Desalination and Water Treatment
www.deswater.com
6 (2009) 227–233

Market and design considerations of the 37 larger MBR plants in Europe

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Received 15 September 2008; accepted 16 April 2009

ABSTRACT

By the end of 2007, 10 years after the commissioning of the first full-scale municipal MBR plant in Europe, 37 large MBR plants with a nominal capacity greater than 5,000 m^3/d were in operation in the region, demonstrating the maturity of the technology. This article presents a review of these large MBR plants, not only in terms of market expectation, but also with regards to specific design considerations such as filtration flux, filtration layout, plant 'retrofit' and the inclusion of primary clarification. Due to the low operation costs (energy demand) as compared to side-stream membranes, submerged low-pressure filtration technologies will remain the standard for large MBR applications in the near future. At the time of the study, all the plants within this size segment in Europe were equipped by the two MBR filtration leaders GE/Zenon and Kubota, but other technologies should penetrate this market segment in the coming years.

Keywords: Membrane bioreactor (MBR); Zenon; Kubota; Large plants; References; Market; Design; Wastewater; Europe

1. Introduction

The technology of membrane separation of activated sludge, commonly referred to as ''membrane bioreactor'' (MBR), was first commercialized in the 1970s and 1980s for small and niche market applications such as treatment of ship-board sewage, landfill leachate or high strength industrial effluents [1]. MBR systems at that time were based on what have come to be known as side-stream configurations, i.e. the membrane separation step was employed in an external sludge recirculation loop, mainly with in-to-out flow through polymeric or ceramic tubular membranes. More recently, a new generation of MBR units have appeared, based on the so-called immersed filtration system, working with low negative pressure (out-to-in permeate suction) and membrane aeration to reduce fouling. This has resulted in capital and operation cost savings, which render the technology commercially viable for the treatment of municipal and domestic wastewater.

In Europe, the first full-scale MBR plant for treatment of municipal wastewater was constructed in Porlock (UK, commissioned in 1998, 3,800 p.e.), soon followed by the Büchel and Rödingen WWTPs (Germany, 1999, respectively 1,000 and 3,000 p.e.), and Perthes-en-Gâtinais WWTP (France, 1999, 4,500 p.e.). Only a few years later, in November 2002, one MBR line was commissioned in Brescia, Italy, with an initial nominal flow of 38,000 m^3/d, later increased to 42,000

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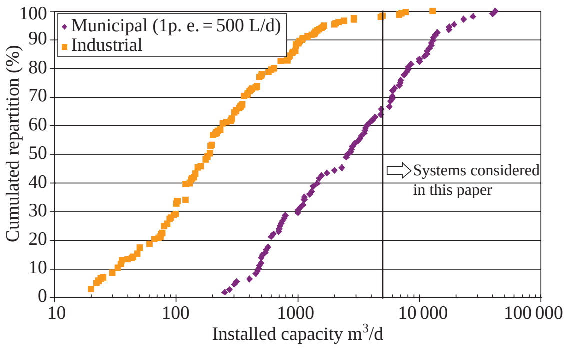

Fig. 1. Cumulate repartition of installed peak flow capacity of MBR units in Europe (by end 2005).

m^3/d. In 2004, Nordkanal MBR plant was commissioned with a design maximum daily flow of 45,000 m^3/d to serve a population of 80,000 p.e. (in Kaarst, Germany). The installations have thus grown from 'small-size WWTPs' to 'large-size WWTPs' within only a few years, and the current market size in Europe is considered to be around € 57 million per year, with a 10% annual growth rate [2].

The rapid development of the technology has resulted in regular and current technology reviews, among which some of the most informative were published by Stephenson et al. [1], MUNLV-NRW [3], Nieuwenhuijzen [4], Pinnekamp and Friedrich [5], or Judd [6]. A recent market study was also completed for the North American continent by Yang et al. [7], together with a literature survey on research activities and trends.

A recent detailed market survey performed for the European region highlighted the following features [8]:

– By the end of 2005, about 300 references of industrial applications (>20 m^3/d) and about 100 municipal wastewater treatment plants (WWTPs > 500 p.e.) were in operation, corresponding to a total installed capacity of about 130,000 m^3/d for the industrial applications and about 1 million of population equivalents concerning the municipal applications (i.e. only 0.25% of the total European population).
– In the coming years, at least 70 new MBR plants are expected to be constructed each year in Europe, from which about 50 are industrial and 20 are municipal applications. This should significantly increase the number of units in operation by the end of 2009.
– Taking the installed membrane surface as an indicator of market share (total installed surface is 670,000 m^2;), the municipal sector represented 75% of the market volume in 2003–2005.
– Immersed MBR filtration systems were predominant in both industrial and municipal sectors: during this 3-year period they represented 99% of the total installed membrane surface (GE/Zenon and Kubota representing, respectively, 63% and 30%).
– As seen in Fig. 1, the 20–80% capacity range of MBR units in Europe was 60–600 m^3/d for industrial applications (ideal size for ''package plants'') and 600–8,000 m^3/d (i.e. 1,000–16,000 p.e.) for the municipal references. The market of plants larger than 5,000 m^3/d (or >10,000 p.e.) was essentially driven by municipal applications and to date (end of 2008) consists exclusively of plants equipped with membrane modules supplied by GE/Zenon or Kubota.
– If the industrial market can be considered mature and stable, the municipal market is expected to witness further growth in the next decade under the combined effects of accelerated plant constructions and increased plant capacity.
– One can therefore expect that in the coming year a very significant share of the MBR market in Europe may consist of plants larger than 5,000 m^3/d. This segment, predominantly consisting of municipal applications, represented up to 85% of the installed membrane surface of the municipal market in 2003–2005, and increased market shares are expected in the future.

Given the significant share of larger MBR plants in the current and future European market, it seems relevant to look at the market development and specific design considerations to date of installations in this size range. For this segment, each plant is designed on a case-by-case basis and optimized to the specific site conditions. It is therefore proposed to look at specific design considerations such as mean design and operation fluxes, plant retrofitting, the presence of primary clarification and the design of filtration systems inside or outside the biological reactor.

This paper reviews the largest MBR installations commissioned in Europe to date (August 2008) with a capacity greater than 5,000 m^3/d design maximum daily flow. The reference lists and design data of the installations were provided by GE/Zenon and Kubota.

2. Market consideration

Among the 37 MBR installations commissioned in Europe to date with a capacity greater than 5,000 m^3/d design maximum daily flow, 23 were equipped with the GE/Zenon filtration systems, and 14 with the Kubota modules. As expected, the larger MBR plants essentially consist of municipal applications (32 versus 5 industrial units). The 3 recent large

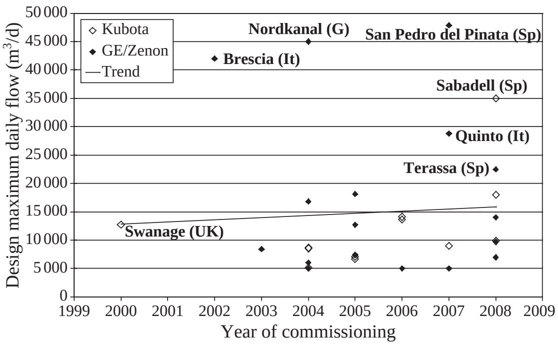

Fig. 2. Market development of large municipal MBR plants >5,000 m^3/d in Europe.

industrial references are petrochemical and refinery sites (all of them in Italy); this appears to be a relatively new sector for MBR technology.

2.1. Market development

Fig. 2 presents the market development of large MBR plants in Europe. The following remarks may be made:

– The first of the large European MBR plants was built in 2000 in Swanage (UK) and equipped with Kubota technology.
– All the large MBR installations are in the range of 5–20,000 m^3/d, with the exception of 6 plants with a nominal capacity of up to 50,000 m^3/d, 5 of them being built in Spain or Italy.
– Linear regression shows a trend of capacity increase (the mean capacity doubles every 10 years) together with an acceleration of plant construction (most plants have been erected in the past 5 years at a rate of about 6 units per year). This demonstrates that the technology has become relatively competitive and accepted in the municipal segment. The trend of accelerated construction and capacity increase is expected to be sustained in the coming decade, which underpins the market growth potential.
– The flat-sheet Kubota technology appears to be especially implemented in the size range 5-20,000 m^3/d, while all plants of greater capacity are being equipped by GE/Zenon, with the exception of Sabadell which was commissioned in 2008.
– Table 1 presents a non-exhaustive list of constructed or awarded large MBR plants worldwide, which will become major references of different suppliers. In Europe, the construction of very large MBR plants (>100,000 m^3/d) should however remain marginal, even though they will attract much attention, as for this size the use of tertiary filtration is expected to be competitive unless plant footprint is a major criterion [9,10].

2.2. Geographical distribution

Figs. 3 and 4 present the geographical distribution per supplier, respectively, of all MBR units of a capacity greater than 500 p.e. and commissioned in Europe by the end of 2005 (as reported in [8]), and of all larger MBR plants (>5,000 m^3/d) constructed by the end of 2008.

Some interesting conclusions can be drawn, as follows:

– Despite numerous MBR filtration technologies being commercialized in the past year in Europe, by the end of 2008, only Kubota and GE/Zenon have supplied filtration systems to the larger European MBR plants. This confirms the technical and commercial advance of these two technologies. One can however mention that recent large-scale contracts were also awarded to other MBR market players (see Table 1) and intense competition between suppliers is expected in the coming years, especially in the segment 5,000–50,000 p.e. (i.e. approx. 5–30,000 m^3/d).
– The four largest MBR plants are shared between Germany, Italy and Spain. The ranking of most countries applies to both size ranges: this demonstrates the homogeneity of the European market in time (evolution between 2005 and 2007) and in terms of plant capacity for the leading countries, at the exception of Spain which shows a quick development of the MBR technology in the past 3 years in the segment of large plants.
– Cyprus appears as a special case: no MBR installation was reported by the end of 2005, but 1 large reference is in operation 3 years later, with another commissioning pending in 2009. This may be in part due to the development of MBR projects in that country through UK and French firms familiar with the technology. Given the size of the population in this country, the market is however expected to be saturated very soon.

The cases of Spain, Italy, Cyprus, but also the Middle East states (besides the Al Ansab plant in Oman, 5 large MBR plants (over 5,000 m^3/d) will be commissioned by the end of 2009 with Kubota, and 6 with Zenon) indicate that the specific climate and water management conditions around the Mediterranean basin appear favorable to the erection of large MBR plants. Although countries like Greece or Portugal, among the poorest nations in the EU, do not yet host any large MBR units, we can expect

Table 1
Constructed or awarded larger MBR plants per supplier in Europe/Middle-East and worldwide

Supplier	Location	Country	Design maximum daily flow (m^3/d)	Commissioning year
GE/Zenon	Lusail	Qatar	60,000	2007
Siemens/Memcor	Bei Xiao He/Beijing	China	80,000	2008
Kubota	Al Ansab	Oman	78,000	2009 (planned)
Norit/X-flow	Palm Jumeirah	Dubai	17,000	2009 (planned)
KMS/Puron	Avranches	France	15,000	2009 (planned)
GE/Zenon	Jumeirah Golf Estates	UAE	269,000	2009 (planned)
KMS/Puron	Griffith	Australia	30,000	2010 (planned)

market opportunities in the near future within such countries.

2.3. Capital and operation costs

Depending on the size and local conditions, the specific capital costs of these plants ranged between 200 and 400 €/p.e. The total specific energy requirement of modern and optimized large scale MBR plants is often reported to lie between 0.6 and 1 kWh/m^3. This is less than required by the early generations of low-pressure membrane systems (Judd et al., 2006), but remains greater than conventional activated sludge with tertiary disinfection (sand filtration + UV or tertiary membrane filtration with microfiltration or ultrafiltration, see [11]).

3. Design consideration

3.1. Mean design and operation flux

Based on the design maximum daily flow, the range of design maximum daily net flux of the municipal installations is 14–48 L/h m^2 with the Kubota system (mean value at 32 L/h m^2), and 20–37 L/h m^2 with the GE/Zenon modules (mean value at 29 L/h m^2). To be noted that the real average operation net flux is in most times significantly lower, and lies by about 18 L/h m^2 for both systems (range 8–25 L/h m^2). The broad range of design and operation fluxes observed on both technologies is surprising for similar domestic applications. This cannot be accounted for a difference between new plants and 'retrofit' plants, neither by less or more conservative design depending on plant capacity (Fig. 5). As seen in Fig. 6, the averaged trend of the design maximum net flux and operation mean flux have in the past 6 years moderately increased by only +3 L/h m^2. This must then be possibly explained by the combination of the 3 following trends:

(i) *commercial risk*: due to the greater prices of modules, more operational risks were taken in the early days in terms of nominal flux to make competitive offers,
(ii) *technology development*: greater sustainable flux may be achieved with lower specific aeration demand per unit volume of treated permeate, and

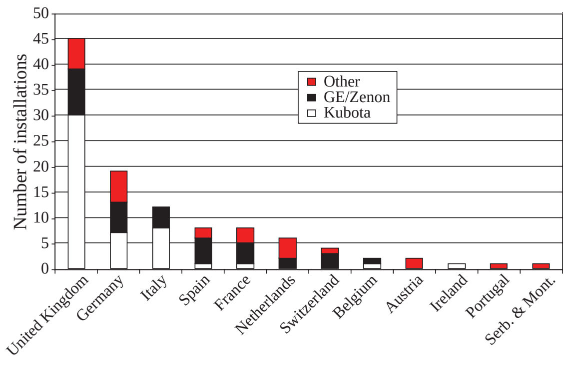

Fig. 3. Geographical distribution of municipal MBR plants >500 p.e. by the end of 2005 in Europe per supplier (109 references in graph, adapted from [7].)

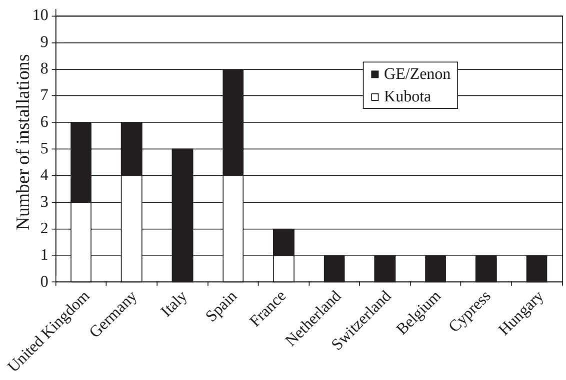

Fig. 4. Geographical distribution of municipal MBR plants >5,000 m^3/d by the end of 2008 in Europe per supplier (32 references in graph).

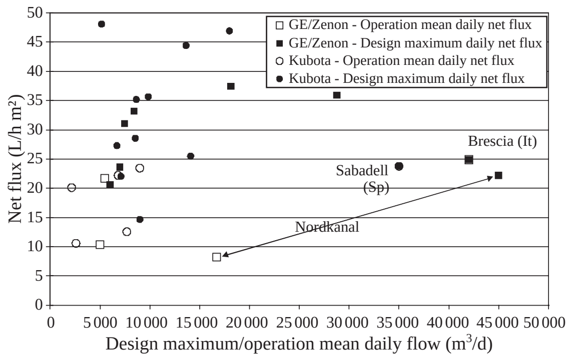

Fig. 5. Design maximum and operation mean daily net flux in relation to the plant capacity.

(iii) *tender specifics*: recent projects sometimes specify a maximum design flux to reduce the operational risk.

The difference between design maximum and operation mean daily fluxes may be close to zero for plants designed in parallel to conventional activated sludge systems which can absorb the peak flows, and work under constant flow (''hybrid'' systems such as in Brescia with GE/Zenon in Italy, or Sabadell with Kubota in Spain). In contrast, some plants prone to rain weather flow exhibit a strong discrepancy between design maximum and operation mean daily fluxes, with a typical peaking factor of 2–3. The case of Nordkanal is a good example of this: designed with a relatively conservative flux of 22 L/h m^2, the effective mean daily flux is as low as 8 L/h m^2 due to infrequent rain event. In addition, due to specific requirements the Nordkanal plant was designed for $N - 2$ redundancy, i.e. even under worst case conditions (lowest temperature) the maximum flow rate must be treatable with $8 - 2 = 6$ membrane trains in operation for an unlimited period of time.

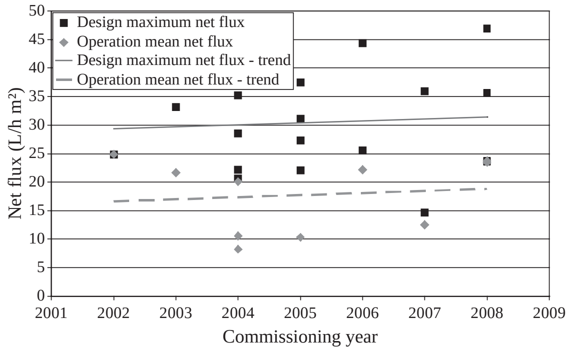

Fig. 6. Evolution in time of design maximum and operation mean daily net flux.

Table 2
Statistic of larger municipal European plants in regards to retrofitting and hybrid options

	Total	100% new	Retrofitting	Of which hybrid
GE/Zenon	20	14*	6	4
Kubota	12	6	6	2
Total	32	20	12	6

*2 installations reusing roadwork only of existing site.

3.2. New plants or retrofitting

The retrofitting or upgrading of existing conventional activated sludge plants may be cost-effective with the MBR process compared with other solutions. MBR technology is often competitive to improve the hydraulic or biological load of a plant while increasing treatment performance and making best use of the existing infrastructure [12-14].

Table 2 presents a synthesis of the design option of the larger European municipal MBR plants with regards to the options ''new plants'', ''plant retrofits'' or ''hybrid systems'' (in case of retrofitting) and demonstrates the large occurrence of MBR plants for plant retrofitting. About 40% of the larger European municipal MBR plants were constructed within existing sites. In half of these cases (i.e. 20% of total), the designers decided to resort to hybrid systems. In the latter cases, the MBR handles from 25% up to 63% of the total wastewater flow, and the rain weather flow is usually diverted to the conventional activated sludge plant in order to keep a relatively constant filtration flux. It can be observed that both systems supplied by Kubota and GE/Zenon can be similarly used for all options. It should be noted that no new plant was purposely constructed as a hybrid system, although where complete disinfection is not required this may be an interesting option to address situations with high peaking factors.

3.3. Primary clarifier

All the MBR plants in operation today in Europe have a capacity under 100,000 p.e., and most of them are designed for aerobic stabilization with a sludge age greater than 25 days. Primary clarification therefore typically was not considered for those plants, as it was not economical enough, except for cases of 'retrofit'. For larger MBR plants >100,000 p.e. primary clarification with shorter sludge age can however be economical and is included in recent design considerations for plants with a capacity greater than 20,000 m^3/d.

Table 3
Statistic of larger municipal European plants in regards to ''Internal'' or ''External'' layout options

	Total	Internal	External	Of which retrofitting
GE/Zenon	20	2	18	6
Kubota	12	4	8	5
Total	32	6	26	11

In addition to the well-known advantages of primary clarification for conventional plants (such as smaller bioreactor volumes, lower oxygen demand, reduced surplus sludge volumes, enhanced phosphorus removal, increased energy recovery, etc.) there are benefits for MBR systems due to improved removal of solids and fibers. Enhanced flocculation/coagulation may be also beneficial to reduce long term organic fouling.

3.4. Inside or outside?

As pointed out by Brow et al. [15], the issue of locating the immersed membrane modules within the biological reactor or in an external dedicated filtration reactor is a very crucial choice which impacts not only the overall design of the plant, but also the operation and related costs. The ''external'' option necessitates the usage of a recirculation pump handling up to 500% of the filtrate flow and may be potentially more costly to build, however it shows other advantages. Brow et al. [15] pointed out that the ''external'' layout option may provide enhanced ''cross-redundancy'' between the biological and filtration capacities. The separation of the filtration unit from the bioreactor may be beneficial in case of advanced nutrients removal [16-19], as it may enable independent adjustment of MLSS concentration both in the biological tank(s) and the membrane tank(s), and may enhance dissolved oxygen control for intermittent nitrification/denitrification (CWA, 2008) [20]. Moreover, in certain systems having separate tanks may facilitate the maintenance (inspections, maintenance chemical cleanings).

Table 3 summarizes the layout selected by the designers of the larger European municipal MBR plants. The results show that for both membrane systems, the large MBR plants are most often set up with an external dedicated filtration vessel. All but one reference constructed with the ''internal'' layout were commissioned before year 2005. Nowadays, large MBR systems are typically designed with separate membrane tanks perhaps for greater control of biological conditions and easier maintenance cleaning. It can also be observed that with only one exception, all ''retrofit'' plants are designed with external filtration layout. This could be because in most cases the depth of the existing tanks may not be adapted to the height of the filtration systems: it therefore could make more sense to construct a new tank to house the membrane modules [19].

4. Conclusion

By the end of 2008, 10 years after the commissioning of the first full-scale municipal MBR plant in Europe, there were 37 large plants (>5,000 m^3/d), homogeneously distributed throughout European countries adopting the MBR technology, of which 32 were municipal installations. Depending on the size and local conditions, the specific capital cost of these plants ranged between 200 and 400 €/p.e. Expected growth is about 6 large installations per year, with the doubling of operating capacity within 10 years. The increased number and capacity of plants shows that the municipal market is still growing and is not yet saturated. Due to the low operation costs (energy demand) as compared to side-stream membranes, submerged low-pressure filtration technologies will likely remain the standard for large MBR applications in the near future. At the time of the study all the plants within this size segment in Europe were equipped by the two MBR filtration leaders GE/Zenon and Kubota, but increased competition is expected with recent successes of several new European and Asian membrane technologies and other suppliers should penetrate this market in the coming years.

The average value of design maximum daily net flux for the plants investigated is 29 and 32 L/h m^2 for both technologies. This flux rate drops to 18 L/h m^2 in both cases for average daily operation (dry weather flow). The greatest variability is noted for plants handling rain weather flows. A typical peaking factor of 2–3 for such plants is not untypical. Primary clarification is up to now not included in plant designs, except for existing plant retrofits, but it is expected that including primary treatment and sludge digester may be economical for very large MBR plants. Most large MBR plants and the majority of retrofit systems are designed with an external filtration layout, where the membrane module is located in a dedicated vessel. About 40% of the installations involved existing plant upgrades or retrofits and 20% were ''hybrid'' plants (a combination of MBR and conventional activated sludge plant). Hybrid systems may remain in significant demand, particularly in Central and Eastern

Europe where existing infrastructure requires revamping. Water reuse should motivate large MBR projects in southern Europe with emerging markets expected in water-scarce but poorer countries such as Greece and Portugal.

Acknowledgements

The study reported in this article was performed within the FP6 European project ''AMEDEUS'' (Contract No. 018328, www.mbr-network.eu). The Berlin Centre of Competence for Water acknowledges gratefully the European Commission and Veolia Water for the financial support.

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