Membrane bioreactors for sustainable water management

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Published in "Everything about Water", Issue December 2007

Introduction

The Membrane Bioreactor (MBR) process (membrane activated sludge process) is an advanced wastewater treatment technology and constitutes a suspended growth activated sludge system, which instead of secondary clarifiers utilises low-pressure membranes for solid/liquid separation. As opposed to secondary clarification, the quality of solids separation is not dependent upon the mixed liquor suspended solids concentration, or the settling characteristic. Hence the fact that MBRs can operate with much higher mixed liquor suspended solid concentrations, which provides an intensified biological process. Accordingly, the two major benefits of the MBR process are substantially reduced land and space requirements, and the reclamation of water (permeate) of excellent quality, which is a valuable source for higher demand reuse applications.

In recent years, increasingly stringent purification standards, the growing public awareness of water issues, the need for wastewater reuse and falling membrane prices have led to a boom in membrane bioreactor (MBR) technology. At present, approximately 800 MBRs with a total capacity of nearly 1.2 million m³/day are treating municipal wastewater worldwide. Indeed, since 2000, the number of plants has tripled and total capacity has increased by a factor of 20 (Pinnekamp 2007). Most of the plants have been built in Asia (303 MBRs) followed by North America (295 MBRs), while in Europe only 169 MBRs have been realised. However, if the total capacities are considered, the picture is quite different, i.e. North America: 492,000m³/day, Europe: 423,000 m³/day, Asia: 268,000 m³/day. A similar differentiation is provided when the membrane systems are considered. Plate modules predominate with 485 MBRs, as compared to 312 MBRs employing hollow fibre membrane systems. Moreover, the total hollow fibre membrane capacity amounts to 800,000 m³/day, while plate membrane systems only handle 463,000 m³/day. It can also be said that in North America hollow fibre systems are used most frequently and in Asia, plate modules.

As mentioned above, in comparison with the classical activated sludge process, the major advantages of the membrane activated sludge process are its far lower space requirement and much higher effluent quality. The engineering company, VA TECH WABAG, was one of the first to recognise the market potential of this technique for direct discharge and wastewater reuse applications and believes that the current decline in membrane prices and water shortages will further encourage the use of this highly efficient process. Some of the major MBR projects completed in recent years by VA TECH WABAG in different markets (United Kingdom, Germany, Switzerland, China and Oman) are subsequently highlighted.

Case studies

WABAG already successfully used membrane bioreactors with pressure-driven external ultra-filtration (UF) systems in the first half of the 1990s for landfill leachate treatment. When by the mid-1990s submerged MBR modules finally reached market maturity, WABAG began to build several MBR facilities using submerged plate membrane modules under a licence from the Japanese manufacturer Kubota. A perfect example showcasing this technology is the MBR in Daldowie/UK (capacity 12,000 m³/d), where process water (effluents from belt pressing, rotary drum vacuum filtration and centrifugation) from the central sludge treatment plant servicing the **Greater Glasgow** area is purified for direct discharge into the River Clyde. Based on BOD, the Daldowie facility (Fig.1) even boasts a capacity of 300,000 population equivalents (PE) and is thus one of the largest facilities of its kind worldwide.

Fig.1 Daldowie MBR – Nitrification Process Step

In the planning phase, SBR technology was also considered for liquor treatment, however due to large organic loading fluctuations, MBR technology was seen as providing much higher process safety (Judd 2007). The guarantee values are < 10 mg/L for BOD, < 10 mg/L for TSS and < 3 mg/L for NH_4-N. The sludge liquor is characterised by high ammonium (e.g. average value in the commissioning phase: 210 mg/L) and organics levels (e.g. COD average in the commissioning phase: 3,000 mg/L). The nitrification and carbon removal performance has been excellent, e.g. in the commissioning phase, nitrification was > 99%, i.e. the average permeate NH_4-N concentration was 0.12 mg/L and COD removal was > 98%, i.e. the average permeate COD concentration was 45 mg/L.

Since technical and cost factors persuaded WABAG to convert to Zenon MBR systems in 2000, the company has become a significant market player with regard to the completion of facilities with submerged, Zenon hollow fibre membrane modules. Examples include the MBRs at Nordkanal (Germany), Schering (Germany) and Waedenswil (Switzerland).

The facility in **Nordkanal** services a population of 80,000 and is thus the largest MBR (total membrane area 84,500 m²) used in a municipal sewage treatment plant in Germany. It is also unique due to the fact that the submerged UF modules are integrated into the nitrification stage (Klegraf 2006). This option has various advantages, such as a low space requirement. Moreover, although the increased risk of membrane fouling was accepted as a potential process disadvantage, plant operation thus far has revealed that there is no need for more frequent cleaning for the removal of biofouling.

After three and a half years of operation, the MBR (Fig. 2) shows excellent and stable operating results (Engelhardt 2007). The COD elimination rate is around 97 %. Even at inlet concentrations of more than 800 mg/L, the peak outlet concentrations are less than 32 mg/L, while the annual average concentration is lower than 20 mg/L. Permeability has been successfully maintained at a high level due to the flexible membrane cleaning strategy and an effective 1 mm mesh sieve is employed to prevent membrane clogging by fibres.

Fig.2 Nordkanal MBR – Membrane Scouring and Permeate Pipes

The MBR at **Schering´s** Bergkamen-based facility purifies effluents from chemical /pharmaceutical manufacturing (metal alkyls, x-ray contrast agents, resins, pharmaceuticals) for direct discharge into the River Lippe. This requires inter alia a minimum of 85 % COD removal. The MBR has a hydraulic capacity of 4,800 m^3/d and handles organic loads of up to 18 t of COD (Achtabowski 2006). It is thus the largest MBR used in German industry. The main reasons for the employment of an MBR are the enrichment of specialised bacteria for the degradation of recalcitrant or toxic organic compounds and the provision of a safety barrier (UF) for biomass, especially when biological process disruptions occur. This is very important for the fulfilment of the aforementioned COD standard at all times, as biomass losses would cause a substantial increase in this parameter in the plant outlet. In the meantime, four years of experience have demonstrated that the process offers stable running and that the standards for direct discharge have been safely met. An aerial view of the plant can be seen in Figure 3.

Fig.3 Schering MBR – Aerial View

Waedenswil is the largest MBR in Switzerland, servicing 22,000 PE. In this facility the membrane activated sludge process is used to ensure that the stringent thresholds for suspended solids and phosphorus are safely met, and to provide optimum protection for the waters of Lake Zurich, which is one of the largest potable water sources in Switzerland. Figure 4 shows the MBR and the existing conventional activated sludge process in parallel operation.

Fig.4 Waedenswil MBR

Table 1 summarises a performance comparison between the MBR and the activated sludge process (Baggenstos 2006). As is evident, the cleaning efficiency of the MBR is far superior to that of the conventional process. For example, the Dissolved Organic Carbon (DOC) concentration in the MBR effluent is 50% lower, a fact that can be explained by the intensified biological process used in the MBR (higher biomass concentration, lower F/M). The Chemical Oxygen Demand (COD) concentration in the MBR effluent is even lower at 65% due to both the better DOC and the improved total suspended solids (TSS) removal.

Table 1 Waedenswil MBR – Comparison MBR and conventional Activated Sludge Process

Effluent-Parameter	MBR	Conventional Activated Sludge
BOD [mg/L]	2.3	7.9
COD [mg/L]	14	40
DOC [mg/L]	5.7	11.4
NH_4-N [mg/L]	0.5	27
TSS [mg/L]	0	6.1
P_{tot} [mg/L]	0.037	0.23

In recent years, the choice of MBR systems has greatly diversified without any noticeable difference in efficiency among the various options. This explains why in 2005 WABAG adopted a strategy of choosing the best and the cheapest technical solution available on the market for each specific task. MBR projects where this has been achieved include Bei Xiao He in Beijing (Memcor system; Q = 60,000 m³/d) and Al Ansab in Muscat (Kubota system; Q = 53,000 m³/d, both of which produce water for reuse.

The city of **Beijing** is confronted with water quality problems and a water shortage (sinking groundwater levels). In order to cope with these problems, the aim is to reuse 50 % of the wastewater treated by the year 2008 (Beijing Drainage Group, 2005) (Ernst, 2005). This is essential for sustainable development, which within the framework of the 2008 Olympic Games, has been allocated the highest priority.

In May 2006, the Beijing Drainage Group awarded a contract for the Bei Xiao He Water Reclamation Plant to Siemens Water Technologies and VA TECH WABAG, which is in charge of the overall process design. The plant under construction basically consists of a pre-treatment system, a membrane bioreactor (Memcor; Fig. 5) with a capacity of 60,000 m³/d (total membrane area is 183,000 m²) and a partial stream reverse osmosis system, which produces "high-quality reclaimed water" (3,000 m³/d). This will be reused in the central area of the Olympic Park and mainly serve the supply of a small lake with fountains. The quality of the RO permeate has to meet surface water classification III (BOD_5 ≤ 4 mg/L, COD ≤ 20 mg/L, total nitrogen ≤ 2 mg/L, total phosphorus ≤ 0.2 mg/L, etc.).

50,000 m³/d are to be pumped into the urban recycled water network. The bases for the quality of the reclaimed water (MBR permeate) are provided by various national water quality and reuse directives. In each case, the parameter applied is the most stringent of those contained in these directives (BOD_5 ≤ 6 mg/L, COD ≤ 30 mg/L, suspended solids ≤ 2 mg/L, ammonia nitrogen ≤ 1.5 mg/L, total phosphorus ≤ 0.3 mg/L, etc.). Start-up of the reclamation plant is scheduled for January 2008, in order that the project can be completed in time for the Olympic Games in August 2008.

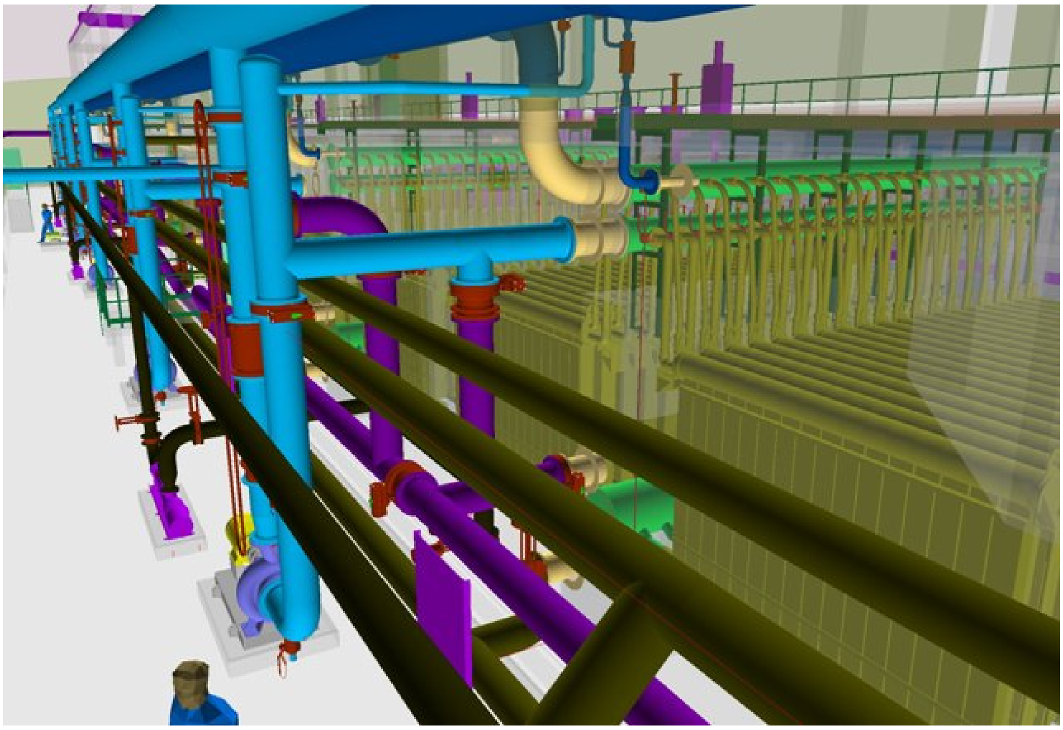

Fig.5 Beijing/Bei Xiao He MBR

Muscat, the capital of the Sultanate of Oman, is the political and economic centre of the country and is also an increasingly popular tourist venue. The population growth is correspondingly high and as Muscat is situated in an arid region, it is a water stressed city. In order to cope with water management needs, the government has established the Oman Water Services Company which has developed an ambitious wastewater master plan that foresees inter alia the serving of 90 % of the population by 2017 and starting in 2008, advanced sewage treatment including the supply of reclaimed high quality irrigation water. For this purpose, an MBR process with a capacity of 53,000 m³/d is to be employed in the Al Ansab WWTP.

The main contractor for this project is Galfar Engineering & Contracting C. LLC, which awarded an EPC contract to WABAG India. This contract consists mainly of the engineering, the supply of mechanical, instrumentation and control equipment, the supervision of installation, and the commissioning of the entire plant. In addition, the supply of the DCS and SCADA for the WWTP and the sewage & irrigation network is included. Kubota membranes are employed (124,000 flat-sheet cartridges with a total membrane area of 99,000 m²) in the MBR process, which is designed for carbon and nitrogen removal. The reclaimed water quality is as follows: BOD < 10 mg/L, TSS < 10 mg/L, NH_3-N < 1 mg/L, NO_3-N < 8 mg/L, fecal coliforms < 2.2 c /100 ml, viable helminth ova < 1/L and turbidity < 2 NTU (all at 95%ile limits). Start-up of the plant will be in Q.? 2008. Figure 6 shows rotary drum screens (opening 3 mm) which are employed for the MBR pre-treatment.

Fig.6 Al Ansab MBR – Wastewater Sieving

MBR Research and Development

The membrane activated sludge process is a relatively new technology, which still demands considerable R&D, especially in the fields of wastewater pre-treatment (fibre separation), chemical and mechanical membrane cleaning, fouling and scaling. Additional research is going into alternative membrane systems, which offer advantages with regards to chemical cleaning, specific flow rate, space requirement, etc. In response to this challenge, WABAG has developed its MARAPUR™ process for market launch. This process relies on the use of compact membrane modules (MEGAMODUL™, Fig.7), which enable the aforementioned advantages to be achieved. Unlike most other MBR systems, the technique is based on an inside-outside filtration flow. This requires efficient fibre separation in the raw effluent, but also offers defined filtration, combining a higher specific flow rate with the option of targeted purification.

Figure 7 WABAG MEGAMODUL™

WABAG is currently working on a joint project with a leading machine manufacturer (Passavant-Geiger), which has the aim of upgrading a sieving machine in such a way that a high level of pre-treatment efficiency is attained at reasonable cost. This is achieved by inserting a mesh screen and developing an innovative sieve cleaning concept. The adequate pre-treatment of municipal wastewater, i.e. the elimination of fibres and hair, is an essential element in the employment of any MBR system and especially the MEGAMODUL, due to the inside-outside filtration mode. Conventional primary clarification cannot be considered, as MBR plants are only realised with simultaneous sludge stabilization. Thus wastewater sieving is the most appropriate process for MBR pre-treatment.

Slot sieves with gap widths of 0.5 mm and mesh sieves with mesh sizes of 1 mm have already been employed (Frechen, 2006). However, the filter elimination performance of these sieves is insufficient for MEGAMODUL pre-treatment, which uses multi tubular membranes with a 5 mm inner diameter (Fig. 7). The ability of short cellulose fibres to crosslink and form larger aggregates can be a special problem for the MARAPUR process. For the solution of this problem, VA TECH WABAG employs the aforementioned fine sieving process, which uses a drum sieve with a mesh size of 0.25 mm (Klegraf 2007).

Initial sieving results with a mesh size of 0.25 mm are summarized in Table 2. The performance accomplished guarantees the safe and reliable operation of the MARAPUR process and is also an interesting option for other MBR processes. However, the fine sieving process still has some optimization potential. Therefore, in the upcoming testing phase, parameters such as mesh size (0.1 - 1 mm) and sieve machine specific settings (circumferential, etc.) will be examined.

Table 2 Sieving results

Fibre elimination	
> 1 mm length	100%
0.2 - 0.5 mm	95%
< 0.2 mm	90%
Solids elimination	300 mg/L
Retaining concentration	25%
Specific sieve performance	20 $m^3/m^2 \cdot h$

Current pilot testing at the Vienna Main Wastewater Treatment Plant will be completed in Q.1 2008. The first large-scale customized MARAPUR plant using fine sieving and the MEGAMODUL should then be installed in the second half of 2008.

Conclusion

The MBR process has become a key technology for both water reclamation and reuse and for the higher purification targets that have to be met, e.g. when direct discharge into a sensitive recipient is the aim, i.e. an indispensable process within sustainable water management. Due to its benefits, such as a low space requirement, excellent effluent quality and falling membrane prices, the number of plants and total installed capacity are growing very quickly. Therefore, a lot of experience is already available, which means that MBR has become a proven process. Nonetheless, it still offers high optimisation potential for pre-treatment (sieving), mechanical and chemical cleaning, fouling and scaling prevention, membrane life and a reduction in energy demand. For the engineering company, VATECH WABAG, it is therefore essential that continuous research and development be conducted in tandem with innovative application engineering for the upgrading and optimisation of the technology, in order that it can maintain its leading position in the MBR field.

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