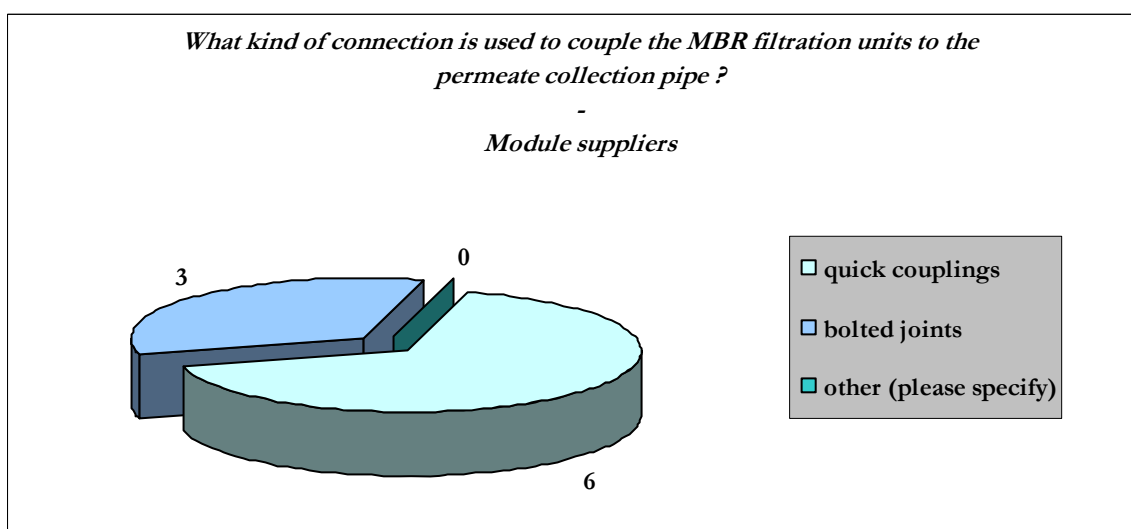


Figure 35. Kind of connection to couple the filtration modules to the permeate collection pipe

Apparently most filtration modules use quick couplings to allow easy and fast connection to the permeate manifold. Only 3 modules use bolted joints. No



distinction can be made between FS or HF modules. Due to the common practice of quick couplings, and because re-designing an existing module with another connection type is relatively easy, the importance of this item within a possible standardisation process will be rather low.

D. Air connections

D1. Number of connections

Not only the connections of a module to the permeate evacuation manifold, but also the connection of the air supply manifold to this module is an important consideration for a possible standardisation process. A module with two connections to the air supply manifold can never be replaced with a module featuring only one connection, unless additional re-investment costs are made to the air supply manifold. This issue is addressed in Figure 36.

A module with two air supply connections can never be interchangeable with a module featuring only one connection without making additional re-investment costs.

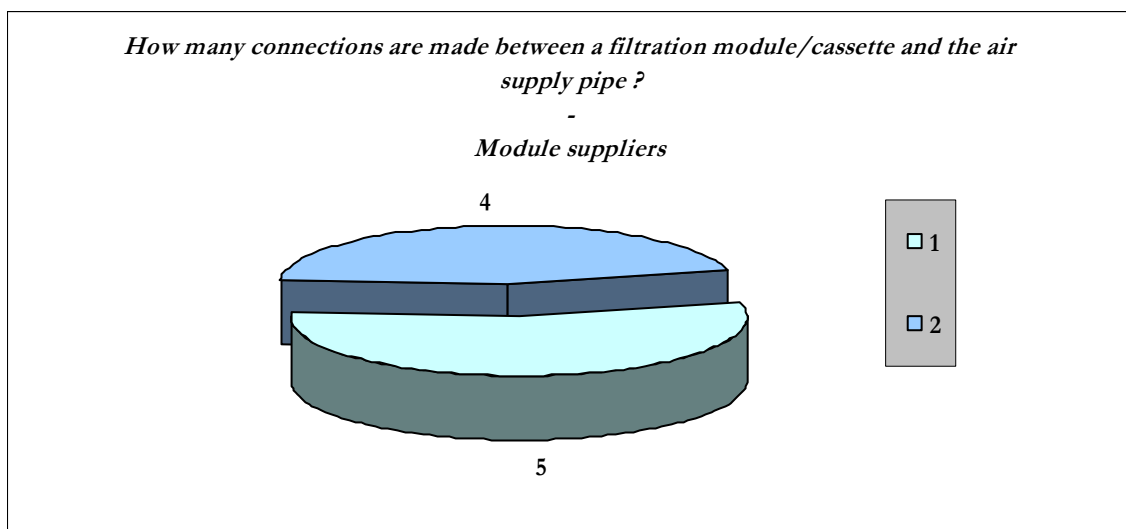


Figure 36. Number of connections between a filtration module and the air supply pipe

This figure indicates that this factor could be of importance in a standardisation process: one third of the modules have two connections to the air supply pipe, two thirds of the modules have only one connection. Accidentally, these numbers are equal to the data provided for the connections to the permeate evacuation. The number of connections between permeate and air manifold are not always similar for each module: some exhibit only one permeate connection and two air connections, and the other way around. No patterns within the group of FS or HF membranes can be discovered. It can be concluded this factor is moderately important in a possible standardisation process.

D2. Diameter



In Figure 37 the different diameters used to connect the filtration module to the central air supply manifold are shown. Also here, interchangeable filtration modules would require the same diameter to allow an easy connection to the existing air supply pipe.

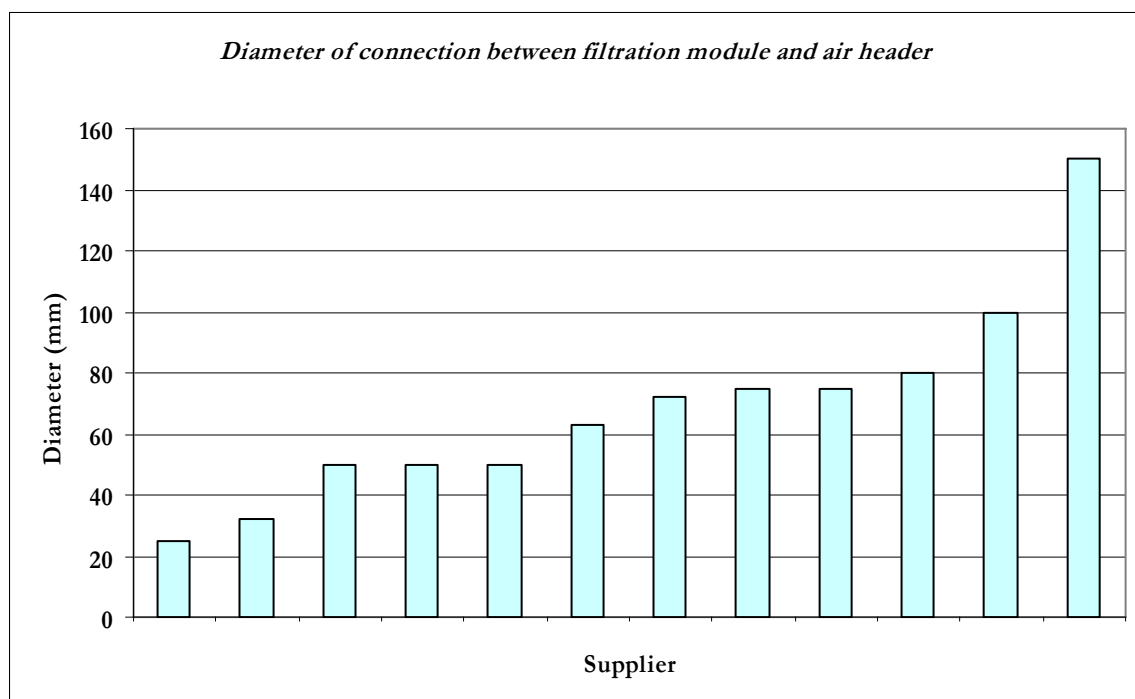


Figure 37. Diameter of the connections between a filtration module and air supply pipe

No real division can be made between FS and HF modules, and just like in the case of the permeate connection diameter, it can be concluded this factor is moderately important in a possible standardisation process. Also here it can be noted that this diameter is probably related to the aeration requirement of the module: harmonising the aeration need should lead to the identification of a standard diameter.

D3. Type

The type of connection used to couple several commercial MBR filtration modules to the air supply pipe is presented in Figure 38.

The same systems which use quick couplings to connect to the permeate manifold, also use this type for connecting to the air supply pipe. About one third use bolted joints. No distinction can be made between FS or HF membranes. The relevancy for this item in a possible standardisation process is rather low.



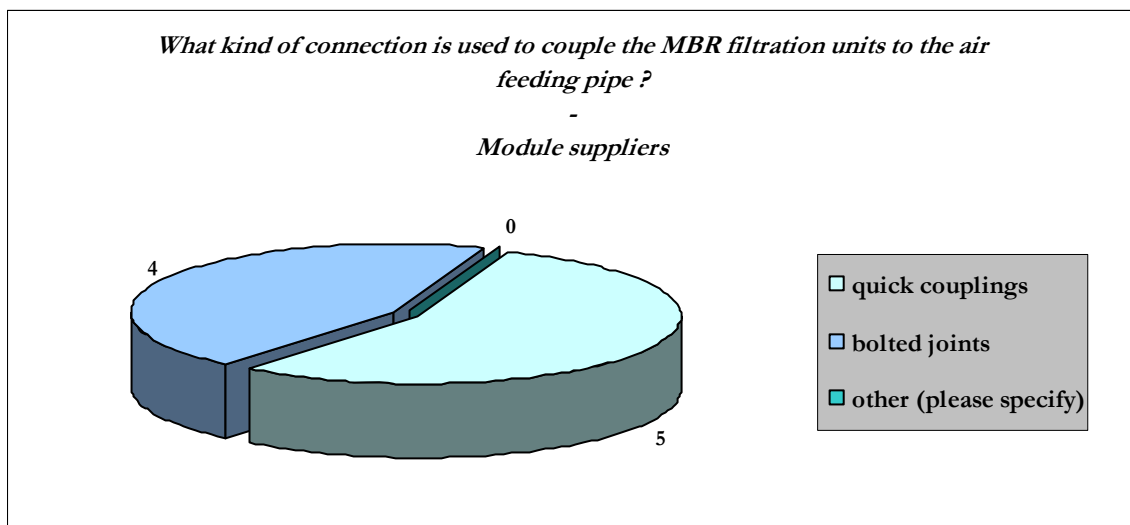


Figure 38. Kind of connection to couple the filtration modules to the air supply pipe

5.1.2.3 Filtration tank

A. Special provisions manifolds

A1. Permeate

Often, the permeate collection manifold in membrane bioreactors is designed with some kind of air release system. Should some modules require such a system while others should not, this is an issue when installing interchangeable modules. In Figure 39 information can be found about whether or not module suppliers advise or require such an air release system.

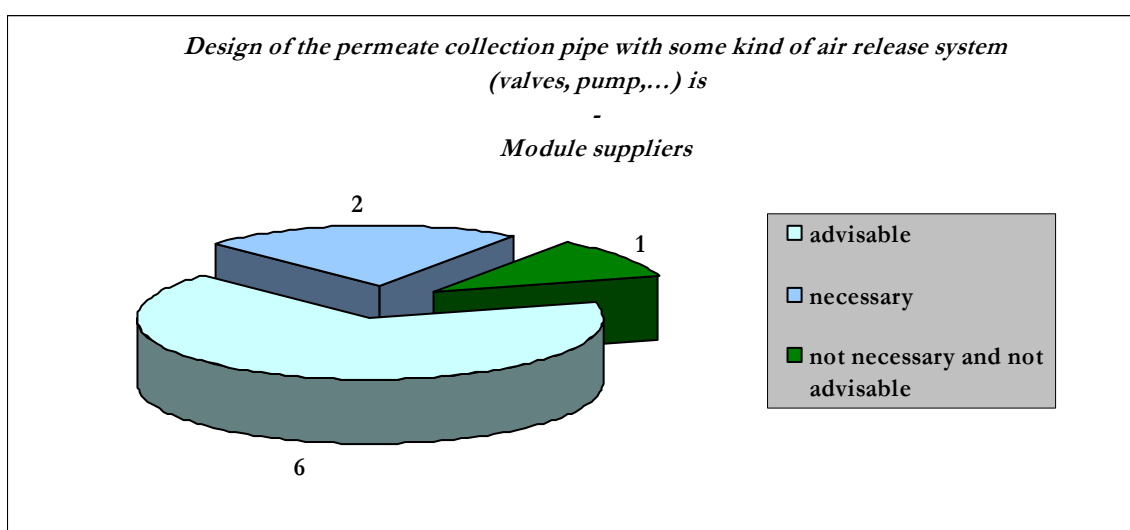


Figure 39. Opinion of the surveyed module suppliers on an air release system installed on the permeate collection pipe



This figure indicates that for most modules such an air release system is advisable or required. Only one module supplier answers that it is not necessary to install it, and therefore this factor cannot be considered as an important issue regarding filtration module standardisation.

A2. Sludge

For some suppliers or constructors, it is a necessity that the sludge is fed and recycled equally over the length of the filtration tank. For others it is merely advisable. Depending on the distribution of these opinions, this design practice can be an important issue in a standardisation process. This information is represented in Figure 40

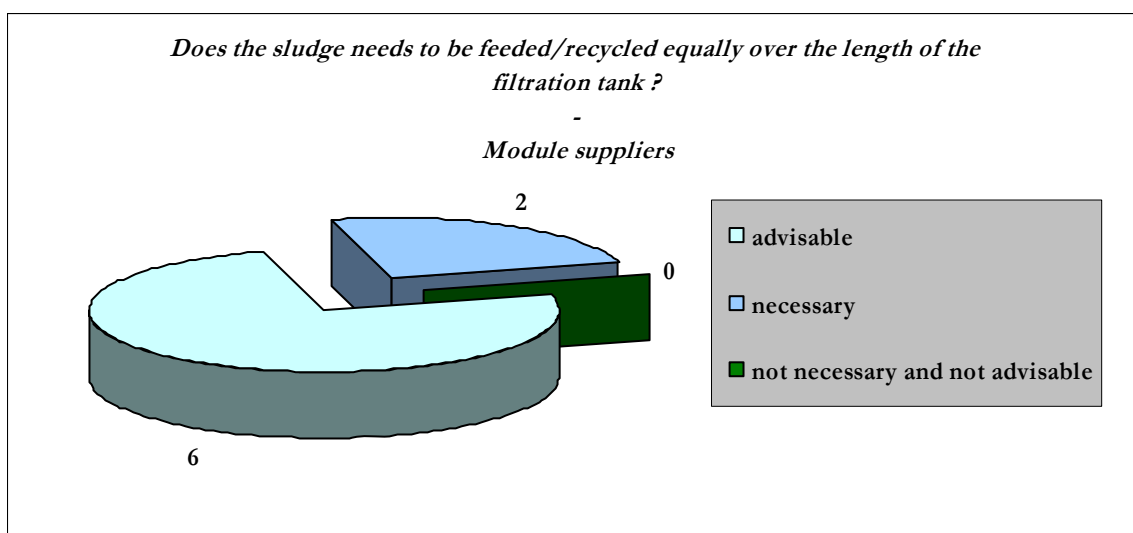


Figure 40. Opinion of the surveyed module suppliers on an equal distribution of sludge in the filtration tank

As with air release systems on permeate pipes, quite a good consensus is reached preferring an equal distribution of sludge over a filtration tank.

A3. Air

The coarse bubble aeration design and mode of operation has an impact on two important aspects to be considered in a standardisation process:

- Provisions to allow sequenced aeration (e.g. valves)
- Provisions to allow for flushing or cleaning the aeration piping system

If additional equipment needs to be designed for this purpose it can be a point of attention in a future standardisation process. Information about the mode of operation of the coarse bubble aeration (continuous or not), and the necessity for a special cleaning or flushing system is depicted in Figure 41, Figure 42 and Figure 43.



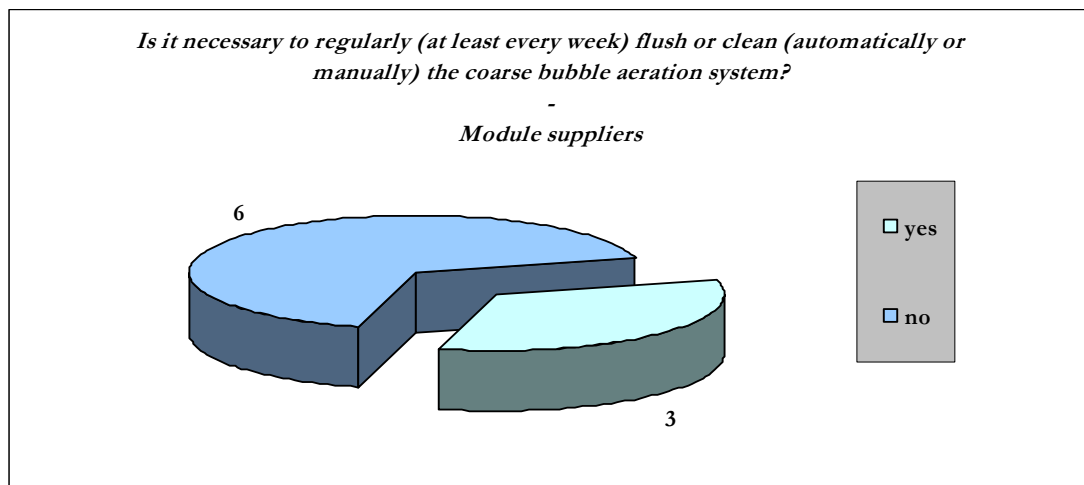


Figure 41. Opinion of the surveyed module suppliers on a flushing or cleaning system on the coarse bubble aeration supply pipes

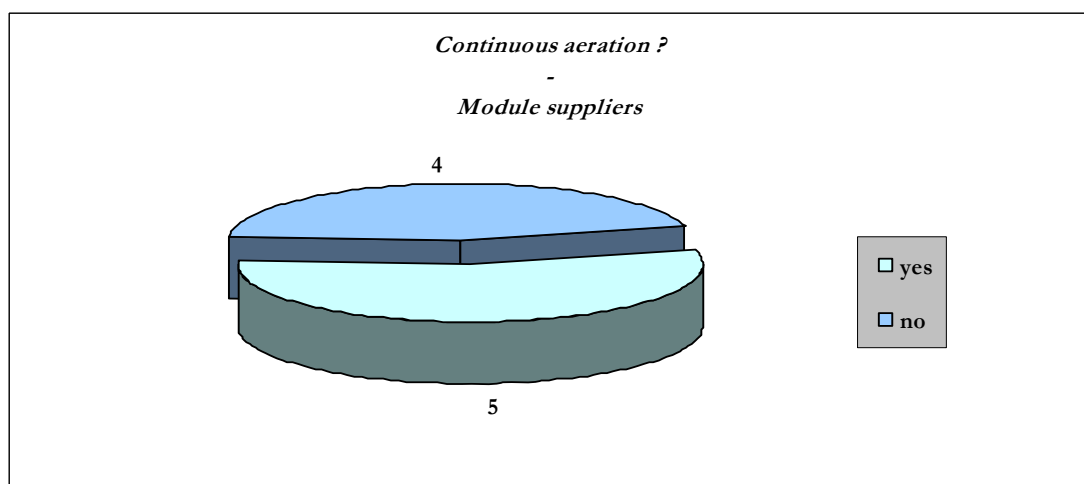


Figure 42. Mode of aeration for the surveyed module suppliers

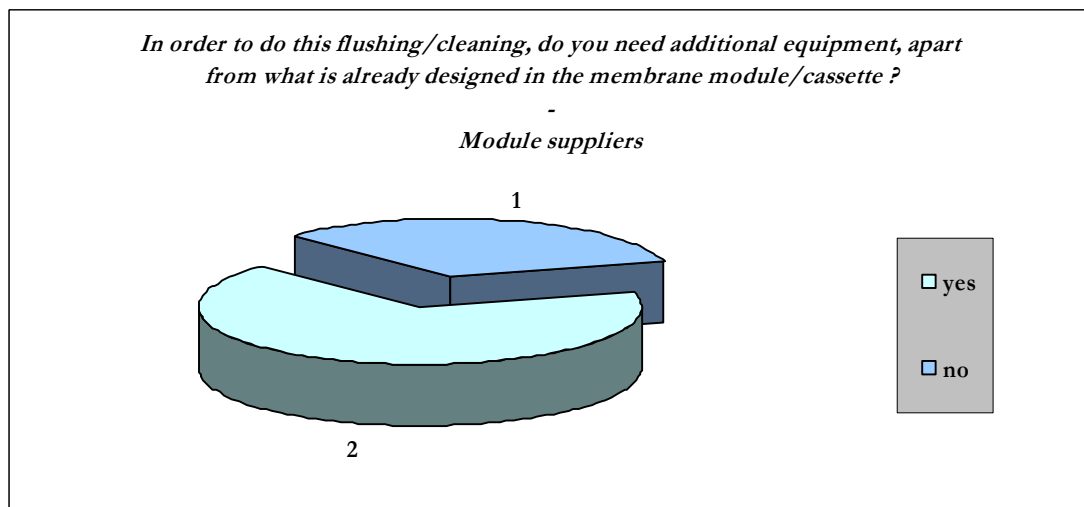


Figure 43. Requirement for additional equipment in order to flush or clean the coarse bubble aeration supply pipes



These figures indicate that five of the nine MBR filtration modules studied use continuous aeration (of which four are FS modules, not shown on the graph). For three of the nine (of which two use continuous and one intermittent aeration) it is necessary to regularly flush or clean the coarse bubble aeration pipes, and two of these (both FS modules) need additional equipment to do this.

B. Dimensions

What are the dimensions of a filtration tank allowing for the largest variety of filtration modules to be installed? Designing and constructing this kind of standardised membrane filtration tank has two main advantages:

- Tendering of the membrane modules can be postponed until after the construction of the tank. Therefore, maximal advantage can be taken from the latest developments and cost decreases.
- Other types of membrane modules could be installed if necessary (e.g. because of membrane lifetime, failures,...)

The necessary dimensions of a filtration tank for installing 2000 m² of membrane surface area of different modules, can be found in Figure 44, Figure 45 and Figure 46. It should be noted that an equal membrane surface area does not mean that equal capacities can be treated (see paragraph 5.1.2.2 B).

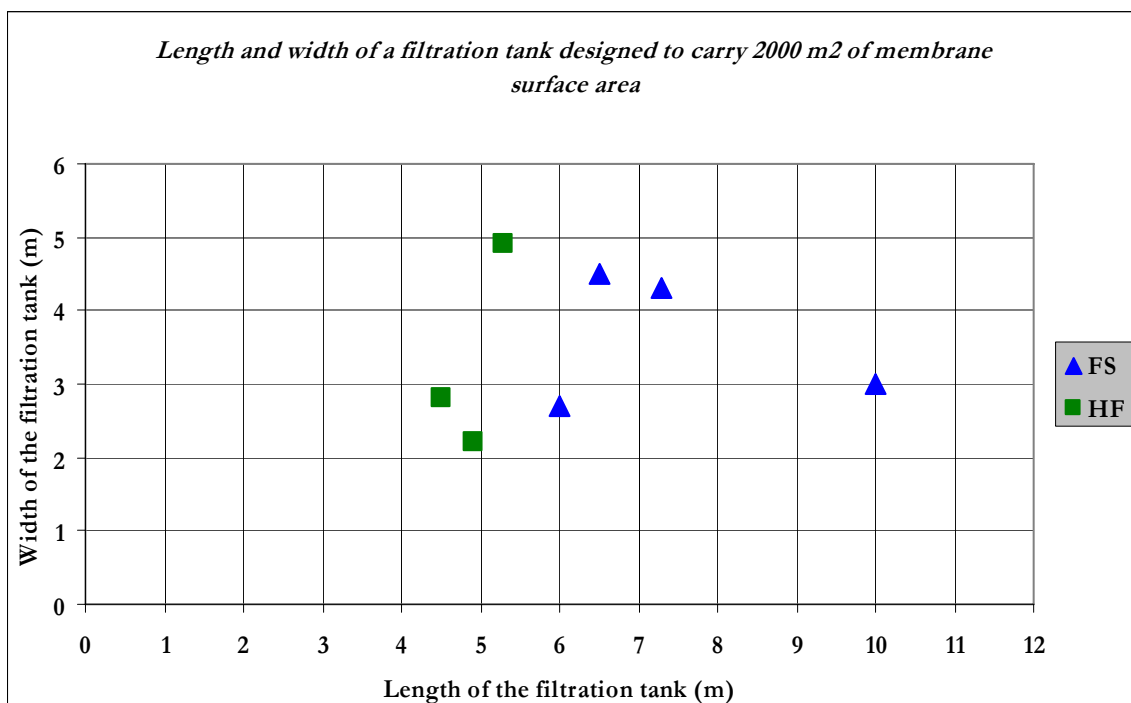


Figure 44. Length and width of a filtration tank to carry 2000 m² of membrane surface area, for the surveyed modules



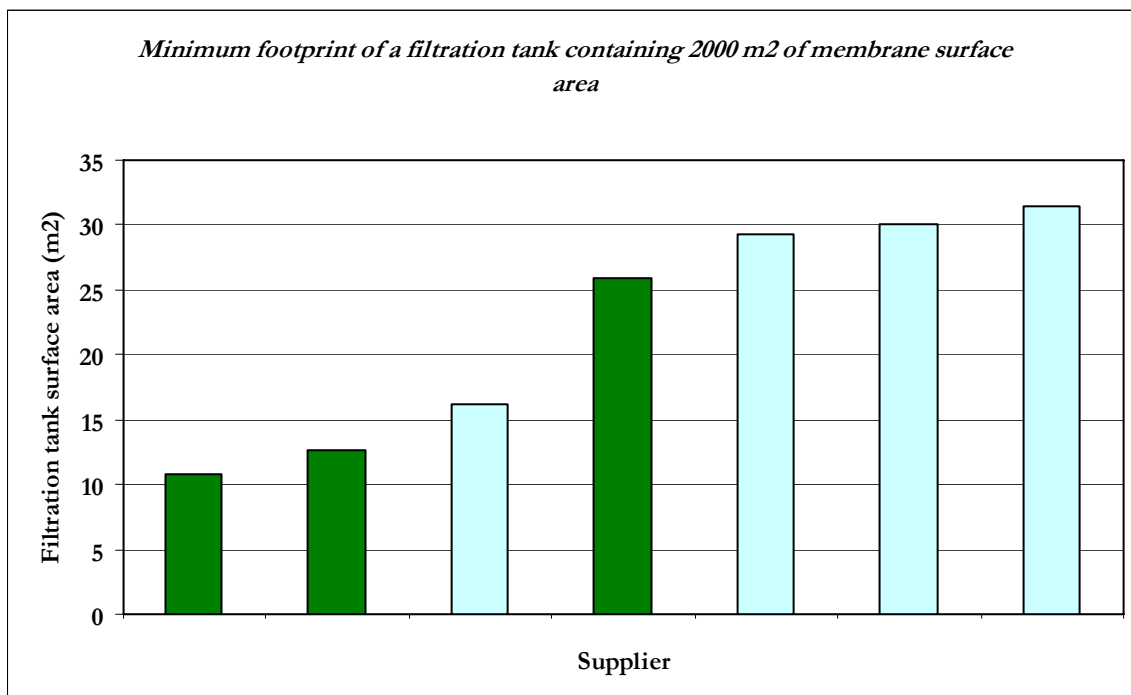


Figure 45. Minimum footprint of a filtration tank containing 2000 m² of membrane surface area
Note: blue=FS, green=HF

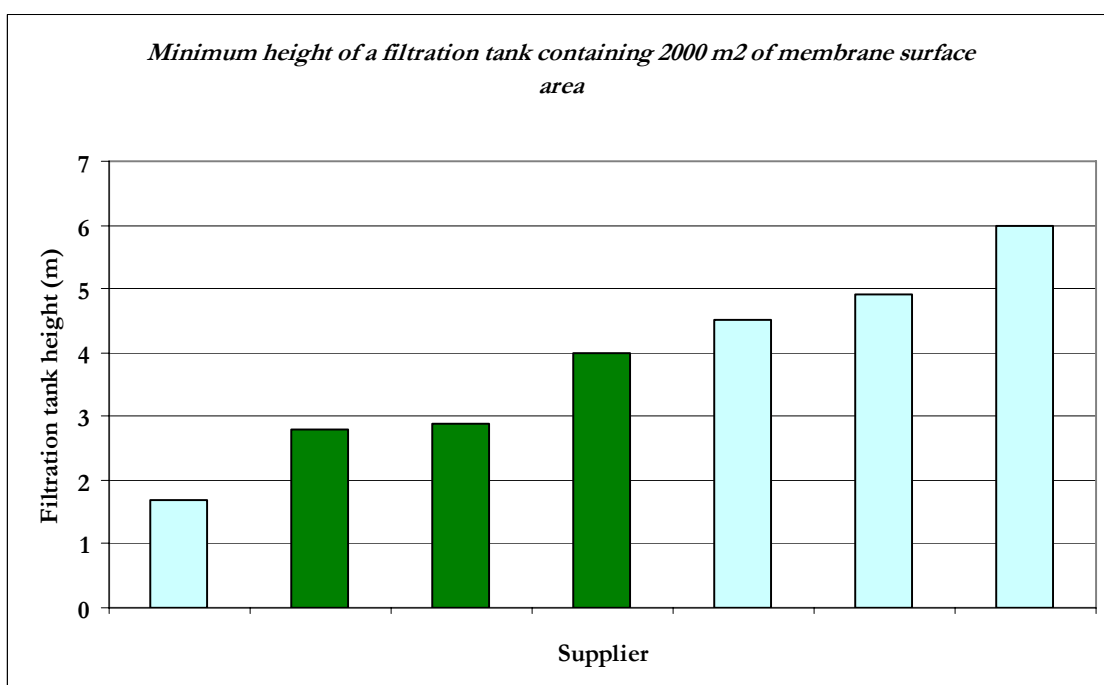


Figure 46. Minimum height of a filtration tank containing 2000 m² of membrane surface area
Note: blue=FS, green=HF



These figures show that:

- the most compact systems (in terms of filtration tank):
 - are HF membranes/modules
 - need two to three times less filtration tank surface area than the larger modules
 - are generally those systems with the highest design flux, which makes the contrast even more pronounced
- a factor two difference between the different filtration modules is visible in the total surface area as well as in the filtration tanks
 - length/width ratio
 - height

Without elaborating on the details, it can be concluded that designing an optimal "standardised" filtration tank:

- which would fit all modules can currently not be done without drastically over-dimensioning
- which would fit only FS or HF modules is much more realistic, but still not straightforward

C. MLSS/sludge recycling factor

The membrane bioreactor volume is mostly designed depending on a pre-supposed biological loading rate and a maximum limit of MLSS concentration desired around the membranes. So once the bioreactor is built, a certain minimum MLSS concentration has to be maintained in order to guarantee the treatment performance. However, not all filtration modules can cope with the same MLSS concentration. If installing an interchangeable module means that the MLSS concentration in the bioreactor has to be lowered to guarantee a stable filtration performance, this interferes with the boundary conditions necessary to reach the treatment objectives. The maximum desired MLSS concentration (to allow a long-term stable filtration) in a filtration tank for different MBR filtration modules is depicted in Figure 47.

While the differences between the modules may not seem big, the consequences can be quite far-reaching. Installing interchangeable filtration modules which allow a lower MLSS concentration than the one installed before, can lead to unrealistically large sludge recycle pumps.



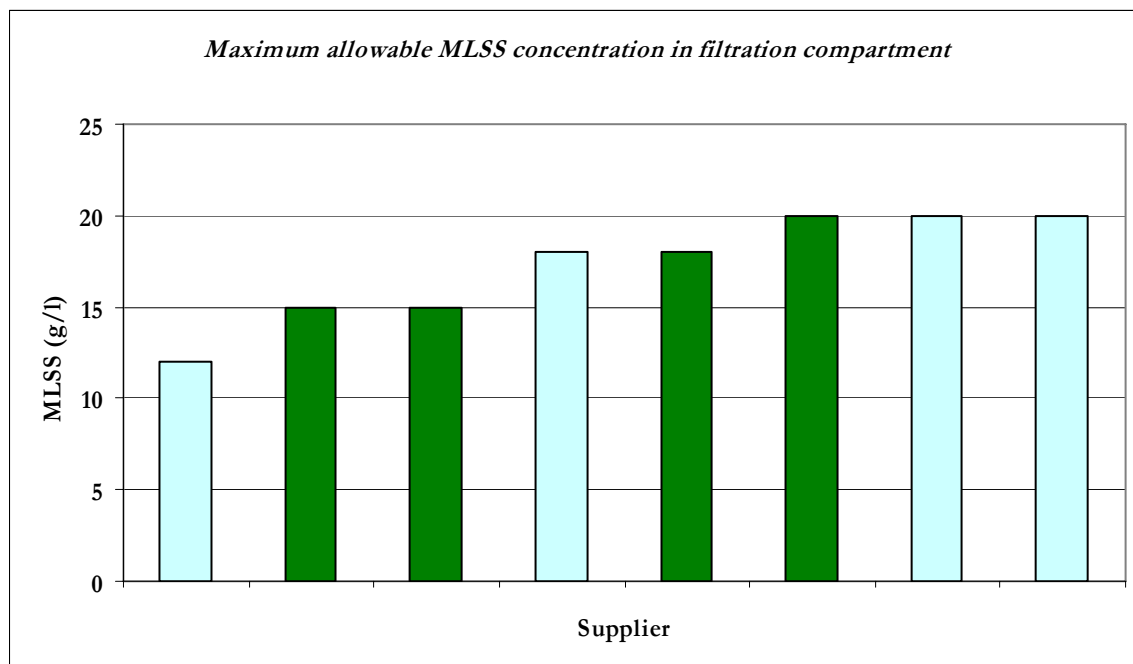


Figure 47. Maximum allowable MLSS concentration in the filtration compartment
 Note: blue=FS, green=HF

This can be illustrated with an example, at the same time showing the relation with the sludge recycling factor:

- Original MBR designed:
 MLSS bioreactor = 14 g/l, MLSS filtration tank = 19 g/l, ratio sludge recycled/permeate produced = 2,8
- Interchangeable filtration modules placed allowing an MLSS of only 16 g/l:
 MLSS bioreactor = 14 g/l, MLSS filtration tank = 16 g/l, ratio sludge recycled/permeate produced = 7,0

There is no difference between the FS and HF modules where this factor is concerned.

The importance of this factor in a future standardisation process is moderately high. Going towards interchangeable filtration modules will mean that the MLSS in the filtration tank cannot be designed too high, i.e. above 15-16 g/l.

D. Cover

If some module suppliers require covered membrane filtration tanks as a prerequisite before installing their modules, additional costs will be necessary if they deliver an interchangeable module in an existing uncovered filtration tank. This issue is addressed in Figure 48.



None of the suppliers require covering of their membrane filtration tanks as a prerequisite.

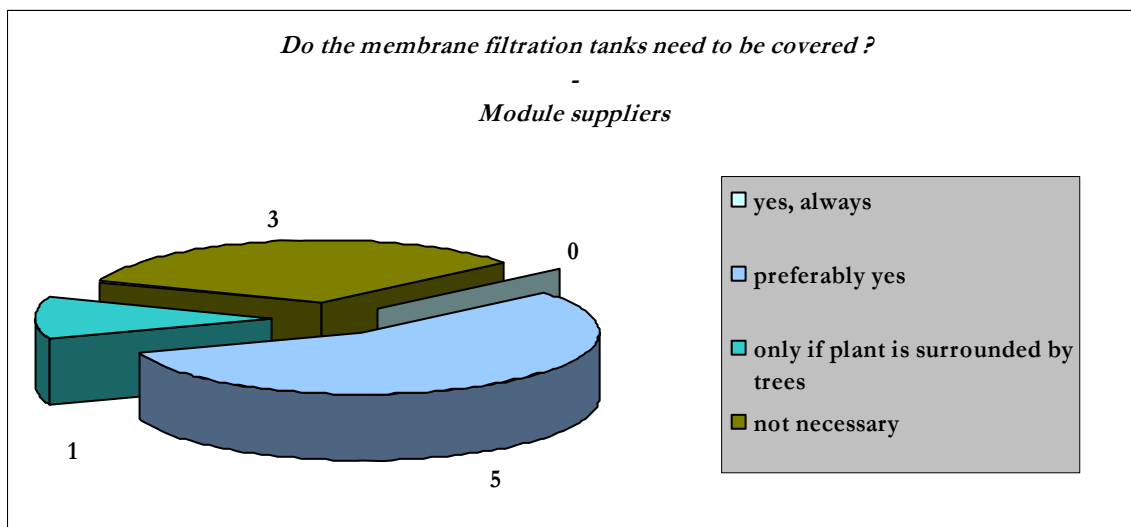


Figure 48. Requirement for covering the filtration tank(s)

As shown in this figure, none of the module suppliers require a covered filtration tank. Therefore, this issue can be seen as insignificant in a possible standardisation process.

5.1.2.4 Peripheral (electromechanical) equipment

A. Permeate pump(s)

A1. Gravity filtration

What if the permeate flow in an MBR is designed without permeate pumps, but with gravity filtration ? If it would be impossible for certain filtration modules to work properly without permeate pumps, this could be a point of attention: additional costs will have to be made for installation of permeate pumps, should the interchangeable modules be installed. This issue is covered in Figure 49.

From this figure it can be observed that gravity filtration is feasible and advisable (given the boundary conditions do not pose any problems) for half of the products, but not impossible nor advisable for the other half. In other words: this aspect is important to consider, not as a technical bottleneck (since permeate pumps can always be added to the design), but rather as a factor which could increase the investment cost for membrane replacement. Since the two systems for which gravity filtration is not feasible are HF modules, this issue is more pronounced for HF than for FS membranes.



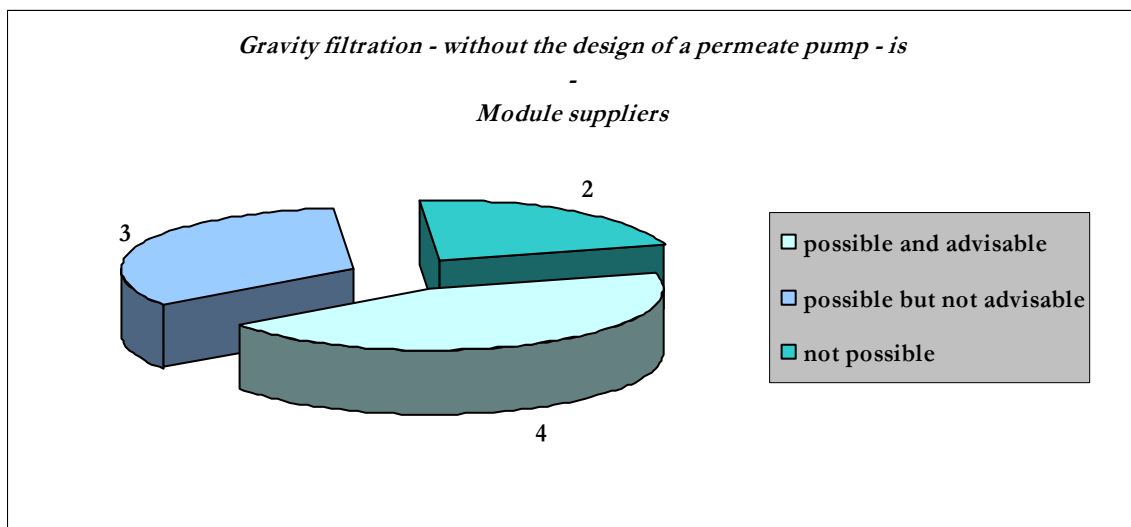


Figure 49. Possibilities for gravity filtration of the surveyed modules

A2. Type

Permeate production pumps can be operated in many different modes, depending on the filtration module installed. Duration of filtration, backwashing and relaxation can be very different, and therefore also the design of pump used. If a significant number of modules can only work with one or two specific types of permeate pump, additional re-investments may be necessary to change the existing pump if it is not compatible with the new interchangeable modules.

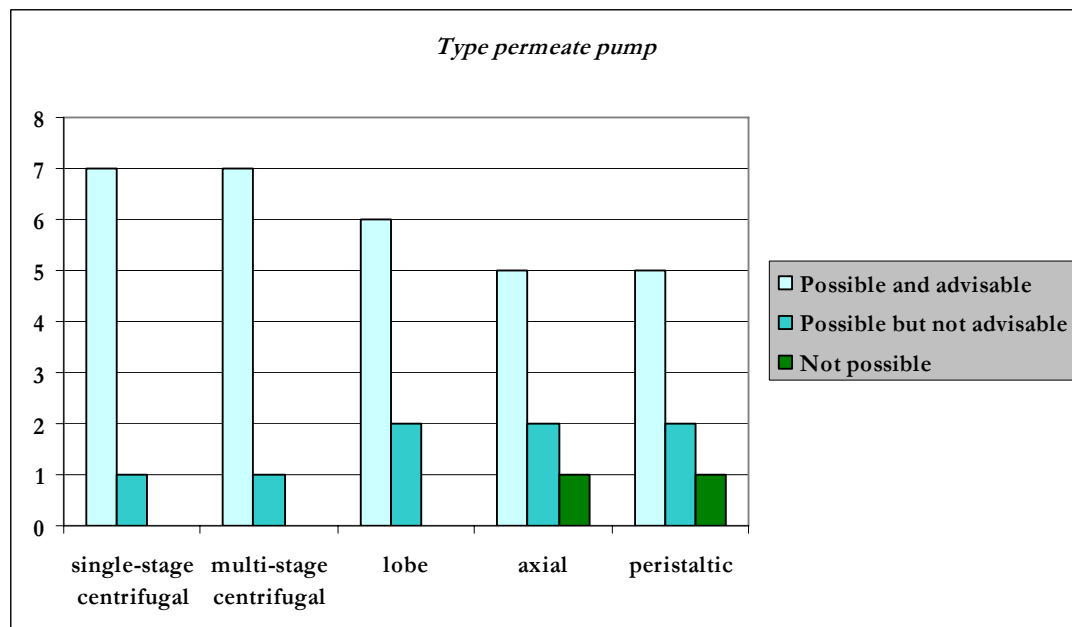


Figure 50. Type of permeate pump to be applied for the surveyed modules



This graph indicates that for different pump types, only one or two suppliers mention it is not advisable or feasible to apply in combination with their product. No differences can be made between HF or FS products.

A3. Reversibility

Some membranes are designed to allow regular backwashing, others are not. If an interchangeable module needs a 2-way permeate pump, this can lead to additional costs in case the original module was not operated with regular backwashing. In Figure 51 and Figure 52, information can be found on how many filtration modules allow regular backwashing of the membranes, and about the typical durations of filtration, backwashing and relaxation.

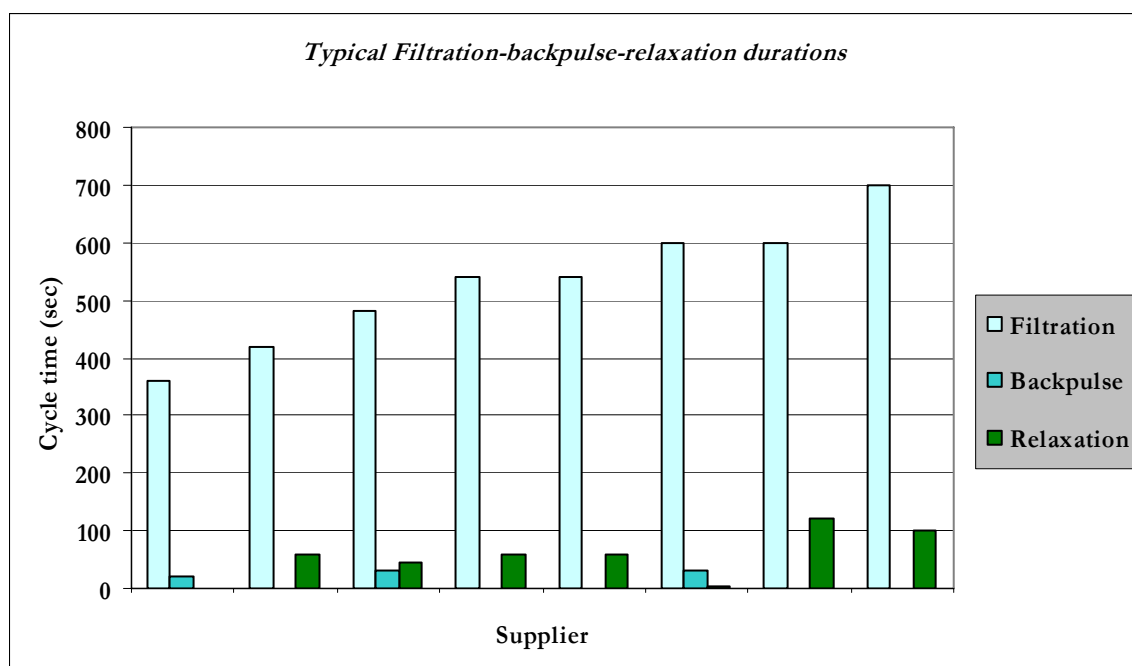


Figure 51. Typical filtration-backpulse-relaxation durations for the surveyed modules

From the five membrane modules allowing a regular backwashing, three are HF and two are FS. It should be noted that at least one of these two FS modules allows backwashing on a low frequent basis only (few times per day), and not frequently (every 6 to 10 minutes) like the HF modules.

It can be concluded that reversibility of the permeate pump is an issue moderately important for both FS and HF modules: in both groups modules can be found which are operated either with or without a backwashing.



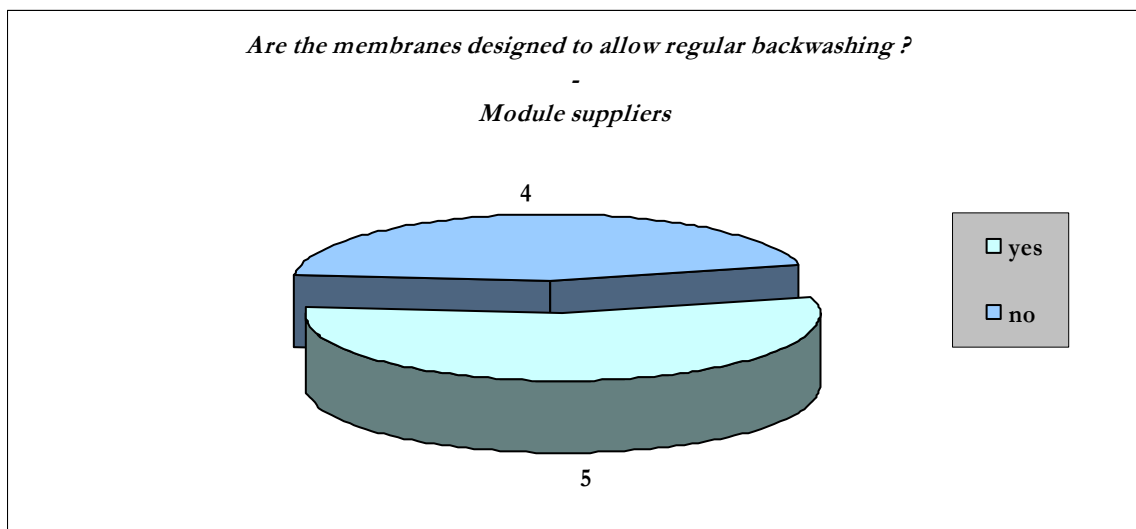


Figure 52. Possibility for regular backwashing of the surveyed modules

B. Flow rate sludge feeding/ recycling pump(s)

If the membrane modules are suspended in a separate filtration tank, the maximal flow rate of the sludge feeding or recycle pumps is designed based on the desired MLSS concentration in the bioreactor and filtration tank. If interchangeable modules that can only be operated at a lower MLSS concentrations are installed in the filtration tank, the sludge recycling rate will need to be increased. This issue was already addressed in paragraph 5.1.2.3.3.

C. Blower(s) coarse bubble aeration

C1. Type

Depending on the filtration module and their aeration regime, some module suppliers may argue that it is not feasible or advisable to operate their product with a specific type of blower. This issue is addressed in Figure 53.

This figure indicates that the type of blower is not a point of attention in a possible standardisation process for MBR filtration modules.

C2. Flow rate

The specific air flow ($\text{Nm}^3/(\text{m}^2 \text{ membrane surface area} \times \text{h})$) needed to aerate a filtration module installed in an MBR, is highly variable. Installing interchangeable modules means that the specific air flow demand for the new modules must be equal or lower than the air flow capacity installed. The specific net air flow demand for different filtration modules is plotted in Figure 54.



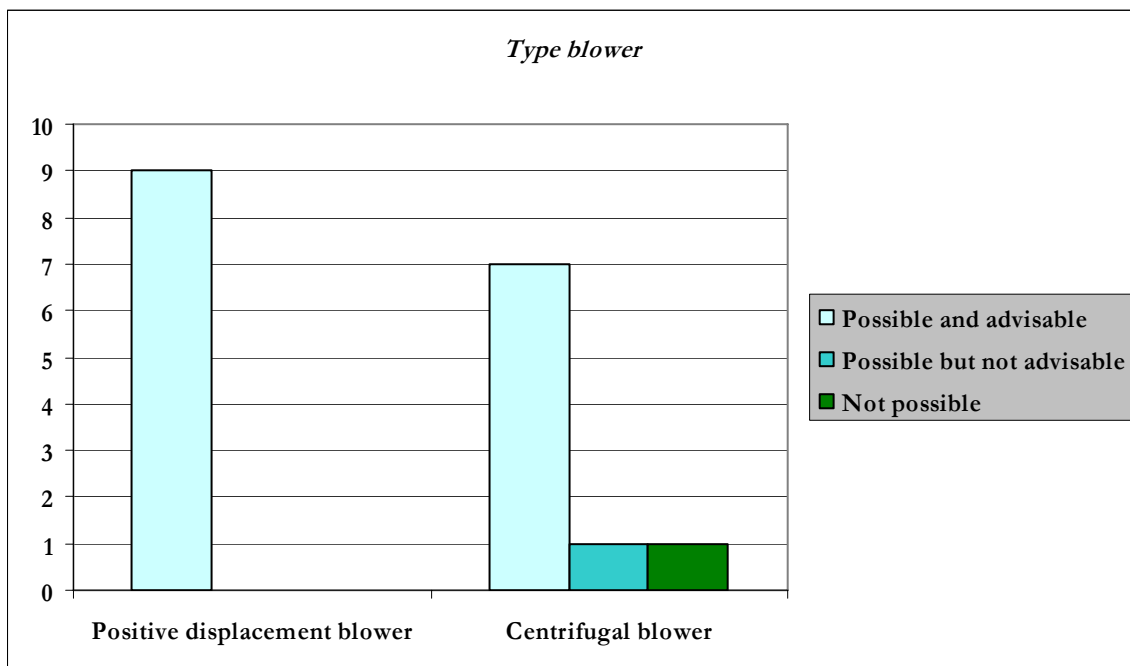


Figure 53. Type of blower to be applied for the surveyed modules

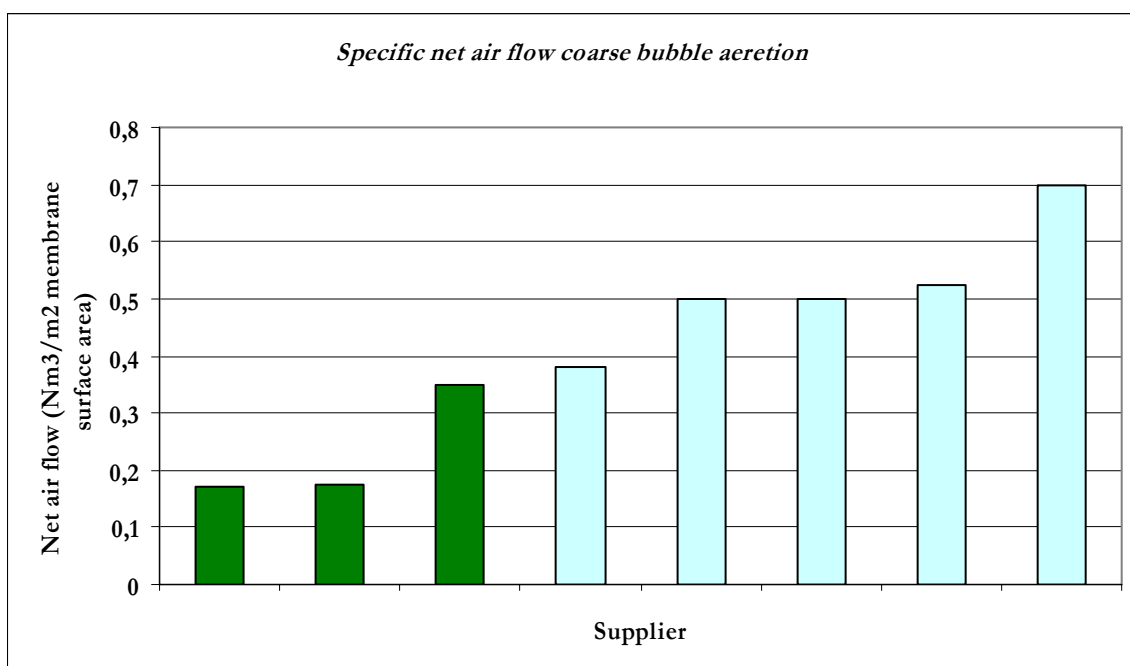


Figure 54. Specific net air flow demand for the coarse bubble aeration

Note: blue=FS, green=HF

It can be concluded that:

- The difference in specific net air flow demand between the modules surveyed is equal to a factor 2 to even 4
- HF modules are less air flow demanding than FS modules

The specific air flow demand for some HF modules is two to three times less than for most FS modules. This is a major issue in a standardisation process.



- In general, the most mature products on the market exhibit the lowest air flow demands (not shown on the graph)

This issue is therefore a major factor to consider in a standardisation process. If only standards within the group of FS or HF modules are considered, this issue becomes less important, but still very relevant.

C3. Pressure

What if certain filtration modules would require a blower pressure much higher than the maximum blower pressure initially installed ? The minimum, average and maximum pressure of the coarse bubble aeration blowers are plotted in Figure 55.

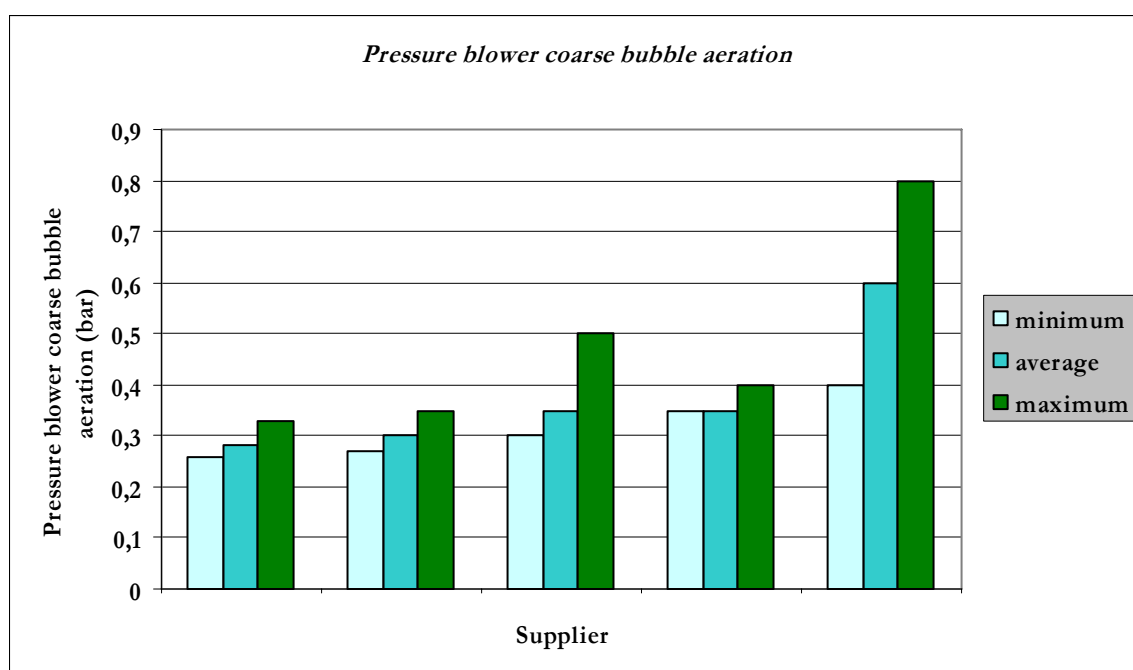


Figure 55. Pressure of the coarse bubble aeration blower

For the five surveyed filtration modules, all values are within a comparable range, except one. It can be concluded this factor will only be a minor point of attention during a standardisation process.

C4. Redundancy

If module suppliers had completely different desires or stipulations regarding the design of the proper redundancy of the coarse bubble aeration blowers, this could be a point of attention. In Figure 56 information is provided on this item.



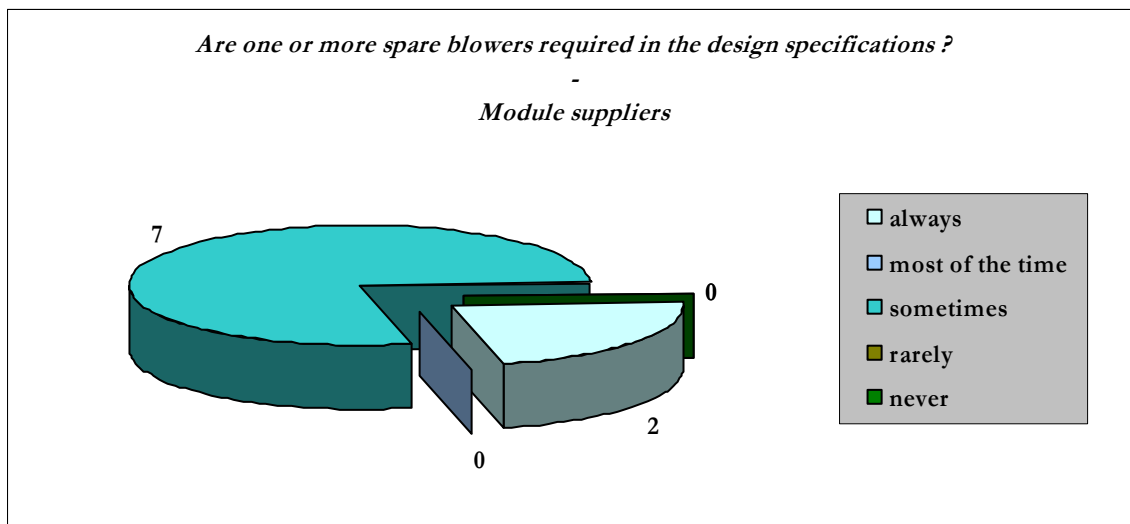


Figure 56. Requirement for one or more spare blowers in the design

Only two module suppliers (both of HF modules) argue it is necessary to design at least one spare blower for their system, while all the others mention this is only required in some cases. It can be concluded this item is not a real issue in a possible standardisation process.

D. Permeate collection tank

Sometimes membrane bioreactors are designed with small separate permeate collection tanks (e.g. to have permeate available at all time for backwashing or for chemically cleaning the membranes). If this is a prerequisite for some modules, while it is only optional for others, this factor must be borne in mind during a standardisation phase. Figure 57 shows whether a separate permeate collection tank is necessary, advisable or neither, for the nine different types of filtration modules

A clear distinction can be noticed between HF and FS modules. For HF modules it is either necessary or advisable in most of the projects. For the FS modules the answers are much more heterogeneous: for two it is always necessary, for one it is never necessary and for two it is advisable in some projects (not shown in the figure). It can be concluded that this issue is an important point of attention if standards need to be developed common for HF and FS membranes. Within the group of HF modules the impact of this aspect in the standardisation process will be smaller than in comparison with the FS modules, therefore two standard groups would be recommended.

HF modules either require or advise a small, separate permeate collection tank.

For some FS module suppliers such a tank is not necessary, for some it is always necessary, and for others it is advisable in some projects.



Design of small permeate collection tanks (e.g. in order to use permeate for back washing) is :

Module suppliers

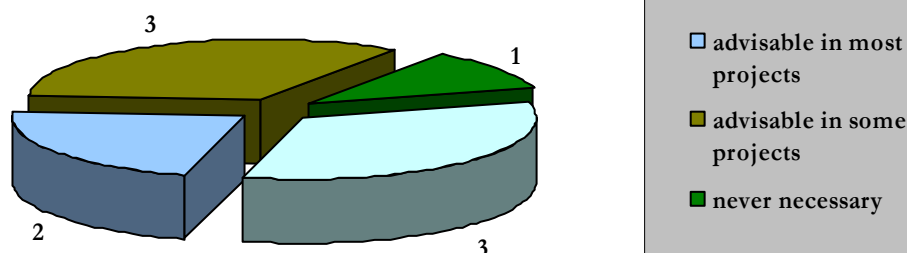


Figure 57. Requirement for design of a small permeate collection tank

5.1.2.5 Bioreactor

A. Internal re-screening of sludge

In the most recently designed membrane bioreactors, often an internal recycling of sludge at very low flow rates over the pre-treatment is designed in order to be able to (discontinuously) purify the sludge from debris accumulated in the bioreactor. If this was a prerequisite for module suppliers for a proper operation of their system, it would be a factor to consider in a standardisation process. This issue is addressed in Figure 58.

Designing a sludge recycling over pre-treatment (at low flows) is

Module suppliers

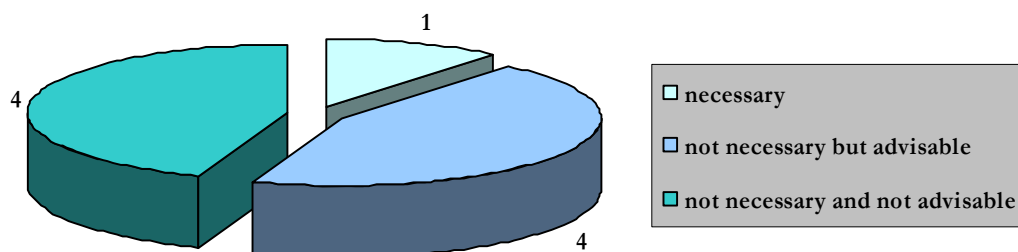


Figure 58. Requirement for design of a separate sludge sieving system over the pre-treatment

From this figure it is clear that if it is up to the suppliers, this measure will not become common practice in MBRs. Almost everyone thinks it is merely advisable.

If it is up to the suppliers, designing a separate re-screening of sludge will not become common practice in MBRs.



B. Cover

What is the benefit of an intensive 1 mm pre-treatment, if the bioreactor is e.g. surrounded by trees and not covered? Do module suppliers find it necessary to cover the bioreactor at all times? This information can be found in Figure 59.

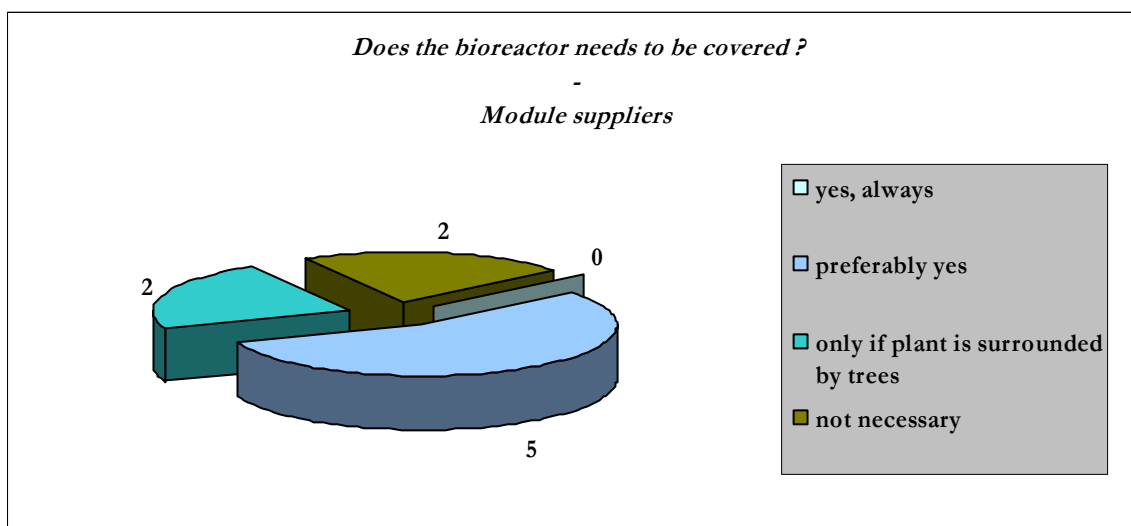


Figure 59. Requirement for covering the bioreactor

Since nobody argues that covering the bioreactor is a necessity, this item cannot be considered as an important point of interest in a standardisation process. On the other hand there is no unanimity between the module suppliers. Most suppliers prefer a bioreactor cover, for some it is merely advisable and for others it is not necessary at all. Therefore, this issue can be a potential factor affecting e.g. the membrane guarantees which are given for the interchangeable modules.

5.1.2.6 Chemical cleaning

A. Chemicals

A1. Kinds of chemicals

Depending on the membrane material and the membrane module, membrane suppliers have developed their own optimal chemical cleaning strategies over the last decade. Different chemicals can be applied in different concentrations with different contact times. If, during a membrane module replacement, the interchangeable modules need entirely different kinds of chemicals than those foreseen in the design and construction of the plant, additional investment costs will be necessary. Therefore, this factor needs to be considered in a standardisation process. In Table 8



information can be found on recommended chemicals for different MBR filtration modules.

Table 8. Different chemicals recommended for the surveyed modules

Module supplier	NaO Cl	citric acid	oxalic acid	NaOH	H ₂ O ₂	HCl	sulphuric acid	TOTAL
1								7
2								6
3								6
4								5
5								5
6								4
7								3
8								3
9								2
TOTAL	9	7	6	5	5	5	4	

It can be observed that – depending on the boundary conditions of the project – a lot of chemicals can be applied for the different filtration modules. This factor is moderately important for standardisation: if other chemicals need to be applied after changing the modules in an MBR, this could slightly increase the investment costs. There is no noticeable difference between HF and FS membrane modules.

A2. On-site storage and dosing pump

Not only the kind of chemical applied, but also the necessity of on-site storage of chemicals is important to consider during a standardisation process. Changing chemicals in an existing plant is quite straightforward, but redesigning and constructing additional piping and a chemical storage tank, and acquiring new environmental permits is much harder. This issue is addressed in Figure 60.

This figure indicates that this aspect is important in a standardisation process: for half of the suppliers, on-site storage of chemicals at the plant is required, for the other half it is not a necessity.



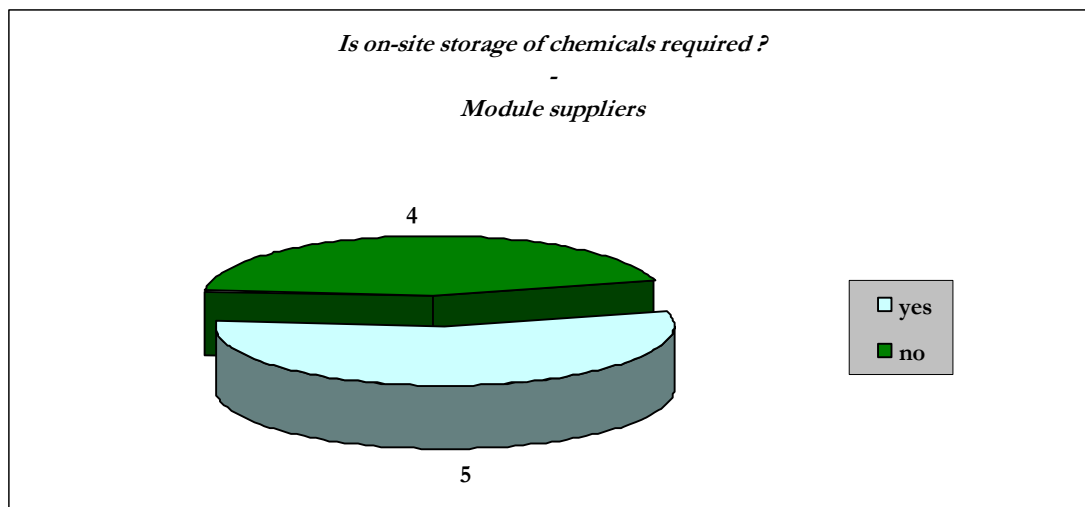


Figure 60. Requirement for on-site storage of chemicals

B. Heating

What if it is common practice for one module supplier to design a separate tank with heating elements (to be used during the chemical cleaning of the modules), but not for another ? Information on this issue can be found in Figure 61.

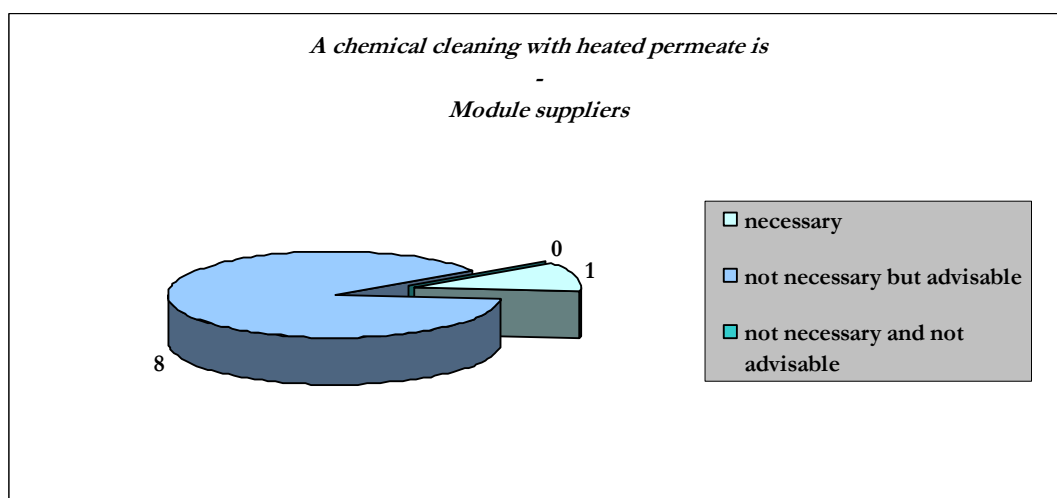


Figure 61. Requirement for a chemical cleaning with heated permeate

Clearly, membrane suppliers do not think such a heating element is necessary, but on the other hand it is clearly not something they will definitely exclude from their design. It can be concluded that the importance of this issue in a standardisation process is fairly low.



5.1.2.7 Others

A. Guarantees

A1. Energy consumption

The energy consumption related to the filtration part of a membrane bioreactor will depend on the filtration module installed. Some modules exhibit much higher energy consumptions than others, especially due to a different specific aeration demand. This can be a factor to account for in a standardisation process, not because it will be a bottleneck for standardisation, but because it will affect the number of modules which can be offered on the market as “interchangeable”. A module which would be offered on the market as interchangeable in terms of size and permeate production capacity, would not be really interchangeable if its specific energy consumption is the double of that initially installed. This issue is addressed in Figure 62.

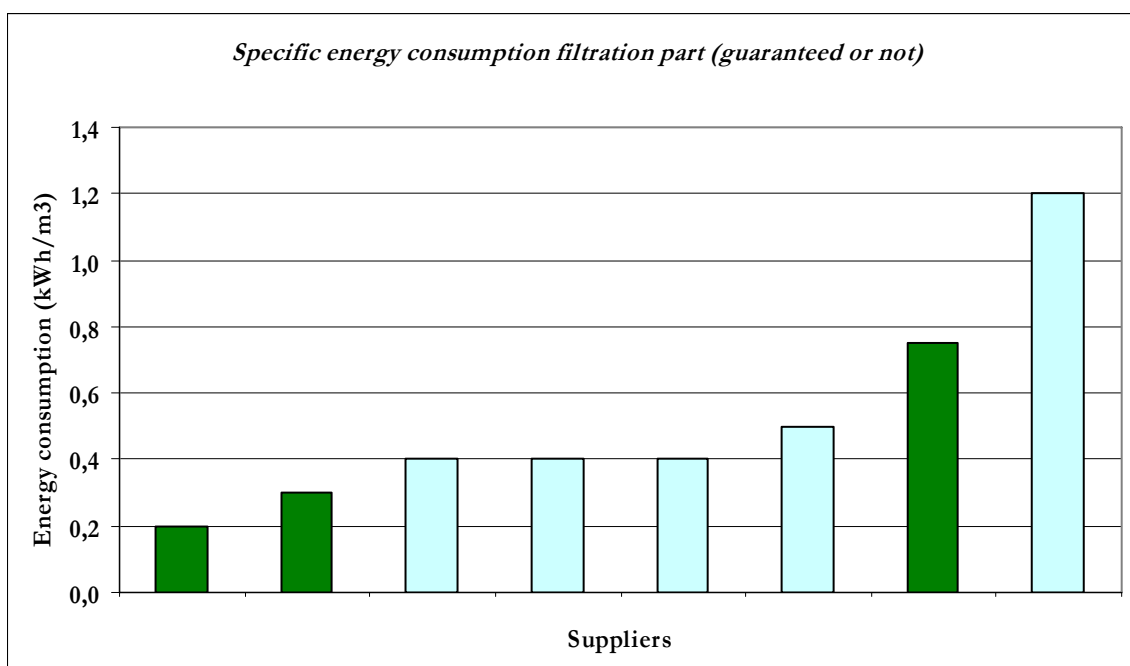


Figure 62. Specific energy consumption for the filtration part of different module suppliers
Note: blue=FS, green=HF

A Few things can be learned from this graph:

- Different membrane modules are characterised by a large variety of energy consumptions (easily factor 2 to 3 or even larger)
- Two HF modules have a (much) lower energy consumption than the other modules.
- For both the HF and the FS category, there are immature products on the market which still have a long way to go to decrease their energy consumption.

For both categories of HF and FS modules, there are immature products on the market which still have a long way to go to decrease their energy consumption level.



A2. Temperature

Another factor which could be potentially important in a standardisation process is the maximum and minimum temperatures for which a certain permeate production rate is guaranteed. This information can be found in Figure 63.



Figure 63. Minimum and maximum allowed temperature

From this figure it is clear that, despite the differences which exist between the different modules, this will never be a big issue in a standardisation process. They are all designed to work with the usual range of temperature found in municipal WWTP (5-30°C).

A3. pH

Also the minimum and maximum pH under which a stable filtration performance of the membrane is guaranteed is important. These values are plotted in Figure 64. Just as with temperature, it is not expected that this will be a point of attention in a standardisation process (not during regular operation, not during chemical cleaning).

B. Lifting tackle or crane

Another very practical factor which could lead to additional costs during a membrane replacement process with interchangeable modules, is a lifting tackle or crane, necessary to install the modules or to pull them out of the filtration tank for e.g. visual membrane inspections. In order to determine the capacity of the lifting tackle or crane, the weight of a filtration module must be known. This information is plotted in Figure 65.



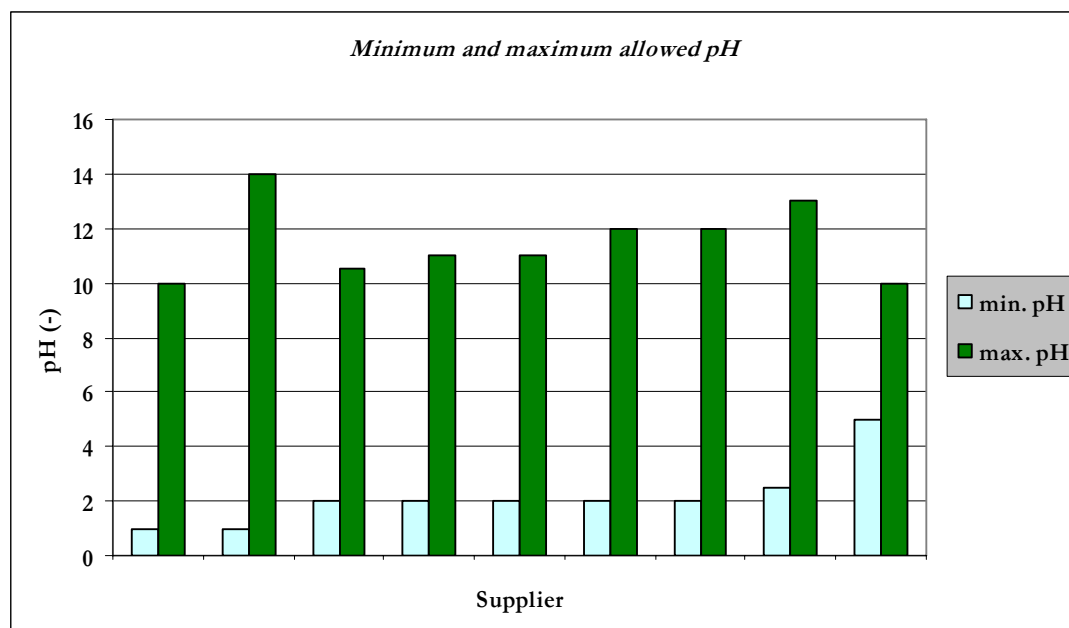


Figure 64. Minimum and maximum allowed pH

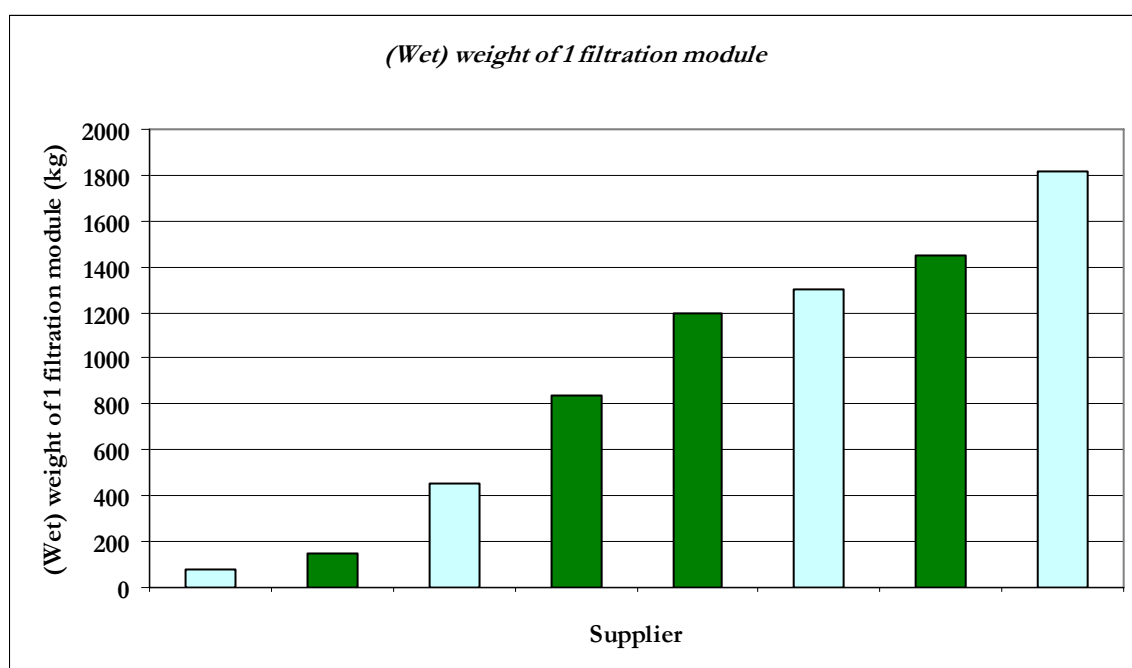


Figure 65. (wet) weight of one filtration module

It is clear that there are huge differences between filtration modules, mainly related to their size. While certainly not a main point of attention, it could be useful to consider this element in a standardisation process.



5.1.3 Summary

The technical potential of a standardisation process towards interchangeability of MBR modules is presented in Table 9.

Table 9. Potential for nuisance of technical factors in a standardisation process towards interchangeable MBR modules (L=low; M=moderate; H=high).

Technical component			Standard(s) common for...		
			flat sheet modules	hollow fiber modules	both flat sheet AND hollow fiber modules
Intensive pre-treatment	Screen type		L	M	M
	Mesh width		L	L	M
	Redundancy		M	M	M
	Bypass		L	L	L
Filtration module	Size		H	H	H
	Capacity: packing density and design flux		M	H	H
	Permeate connections	Number	M	M	M
		Diameter	M	M	M
		Type	L	L	L
	Air supply connections	Number	M	M	M
		Diameter	M	M	M
		Type	L	L	L
Filtration tank	Special provisions manifolds	Permeate	L	L	L
		Sludge	L	L	L
		Air	M	L	M
	Dimensions		M	M	H
	MLSS		M	M	M
	Cover		L	L	L
Peripheral (electromechanical) equipment	Flow rate permeate pump(s)	Gravity filtration	L	M	M
		Type	L	L	L
	Reversibility		M	M	M
	Flow rate sludge feeding/recycling pump(s)		M	M	M
	Blower(s) coarse bubble aeration	Type	L	L	L
		Flow rate	M	M	H
		Pressure	L	L	L
		Redundancy	L	L	L



Technical component			Standard(s) common for...		
	Permeate collection tank		M	L	M
Bioreactor	Internal re-screening of sludge		L	L	L
	Cover		L	L	L
Chemical cleaning	Chemical(s)	Kind	L	L	L
		On-site storage and dosing pumps	M	M	M
	Heating		L	L	L
Others	Guarantees	Energy consumption	M	M	M
		Temperature	L	L	L
		pH	L	L	L
	Lifting tackle or crane		M	M	M
		Total number	19	19	16
		Total number	16	15	16
		Total number	1	2	4



5.2 MBR characterisation methods standardisation

(note: this section was prepared under responsibility of Anjou Recherche)

5.2.1 Introduction

As mentioned in chapter 4.2, it will not be easy to standardise some of the testing techniques. All stakeholders in the industry employ various methods of module receptions and membrane characterisations, without any real standardisation of practices so far. Assessing and analysing these characterisation methods will help us to identify some simple and common criteria, acceptable by the entire market, which could be included in a standardisation process.

In order to establish a common system of reference, we tried to:

- List the existent techniques and those most widely applied
- Assess the available means of end-users to operate their filtration system.
- Identify some parameters for integration in a standardisation process

Replies of 25 companies were analysed: 10 operators, 5 constructors and 10 membrane module suppliers. In this part, constructors are considered as end-users, as they have to operate the plant during commissioning and some of them during operating contracts. In this analysis, high capacity plants (more than 1000 m³/d) are well represented and respondents have much experience on the subject (14 companies have more than 6 years of experience).

In this section an overview of the current procedures is presented by following a logical order:

- Reception of the module at its delivery
- Acceptance procedure of the filtration system at plant commissioning
- Membrane monitoring procedures during operation
- External analysis/evaluation of the membrane in case of membrane fouling, deterioration or ageing.

At each step, data concerning current practices were analysed from end-users (operators and plant constructors) and module suppliers. At the same time the requirements were assessed they (all) would like to include in a process of standardisation and this for each period of the membrane life cycle.

None of the respondents will be explicitly named or linked with a specific answer they provided in the questionnaire.

An overview table summarising all this information can be found in the conclusion part of this chapter.



5.2.2 Results and discussion

5.2.2.1 Characterisation sheet at module delivery

11 end-users (79 %) receive a characterisation sheet upon the delivery of new modules. 8 out of 10 membrane suppliers (80 %) deliver this sheet.

The breakdown of the information provided in the characterisation sheet is shown in the following table:

Table 10. Membrane characterisation sheet content

Topic	Number of respondents who ticked the parameter	Total number of respondents
Product reference (model, prod. number)	18	19
Material type	17	19
Maximum pressure	17	19
Chemical resistance	17	19
Maximum temperature	17	19
pH range	16	19
Minimum temperature	15	19
Clean water flux	14	19
Quality control assessment	13	19
Pore size distribution	13	19
Cut off value	9	19
Storage temperature	5	19
Time limitation before use	4	19

The current format and content of the characterisation sheets appear to be rather complete and sufficient.

The majority of the end-users have no opinion on the usefulness of the membrane characterisation sheet.

Constructors check membranes and have good opinion on this characterisation sheet. This is shown in the Figure 66 and Figure 67.

79 % of the end-users receive a characterisation sheet upon the delivery of new modules



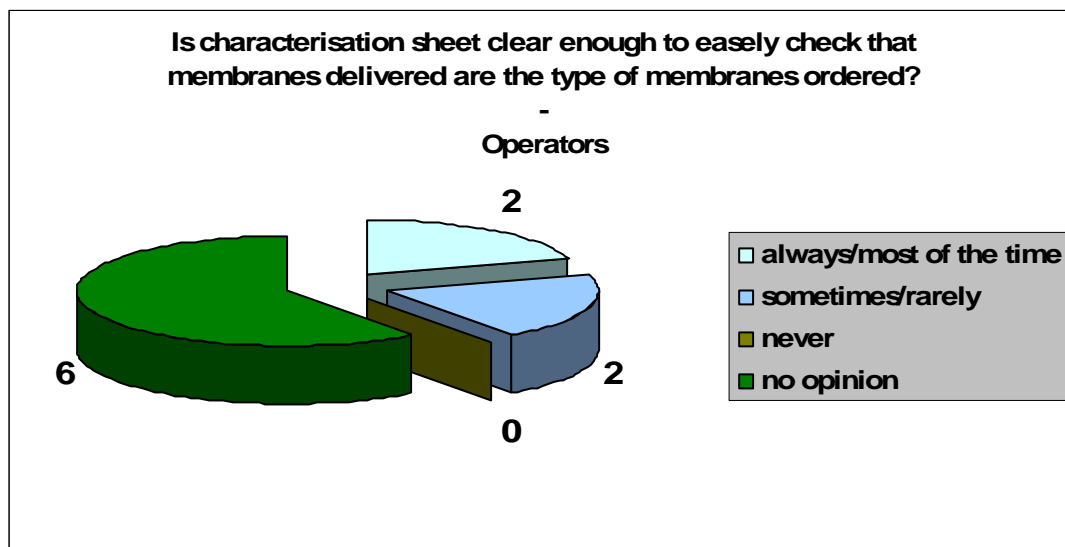


Figure 66. Operators' opinion on membrane characterisation sheets.

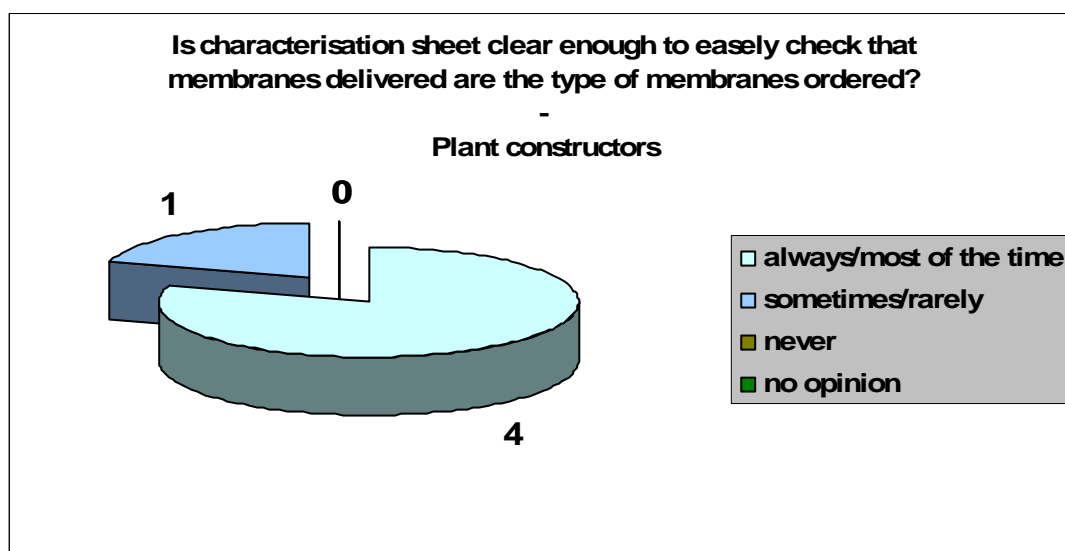


Figure 67. Plant constructors' opinion on membrane characterisation sheets.

The standardisation of this sheet at module delivery doesn't seem to represent a priority, but it will probably be supportive to increase the confidence in MBR technology and lead to a larger involvement of the end-user.



5.2.2.2 Acceptance test at membrane module delivery

In this part it is investigated if some procedures or tests were specified when an operator receives new modules before the plant is in operation (and not at the commissioning of the plant).

This issue is addressed in Figure 68 and Figure 68.

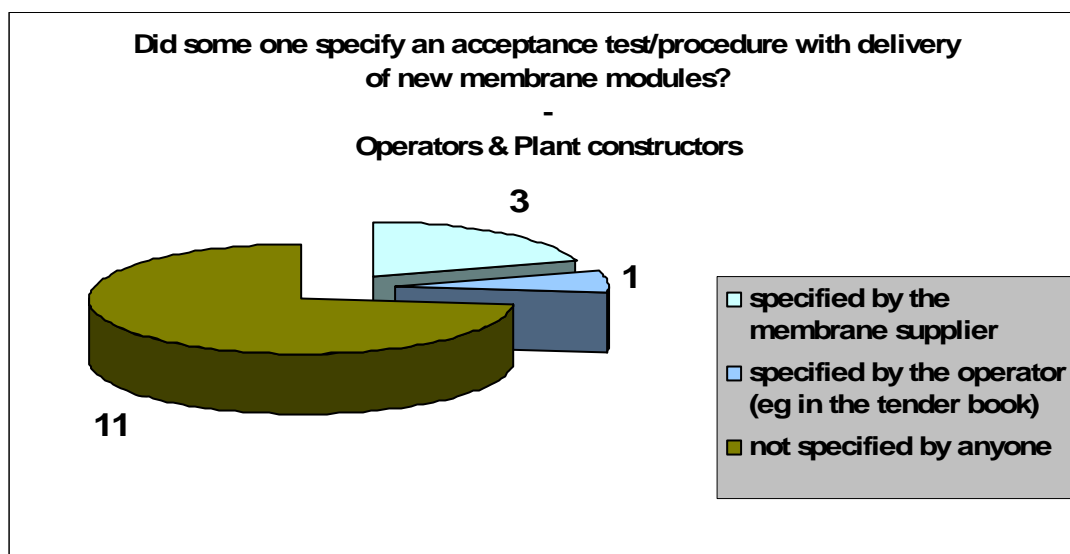


Figure 68. End-users' acceptance procedure at module delivery

A majority of end-users do not have any acceptance test. Amongst the remainders, only one described the acceptance procedure at module delivery.

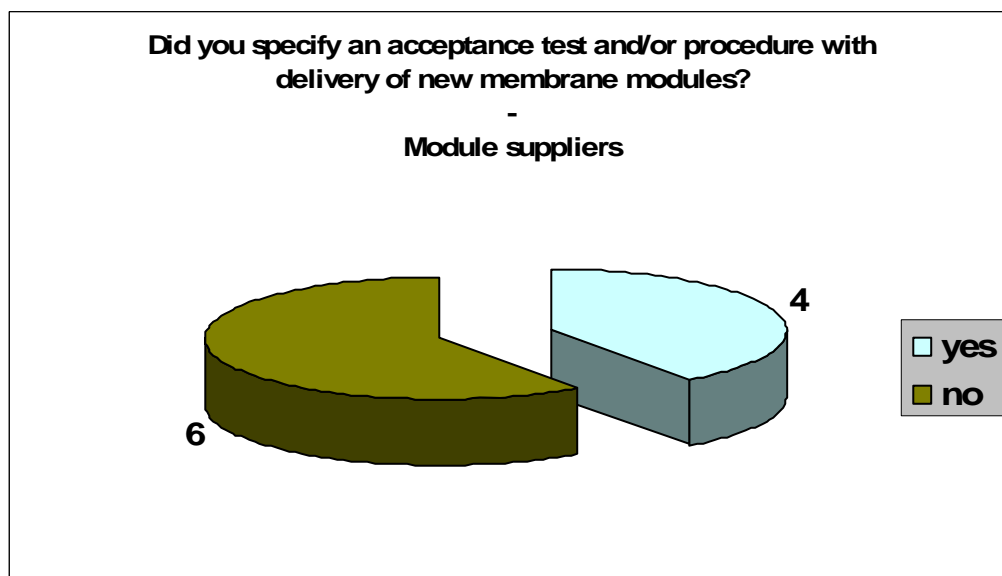


Figure 68. Acceptance procedures supplied by membrane manufacturers at module delivery

73 % of the end-users do not specify any acceptance test at module delivery



Only 4 membrane/module suppliers deliver acceptance procedures with new modules.

Eight end-users (5 operators and 3 constructors) have already replaced their modules and 2 of them experienced problems with the delivery of new modules.

The difficulty to define field tests and the important large variety of existing membranes seem to be the main obstacles to a standardisation. A simple and fast procedure along with a visual inspection will probably help end-users and constructors to save time and to prevent problems. This will improve the quality of the overall delivery procedure of the membrane supplier.

5.2.2.3 Acceptance test at plant commissioning

Figure 69 and Figure 70 show who specifies acceptance procedures, at plant commissioning.

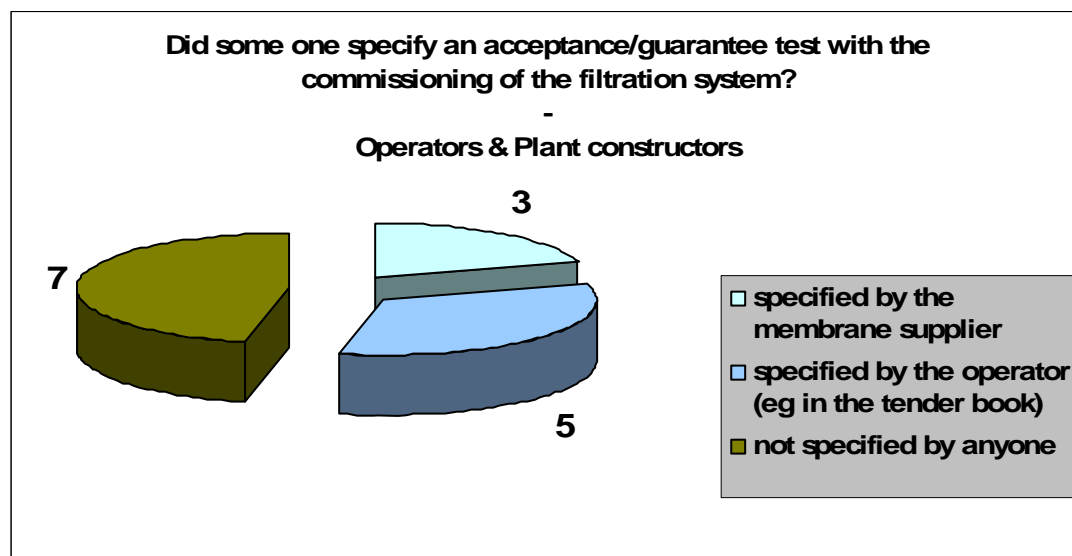


Figure 69. Existing acceptance procedures at plant commissioning

Only three end-users mention that an acceptance procedure at plant commissioning was specified by the membrane supplier. Five end-users have a procedure specified in the tender book and two of them (both operators) modified it. The causes of these modifications were:

- Trustworthiness of test results for one of them
- Adaptation to real situation for the other

Four operators never specified any procedure.

Half of the end-users do not specify any acceptance test at plant commissioning



Three plant constructors specify that no procedure was supplied either by module supplier, neither in the tender book: two of them (both constructors) developed their own procedure.

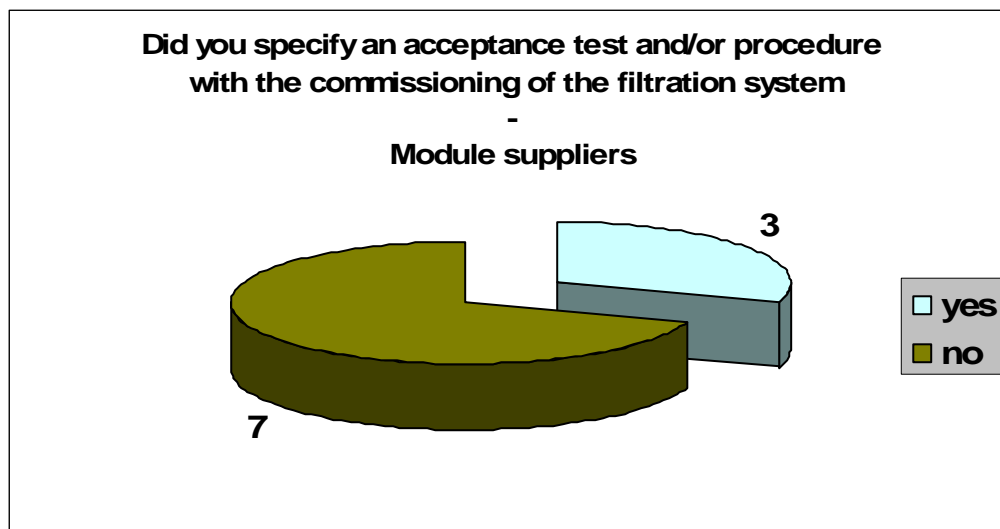


Figure 70. Acceptance procedures supplied by membrane manufacturers at plant commissioning

Three membrane/module suppliers (only 30 %) answered that they specified an acceptance test to their client during plant commissioning.

At plant commissioning, only half of the end-users had a final acceptance test for their filtration system. This percentage is significantly low and shows the need for increased confidence in MBR technology.

Only three respondents gave a rough description of the procedure used at plant commissioning. These descriptions are different from one respondent to another, and no common parameters seem to stand out, except a continuous operating period at the design filtration flow. The period is different from one respondent to another (from 72 h to 12 weeks).

How can a decision maker, or an operator, opt for a technology in absence of clear parameters and acceptance methods at the plant commissioning? The results confirm that standardisation at plant commissioning is a priority prerequisite for the MBR market development, as we showed earlier in part 3.2.2.3.

The main parameters quoted to account for in a standardisation process, are permeability and capacity test (numbers of hours operated). These two points are essential to check the performance of the filtration system.

All the requirements quoted for acceptance test at plant commissioning, are:

- Permeability in clear water
- Permeability in sludge
- Integrity test & bubble test
- Maximum flux & critical flux
- Capacity test: means checking that membrane/module is able to sustain the nominal permeability or the maximum flux during a specific period



5.2.2.4 Characterisation methods to monitor during operation

To evaluate the existing techniques and the state of the art of membrane characterisation methods monitored during plant operation, respondents were questioned in the following way:

- To membrane suppliers: which techniques do you recommend ?
- To end-users (operators and some constructors): which techniques are recommended by the membrane suppliers ? Which techniques do you really use during operation ?
- To both groups: which requirements would you like to include in standardised methods ?

The results are shown below, for membrane fouling, membrane deterioration and membrane ageing monitoring.

A. Membrane fouling

In Figure 71 and Figure 72, it can be seen the main parameters recommended to monitor membrane fouling.

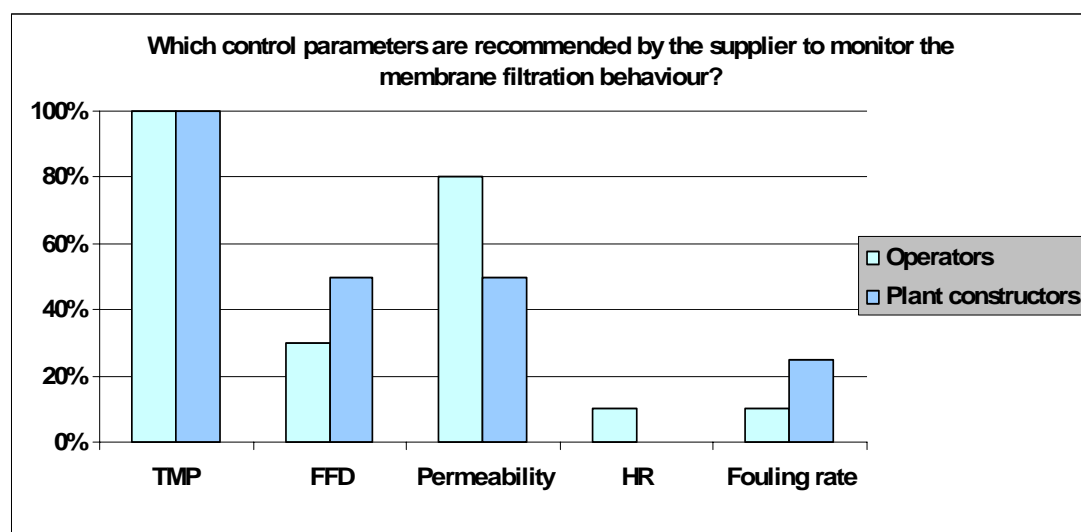


Figure 71. Main parameters recommended for membrane filtration behaviour monitoring



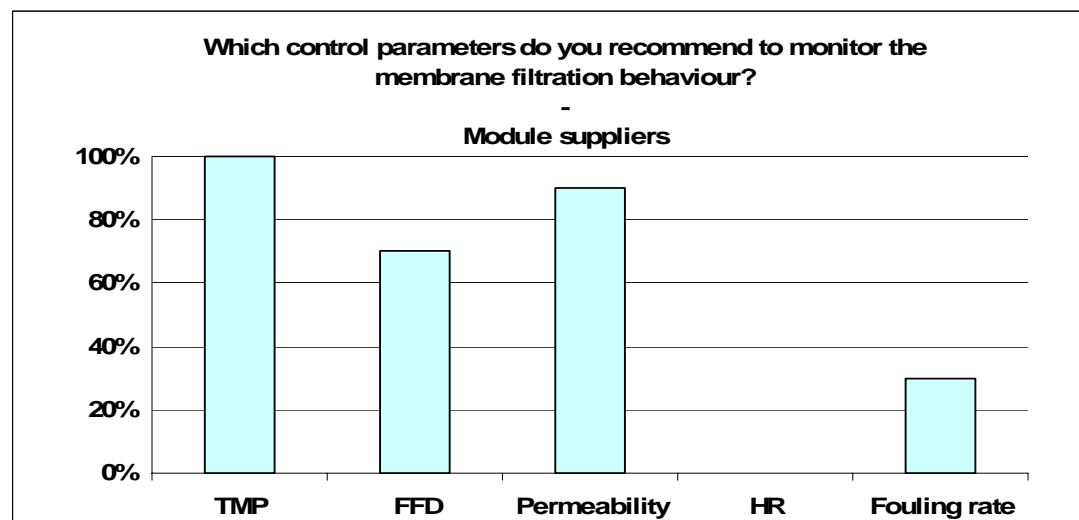


Figure 72. Main parameters recommended by suppliers for membrane filtration behaviour monitoring

Note: TMP: transmembrane pressure - FFD : Filtration Flux Decay at constant TMP - HR: Hydraulic Resistance

Although 3 of the above parameters are the most recommended by suppliers (transmembrane pressure, permeability, and filtration flux decay at constant TMP), mainly two of them are used by end-users, to monitor the filtration behaviour of their plant: transmembrane pressure and permeability. Filtration flux decay is recommended by supplier but not frequently applied by end-user.

The minimum requirements end-users would like to include in a standardised fouling monitoring method are variable but all these respondents seem to need a clear methodology to predict future membrane fouling

We can list the following requirements quoted for membrane fouling monitoring:

- Prediction of duration to maintain flux level at specified conditions
- Monitoring and control biological parameters which may cause fouling
- Permeability and transmembrane pressure

B. Membrane deterioration/integrity

Concerning membrane deterioration, end-users specify that the main methods recommended by the suppliers were:

- Visual control (77 %)
- Chemical and biological parameters in permeate (69 %): turbidity, permeate suspended solids, BOD and COD. Four of the end-users comment that no threshold value was given by supplier.

Figure 73 shows how many end-users developed their own procedure.



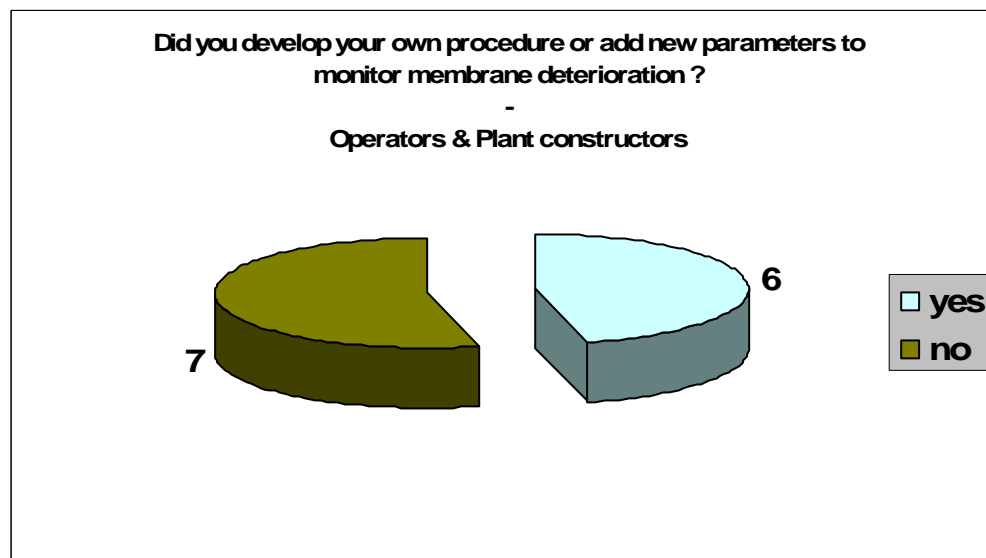


Figure 73. Membrane deterioration monitoring methods developed by end-users.

Half of the end-users (operators and constructors) added some parameters to those recommended by suppliers, like visual control, and micro-organisms in the permeate.

The main deterioration problems encountered are module-related problems such as: damaged potting, broken modules, leakage of piping system and seals failure. Only two of the respondents indicated de-lamination and clogging of pores.

The following requirements quoted for membrane deterioration monitoring can be listed (not in order of importance):

- Turbidity measurement
- Pressure decay test
- Integrity indicators
- Visual control

C. Membrane ageing

Only four end-users received a procedure to monitor membrane ageing from their supplier. Only four module suppliers state that they supply a procedure to their client. The parameters recommended to monitor membrane ageing are shown in Figure 74 and Figure 75.



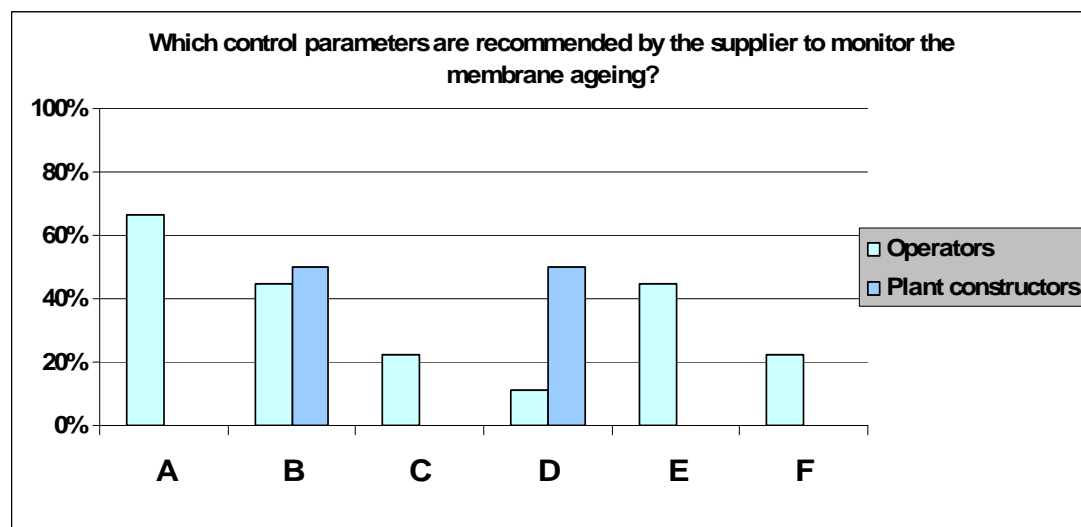


Figure 74. Main parameters recommended to end-users to monitor membrane ageing

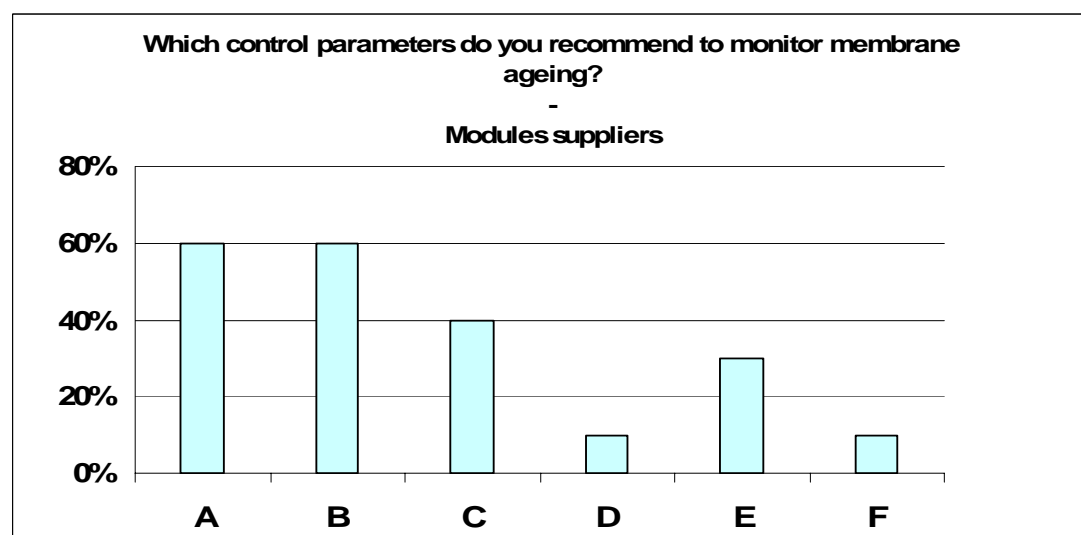


Figure 75. Main parameters recommended by suppliers to monitor membrane ageing

Note:

- A : Transmembrane pressure
- B : Permeability in activated sludge
- C: Permeability in clean water
- D: Hydraulic resistance
- E: Broken membrane %
- F: Cleaning rate %

Transmembrane pressure and permeability (in activated sludge and in clean water) measurements are the main parameters mentioned by both end-users and membrane suppliers.

From some operators' comments, it seems that suppliers didn't supply procedures to their client but only monitoring parameters. No threshold values to monitor membrane ageing were given by the repliers.



Figure 76 shows how many end-users developed their own procedure.

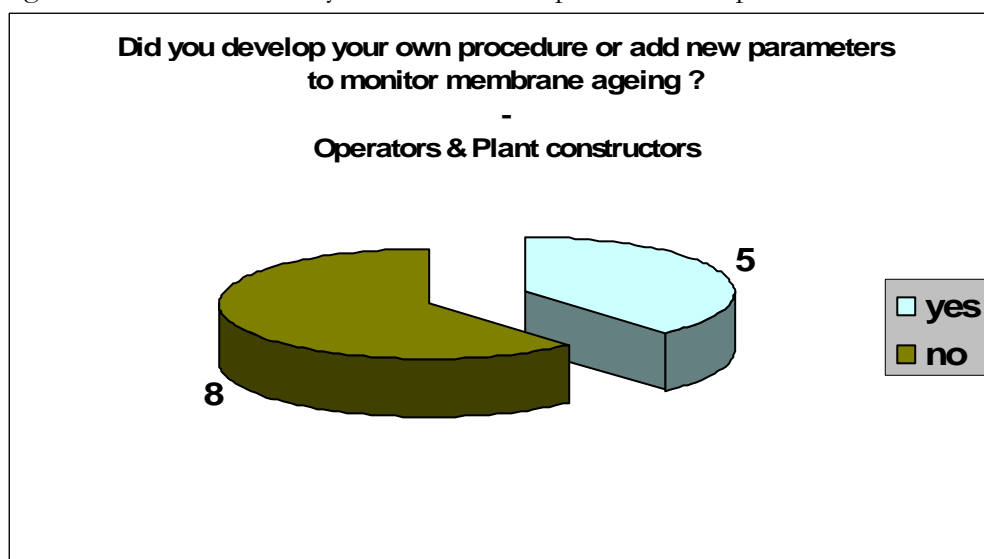


Figure 76. Main parameters recommended to monitor membrane ageing

38 % of them (operators and constructors) developed their own procedure but none of them described the parameters used.

Transmembrane pressure (TMP) and permeability are the most widely used by both operators and constructors, to determine the need for membrane replacement.

Only five respondents commented minimum requirements: the tests have to be simple, easy to use, as visual control or turbidity measurement.

The following requirements quoted for membrane ageing monitoring can be listed (not in order of importance):

- Membrane surface investigation in laboratory
- Threshold values for evolution of normalized flux after chemical cleaning
- Permeate quality (Total Suspended Solids)

One respondent specifies that membrane ageing monitoring should allow a preliminary detection of possible end-of-life as replacement needs planning and takes time.

5.2.2.5 External expert analysis/evaluation

Even if the plant is well operated, membrane fouling or deterioration can occur: finding out the cause is essential in order to avoid any other problem.

In this part it is evaluated if end-users needed external help and analysis to identify the cause of membrane fouling or membrane deterioration.



A. Membrane fouling:

Nine end-users having experienced continuous fouling needed an external opinion/analysis to analyse the cause. The efficiency of these analyses in identifying the causes of the fouling is shown in Figure 77.

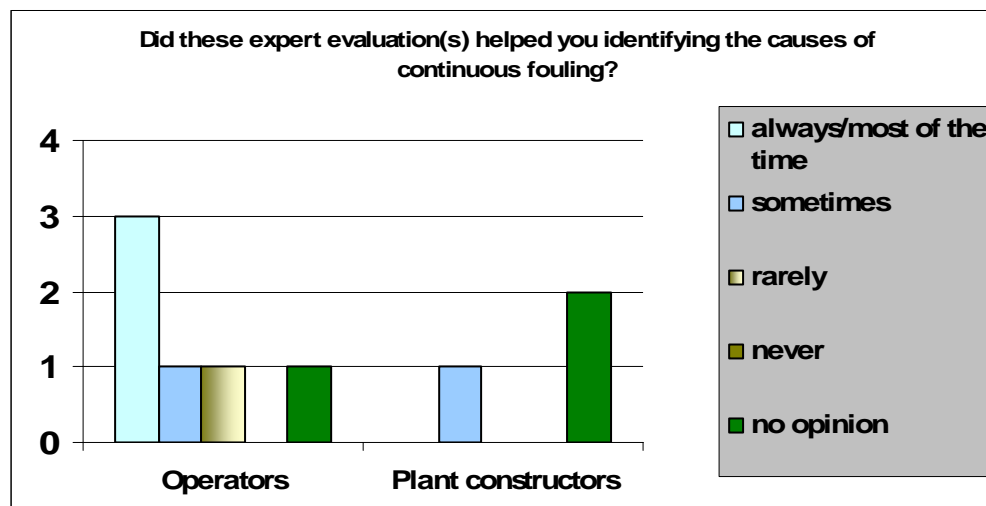


Figure 77. Expert evaluation/analyses efficiency

Among those who asked for an expert analysis (Figure 77):

- Three of them were satisfied by the expert evaluation as it helped them to find the cause.
- Three of them have no opinion: maybe the analyses were misunderstood or too technical.

Figure 78 shows the main techniques used to perform this expert analysis.

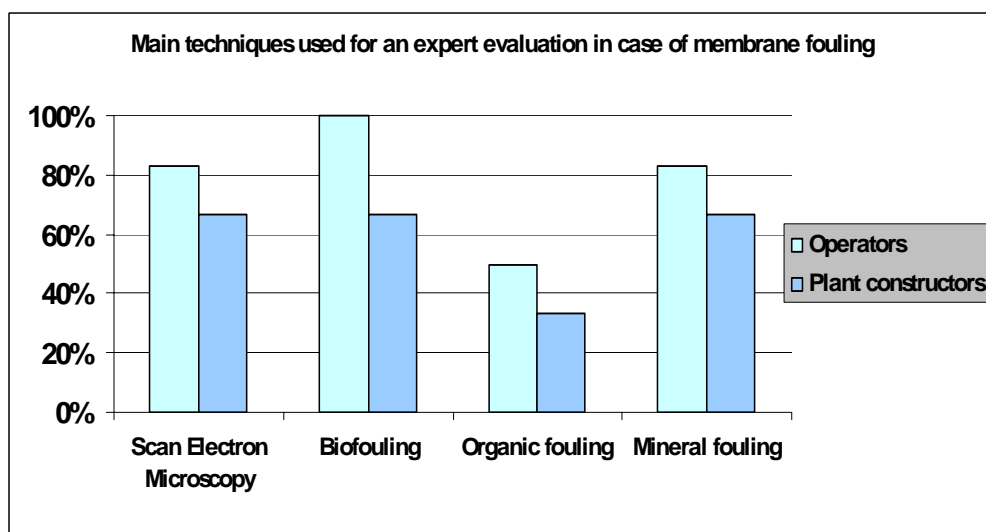


Figure 78. Techniques used to investigate the causes of membrane fouling



Note:

Biofouling: microbiological characterisation

Organic fouling: LC-OCD / SEC / FFF characterisation

Mineral fouling: analysis of precipitates

All techniques are equally used.

As only three of the nine end-users asking for an external expert analysis, were always satisfied and found the cause of their membrane fouling by the means of expert evaluation, it can be assumed that in some cases the analyses used were not effective or adapted. To identify the events causing fouling, techniques have probably to be improved and more research and development is needed.

B. Membrane deterioration:

Only four end-users (three operators and one constructor) requested an expert analysis to identify the origin or extend of membrane deterioration. Three of them replied that these evaluations helped them to identify the origin of membrane deterioration.

Figure 79 shows the main techniques used to perform this expert analysis.

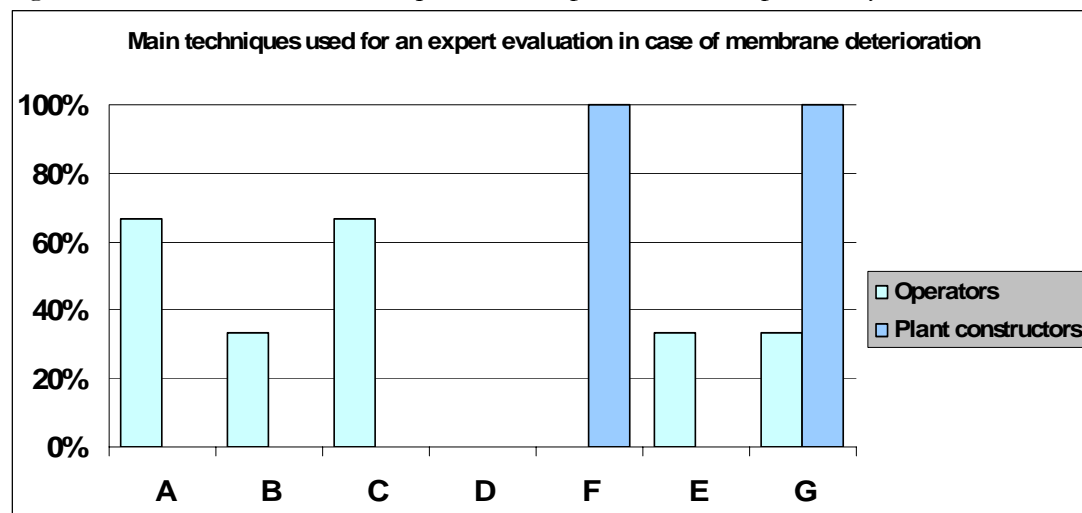


Figure 79.: Techniques used to investigate the causes of membrane deterioration

Note:

A: Scan Electron Microscopy

B: Flux measurements: hydraulic pore radius, clean water flux

C: Structure: top layer thickness, surface porosity, qualitative structure analysis,..

D: Morphology: pore size distribution

E: Retention and selective permeation: cut off, selectivity

F: Mechanical properties: maximum pressure, membrane compaction

G: Integrity test



C. Membrane ageing

Only one operator performed an expert analysis to monitor membrane ageing. There are no significant results to analyse the techniques.



5.2.3 Summary

The tables below show a summary of the techniques commented by the respondents at different moments in the membrane life cycle.

Table 11. Summary of main acceptance tests procedures

	Acceptance tests	
	At module delivery	At plant commissioning
Main procedures used	27 % of end-users have a specific procedure supplied No description provided	53 % of end-users have a specific procedure supplied Main procedure: continuous filtration during a specific period
(Additional) requirements/considerations in a standardisation process		Normalised permeability in clean water Normalised permeability in sludge Integrity test & bubble test Maximum flux & critical flux Capacity test

Table 12. Summary of main membrane monitoring methods

	Monitoring methods		
	Membrane fouling	Membrane deterioration	Membrane ageing
Main procedures used	TMP Permeability	Visual control Chemical & biological parameters in permeate.	TMP Permeability in activated sludge Permeability in clean water
(Additional) requirements/considerations in a standardisation process	Prediction of duration to maintain flux level at specified conditions Monitoring and controlling biological parameters	Turbidity measurement Pressure decay test Integrity indicators Visual control	Membrane surface investigation in laboratory Threshold values for evolution of normalized flux after chemical cleaning and performance after an active cleaning Turbidity





6 Conclusions

6.1 General

6.1.1 First information source publicly available

The general value of this paper lies in the fact that it provides the first real publicly available source of information on standardisation of membrane bioreactor technology in Europe. It provides a comprehensive overview of market interests and expectations, based on an extensive market survey of 45 companies and institutions active in the MBR sector in Europe. The technical factors which should be considered in a possible standardisation process are identified, quantified and compared for different products available on the market. This study will initiate and fuel a public discussion on standardisation of MBR technology.

6.2 MBR filtration module standardisation

6.2.1 Relevance/need and scope/timing/impact

The analysis of module standardisation interests and expectations of 45 relevant companies active on the MBR market in Europe indicates that:

Relevance

- The majority of market players recognise that efforts towards a standardisation study like this one are useful or very useful.

Need and scope

- There is a specific interest in guidelines/standards on interchangeable filtration modules in MBRs from every side of the market, for small (100-1000 m³/day), medium (1-100 MLD) and large (>100 MLD) capacities. This interest is more pronounced for small-size MBR plants, whereas it is less for the individual household plants and the package plants.

Timing

- The majority of the MBR operators, constructors, consultants and non-commercial knowledge institutions are convinced this is the right time to initiate a process of MBR module standardisation. On the other hand, some of the module suppliers are under the impression that initiating a module standardisation process now, would be one or few years too early.

Impact

- Most market players expect that interchangeable MBR filtration modules will increase the willingness of decision makers to invest in MBR technology and will contribute to a growth of the municipal MBR market - although they do not believe this standardisation process to be one of the top three driving forces.
- The majority of MBR operators expect a decrease (small or large) in MBR module investment costs as a result of standardisation. While some MBR module suppliers share this opinion, a significant group is more reserved.
- A minority of module suppliers expect that standardised filtration modules will (probably) lead to a decrease in the quality of MBR products and services.



6.2.2. Advantages/opportunities – disadvantages/threats

About 20 potential technological, financial, economical, or environmental advantages/opportunities and disadvantages/threats of MBR module standardisation for suppliers and operators were identified and mapped. It appears that the number of advantages and disadvantages is quite balanced for both sides of the market, the main advantage perceived by the industry being that standardisation should contribute to the growth of the MBR market. Other main advantages/opportunities are avoidance of vendor lock-in, price decrease and increased trust and acceptance. Main disadvantages/threats for the end-user are over-dimensioning of civil constructions and supplementary works and costs to the peripherals (both at initial project stage and at time of module replacement) during replacement. Main disadvantages for the module supplier seem to be the higher competition, lower profit margins and a limitation for innovative module producers to enter the market.

6.2.3. Mapping and assessing the technical factors

The technical potential for standardisation of MBR filtration modules in Europe was evaluated based on a unique analysis of the majority of MBR filtration modules commercially available. Nine products completely different in terms of design and mode of operation were analysed and compared. The analysis showed that a standardisation process common for both flat sheet and hollow fiber membranes/modules is riddled with difficulties and challenges. In order to achieve interchangeability of filtration modules not only the prospect of pure dimensional standards for the module itself need to be considered, but also design and mode of operation of the peripheral components, like the filtration tank, pumps, blowers and pre-treatment. More than thirty technical factors hampering or interfering with a standardisation process were identified and quantified, and their relative potential for affecting the possible outcome was evaluated (Table 9).

- 4 factors with a high to extremely high capacity for nuisance

Module dimensions, filtration tank dimensions, specific permeate production capacity, coarse bubble aeration demand.

These factors are mainly the result of a totally different geometry and design of the filtration module and discussions for the standardisation of MBR filtration systems should in essence focus on these factors.

- 16 factors with a moderate to high capacity for nuisance

Pre-treatment (screen type, mesh width and redundancy), number and diameter of connections to the permeate collection and air supply manifold, MLSS concentration of sludge surrounding the membranes (and related to that: capacity of the sludge feeding/recycle pumps), flushing system of the coarse bubble aeration piping, whether or not to design permeate pumps - a permeate collection tank - chemical storage tank(s) and a lifting tackle or crane, energy consumption

These factors are mainly the result of the fact that either a number of products are still in the early development phase of their life cycle, or because they will (drastically) increase total costs of module replacement because of required adaptation works to the peripherals.

- 16 factors with a low to moderate capacity for nuisance

Bypass of the pre-treatment, type of connections to the permeate collection and air supply manifold, air venting system on the permeate manifold, equally distributed feeding or recycling of sludge to or from



the modules, type of permeate pump(s), type-pressure-redundancy of blower(s) coarse bubble aeration, kind of chemicals, pH and temperature guarantees, whether or not to cover the filtration tank and/or bioreactor - design re-screening of activated sludge over the pre-treatment - permeate heating tank

These factors will only be a minor issue since they are either part of the common knowledge or practice, or because the module supplier will resign to the design at the moment of membrane replacement.

6.2.4. Flat sheet – hollow fiber modules

The study on the technical aspects of MBR filtration module standardisation in Europe also revealed that it would be easier and technically wiser to consider two separate standardisation groups: one for flat sheet modules and one for hollow fiber modules. From this study, it cannot be deduced whether a standardisation process would be more straightforward or would go faster for one category as opposed to the other. For each category, more or less the same number of obstacles lies ahead. Nevertheless, the nature of some of these obstacles or points of attention can be different. Some factors are specifically important for FS modules (e.g. flushing of air supply pipes, design of a permeate collection tank), others for HF modules (e.g. type of pre-screening, gravity filtration or not).

6.3 Membrane characterisation methods standardisation

6.3.1 Market interest for harmonisation of module acceptance tests

The majority of the respondents, except the plant constructors, believe the harmonization of membrane acceptance tests at module delivery, will probably have a positive impact on municipal MBR market growth.

Plant constructors feel that acceptance tests standardisation at plant commissioning can lead to an increase of MBR market growth, while module suppliers are divided about a possible positive impact of standardised tests at plant commissioning.

There is a need for operators to receive documentation on the modules they have bought (a kind of traceability protocol), and there is a need for plant constructors to have a method to check the modules at commissioning, as they are in most cases the ones who have to deal with start-up issues. In both situations, either during plant commissioning or module delivery, membrane suppliers are divided on harmonisation of protocols.

Various factors, defined by sceptical membrane suppliers and plant constructors, may hamper a process of standardisation:

- The large number of different membranes
- The operational recommendations specific to each supplier
- No simple test method - difficult to implement the test for each module at reception



6.3.2 Market interest for harmonisation of filtration systems monitoring methods

Membrane bioreactor stakeholders mainly agree that it is time to initiate a process of standardisation of membrane characterization tests.

The majority of the companies is concerned by this topic and expects that a harmonization of the membrane fouling, integrity and ageing methods will lead to an increase of MBR market growth and competitiveness.

Respondents show a specific interest for membrane characterisation methods standardisation, specifically for small to large size plants (from 100 m³/d to 100 MLD).

More accurately, between 70 and 80% of the respondents has currently an interest in European technical guidelines for a characterisation method on:

- Membrane fouling
- Membrane integrity
- Membrane ageing

Standardisation is not the single solution. Guidelines would be more suitable to start with. The study also revealed an urgent need for common and uniform definitions.

6.3.3 Advantages/disadvantages

The main advantages specified by the respondents are better comparison between membrane manufacturers, better understanding and more trust in membrane technology.

While several advantages are mentioned, one real disquiet appears: the difficulty to find the right methods that could be applied to all types of membranes.

6.3.4 Technical potential

End-users and module suppliers were questioned on existing membrane fouling, ageing and deterioration measurements. The main operating techniques applied were assessed, and some parameters were identified for integration in a standardisation process.

- Only 27 % of end-users received a procedure for membrane acceptance at module delivery and 53 % at plant commissioning.
- No procedure for membrane acceptance neither for membrane monitoring methods were described by the respondents. No threshold values were provided.

It can be noticed that amongst the additional parameters required by end-users in a standardisation process, some can serve as characterisation methods of several aspects.

For example, they consider that:

- Integrity test or turbidity measurement can be a useful parameter at commissioning, but also to monitor membrane ageing or membrane deterioration.
- Transmembrane pressure or permeability can be useful parameters for fouling and for ageing measurement.



No threshold values and very few method descriptions were provided by the respondents. It's difficult to know if this is due to confidentiality or because these methods are not clear enough for end-users.

A real effort has to be made to harmonise the methods used and recommended by suppliers and consultants.

Simple, well-assessed and well-defined methods to operate membrane filtration systems and to better predict membrane behaviour are necessary. An official and common standard test to check product quality and performances at module delivery and at plant commissioning will probably confirm and extend the position of membrane technology in the wastewater treatment world.

This study emphasizes some important parameters for which a common definition and measurement protocol could be helpful, such as:

- Clearly defined and harmonised parameters to monitor membrane fouling, integrity and ageing.
- A common definition of “membrane life time” for the guarantee clause
- Determination / definition of flux (operation and nominal design)
- Common definition for sustainable peak hydraulic load
- Harmonised tests to check membrane performances over a defined period and under specific conditions

In a second step, the industry would welcome if the following guidelines and characterisation protocols could be established and harmonised:

- Characterization method for membrane acceptance at module delivery
- Minimum requirements and technical methods to check membrane performance at plant commissioning
- Monitoring methods of normalized permeability in clear water, permeability in sludge, trans membrane pressure and fouling rate
- Monitoring methods of sustainable flux and maximum flux
- Operating conditions (biology and filtration systems) for warranty clauses

Harmonisation of parameters definition and measurement methods should precede, or accompany the harmonisation of the technologies in sight of product interchangeability: this will increase trust in the technology, and will also reduce the risk of lower quality products.

The production of such common definitions and characterisation protocols could answer to a real need in the European MBR industry. This approach seems to be a good way to increase trust and reliability of wastewater membrane technology and to reduce the fear of innovative process. Such a harmonisation of selected definitions and methods should be possible to achieve in short to mid-term within the European MBR industry, and is expected to benefit the entire sector.





7 Workshop and recommendations

7.1 A workshop hosted by CEN

Developing European MBR standards will definitely be a time-consuming and delicate process, but meanwhile CEN Workshop Agreements (CWAs) might be a good approach to reach this objective within 1 to 2 years only. A CWA bridges the gap between consortia documents and European Standards (EN). It is a technical agreement, developed by the participants in an open CEN workshop structure within the framework of CEN and owned by CEN as a publication. It is this openness that distinguishes the CWA from documents developed by industry consortia featuring limited participation (commonly known as de facto standards). Participants to a CEN Workshop are interested in developing one or more reference documents where neither the lack of openness of a de facto standard nor the rigour and consensus of a EN is judged to be appropriate, but which still possesses the authority derived from openness of participation and consent. Participation in such a workshop will be open to anyone and the opportunity to participate will be widely advertised in advance by its proposers and by CEN. A CWA may be further developed into a EN if such additional authority is required by the market by transferring it into the traditional CEN committee process.

On 24/11/06 a workshop was organised in Berlin by the AMEDEUS consortium together with the Deutsches Institut für Normung (DIN), the national normalisation institution secretary of CEN/TC165, to present the White Paper on MBR standardisation to the industry, to debate the outcomes of this study and to discuss future actions. 35 MBR representatives from 9 different countries and 29 different companies participated in this workshop: 11 membrane/module suppliers, 10 research centres/consultants/academics, 5 MBR constructors and 3 MBR operators. Most of them were industry representatives who took part in the study through the survey, but a minority of them attended the workshop although they did not actively contribute to the study. Few weeks before the workshop, the interim version of the present White Paper was made publicly available on the website www.mbr-network.eu (about 250 downloads recorded over November 2006 – January 2007), and each workshop participant received a paper copy.

7.2 Workshop outcomes and recommendations

Three questions were asked to each participant during the workshop, and after presentation of the White Paper:

- 1/ Can the White Paper be used as a reference document to initiate a procedure of standardisation within the MBR industry ? (Figure 80)
- 2/ Which type of standardisation approach is needed for submerged MBR filtration and membrane characterisation methods ? (Figure 81)



3/ Would your company be interested to commit in a process of standardisation of submerged MBR filtration systems and membrane characterisation methods in the coming years ? (Figure 82)

The major outcomes are:

- The White Paper was accepted by plebiscite: the participants replied unanimously positive to the question “Can the White paper be used as a reference document to initiate a procedure of standardisation within the MBR industry?”
- A minority of the participants believe normative standards are not needed for submerged MBR filtration systems (25%) or membrane characterisation methods (15%). Instead they favour the development of technical guidelines.
- A significant amount of the participants (40%) argue that normative standards for both MBR filtration systems and membrane characterisation methods are needed only within a few years.
- A large majority of the companies argues that their company would be interested one way or another to commit/participate in a process of standardisation of submerged MBR filtration systems (75%) and membrane characterisation methods (90%) in the coming years.

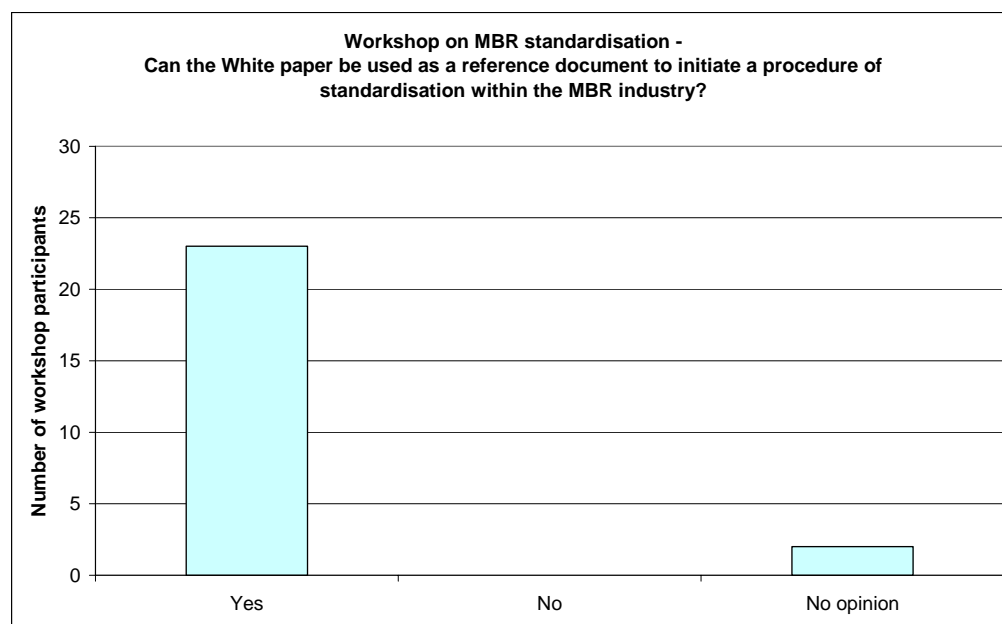


Figure 80 Can the White Paper be used as a reference document to initiate a procedure of standardisation within the MBR industry ? (1 reply per company, CEN representatives not included)



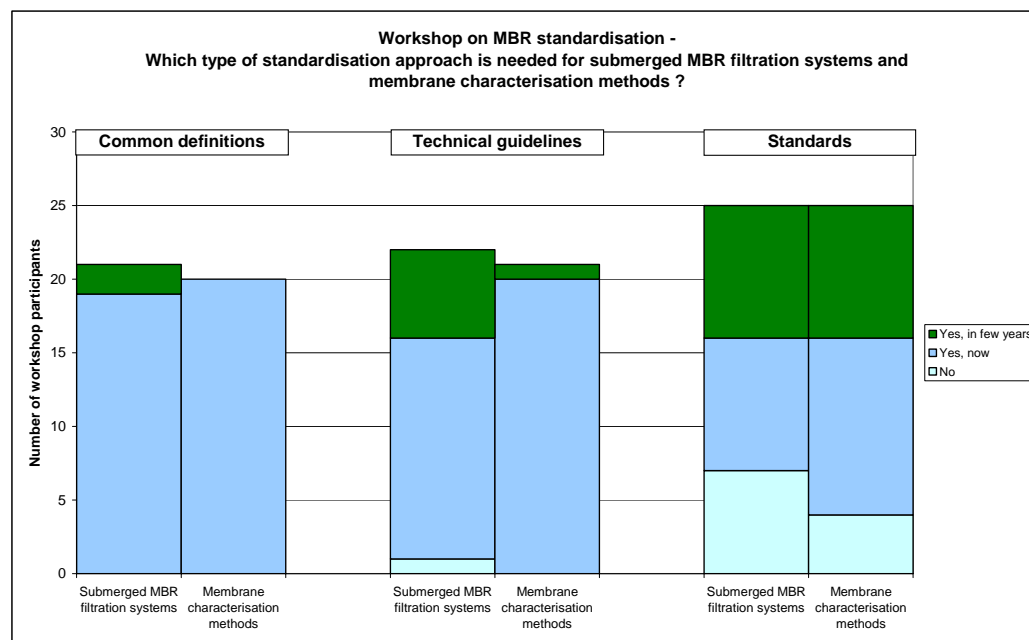


Figure 81 Which type of standardisation approach is needed for submerged MBR filtration and membrane characterisation methods ? (1 reply per company, CEN representatives not included)

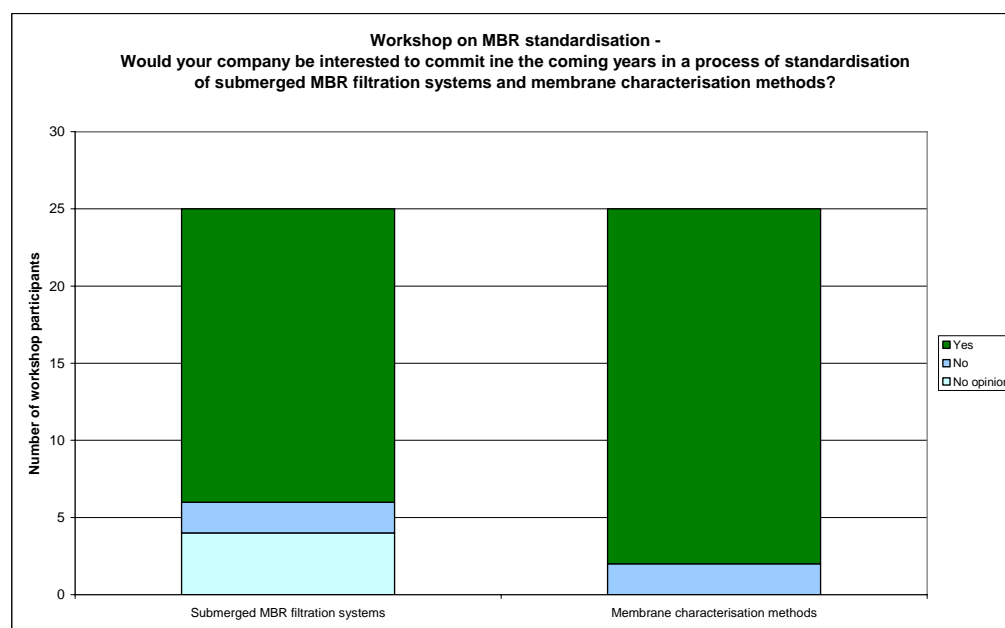


Figure 82 Would your company be interested to commit in a process of standardisation of submerged MBR filtration systems and membrane characterisation methods in the coming years ? (1 reply per company, CEN representatives not included)

Finally, the following recommendations were agreed upon by the workshop participants:

“The representatives of the MBR industry present at this workshop:

- *decided to initiate a standardisation process on submerged MBR technology through a CEN*



Workshop Agreement (CWA)

- *decided that the scope of this CWA may include the following:*
 - *common terms and definitions of MBR technology*
 - *characterisation and test methods of the product (acceptance tests) and operation (monitoring tests)*
 - *set of guidelines to facilitate interchangeability of MBR filtration systems*
- *decided to ask the AMEDEUS project and DIN to develop the draft Business Plan in cooperation with interested parties”*

According to the debates observed during the workshop, the authors of the report believe that a consensual agreement could be obtained without much trouble within the European MBR industry for items 1 and 2. As foreseen by the technical study, reaching a consent for item 3 is expected to be more difficult, the suppliers of MBR filtration systems defending the specificity of their products. On this specific issue, a constructive and pragmatic approach could well be to set up first a working group of independent MBR operators and constructors who could devise and propose a relevant set of guidelines to the industry as basis for discussion.

7.3 Perspectives

The White Paper and preliminary workshop are expected to pave the way for an appropriate standardisation process of MBR technology. The study undertaken by the AMEDEUS team together with the European MBR industry conducted to the initiation of an official standardisation procedure through a CEN Workshop Agreement. This will provide the European MBR industry with a formal framework, based on the technical outcomes of this present report, to agree upon relevant standardisation criteria for the MBR technology.

This industrial -based approach, instead of the natural market organisation under commercial and economical forces only, will ultimately benefit the entire European MBR industry. The standardisation of the MBR technology is expected to improve the competitiveness of the process together with the increased market competition, and therefore to contribute to market growth.



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- the co-operation of the various MBR module suppliers, operators and all companies or institutions and experts who actively contributed by sending their reply to our questionnaire
- the people involved in the administrative support for processing the replies to the questionnaire and the people involved in reviewing this document

The recommendations herein are those of the authors, and do not necessarily reflect the positions of the EC, CEN, DIN or any of the companies who replied to our questionnaire.





Annexes

Annex 1: List of contacted companies for this study





Annex 1: List of companies and institutions contacted for this study

	COMPANY	COUNTRY
1	A3 water solution	Germany
2	Aggerwasser	Germany
3	Anglian Water	UK
4	Aquafin	Belgium
5	ASM Brescia	Italy
6	Balteau	Belgium
7	Biwater	UK
8	Busse	Germany
9	Cabinet Marc Merlin	France
10	Copa MBR Technology	UK
11	Degremont	France
12	Delta MBR	Netherlands
13	DHV	Netherlands
14	Earth-Tech Umwelttechnik	Germany
15	EAWAG	Switzerland
16	Envi-pur	Czech Republic
17	Ertverband	Germany
18	GE Zenon Membrane Solutions	Germany
19	Grontmij	Netherlands
20	Hans Huber AG	Germany
21	Hera Amasa S.A.	Spain
22	Hoogheemraadschap Hollands Noorderkwartier	Netherlands
23	Inge	Germany
24	INRA Rennes (Club français des membranes)	France
25	Kamps	Belgium
26	Keppel Seghers Belgium NV	Belgium
27	Kiwa Water Research	Netherlands
28	Koch Membrane Systems (Puron)	Germany
29	Kommunale Wasserwerke Leipzig GmbH	Germany
30	Krüger Wabag	Germany
31	Kubota Membrane Europe	UK
32	Ladurner	Italy
33	Martin Systems	Germany
34	Microdyn Nadir	Germany
35	Millenniumpore	UK
36	Mitsubishi Rayon	Japan
37	Naston Ltd	UK
38	Northern Ireland Water Service	UK
39	Northumbrian Water Ltd	UK
40	Polymem SA	France
41	Rotreat Abwasserreinigung GmbH&CoKg	Austria
42	Royal Haskoning	Netherlands
43	Ruhrverband	Germany
44	Sântis Schwebebahn	Switzerland
45	Saur France	France
46	Scottish Water	UK
47	Severn Trent Water	UK
48	Siemens - US Filter – Memcor	UK
49	Solis Engineering bv	Netherlands
50	South West Water Ltd	UK
51	Stadtwerke Schramberg	Germany
52	Stereau	France
53	STOWA	Netherlands
54	TNO	Netherlands
55	Toray Industries	UK
56	Triqua	Netherlands
57	Vatech Wabag	Switzerland
58	Veolia Eau Direction Technique	France
59	Wasserverband Eifel Rur	Germany



60	Waterboard Aa en Maas	Netherlands
61	Waterboard Rivierenland	Netherlands
62	Waternet	Netherlands
63	Waterschap Hollandse Delta	Netherlands
64	Waterschap Regge en Dinkel	Netherlands
65	Waterschap Rijn en IJssel	Netherlands
66	Welsh Water / Meica Process	UK
67	Wessex Water Services Ltd	UK
68	Wetsus	Netherlands
69	Witteveen+Bos	Netherlands
70	Yorkshire Water	UK

European academic experts

71	Prof. Ben Aim (INSA Toulouse, Chair IWA Membrane Specialist Group)	France
72	Prof. Frechen (Kassel University, Chair of DWA Workgroup on MBR)	Germany
73	Prof. Grasmick (Montpellier II University)	France
74	Prof. Melin (RWTH Aachen)	Germany
75	Prof. Judd (Cranfield University)	UK

International academic experts

76	Prof. Cicek (University of Manitoba)	Canada
77	Prof. Leslie (University of New South Wales)	Australia
78	Prof. Noh (Yonsei university, President of Membrane Society of Korea)	Korea
79	Prof. Watanabe (Hokkaido University)	Japan





