



Membrane bioreactor for domestic wastewater: current expectations from the Dutch Water Authorities

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In 2000, a large-scale pilot study was started into the use of membrane bioreactors (MBR) for the treatment of municipal wastewater in the Netherlands. Under Dutch conditions, with wastewater treatment plants having to handle large volumes of rainwater, a very compact plant should be able to bring about a considerable improvement in effluent quality. Lower membrane costs were also predicted. Moreover, significant cuts in energy consumption appeared feasible. It was found that the flux can be increased, so that less membrane surface area is needed. The membrane cleaning procedure can also be improved. Furthermore, it was found that a significant improvement in the quality of the effluent can be achieved, although some expectations, especially with regard to micro pollutants, could not be fulfilled. It proved possible to reduce energy consumption, but not to the extent required, and this, together with the higher costs of an MBR, is still a major bottleneck with regard to future (large-scale) applications. In certain situations, however, an MBR, possibly in hybrid form, may be the best solution.

Artist's impression of the Hilversum WWTP's office building; the plant itself will be constructed in the hill (contaminated soil).

Pilot research has been carried out in the Netherlands since the beginning of 2000 on the use of membrane bioreactor (MBR) technology for domestic wastewater treatment[4].

Based on experiences abroad, full-scale applications were expected to be possible in the short term. Several wastewater treatment plants were scheduled for an MBR upgrade for different reasons[3),6),8)]. With respect to the WWTPs at Beverwijk (452,000 p.e.), Hilversum (91,000 p.e., 1,500 m^3/h) and Dordrecht (265,000 p.e.), lack of space to accommodate an extension played an important role. For the Hilversum and Varsseveld (23,150 p.e.) WWTPs and the smaller Maasbommel WWTP (7,400 p.e.), another reason to consider MBR technology as an option was the required effluent quality.

One major expectation with respect to the MBR was a superior effluent quality. The aim was to achieve maximum tolerable risk (MTR) quality without major problems, and the expectation was that many micro pollutants would be removed more efficiently when compared to conventional techniques. Examples of micro pollutants are heavy metals, pesticides and endocrine-disrupting compounds. These expectations were not based on research data, however, and the ongoing research programme was expected to confirm them. Neither process engineers nor decision-makers had any serious doubts about the potential of the MBR.

Problems in development

Although the aim was to develop a large-scale practical application, some problems had to be solved five years ago. The MBR was much more expensive than conventional techniques, especially when treating large hydraulic peak flows. Combined sewerage systems dominate in the Netherlands, resulting in large-volume flows during storm weather. Another disadvantage was the higher energy requirement caused by intensive membrane aeration and by lower aeration efficiency in the activated sludge tanks.

Some uncertainties remained, for example various operational aspects and the lifetime of membranes. There were several membrane suppliers, but it was uncertain which supplier and which system were favourable.

Foreign experiences

As many MBR facilities had been built abroad prior to 2000, the suggestion was to copy such concepts and use them in the Netherlands. It became clear that further research was required for several reasons before MBR technology could be applied in the Netherlands.

The first reason was the scale of application. Many of the previous plants were built in Japan and have a very small capacity. Factors such as costs and energy requirement are less decisive at smaller scales. Copying such concepts for large-scale applications would result in extremely expensive MBR facilities.

The second reason was the required effluent quality. Several MBR plants have been built in the UK, for example, but none of them has reached MTR quality. In some cases, the plants are not even required to remove nitrate. As a result, such MBR plants are of a much simpler construction than those built to meet MTR quality.

Several MBR plants in Germany were built to produce an improved effluent quality. The same problems arose at those plants as during the pilot research programme in the Netherlands, with the conclusion being that some of them could have been built more efficiently with the knowledge we have now acquired.

Results of five years of research

Research involving pilot plants has been carried out at Beverwijk, Hilversum and Maasbommel for the past five years[5,7]. A large number of suppliers have demonstrated their MBR systems and it was possible to achieve many optimisations. The research has brought MBR technology for MTR quality to the point where large-scale application is now possible. Note that five years ago, it was already expected that the technology would advance almost to this point.

Membrane performance improved impressively following the research, resulting in higher permissible fluxes and, as a result, in only a limited membrane surface being required. This has had a favourable impact on investment costs, operational costs and the energy requirement.

The energy requirement itself has also been optimised. Discontinuous aeration in the membrane tanks limits the energy requirement. Improving the biology may have a favourable effect on the alpha factor, and therefore on the aeration efficiency in the activated sludge tanks. Sludge concentrations of 20 g mlss/l turned out to be unfavourable, and design concentrations are currently limited to approximately 10 g mlss/l. Even with this restriction, the MBR can still be considered very compact.

Improved pre-treatment is essential for safe operation. Screening at less than 1 mm will considerably reduce the risk of membrane failure. In addition, knowledge of chemical cleaning contributes to the safer operation of MBR plants.

MBR pilot plant at the Maasbommel WWTP.

The effluent quality was less favourable than expected, however. It may still be possible to achieve MTR quality for nitrogen (2.2 mg/l) and phosphorus (0.15 mg/l), although several pilot plants were only able to reach these values after addition of an external carbon source and an iron salt.

With respect to micro pollutants, the results were disappointing. At Maasbommel, the effluent of the pilot MBR was compared to the effluent of the conventional WWTP[1,7], and no significant difference was found in the removal of micro pollutants. Most of these components may well be dissolved or adsorbed to natural organic matter and thus able to bypass the membranes. Although the MBR and the conventional effluent did not differ significantly with respect to the measured concentration of endocrine disrupting components, the endocrine potential was 70% lower.

The MBR was an effective disinfection option. Both bacteria and viruses were found to have been reduced to very low effluent concentrations.

Present status

Although much progress has been made, MBR plants are still more expensive than conventional activated sludge systems built according to the latest designs. More effort will be required to achieve a further cost reduction. Costs can be reduced by improving membrane performance, and the unit costs of the membrane surface may also decrease in the future due to the larger-scale application of MBR. More full-scale plants will have to be built to achieve both factors.

The energy requirement for MBR still exceeds the requirement for conventional activated sludge systems. The requirement can be further optimised to some extent by limiting the membrane surface, but also by optimising the performance of the biology, improving the alpha factor and consequently the aeration efficiency. Full-scale applications can contribute to both developments. From the point of view of sustainability, it should be noted that a further reduction of the energy requirement is considered essential.

Several pilot and full-scale experiences demonstrate that the operation of an MBR is much more critical than the operation of a conventional plant. Well-trained process operators are required, as well as a sophisticated process control and automation system. Basically, this is an issue that can be solved, but it will require more attention. It will be easier to handle this aspect when more full-scale MBR plants are in operation.

The effluent quality falls short of the expectations of five years ago. There is hardly any doubt as to the potential of the MBR with respect to nitrogen and phosphorus removal, but it is unlikely to remove micro pollutants effectively enough. On the other hand, MBR effluent is free of suspended solids and is suitable as a starting point for more advanced techniques when further treatment is indicated. Clarifier overflow is less suitable at this point. The MBR was also shown to be an efficient technology for disinfection.

What is the future?

Because MBR still has two major disadvantages (costs and energy requirement), the question is whether the MBR technology has a future in the Netherlands. In spite of these disadvantages, there are still several good reasons to embark on the full-scale application of MBR. The main reasons will be discussed below.

Although effluent quality does not live up to the original expectations, especially in respect of micro pollutants, it is still better than the quality achieved by conventional treatment. Suspended solids are absent in the effluent; as a result, nitrogen, phosphorus and heavy metals, part of the suspended solids, are reduced to some extent. In theory, the concentration of micro pollutants can also be reduced, as these components will be partly adsorbed to suspended solids. Further research on this possibility is necessary.

The MBR blocks all bacteria and some viruses. Disinfection is not very common in the Netherlands, but is favourable from a hygienic point of view.

A second reason to select MBR technology is the compact set-up of MBR plants. The space available to upgrade WWTPs is sometimes limited. This problem is expected to grow in the future, as the population figures rise and urban areas expand quickly.

A further advantage besides the space-saving aspect is that MBR plants can be covered more easily than conventional plants, thereby limiting the environmental impact in terms of noise and odour. Occasionally, it may be easier to introduce a short-term extension in an MBR plant than a conventional one.

A third reason in favour of MBR is the possibility of reusing WWTP effluent. MBR effluent in itself may not yet be suitable for direct reuse, but in combination with other techniques MBR can play an important role in the production of water for several different purposes, for example agricultural use and industrial water of different qualities. Its direct reuse in drinking water production is not very likely in the Netherlands, but it may be a possibility in more drought-prone regions of the world. An example of the direct reuse of wastewater to produce drinking water can be found in Namibia and Singapore.

Further development

In view of the potential of the MBR, more research will be necessary to solve the cost and energy requirement problems. These two aspects have been optimised in the pilot research carried out during the past five years. Further optimisation can only be achieved by building full-scale applications and by optimising these MBR plants on a practical level. For this reason, the Dutch water boards co-operated in setting up a full-scale MBR facility at the Varsseveld WWTP. This will result in an improved design for the next generation. In addition, the cost price for membrane modules will fall when membranes are produced on a larger scale.

MBR Varsseveld with old aeration tanks and clarifier in the background (photo: Aerofoto Brouwer - Brummen).

Further optimisation will not cease with the development of MBR systems. Wastewater properties can also have an important effect on the cost effectiveness of the MBR, as well as the energy requirement.

An important factor influencing wastewater properties is the sewerage system. In the Netherlands, combined sewers dominate, resulting in large RWF to DWF ratios. Disconnecting rainwater drainage from wastewater sewers will result in much smaller hydraulic capacities, which is favourable for the MBR. There has been a trend in the Netherlands to disconnect rainwater drainage from the sewers, but separate collection has had only a minor impact as yet. It will in any event take several decades before there is any substantial effect on the RWF/DWF ratio.

A second factor involved in wastewater collection is the inflow of infiltration water into sewers, for example groundwater and surface water. A study by STOWA pointed out that the dry weather flow increases by 60% on average owing to other water sources[2),9)]. Even when rainwater is disconnected from sewers, the hydraulic capacity can be further reduced if the sewers are in good condition, preventing the inflow of groundwater and surface water. This would naturally be favourable for MBR applications.

Another development is the hybrid MBR. This concept is suitable when a conventional WWTP is upgraded with an MBR. Two hybrid plants are currently under construction at WWTPs in Heenvliet and Ootmarsum. In this concept, the MBR is not supposed to receive the entire hydraulic load, nor, consequently, the entire organic load. Wastewater is distributed between the MBR and the conventional plant. In dry weather, the MBR receives relatively more wastewater and membrane capacity is therefore used efficiently. In storms, the MBR has limited hydraulic capacity and receives relatively less wastewater. The overall effluent quality results from mixing the MBR effluent and effluent from the conventional plant, so removal efficiency will be a compromise between costs and result. By using a wastewater storage tank in dry weather conditions, or even in storms, the compromise can be optimised further.

The end result must be borne in mind in any further development. The present designs will become obsolete and suboptimal after a few years, but they can play a decisive role in the MBR development. It would be well to bear in mind the status of MBR technology that we will have achieved in the future, for example after ten years of practical use.

The DWR deignteam visits the Varsseveld MBR.

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Conclusions

The following conclusions can be drawn, based on five years of research in the Netherlands:

- Owing to more stringent effluent requirements, more advanced designs and operational aspects are needed for MBR plants in the Netherlands compared to plants in most other countries;
- Pilot research appeared to be essential in order to make MBR technology suitable for the Dutch situation. Experiences abroad are inadequate by themselves;
- After five years of pilot research, the time is right to construct the first full-scale MBR plants. The first plant recently came on stream at the Varsseveld WWTP. The time schedule seems to make sense;
- The present state of MBR technology means that it is still not suitable for widespread, large-scale application. Further optimisation must be achieved, especially with respect to costs and energy requirement. This only becomes possible by building full-scale plants and learning from them. The experience gained operating the Varsseveld WWTP and, next year, the Heenvliet and Ootmarsum WWTPs, and the research data produced at these WWTPs will contribute to such optimisation;
- The future of MBR technology has to be borne in mind, both with respect to wastewater collection and the status of MBR technology. Existing and upcoming MBR plants will not be fully representative of the future. Close co-operation within the Dutch water sector and financial incentives within a span of about eight years after the start of the Dutch MBR research should produce enough expertise and experience to achieve a competitive and reliable MBR system. ¶

Samenvatting

In 2000 begon een grootschalig pilotonderzoek naar de toepassing van de membraanbioreactor voor de zuivering van communaal afvalwater in Nederland. De verwachtingen waren hooggespannen. In een zeer compacte installatie zou onder Nederlandse condities, met onder andere veel regenwater op de rwzi, een belangrijke verbetering van de effluentkwaliteit kunnen worden bereikt. Het pilotonderzoek heeft de nodige resultaten opgeleverd. Zo kon de flux worden opgevoerd, waardoor minder membraanoppervlak nodig is. Ook kon de reinigingsprocedure voor de membranen worden geoptimaliseerd. Daarnaast bleek een belangrijke verbetering van de effluentkwaliteit mogelijk, hoewel sommige verwachtingen, met name voor wat betreft de microverontreinigingen, niet waar konden worden gemaakt. Het energiegebruik kon weliswaar worden verlaagd, maar nog in onvoldoende mate, en vormt samen met de hogere kosten van een MBR nog steeds een hindernis voor toekomstige (grootschalige) toepassingen. Daar waar sprake is van bijzondere situaties zal een MBR echter, al dan niet in hybridevorm, uitkomst kunnen bieden.

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