LES SYNTHÈSES

de l'Office International de l'Eau

Membrane Technology for Wastewater Treatment

Patricia GARCIA GOMEZ

February 2016

Office International de l'Eau

In partnership with higher education institutions, IOW offers states of art on various topics related to water. These synthesis are written by students as part of their study program.

This synthesis « **Membrane Technology for Wastewater Treatment** » was performed by **Patricia García Gómez,** student in the AgroParisTech-ENGREF specialized master "Water Management" (post-master degree) in Montpellier.

SYNTHESIS

Membrane Technology for Wastewater Treatment

Patricia García Gómez

patriciagargo@gmail.com

February 2016

AgroParisTech
Centre de Montpellier
648 rue Jean-François Breton – BP 44494
34093 MONTPELLIER CEDEX 5
Tél. : (33) 4 67 04 71 00
Fax : (33) 4 67 04 71 01
www.agroparistech.fr

Office International de l'Eau
Service gestion et valorisation
de l'information et des données
15 rue Edouard Chamberland
87 065 LIMOGES CEDEX
Tél : (33) 5 55 11 47 47
www.oieau.org

RESUME

En Europe et dans de nombreux pays à travers le monde, le problème du stress hydrique n'a cessé de croître au cours des dernières décennies, à la fois en termes de pénurie d'eau et de détérioration de la qualité. En réponse à ce problème, il y a eu un intérêt croissant au cours des dernières années pour le développement et l'amélioration des technologies de traitement des eaux usées afin de respecter les limites de rejet de plus en plus contraignantes ou d'ajuster la qualité de l'eau pour les pratiques de réutilisation ou de recyclage des eaux usées. Dans ce contexte, les technologies membranaires jouent un rôle décisif en assurant une eau de qualité et sont toujours plus concurrentielles par rapport aux traitements conventionnels. Non seulement les opérations unitaires qui comprennent la microfiltration (MF), l'ultrafiltration (UF), la nanofiltration (NF) et l'osmose inverse (OI), mais aussi le couplage avec d'autres opérations unitaires, comme la combinaison des procédés biologiques avec filtration sur membrane (BRM et anBRM) ou les procédés d'oxydation avancé, sont de plus en plus utilisées pour le traitement des eaux usées urbaines et industrielles. Le but de cette synthèse est de présenter l'état de l'art des technologies de membrane en fonction du type d'eau à traiter ainsi que leur avenir dans le traitement des eaux usées.

Mots clés : technologies de membranes, bioréacteur à membranes, eaux usées urbaines, eaux usées industrielles, eaux pluviales, recyclage, réutilisation.

ABSTRACT

In Europe and in many countries all around the world, the problem of water stress has been growing during the last decades, both in terms of water scarcity and quality deterioration. In response to this problem, there has been an increasing interest in recent years in developing and improving wastewater treatment technologies in order to meet the restrictive discharge limits or adjust the quality of water for reclaim or reuse practices. In this context, membrane technologies play a decisive role by assuring high quality water and they are becoming more and more competitive compared with conventional treatment processes. Not only the unitary operations which include microfiltration (MF), ultrafiltration(UF), nanofiltration (NF) and reverse osmosis (RO), but also the coupling of biological methods with membrane filtration (MBR, AnMBR) or combined process with ozone or adsorption are on the rise in urban and industrial wastewater treatment. The purpose of this synthesis is to present the state of the art of membrane treatments depending on the type of water treated, as well as the prospective.

Keywords: membrane technologies, membrane bioreactor, municipal wastewater, industrial wastewater, rainwater, wastewater reclamation, water reuse.

SUMMARY

FIGURE LIST

TABLE LIST

GLOSARY

AnMBR	Anaerobic Membrane Bioreactor
AOP	Advanced Oxidation Process
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
MBR	Membrane Bioreactor
MF	Microfiltration
NF	Nanofiltration
NT	Total Nitrogen
PE	Population Equivalent
RO	Reverse Osmosis
TP	Total Phosphorus
TSS	Total suspended solids
UF	Ultrafiltration
UV	Ultraviolet
WHO	World Health Organisation
WWTP	Waste Water Treatment Plant

INTRODUCTION

The over exploitation of water resources, in addition to more frequent drought periods, regions under strong hydric-stress, water pollution or salinization of the groundwater, force the legislation to become more and more strict. Obviously, this has a direct implication on water supply and discharge limits. In this context, all additional efforts in matter of water treatment and recycling of wastewater seem to be essential to achieve the goal of good environmental status of natural habitats in 2015 established by the European Water Framework Directive (2000/60/EC) (Ministère de l'Écologie, du Développement Durable et de l'Énergie, 2013).

Water scarcity and quality deterioration are then the key-factors to be considered in water treatment. In response to these problems there has been increasing interest in recent years in developing and improving wastewater treatment technologies in order to meet the restrictive discharge limits. Processes based on membrane separations are highly ranked as a solution to achieve these goals. Actually, by playing the role of a physical barrier, membranes produce high reliability and water complying with rejection requirements. Already introduced in wastewater treatments, they may be a determinant tool for water recycling and reuse, serving as a solution for the quantity-issue.

HISTORY

The application of membrane technology has increased dramatically over the last decade in Europe and in France for both municipal and industrial wastewater treatment. However, membrane technology is not a new one.

Membrane bioreactor technology was introduced for the first time by Dorr-Olivier in 1969, with application to ship-board sewage treatment (Kraume et Drews, 2010; Le-Clech et al., 2006; Judd, 2010). First commercial installations were developed in the 1970s and 1980s, especially in Japan and USA, but they were limited to small size plants. In Europe, MBR emerged in the 1990's for municipal wastewater treatment (Yang et al., 2006; Gresle et al., 2007; Seyhi et al., 2011; Yang et al., 2006; Judd, 2010; Drogui et al., 2012; Irstea, 2014). From that point onward, design practice has evolved over five generations of membrane bioreactors. Both number and size have increased at the same time while investment costs have decreased. Nowadays, membrane technology is adapted to all sizes of plants up to 150.000 m^3/d (Gresle et al., 2007; Kraemer et al., 2012).

WATER REUSE AND RECYCLING – EUROPEAN CONTEXT

Wastewater reuse practices have been carried out since long time and even without any water treatment. In 1971, the World Health Organisation (WHO) developed reference guidelines for wastewater reuse in agriculture. The regulations for water quality were still too strict. During the last decade water reclamation and technologies available for this issue have been improved significantly and a growing number of countries has adopted a regulatory framework for wastewater reuse. In order to develop this practice in Europe, AQUAREC research project "Integrated Concepts for Reuse of Upgraded Water" was released in 2002; it wishes to develop concepts and methodologies for the reuse of treated wastewater. The use of membranes is as one of the most common options (see Appendix A).

The term water recycling is generally used synonymously with water reuse, but it is not exactly the same. Water reuse is defined as the 'beneficial reuse of appropriately treated wastewater'. Water recycling is the reuse of treated water in the same factory where it was produced.

There is a wide range of reuse application of treated urban or industrial water (Monchalin et Aviron-Violet, 2002; Paquet et Rotbardt, 2011).

- Non-potable urban uses: landscape irrigation (public parks, golf courses, etc.), street cleaning, fire protection systems, toilet flushing (extended used in Japan);
- Agriculture irrigation;
- Industry uses: cooling water, process water, aggregate washing, dust control, etc.;
- Environmental and recreational uses: aquatic ecosystem restoration, stream augmentation, aquifer recharge (for saline inclusion control and delayed abstraction to increase water resources in quantity and quality.

Regarding potable water production, there are not many cases of direct wastewater reuse. However, the indirect wastewater reuse for drinking water production through the deliberate incorporation of reclaimed water into a raw water supply such a river or an aquifer is a common situation, for example in USA or Australia (Monchalin et Aviron-Violet, 2002; Paquet et Rotbardt, 2011).

In Europe there are more than 200 water reuse projects as well as many others in an advance planning phase. Figure 1 shows the geographic distribution of water reuse schemes sorted by size and field of sectoral water uses. The areas of application are split into four categories: (1) agriculture; (2) industry; (3) urban, recreational and environmental uses, including aquifer recharge; and (4) combinations of the above (mixed uses). The scale of the projects is also split into four classes: very small (<0.1 Mm^3/y), small (0.1– 0.5 Mm^3/y), medium (0.5–5 Mm^3/y) and large (>5 Mm^3/y).

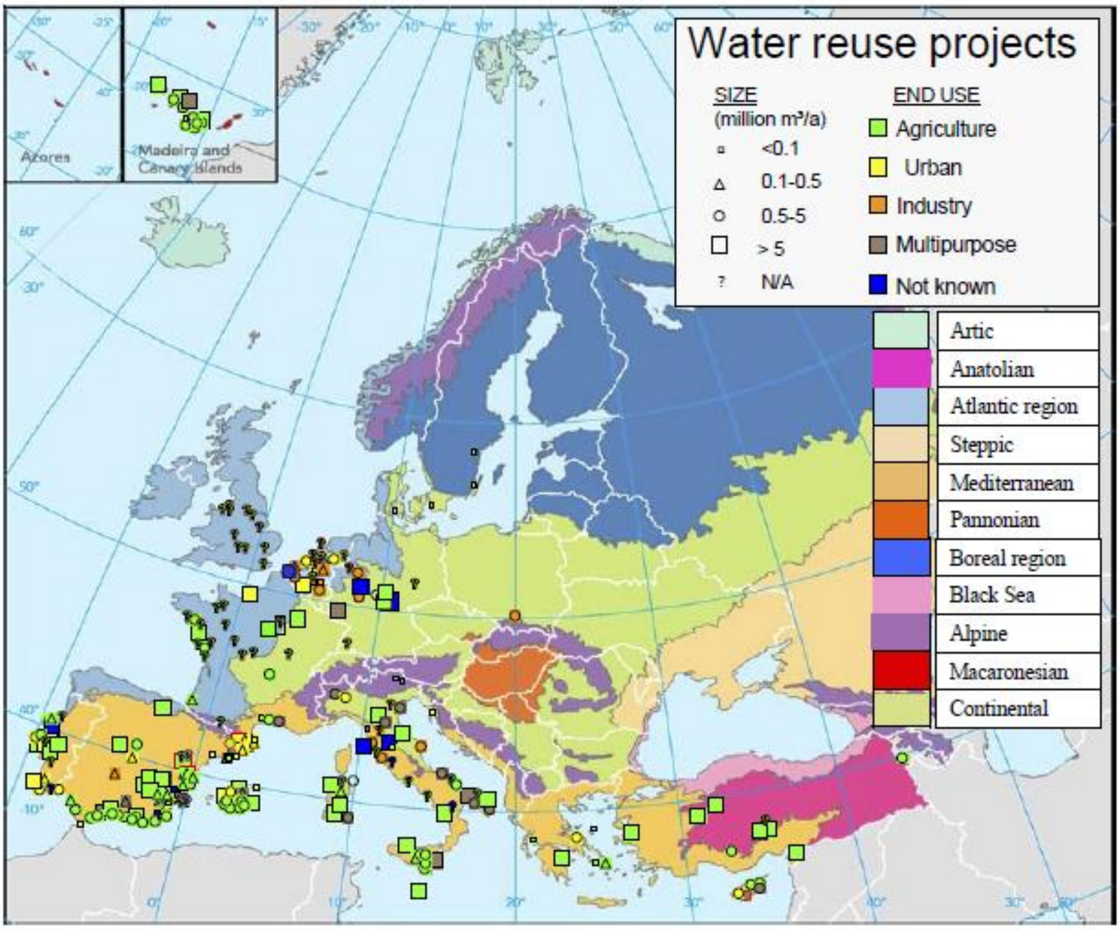


Figure 1.- Identifiable water reuse projects in Europe, including their size and intended use (Bixio et al., 2008).

In spite of its numerous advantages and development potential, the reuse of reclaimed water is not widely implemented in many Member States. There are many lost opportunities to develop water reuse schemes due to the lack of clarity in the regulatory framework. Insufficient price differentials between reused reclaimed water and freshwater, very stringent water reuse standards (sometimes similar to those for drinking water even for non-potable uses) or some technical barriers are some of the issues which limit the economic attractiveness of water reuse projects (BIO by Deloitte, 2015).

WHY CHOOSE AN ALTERNATIVE TO CONVENTIONAL TREATMENT?

Conventional treatment techniques are able to remove, in variable proportions, suspended material and organic material. However, these techniques don't guarantee the full removal of health risk or several emerging contaminants (drug metabolites, pharmaceuticals, household chemicals, etc.). Membrane technology can reach a better quality because of a higher purification efficiency by complete retention of particles and bacteria, and, depending on the membrane process, also viruses, and a better removal of organic trace substances (Monchalin et Aviron-Violet, 2002; Gresle et al., 2007; Drogui et al., 2012).

If the same water quality is reached, membrane technology can replace several stages of conventional treatments, such as a sand filtration or a UV disinfection. The very compact design allows the construction of treatment plants with a smaller land occupation and a large variability in their capacity.

The quality of treated water for its recycling or reuse depends on the final use, always taking into account the economic viability of the project and health implications related to micro-organisms. In this context, membrane technology is one of the technologies available which assures good water quality, even disinfected, alone or combined with other processes such as UV disinfection (Gresle et al., 2007).

MEMBRANE TECHNOLOGY

There are different kinds of membrane processes which are well-known and currently used. Membrane filtration is a physical separation process where the driving force is a pressure difference which allows the material separation through the membrane. These are the ones that will be developed in this report. There are also other technologies like pervaporation (based on a chemical potential gradient) or electrodeionization (based on an electrical gradient) (Arzate, 2008).

MEMBRANE UNITARY OPERATIONS

Membrane filtration is defined as the method of liquid phase separation by permeation through perm-selective membranes under the action of a pressure gradient. There are various processes which differ in their molecular separation size (pore size) and the driving force which has to be expended. Different membrane processes and their characteristics are presented in Appendix B. There is no unified standard in pore size classification and there may be some differences according to the source.

Microfiltration (MF) allows the separation of particles between 0.1 and 10 µm at pressures between 0.1 and 3 bars. These membranes ensure the passage of all dissolved species and only suspended materials are retained. The sizes of the pore of the ultrafiltration membrane (UF) vary between 0.01 and 0.1 µm; the operating pressures are between 0.1 and 5 bar. The inorganic salts and organic molecules pass through the membrane while the macromolecules are stopped. Multivalent ions and organic solutes of smaller sizes are perfectly retained on the nanofiltation membrane (NF) for working pressures between 3 and 20 bar. In the case of reverse osmosis (RO), the separation of all the previous particles are added the low molecular weight compounds, such as monovalent ions or sugars. The work is performed at pressures between 5 and 120 bar.

MEMBRANE COUPLING WITH OTHER UNITARY OPERATIONS

The membranes can be associated with unit operations of a different nature: biological (MBR AnMBR) or physic-chemical (ozone treatment, adsorption, crystallization, etc.).

Biological coupling: Membrane bioreactors (MBR and AnMBR)

A membrane bioreactor (MBR) combines the activated sludge process with a membrane separation process. The reactor is operated similar to a conventional activated sludge process but without the need for secondary clarification (Seyhi et al., 2011). Low-pressure membrane filtration, either microfiltration (MF) or ultrafiltration (UF), is used to separate effluent from activated sludge. The two main MBR configurations are shown in Figure 2 (Degrémont, 2005)**:**

The membrane bioreactor (MBR) is a combination of biological wastewater treatment according to the activated sludge process and the separation of the sludge- water mixture by membrane filtration (micro- or ultrafiltration). This technology improves the conventional biological process: a secondary settling tank for phase separation downstream of the bioreactor is remplaced by the membranes (Seyhi et al., 2011). There are two main MBR process configurations, as showed in the Figure 2 (Degrémont, 2005)**:**

- Side-stream (or external) configuration: the membrane is installed outside the bioreactor. They are usually tubular or flat modules, installed in serie and/or parallel. The filtration takes place from inside to outside (cross-flow filtration).
- Immersed configuration: the membrane is integrated inside the bioreactor. They are hollow-fibre modules or flat modules and filtration takes place from outside inwards.

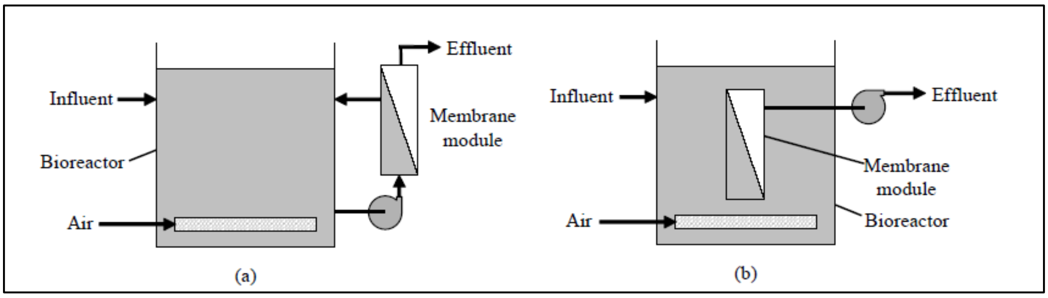


Figure 2.- Configuration of MBR systems: (a) submerged MBR, (b) side-stream MBR configuration (Ng et Kim, 2007).

External MBRs are considered to be more suitable for industrial wastewater streams, characterized by high temperature (ex.: 40ºC), high organic contamination load or extreme pH (Yang et al., 2006). On one hand, this equipment is not compatible with important water flow rates and low organic contamination load as are municipal wastewater. On the other hand, submerged MBRs are cused cnsiderably more for urban wastewater (Boutin et al., 2008).

The anaerobic membrane bioreactor (AnMBR) is a technological alternative for wastewater treatment, with a lower power consumption and a lower sludge production. Additionally, the anaerobic degradation of organic matter produce biogas, wher value can be added. AnMBR module arrangement is the same as MBR, either immerged or external membranes.

Other Couplings

Progress in terms of treatment of water by membrane technologies is also related to couplings with other technologies, always looking for to optimize overall performance and minimizing environmental impact. This is the case, for example, the coupling between a membrane filtration and an advanced oxidation process, an adsorption process or crystallization.

MEMBRANE TECHNOLOGY FOR WASTEWATER TREATMENT

The various existing membrane technologies are studied in this chapter. They are presented according to the nature of the water to be treated: urban wastewater, industrial wastewater and rainwater.

URBAN WASTEWATER

Urban wastewater is composed mainly of domestic sewage, which include domestic sources (washing machines, kitchens, bathrooms) and toilet flushing (including urine and faeces). It is possible that industrial wastewater joins the municipal sewage if their characteristics are similar to urban wastewater (Degrémont, 2005; Conseil Général Hauts-de-Seine, 2012).

Depending on the final goals of water treatment and the integration of the membrane stage in municipal wastewater treatment plant, three different possibilities are showed in the Figure 3 below:

- Membrane bioreactor
- Tertiary treatment: membrane technology (MF or UF) is placed after a conventional activated sludge process, working at low pressure, either external or immerged configuration.
- Quaternary treatment: for water desalination and organic micropollutant removal by NF or RO, or EDI.

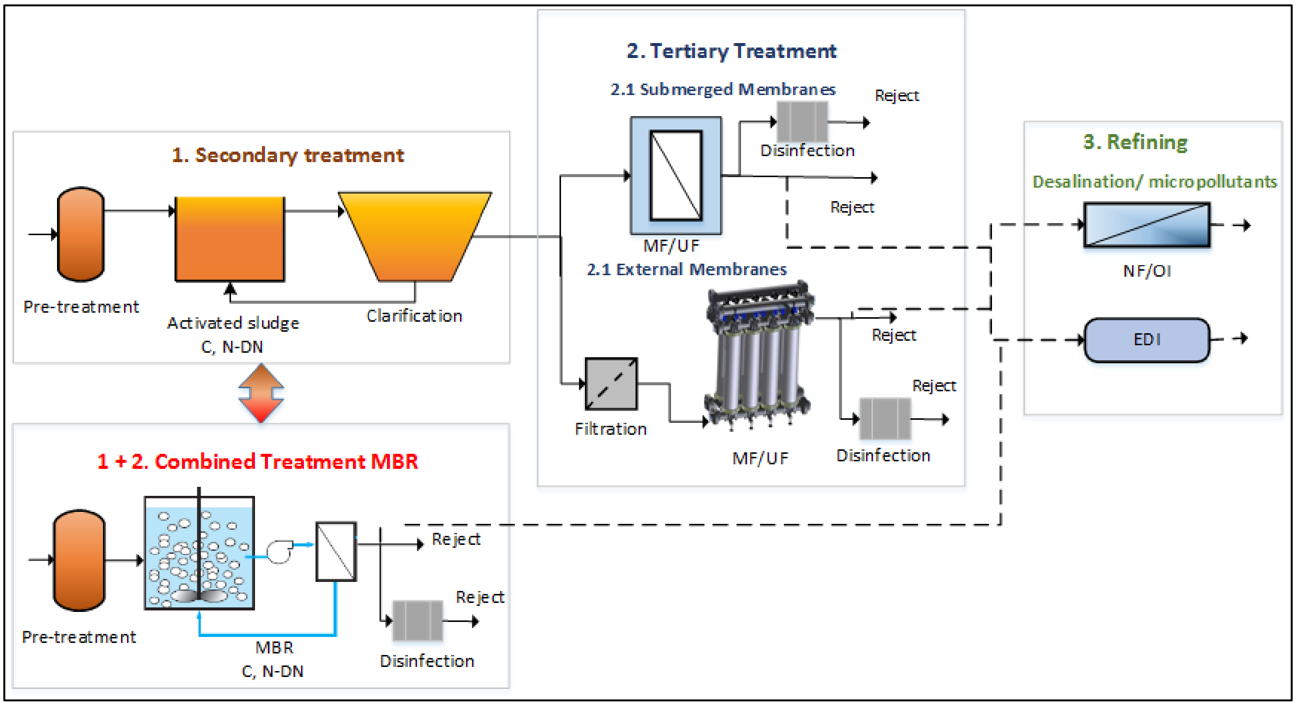


Figure 3.- Diagram of the main membrane processes. Adapted from Gresle et al., 2007.

Membrane bioreactors for secondary treatment

The membrane bioreactor process is the combination of a biological reactor and a physical separation by membranes (micro- or ultrafiltration): the membranes ensure the role of conventional clarifiers with a more efficiency in disinfection.

For financial reasons only immersed membrane systems are used in municipal wastewater treatment (Stephenson et al., 2000). Nevertheless, in recent years a new configuration has been developed: side-stream immersed membrane bioreactors: membranes are immerged in an external module.

This concept allows the uncoupling between the aeration destined to the biological treatment and the aeration for the filtration process, at the same time it facilities the cleaning stages, while improving purification performance (Gagnaire et al., 2008; Léna, 2007).

The substitution of the clarifier removes any difficulties brought by the sludge settling (bulking sludge, foaming and sludge rising). Sludge production is also reduced (Pronost, 2002). This system also saves space, thanks to the possibility of increasing the concentration of the purifying biomass, thereby reducing the size of the aerator (up to 75%). The rehabilitation of stations is possible with the MBR via their adaptation to any tank geometry, allowing improved performance with very little additional work.

Furthermore, when water quality is important (especially the rejection to a sensitive environment), MBRs are an economically attractive solution. The quality of the effluent is better than the one from the conventional activated, particularly in TSS concentration, in organic material (COD, BOD, TP, NT, etc.) and in bacteriological parameters (bacteria, virus, parasites). If further UV treatment is necessary, it will be improved thanks to the very low concentration of TSS (Stricker et al., 2013). In addition, the elimination of organic micro-pollutants (pesticides, hydrocarbons, pharmaceuticals, cosmetics, etc.) is well demonstrated.

The main limitation of this technology is membrane fouling. It determines the chemical cleaning in number and frequency and sometimes it limits the life-service of the membranes, which is very variable (few months up to ten years) depending of the technology and its operation. Fouling directly affects the operating costs because of the chemical composition and membrane replacement.

Mastering both fouling and washes is an essential operating constraint although significant progress has been made in this area. Energy consumption is greater than in the case of a conventional activated sludge. Good technical skills, including automation, are required for the personnel (Stricker et al., 2013).

The implementation of this technique still faces high costs for investment and operating (energy, maintenance, reagents, membrane replacement). However, these costs have been significantly reduced over the last decade (Gresle et al., 2007).

Membrane bioreactors play an important role in decentralised systems for wastewater treatment. MBRs were initially used for water recycling in buildings: wastewater from kitchens, bathrooms and toilets are collected and treated by a MBR, then stored and disinfected by sodium hypochlorite. Hundreds of similar facilities currently exist in Japan and Korea (Aptel, 2006). In Europe, the number of hotels and buildings that uses membrane filtration for wastewater treatment is clearly increasing. With this technology, small wastewater treatment plants are able to attain higher cleaning efficiencies such that it can be recycled for non-potable uses (e.g. for toilet flushing or garden irrigation). Boats, ships or mobile installations for military use are also equipped with MBR. To cite an example: The Royal Mail Ship Queen Mary 2 treats their own wastewater (kitchen, maintenance, sanitation) on board via a MBR before being discharged into the sea (Pinnekamp et Friedrich, 2006; Gagnaire et al., 2008).

Anaerobic Bioreactor

In recent years, the anaerobic digestion process for wastewater is increasingly being researched as a cost-effective alternative on account of the energy that can be recovered (methane-rich biogas), the nutrient rich effluent and the low sludge production (Smith et al., 2012). Despite the advantages, the high solid retention required to promote the slow growing anaerobic biomass increase the volume of the reactor needed to ensure proper performance, which limits the widespread application. Furthermore, the anaerobic process is sensitive to temperature changes, so the effluent quality could not meet quality requirements: in these cases a post-treatment stage is necessary in order to respect quality standards (Vera et al., 2014).

Anaerobic processes are in generally performed at moderate temperature. The AnMBR may be considered in areas with temperate or tropical climate, such as Brazil, India and Canary Island for example. Since macronutrients such as ammonium and orthophosphates are not removed by anaerobic bioprocess and pathogens can be retained by the membrane unit, water treated by AnMBR is certainly of interest for agricultural use (Ozgun et al., 2013).

Even if AnMBRs are an attractive alternative in wastewater treatment, the implementation of this technology still faces several problems, especially membrane fouling but also problems associated with anaerobic processes. Nowadays, there is no description of real industrial application in the literature, its development needs further research and industrialisation application (Skouteris et al., 2012).

Tertiary / Quaternary treatment

The non-potable urban uses (such as landscape irrigation, street cleaning or toilet flushing, fire protection systems or wetland recreation, for example) require thorough disinfection, and it can be assured by a single membrane stage: MBR or a tertiary treatment by MF or UF. In some cases, additional disinfection by weak doses of chlorination ensures the maintenance of an enough residual chlorine in water to prevent bacterial re-growth or recontamination of the treated water in distribution networks.

Other uses classified as high health risk, such as groundwater recharge or the indirect wastewater reuse for drinking water production, as well as some industrial uses such as boiler or cooling water, require the implementation of more complex treatment processes. For example, different stages of micro- or ultrafiltration added to a reverse osmosis plus another complementary stage like active carbon filtration or advanced oxidation for removal of organic micropollutants (Gresle et al., 2007).

In Spain, to give an example, they reuse wastewater for golf course irrigation. In this context, an additional tertiary treatment is incorporated, and usually it consists of a first stage of MF combined with a further RO polishing so as to assure complet disinfection (Gresle et al., 2007; Léna, 2007).

In coastal areas, many municipalities have adopted membrane technology to protect natural environment and bathing water. For instance, Ghétary and Guilvinec waste water treatment plants, in France, are equipped with MBRs (capillary and plate modules respectively), followed by a final UV disinfection (Gresle et al., 2007; Léna, 2007).

Another example which requires good water quality is wastewater reuse for industrial purpose. The WWTP Arroyo Culebro in Madrid, Spain, includes an advanced tertiary treatment after the secondary clarifier in order to obtain an effluent with a similar quality to drinking water. The treated water is fed back into a paper mill as fresh water. To that end, the water treatment includes the following stages: active carbon adsorption, UV, UF, OI and water remineralisation with calcium hydroxide and CO_2, and a final disinfection with sodium hypochlorite (Pernaute et al., 2012).

The current European legislation does not allow direct wastewater reuse as drinking water. However, other countries like in Windhoek, Namibia, under water-stressed conditions, reuse wastewater for direct drinking water production. The treatment process consists of the following stages: clarification, oxidation/disinfection, biological treatment, active carbon adsorption, membrane filtration by UF and post-disinfection by chloration (Gresle et al., 2007). Treatred water is mixed in a final tank with two-thirds drinking water from other plants before distribution.

INDUSTRIAL WASTEWATER

The application of membrane processes in industry has its origin in the field of production, with most references in the beverage industry, the pharmaceutical industry and for the production of ultra-pure water. Industrial wastewater is often produced discontinuously and its composition may vary significantly depending on the industry. It can be discharged directly into the environment or join the municipal sewerage network, and then it joins the municipal wastewater treatment plants as long as it doesn't disrupt the operation.

Given the increasing price of drinking water, used in industry as fresh water (process water), and a growing environmental concern, the membranes are today more and more frequently used. Generally, when industrial wastewater is submitted to a membrane treatment, one of this typical objectives are contemplated (Truc, 2007):

- Avoidance of wastewater, either for recycling of process water from wastewater, for reuse for another industrial purpose (street or product cleaning, fire protection systems, cooling or boiling circuits), agricultural purpose (irrigation), municipal use (golf courses or playground irrigation) and also for the closure of circulation systems (reuse water in the same factory).
- Improvement of effluent parameters, in order to comply with legal standards, which are becoming more and more strict (especially in sensitive environments).
- Recovery of reusable material, for reutilization in the production process or for marketing (protein, latex, etc.)
- Reduction of space or volume requirements for wastewater treatment.

For uses in which regulation is stricter, the effluent requires a full tertiary treatment, including membrane processing step which may be necessary as shown in the Table 1 .

Table 1.- Technology available for tertiary treatment (Degrémont, 2005).

Removed parameters		Techniques						
	Biological treatment	Oxidation		Membranes (1)		Active Carbon	Resins or specific absorbents (1)	Precipitation Coagulation Flocculation Separation (2)
		O_3 H_2O_2 UV	O_3 + biological	UF	NF/OI			
DBO residual	x							
Phosphorus					x			x
Nitrates	x				x			
MES et COD colloidal				x	x			x
COD soluble		x	x		x	x		x
AOX		x	x		x	x		
Discolouration		x	x		x	x		x
Specific compounds		x			x	x	x	
Anions, cations					x		x	x
Metals					x			x

(1) The use of membranes or resins has the advantage of producing treated water of perfect quality but requires appropriate pre-treatment and especially produces saline concentrates to be managed (for discharge and external treatment or reprocessing on site).
(2) Settling, dissolved air flotation and filtration on granular material, after all or part of the neutralization, coagulation or flocculation steps.

The Table 2 summarizes some examples of industries where their own wastewater treatment plant is equipped with membrane technology: the most common objectives are meet with quality standards and partial or total recycling of the effluent.

Table 2.- Objectives for the utilisation of membrane technology in industrial wastewater treatment (Pinnekamp et Friedrich, 2006).

Industrial branch	**Examples of objectives**
Food industry	• Treatment of wastewater for use as a process water
	• Higher protein output
Paper industry	• Compliance with effluent standards
	• Treatment of wastewater for use as a process water
Textile industry	• Recovery of size baths and indigo dyes
	• Separation of colour pigments
	• Treatment of wastewater for use as a process water
Chemical industry	• Treatment of micropollutants (solvents, salts, catalysts, hormones)
Metal industry	• Separation of oil and emulsions and recycling
	• Recovery of scouring baths
	• Treatment of rinsing water
Petrochemical industry	• Treatment of reaction- and washing water
Power stations	• Treatment of boiler feed water
Mining industry	• Treatment of mine water and radioactive surface water

Food Industry

Common characteristics in effluents from food and beverage industry are essentially organic and biodegradable pollution and a general tendency to acidification and rapid fermentation.

Membrane applications are used in the food industry for effluent reduction (e.g. recycling washing water) and product recovery. MBRs are used for effluents produced by crop treatment (sauerkraut, sugar, wheat, corn, soya, oil), seafood, milk industry and wine industry (Skouteris et al., 2012). For instance, the milk mill in Unigate, France, use membrane technology after a simple treatment: it yields such a quality that recycling is possible (Pinnekamp et Friedrich, 2006).

Combination of secondary treatment followed by a membrane stage is becoming increasingly useful to achieve discharge standards. The company BEECK Feinkost BmbH & Co in Germany produces delicatessen and salad dressings. Wastewater, which has a high COD concentration, is treated by a ultrafiltration stage after the biological stage, in order to comply with discharge limits (Pinnekamp et Friedrich, 2006).

Chemical Industry

The chemical industry is extremely diverse; the following major groups are included in this group: (petrochemical, inorganic chemistry, fine chemistry and pharmaceutical industry). The variability of the composition of the effluent is significant: the effluents are more and more concentrated and more and more complex (presence of toxic and refractory pollutants).

These contaminants escape most of the conventional treatments and, from this point of view, membrane processes are particularly interesting. Studies on the removal of pharmaceuticals and related products (medicines, derived metabolites, cosmetics, etc.) show that these micro-pollutants are removed at very high rates by treatment with membrane bioreactors, alone or combined with a pre-treatment or a final polishing step (Clara et al., 2005; Drogui et al., 2012; Lin et al., 2012).

Advanced oxidation processes such as ozonation, peroxone (O3 / H2O2), UV / H2O2, photo-Fenton, photocatalysis and electrochemical advanced oxidation processes coupled with membrane technology are successfully tested for disposal of pharmaceuticals (Seyhi et al., 2011). However, despite increasing research studies in this field, there is not many large scale applications.

Textile industry

The textile industry is a major water consumer. Rejection volumes and the pollution load are highly variable. Membrane bioreactors in textile effluent treatments were firstly introduced in 1992, more precisely for the treatment of wool scouring effluent by an AnMBR. The last few years, several cases of MBR application have been reported (Lin et al., 2012).

For the industries using textile dyes, recent studies have announced that the combination between MBR and advance oxidation processes (AOP) are promising technologies. After a tertiary treatment by membranes, recycling of some effluents is possible. By way of illustration, the WWTP of the textile finishing plant of Gerhar vam Clewe in Germany is made up of two membrane installations: one with a MF module, and the other with stages of UF, NF and RO in line. Besides compliance with the standards for indirect dischargers, the membrane installation helps to save about 50% of the wastewater costs by a closed process water cycle (Pinnekamp et Friedrich, 2006).

Paper Industry

Paper mills belong to the group of major industrial water users, but also paper industry is a high power consumer and they need expensive raw materials. Therefore, internal recycling seems to be extremely necessary (Degrémont, 2005):

- Fibre recovery in the paper machine, and eventually coating colours recovery by ultrafiltration.
- Water recycling in different points of the paper machine or of the manufacturing process; water quality depends on the type of paper produced.

In general, the waste waters from paper mills are heavily loaded organically and tertiary treatments are needed to achieve reject standards. UF modules are generally used (Judd et Jefferson, 2003). The performance in the treated water by MBR of certain effluents is more than satisfactory. The use of this technology is directly limited by scaling issues (fibrous material or calcium-saturated in water) and the effluent temperature (normally around 50-70ºC).

Another point to mention is that AnMBR have been used since 1990, because they allow producing high quality effluent in moderate temperatures and at the same time they produce biogas where value can be added. Despite the fact that scaling is a strong handicap for this type of installation, the future of AnMBR in paper manufacturing industries seems to be guaranteed (Lin et al., 2012).

Energy

As mentioned before, it is always desirable that every kind of industry restricts, or even avoids completely, water intake from the natural environments. Oil and Gas industry and power plants are also included. For this reason, they need to recycle wastewater and depending on the purpose of this water, membrane technologies are possibly necessary.

One classic example of this type of industry is the recycling of water for the closed-cooling and water boiler systems in thermal power plants. Demineralized water is required while feeding this equipment, so it seems that treatment based on reverse osmosis is totally indispensable. Ultrafiltration membranes are also used as cleaning systems in the cooling circuits of oily water.; this technology represents a high efficiency ratio (Pinnekamp et Friedrich, 2006). In the design phase of a new internal wastewater treatment plant, MBR represents a reliable alternative from the point of view of water recycling (Lin et al., 2012).

RAINWATER HARVESTING

Collection systems used in sanitation are:

- Combined sewers, designed to carry both waste and stormwater. They are treated in wastewater treatment plants, which can be equipped, or not, with membrane technology.
- A separate sewer consists in the separate collection of municipal wastewater and surface run-off (rainwater and stormwater). No case of rainwater treatment with membrane technology for rejection is known: usually, a simple physical-chemical treatment is enough to comply with quality.

Use of greywater or rainwater to substitute non-potable water in buildings is not a novel concept but a powerful tool for sustainable water management. This solution, which is a common practice in Japan, serve for toilet flushing, floor washing, etc. Taking into account potential contact with humans, membrane technology completed with a supplementary disinfection is encouraged to avoid any potential risk of contamination. By way of illustration, the Millennium Dome in England includes a water recycling system as follows: greywater, which is produced by the hand wash-basin in the toilet blocks, rainwater collected from the dome's roof and groundwater from the chalk aquifer located below the site are collected, treated and reclaimed to flush all of the toilets and urinals on the site. The treatment system consist of a specific pre-treatment depending on the water source, followed by an ultrafiltration stage, a reverse osmosis stage and a final disinfection to reduce any health risk (Smith et al., 2000). On the other hand, in hotels for example, membrane bioreactor is a useful treatment to reclaim water and reuse it in showers.

Specially in semi-arid or remote regions where water stress is strong, rainwater harvesting serves as an alternative source of water and this practice has been developed for centuries. When re-use is considered, extensive treatments are needed to meet quality and safety standards. Membrane technology is only required when potable uses are envisaged. As a part of recent research in rainwater utilization, new materials are being tested, such as metal membrane or ceramic membrane for rainwater treatment (Kim et al., 2005; Kim et al., 2007; Helmreich et Horn, 2009).

MEMBRANE COSTS

Investment and operating costs of these processes have been greatly reduced over last decade. We have to highlight that investment and operation costs of a membrane process, in common with other wastewater treatments, are directly attached to the size and complexity of the installation, in addition to the polluting concentration and local conditions.

In comparison with MBR, module costs have been reduced by 7 in seven years. The Table 3 shows the summary values of a study carried out on the facilities of the Adour Garonne basin which compares the investment costs between an activated sludge process and a MBR (Husson et al., 2013). For capacities over 8000 PE, investment costs related to activated sludge with a membrane separation process are near to those resulting from an "classic" activated sludge process (Savary, 2014).

Table 3.- Evaluation of investement costs of an activated sludge process and a MBR in Adour Garonne basin.

	Investement cost (€)		Investement cost (€ / PH)	
PH	**Activated Sludge**	**MBR**	**Activated Sludge**	**MBR**
2.000	1.024.696 €	1.600.902 €	505 €	707 €
5.000	2.041.575 €	2.517.193 €	408 €	478 €
10.000	3.438.984 €	3.210.340 €	347 €	355 €

Even if they have been considerably reduced, global operational costs (power, maintenance, chemical reagents, membranes replacement, screening, wood treatment) are higher than those coming from activated sludge (Gresle et al., 2007). There is not much data on operating costs giving comparative quantitative elements between MBR and activated sludge processes. The latter is associated with the refining step (sand filter + disinfection) so both processes obtain equivalent water quality and the comparison is fair. Because of the great difficulty in obtaining data, the operating costs are reduced to 4 positions: waste disposal, reagents, personnel and power consumption. The Table 4 compares the estimated values of simplified operating costs between a conventional activated sludge treatment with tertiary step and MBR.

Table 4.- Simplified operating costs from Brepols et al., 2010. Adapted from Husson et al., 2013.

	AS + Tertiaty treatment [(1)]				MBR			
	Annual Cost	**%**	**€/m³**	**€/PH**	**Annual Cost**	**%**	**€/m³**	**€/PH**
Waste disposal	25.664 €	17%	0,05	0,007	25.664 €	13%	0,05	0,007
Chemical reagent	11.008 €	7%	0,02	0,003	12.860 €	7%	0,02	0,004
Personnel	70.000 €	46%	0,13	0,019	70.000 €	37%	0,13	0,019
Power consumption	45.990 €	30%	0,08	0,013	82.782 €	43%	0,15	0,023
Simplified Operating Costs	**152.662 €**		**0,28 €**	**0,04 €**	**191.306,00 €**		**0,35 €**	**0,05 €**
Maintenance and remplacement	96.411 €	63%	0,18 €		96.420 €	50%	0,18 €	
TOTAL OPERATING COSTS	**249.073 €**		**0,45 €**		**287.726 €**		**0,53 €**	

[(1)] AS: Activated sludge

According to Brepols's simulations (Brepols et al., 2010), made from real cases and rated load, the operating costs of a MBR are approximately around 25% higher than those coming from activated sludge and tertiary treatments.

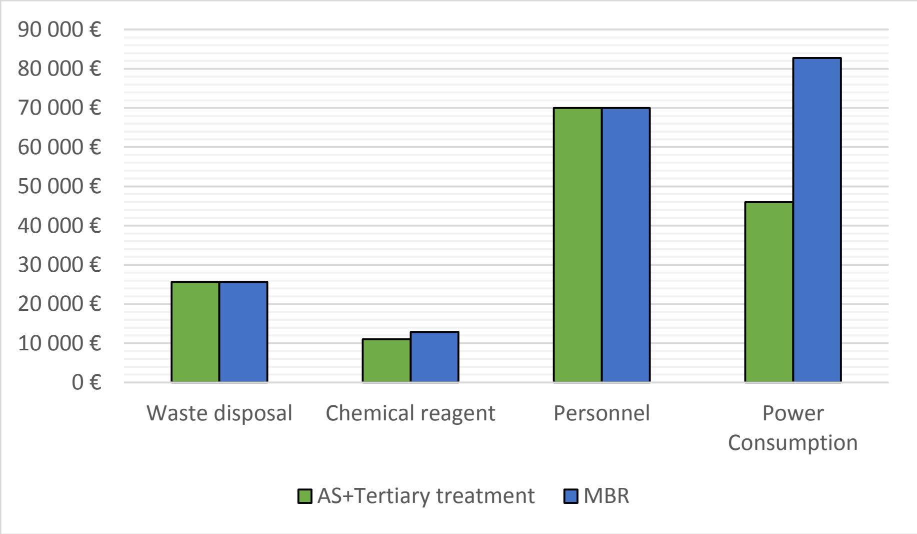


Figure 4.- Comparison of annual Simplified Operating Costs of AS+Tertiary treatment and a MBR (Husson et al., 2013).

In detail, the breakdown by position in Figure 4 highlights the elements that differentiate the two processes: MBR operating costs are higher in regards the chemical reagent consumption, but especially in terms of power consumption, which is 30 to 40% higher than the activated sludge process.

In the case of MF or UF membranes for tertiary treatment, the costs are in the same range of those of MBR, around 0,3 €/m^3. While tertiary treatment by combination of UF/RO or MF/UF are needed, investment and operational costs are higher and can comprise double the cost of a simple MF or UF, especially in power consumption (Gresle et al., 2007).

CONCLUSION

Membrane technologies represent nowadays a reliable and recognized alternative to classic processes for urban and industrial wastewater treatments. Thirty years after their first appearance, their future in the market is clearly guaranteed: they are becoming more and more competitive in relation to conventional treatments.

The use of this kind of technology is required when water quality is the main goal (to achieve quality standards that are becoming more and more strict or to protect sensitive environments) or also when water availability is limited, and, if that is the case, recycling and reuse of used water plays a major role in the process. There are multiple options of water treatment by membranes, from microfiltration to reverse osmose, alone or coupled with other technologies. The decision will be taken based on the quality of the water to be treated and also the quality to be achieve and the end use of the effluent.

There are numerous technological improvements in this field and their applications in wastewater treatment are steady- and quickly increasing. The developments lead to a better chemical resistance or to less sensitive fouling systems. The investment costs trend is decreasing. On the other hand, power costs, fouling or precipitation risks and membranes costs remain as an importer factor, though there are progressively reduced.

BIBLIOGRAPHIE

Arzate A., 2008. *Procédés de séparation membranaire et leur application dans l'industrie alimentaire*. Revue de littérature, projet 642. Québec, ACER, p. 56.

BIO by Deloitte, 2015. *Optimising water reuse in the EU*. Final report prepared for the European Commission (DG ENV), Part I. In collaboration with ICF and Crandfield University. p. 204.

Bixio D., Thoeye C., Wintgens T., Ravazzini A., Miska V., Muston M., Chikurel H., Aharoni A., Joksimovic D., Melin T., 2008. Water reclamation and reuse: implementation and management issues. *Desalination*, 218 (1–3), pp. 13-23.

Boutin C., Héduit A., Helmer J.-M., 2008. *Technologies d'épuration en vue d'une réutilisation des eaux usées traitées (REUT)*. Rapport. Convention de partenariat ONEMA-Cemagref, p. 100.

Brepols C., Schäfer H., Engelhardt N., 2010. Considerations on the design and financial feasibility of full-scale membrane bioreactors for municipal applications. *Water Science & Technology*, 61 (10), p. 2461.

Clara M., Strenn B., Gans O., Martinez E., Kreuzinger N., Kroiss H., 2005. Removal of selected pharmaceuticals, fragrances and endocrine disrupting compounds in a membrane bioreactor and conventional wastewater treatment plants. *Water Research*, 39 (19), pp. 4797-4807.

Conseil Général Hauts-de-Seine, 2012. *Règlement du Service Départemental d'assainissement des Hauts-de-Seine*.

Degrémont, 2005. *Mémento technique de l'eau*. 10e éd. Rueil-Malmaison, Degrémont, 1718 p.

Drogui P., Seyhi B., Buelna G., 2012. Biotraitement à membrane : la technologie du futur pour l'épuration des eaux résiduaires. *Environnement et technique*, pp. 58-63.

Gagnaire J., Moulin P., Marrot B., 2008. Bioréacteurs à membranes : un intérêt grandissant. *L'Eau, l'Industrie, les Nuissances*, 314, pp. 64-74.

Gresle A., Lazarova V., Suty H., 2007. Intérêts techniques et économiques du traitement membranaire en vue du recyclage. *TSM*, (12), pp. 111-136.

Helmreich B., Horn H., 2009. Opportunities in rainwater harvesting. *Desalination*, 248 (1–3), pp. 118 - 124.

Husson A., Stricker A., Senechal M., Racault, AEAG, IRSTEA, 2013. *Bioreacteurs a membrane pour le traitement des eaux residuaires urbaines : retours d'experience*. Available in: http://www.documentation.eaufrance.fr/notice/bioreacteurs-a-membrane-pour-le-traitement-des-eaux-residuaires-urbaines-retours-d-experience0 [Accessed December 8, 2015].

Irstea, 2014. *Les bioréacteurs à membranes pour le traitement des effluents urbains*. IRSTEA. Available in: http://www.irstea.fr/lespace-jeunesse/approfondir/lepuration-des-eaux-usees-les-avancees/les-bioreacteurs-membranes-pour [Accessed December 5, 2015].

Judd S., 2010. *The MBR Book: Principles and Applications of Membrane Bioreactors for Water and Wastewater Treatment*. 2e éd. Elsevier, 537 p.

Judd S., Jefferson B. (Éd.), 2003. *Membranes for industrial wastewater recovery and re-use*. Kidlington, Oxford, UK; New York, NY, USA, Elsevier Science, 291 p.

Kim R.-H., Lee S., Jeong J., Lee J.-H., Kim Y.-K., 2007. Reuse of greywater and rainwater using fiber filter media and metal membrane. *Desalination*, 202 (1–3), pp. 326-332.

Kim R.-H., Lee S., Kim J.-O., 2005. Application of a metal membrane for rainwater utilization: filtration characteristics and membrane fouling. *Desalination*, 177 (1–3), pp. 121 - 132.

Kraemer J.T., Menniti A.L., Erdal Z.K., Constantine T.A., Johnson B.R., Daigger G.T., Crawford G.V., 2012. A practitioner's perspective on the application and research needs of membrane bioreactors for municipal wastewater treatment. *Bioresource Technology*, 122, pp. 2-10.

Kraume M., Drews A., 2010. Membrane Bioreactors in Waste Water Treatment – Status and Trends. *Chemical Engineering & Technology*, 33 (8), pp. 1251–1259.

Le-Clech P., Chen V., Fane T.A.G., 2006. Fouling in membrane bioreactors used in wastewater treatment. *Journal of Membrane Science*, 284 (1–2), pp. 17-53.

Léna P., 2007. Assainissement : Le débarquement des membranes. *Hydroplus*, pp. 30 - 35.

Lin H., Gao W., Meng F., Liao B.-Q., Leung K.-T., Zhao L., Chen J., Hong H., 2012. Membrane Bioreactors for Industrial Wastewater Treatment: A Critical Review. *Critical Reviews in Environmental Science and Technology*, 42 (7), pp. 677-740.

Ministère de l'Écologie, du Développement Durable et de l'Énergie, 2013. *La Directive cadre européenne sur l'eau*. Available in: http://www.developpement-durable.gouv.fr/Les-objectifs.html [Accessed December 5, 2015].

Monchalin G., Aviron-Violet J., 2002. *La réutilisation des eaux usées après traitement*. Paris, Conseil général du génie rural, des eaux et des forêts (CGGREF), 39 p.

Ng A.N.L., Kim A.S., 2007. A mini-review of modeling studies on membrane bioreactor (MBR) treatment for municipal wastewaters. *Desalination*, 212 (1–3), pp. 261-281.

Ozgun H., Dereli R.K., Ersahin M.E., Kinaci C., Spanjers H., van Lier J.B., 2013. A review of anaerobic membrane bioreactors for municipal wastewater treatment: Integration options, limitations and expectations. *Separation and Purification Technology*, 118 , pp. 89-104.

Paquet C., Rotbardt A., 2011. *La réutilisation des eaux usées traitées (REUT). Eléments de méthodologie pour l'instruction de projets*. Rapport. Paris, Agence Français de Développement, p. 29.

Pernaute C., Suárez J., Ontañón N., 2012. *Tratamiento Terciario Avanzado. EDAR de la Cuenca Media-Alta del Arroyo-Culebro (Madrid)*. Reportage. Madrid, RETEMA, p. 13.

Pinnekamp J., Friedrich H., 2006. *Membrane technology for waste water treatment*. 2[e] éd. Aachen, FiW-Verl, 346 p. Municipal water and waste management.

Pronost J., 2002. Les réacteurs biologiques à membranes pour l'épuration des eaux usées urbaines. *Environnement et technique*, (216), pp. 27-30.

Remigy J.C., Desclaux S., 2007. Filtration membranaire (OI, NF, UF) Présentation des membranes et modules. *Techniques de l'ingénieur*, (j2791), p. 24.

Savary P., 2014. *Conception des Stations d'Epuration*. Montpellier, AgroParisTech Engref, p. 72.

Seyhi B., Droguil P., Buelna G., Blais J.-F., Heran M., 2011. État actuel des connaissances des procédés de bioréacteur à membrane pour le traitement et la réutilisation des eaux usées industrielles et urbaines. *Revue des sciences de l'eau*, 24 (3), pp. 283-310.

Skouteris G., Hermosilla D., López P., Negro C., Blanco Á., 2012. Anaerobic membrane bioreactors for wastewater treatment: A review. *Chemical Engineering Journal*, 198–199, pp. 138-148.

Smith A., Khow J., Hills S., Donn A., 2000. Water reuse at the UK's Millennium Dome. *Membrane Technology*, (118), pp. 5 - 8.

Smith A.L., Stadler L.B., Love N.G., Skerlos S.J., Raskin L., 2012. Perspectives on anaerobic membrane bioreactor treatment of domestic wastewater: A critical review. *Bioresource Technology*, 122 , pp. 149-159.

Stephenson T., Judd S., Jefferson B., Brindle K., 2000. *Membrane bioreactors for wastewater treatment*. London, IWA Publ, 179 p.

Stricker A.E., Husson A., Philippe N., Racault Y., 2013. *Procédés Bioréacteurs à Membranes: Conception dimensionnement, performances et coûts - Retour d'expérience sur la technologie BRM appliquée aux ERU (3 000 - 60 000 EH)*. Journées de l'OIEau. Paris, p. 43.

Truc A., 2007. Traitements tertiaires des effluents industriels. *Techniques de l'ingénieur Gestion de l'eau par les industriels*, base documentaire : TIB447DUO (ref. article: g1310),. Available in: http://www.techniques-ingenieur.fr/base-documentaire/environnement-securite-th5/gestion-de-l-eau-par-les-industriels-42447210/traitements-tertiaires-des-effluents-industriels-g1310/ [Accessed December 22, 2015].

Vera L., Ruigómez I., González E., Bodelón P., Rodríguez-Sevilla J., 2014. Biorreactores de membrana anaerobios para tratamiento de aguas residuales domésticas. Estudio Preliminar. *Avances en Ciencias e Ingeniería*, 5 (4), pp. 1-15.

Yang W., Cicek N., Ilg J., 2006. State-of-the-art of membrane bioreactors: Worldwide research and commercial applications in North America. *Journal of Membrane Science*, 270 (1–2), pp. 201-211.

APPENDIX A

AQUAREC model

One of the recommendations from the AQUAREC research program is the development of a logical chain of components depending on the type of wastewater to be treated (Table A.1 to A.4). According to (Boutin et al., 2008).

Table A .1.- Technologies proposed by AQUAREC for REUSE.

Prétraitement	
001	Dégrillage grossier
002	Dessablage
003	Dégrillage moyen
Traitement primaire	
101	Tamisage
102	Décantation avec/ou coagulation
103	Décantation avec coagulation
104	Flottation à l'air dissous avec coagulant
105	Filtration membranaire
106	Actiflo®
107	Lagunes anaérobies
Traitement secondaire	
201	Boues activées haute charge + décantation secondaire
202	Boues activées faible charge avec ou sans élimination de l'azote + décantation secondaire
203	Boues activées faible charge avec élimination de l'azote + décantation secondaire
204	Lit bactérien + décantation secondaire
205	Disques biologiques
206	Filtre aéré immergé
207	Lagunes aérobies
208	Lagunes aérées
209	Lagunes facultatives
210	Bassin artificiel : écoulement de surface
211	Bassin artificiel : écoulement souterrain
212	Bioréacteur à membranes
213	Elimination biologique du phosphore
214	Précipitation chimique du phosphore

Traitement tertiaire	
301	Filtration sur milieu fin poreux
302	Filtration en surface
303	Microfiltration
304	Ultrafiltration
305	Nanofiltration
306	Osmose Inverse
307	Charbon Actif en Grains
308	Charbon Actif en Poudre
309	Echange d'ion
310	Oxydation avancée : UV/Ozone
311	Oxydation avancée : UV/H_2O_2
312	Traitement par le sol
313	Lagunes de maturation
314	Bassin artificiel : finition
315	Floculation
Désinfection	
401	Ozone
402	Acide peracétique
403	Bioxyde de chlore
404	Chlore gazeux
405	UV

Table A.2.- Possible combinations from raw water.

Depuis un effluent brut	
Usage	*Combinaisons possibles (/ = ou ; + = et)*
Industrie	001/003,002,101,212(,304),305/306,401/405 ou 001/003,002,102/103/104/106,202/204/205/206(,315+301/302),315+303/304,305/306,401/405 ou 001/003,002,102/103/104/106,202/204/205/206,315+301/302,307/308,310/311(,309)(,401/405) ou 001/003,002,102/103/104/106,203+214(,315+301/302),(315+)303/304,305/306,401/405 ou 001/003,002,102/103/104/106,213(,315+301/302),(315+)303/304,305/306,401/405 ou 001/003,002,101/102,105,(315+)304,305/306,401/405
Potable	001/003,002,101,212(,304),305/306,401/405 ou 001/003,002,102/103/104/106,202/204/205/206(,315+301/302),315+303/304,305/306,401/405 ou 001/003,002,102/103/104/106,202/204/205/206,315+301/302,307/308,310/311(,309)(,401/405) ou 001/003,002,102/103/104/106,203+214(,315+301/302),(315+)303/304,305/306,401/405 ou 001/003,002,102/103/104/106,213(,315+301/302),(315+)303/304,305/306,401/405 ou 001/003,002,101/102,105,(315+)304,305/306,401/405 ou tous ceux précités
Urbain	*1* : 001/003,002,102/103/104/106,202/203(+214)/204/205/206/213(,401/402/403/404/405) ou 001/003,002,101,212(,401/402/403/404/405) ou 001/003,107,208/(209+)207(,401/402/403/404/405) ou 001/003,210/211(,401/402/403/404/405) ou tous ceux précités *2* : *1* avec 212(,304),305/306,401/405 ou *1* avec ou sans 212(,315+301/302)(,316+)303/304,305/306,401/405 ou tous ceux précités
Recharge de nappe	*1* : 001/003,002,102/103/104/106,202/203(+214)/204/205/206/213(,401/402/403/404/405) ou 001/003,002,101,212(,401/402/403/404/405) ou 001/003,107,208/(209+)207(,401/402/403/404/405) ou 001/003,210/211(,401/402/403/404/405) ou tous ceux précités *2* : *1* avec 212(,304),305/306,401/405 ou *1* avec ou sans 212(,316,301/302)(,316+)303/304,305/306,401/405 ou tous ceux précités
Environnemental et récréatif	001/003,002,102/103/104/106,202/203(+214)/204/205/206/213(,312/313/314)(,401+402/403/404/405) ou 001/003,002,101,212(,401/402/403/404/405) ou 001/003,107,208/(209+)207(,312/313/314)(,401/402/403/404/405) ou 001/003,210/211 ou tous ceux précités
Agriculture	Aucun ou 001/003 ou 001/003,002 ou 001/003,002,101 ou 001/003,002,102/103/104/106/107 ou 001/003,002,101/102,105 ou tous ceux précités

Table A.3.- Possible combinations from a primary effluent.

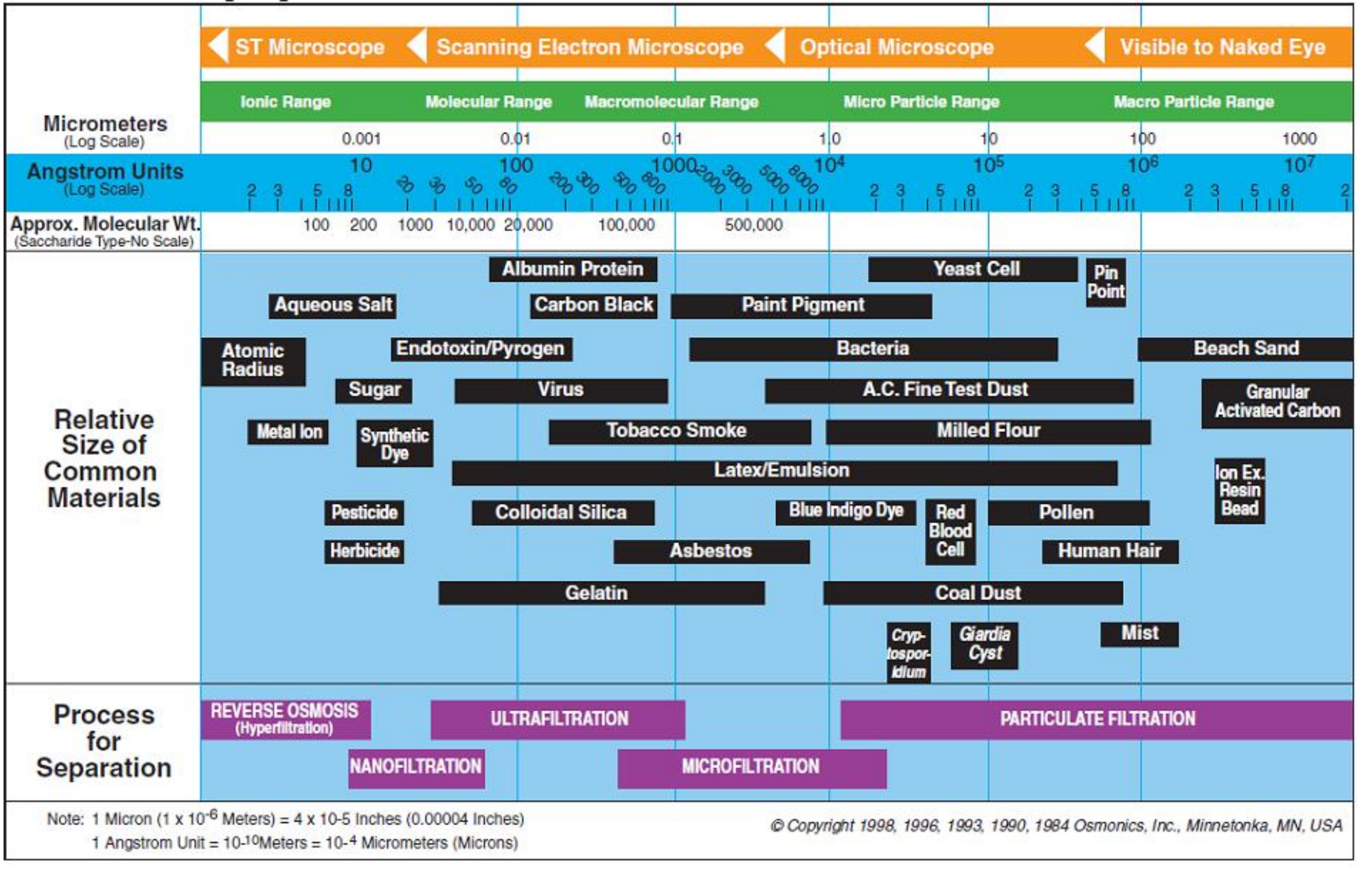
Depuis un effluent primaire	
Usage	*Combinaisons possibles (/ = ou ; + = et)*
Industrie	212(,304),305/306,401/405 ou 202/204/205/206(,315+301/302),315+303/304,305/306,401/405 ou 202/204/205/206,316+301/302,307/308,310/311(,309)(,401/405) ou 203+214(,315+301/302),(315+)303/304,305/306,401/405 ou 213(,315+301/302),(315+)303/304,305/306,401/405 ou 105,(315+)304,305/306,401/405
Potable	212(,304),305/306,401/405 ou 202/204/205/206(,315+301/302),315+303/304,305/306,401/405 ou 202/204/205/206,315+301/302,307/308,310/311(,309)(,401/405) ou 203+214(,315+301/302),(315+)303/304,305/306,401/405 ou 213(,315+301/302),(315+)303/304,305/306,401/405 ou 105,(315+)304,305/306,401/405 ou tous ceux précités
Urbain	*1* : 202/203(+214)/204/205/206/213(,401/402/403/404/405) ou 212(,401/402/403/404/405) ou 107,208/(209+)207(,401/402/403/404/405) ou 210/211(,401/402/403/404/405) ou tous ceux précités *2* : *1* avec 212(,304),305/306,401/405 ou *1* avec ou sans 212(,315+301/302)(,316+)303/304,305/306,401/405 ou tous ceux précités
Recharge de nappe	*1* : 202/203(+214)/204/205/206/213(,401/402/403/404/405) ou 212(,401/402/403/404/405) ou 107,208/(209+)207(,401/402/403/404/405) ou 210/211(,401/402/403/404/405) ou tous ceux précités *2* : *1* avec 212(,304),305/306,401/405 ou *1* avec ou sans 212(,315,301/302)(,316+)303/304,305/306,401/405 ou tous ceux précités
Environnemental et récréatif	202/203(+214)/204/205/206/213(,312/313/314)(,401/402/403/404/405) ou 212(,401/402/403/404/405) ou 107,208/(209+)207(,313/313/314)(,401/402/403/404/405) ou 210/211 ou tous ceux précités
Agriculture	Aucun ou 107 ou 105 ou tous ceux précités

Tableau A.4.- Possible combinations from a secondary effluent.

Depuis un effluent primaire	
Usage	*Combinaisons possibles (/ = ou ; + = et)*
Industrie	(304),305/306,401/405 ou (316+301/302),316+303/304,305/306,401/405 ou 316+301/302,307/308,310/311(,309)(,401/405) ou (316+301/302),(316+)303/304,305/306,401/405 ou (316+301/302),(316+)303/304,305/306,401/405 ou (316+)304,305/306,401/405
Potable	(304),305/306,401/405 ou (316+301/302),316+303/304,305/306,401/405 ou 316+301/302,307/308,310/311(,309)(,401/405) ou 316+301/302),(316+)303/304,305/306,401/405 ou (316+)304,305/306,401/405 ou tous ceux précités
Urbain	***1*** : (304),305/306,401/405 ou (316+301/302)(,316+)303/304,305/306,401/405 ou tous ceux précités ***2*** : (401/402/403/404/405) ou tous ceux précités
Recharge de nappe	***Directe*** : (304),305/306, 401/405 ou (316+301/302)(,316+)303/304,305/306,401/405 ou tous ceux précités ***Indirecte*** : (401/402/403/404/405) ou tous ceux précités
Environne-mental et récréatif	(313/314/315)(,401/402/403/404/405) ou (401/402/403/404/405) ou (313/314/315)(,401/402/403/404/405)tous ceux précités
Agriculture	Aucun ou tous ceux précités

APPENDIX B

Figure B.1.- Filtration Spectrum (Remigy et Desclaux, 2007).



More available synthesis

Title	Publication year
Technical adaptation of mediterranean cities at flood risk in climate change context	2015
Report on adaptation measures related to the management of water resources in climate change context through the SRCAE ("*Schéma Régional Climat, Air, Energie*") and the PCET ("*Plan Climat-Energie Territorial*") of collectivities	2015
Renewable energies: an alternative for production and saving electricity in the field of water and sanitation	2015
Agroforestry and Water Resources: How past practices can help improve the future	2015
The Communal Competence "GEMAPI" How to implement it ?	2015
Valuation & characterisation of environmental damage to water in France	2015
The Oudin-Santini Law: 2005-2015, a Decade on …	2015
The Circular Economy in the Field of Water	2015
Water services management changes between private operators and public structures: transfer of employees and technical means	2014
Water and green economy : challenges, risks and opportunities aound the Mediterranean	2014
Financing access for local actors to invest in water and sanitation services in Africa	2014
Water pricing and Cost Recovery: practice, experience and feedback in Europe	2014
Performance Contracts between public authority and public providers as a tool to improve the performance of water utilities	2014
Wasterwater and excreta reuse	2014
New drug pollution : risks and solution	2014
Critical analysis of water management strategies to adapt to climate change	2013
The integrated management of transitional and coastal water bodies: What is France's strategy?	2013
Sustainable cities: Water, energy and urbanism	2013
Feedback on biogas energy conversion Technical and regulatory constraints	2013

La posición de la hidromorfología en el alcance del "buen estado"	2013
La reforma de la Política Agrícola Común para 2014-2020 y la gestión del agua	2013
Drinking water supply and wastewater treatment: Public procurement contracts in France	2013
Coping with drought in the Mediterranean : The socioeconomic strategies in agriculture	2012
Hydrological and hydrogeological consequences of the exploitation of shale gas	2012
What are the local water management structures designed to implement the Water Framework Directive ? Case study of the Rhône-Méditerranée basin based on experience and innovations acquired in France	*2012*
The European Water Framework Directive / Its implementation for quantitative water resources management	*2012*
Hospital Wastewater	*2012*
What retention capacity of natural areas to absorb residual pollution from households ?	*2012*
The Environmental Quality Standards of the Water Framework Directive History, definition and implementation in France	*2012*
The impacts of France's implementation of the Common Agricultural Policy and of tax measures on wetlands	*2011*
Irrigation - Water markets : What are the impacts ?	*2011*
The performance of Sustainable Urban Drainage Systems in terms of flood mitigation	*2011*
Feedback about the implementation of the Water Framework Directive : What difficulties ? What lessons ?	*2011*
The impacts of France's implementation of the Common Agricultural Policy and of tax measures on wetlands	*2011*
Quantitative joint management of groundwater and surface water	*2010*

Find all available titles:

http://documentation.oieau.fr/publications/syntheses-techniques

648 rue Jean-François Breton – BP 44494
34093 MONPELLIER CEDEX 5

Tél. : (33) 4 67 04 71 00
Fax. : (33) 4 67 04 71 01
www.agroparistech.fr

15 rue Edouard Chamberland
87065 Limoges Cedex

Tél. (33) 5 55 11 47 80
Fax. (33) 5 55 11 47 48
www.oieau.org