



Dutch MBR development: *reminiscing the past five years*

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The MBR research that has taken place at WWTP Beverwijk since 2000 has yielded positive insights into the applicability of the MBR technology for the specific character of Dutch municipal wastewater. The research has been innovative and has proven inspirational to the development of the MBR technology worldwide. The research has fundamentally revolutionised the technology, particularly in the areas of chemical cleaning and process control and automation. In 2002 other initiatives came to light via the WWTPs Hilversum and Maasbommel studies, where the pilot research programmes were specifically aimed at MTR effluent quality. Through Beverwijk, Hilversum and Maasbommel, the first phase of the Dutch MBR development programme has been fulfilled.

In 2000 and 2001 large-scale pilot research at WWTP Beverwijk was carried out under the supervision and coordination of DHV, commissioned initially by the Water board Hollands Noorderkwartier, and followed through by the STOWA. The goal of the pilot research was to confirm the technical feasibility, to further develop the technology, to eliminate uncertainties, and finally to compare the MBR-technology with the conventional activated sludge technology.

In co-operation with four membrane suppliers (Kubota, Mitsubishi, X-flow & Zenon) various MBR pilot systems with a capacity up to 10 m³/h were commissioned. An important aspect of the first phase of the pilot research was to integrate the knowledge of membrane technology and the activated sludge process. From 2002 until mid 2004 the research at WWTP Beverwijk was extended with various other membrane suppliers (Memfis, Seghers-Keppel, & Huber-VRM).

In 2002 other initiatives were taken to give a better insight into the first phase of the MBR development programme. In co-operation between Water board Rivierenland and Royal Haskoning, a Zenon MBR pilot installation with a maximum hydraulic capacity of 20 m³/h was commissioned in April 2002 at WWTP Maasbommel. This research was primarily directed towards the feasibility of MTR quality, and a comparison was made with classical secondary effluent sand filtration. The research received a participation allowance from the STOWA and traversed a two-year duration. Co-operation with the Beverwijk research team occurred regularly with an in depth evaluation of membrane fouling and cleaning.

The end of 2002 saw the start-up of a Kubota MBR pilot with a maximum hydraulic capacity of 5 m³/h on WWTP Hilversum under supervision of the Water Authority DWR. The research was also directed primarily to the feasibility of MTR quality. Much effort has been directed to the design and automation of the pilot so that a better insight could be made regarding the N- and P-removal. This research also received a participation allowance from the STOWA.

All knowledge and experience from the three pilot research programmes was brought together in the Dutch MBR-committee, which was organised via the STOWA. Furthermore, in an effort to disseminate the knowledge, an MBR website has been opened in co-operation with the STOWA at Waterforum Online.

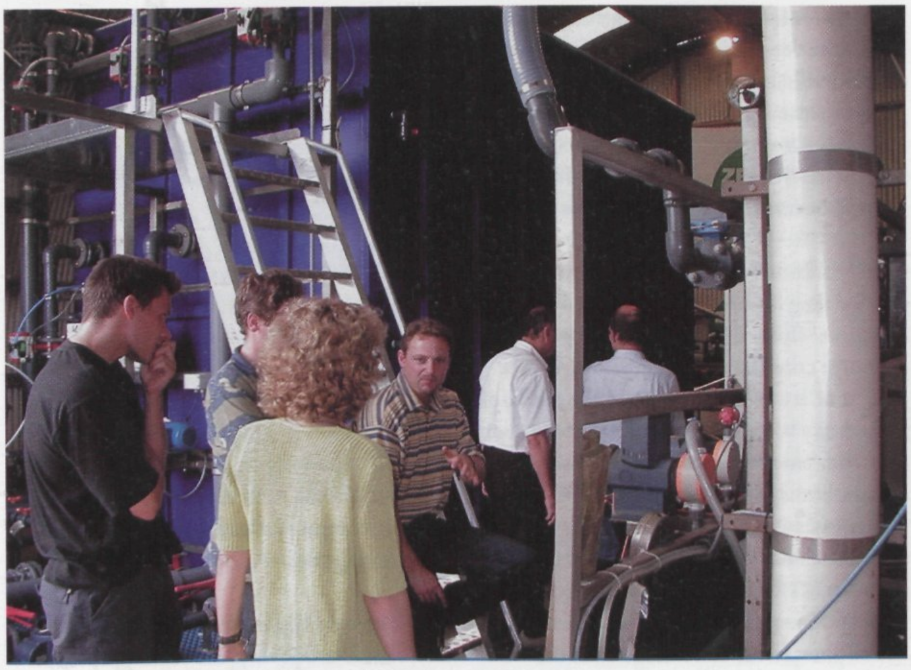
MBR Beverwijk

Beverwijk stands synonymous for MBR since the Water board Hollands Noorderkwartier, STOWA and DHV began the large-scale pilot research in 2000. In a short time, the four pilots of Kubota, Mitsubishi, X-Flow and Zenon were commissioned and more than two years of broad research carried out. This was reported in 2002 via STOWA and via the IWA[1)] for the worldwide audience. However, the MBR research was not finished and remained active till mid 2004. Other MBR pilots, from Memfis, Seghers-Keppel and Huber-VRM were tested alongside some of the original four MBR systems[2)].

The foundation blocks of the MBR knowledge were born out of twelve pilot configurations from seven membrane suppliers, over a period from March 2000 to July 2004, as summarised in table 1.

Table 1: Overview of the Beverwijk pilot research project.

system	speciality	type	pore size (µm)	surface area (m²)	design capacity (m³/h)	research period
Zenon	ZW500a-c-d	hollow fibre	0.035	184-60-95	8	03/2000-10/2003
Kubota	SD / DD	flat sheet	0.4	240	10	05/2000-07/2002
Mitsubishi	3-layer	hollow fibre	0.4	314	7	05/2000-03/2002
X-Flow	AirFlush	tubular	0.03	220	9	05/2000-04/2002
Memfis	MTR	flat sheet	0.035	112	5	05/2002-06/2003
Toray	DD	hollow fibre	0.08	137	5	02/2003-02/2004
Huber	E	rotated flat sheet	0.035	360	15	10/2003-07/2004



The technical advisory committee of the Beverwijk research project.

In 2000 and 2001 the research stood in the realm of development and applicability to the specific Dutch wastewater characteristics, i.e. low process temperatures and variable flow conditions[3)]. The continuous comparison between the four systems made very efficient research possible, where the process operation of the MBR systems could be improved in a very short timespan. The research in 2002 and 2003 directed more to the optimisation of the chemical cleaning of the membranes, and on several pilots various techniques were intensively tested for better cleaning methodologies.

Feed conditioning

From the seven MBR suppliers mentioned two suggested that extensive feed screening was overdone and could be carried out on a more cost effective base with far less stringent final filtration of the nominal 0.8 mm punched holes. Eventually, both pilots were refitted with slightly more extreme final filtration, this was due to the fact that the membranes were relatively free of debris, but the auxiliary membrane equipment was prone to contamination, e.g., the aeration system, module sides and distribution points. Eventually all MBR systems tested at the Beverwijk were fitted with some form of final feed stream filtration between 0.8 mm to 1 mm punched holes. Wedge wire and square mesh was tested on several occasions but proved less efficient at hair removal than the selected punched hole screens. Due to the extra measures required to condition the feed stream to an MBR innovative new ideas have come to light to achieve the required MBR feed stream quality in one simple step.

Biological conditioning

In Holland we are conscious of the fact that the biology and not the membrane does the work in the MBR. The membrane is a simple reliable tool able to achieve a solids free effluent and nothing more. The goal has therefore been set to condition the MBR sludge in such a way that the membrane only sees water and predominantly inert suspended solids. The latter promotes low trans-membrane pressures and high sustainable permeability.

But how do we achieve the optimal biology? This has been a study item ever since aerobic biological treatment systems were first envisaged, the rules of thumb that apply to an operationally perfect conventional treatment works also applies to the MBR, only the speed of events occurs three times faster due to the lower hydraulic retention time. The MBR knowledge base is present, but is often overlooked as the technology has been dominated by the MBR suppliers, who, by trial and error, have generated viable marketable products. Many of these products differ from what would be considered as a 'normal' biological solution - the membranes have dictated the configuration rather than the biological configuration dictating where and how the membranes should be utilised.

Most pilots at Beverwijk where designed for a total nitrogen of < 10 mg N/l with a simple biological process, as the knowledge base increased the discharge levels were forced down to < 5 mg N/l and the biological configurations and automation increased in complexity. The step to MTR quality required advanced biological treatment in the form of Racetrack bioreactors, extended plug-flow design, or plug-flow and racetrack in combination; the latter are displayed in the pilots of Varsseveld, Maasbommel and Hilversum respectively. Key similarities of all the pilots are the energy input devices. Where energy is directly put into the sludge via mixing, pumping or aeration, the device is such that the sludge flock structure is least mechanically affected. Low energy input relates to better sludge quality and better sludge characterisation, and ultimately higher alpha-factors and better membrane performance. As the configurations become more complex, the dissolved oxygen profile becomes more critical throughout the biological reactor. This is a major area of R&D and is detrimentally affected by the air input via the membranes.

Membrane cleaning

In the beginning of the research, the cleaning methodology of that time was applied; this allowed the membranes to foul to a certain point before a recovery clean was necessary. This technique was deemed a large risk to full-scale installations, as at the point when the full hydraulic capacity was necessary, for instance during RWF, the fouled membrane capacity would be insufficient to treat the required throughput. This required a new membrane cleaning philosophy. The solution was simple - don't let the membranes foul. For most membrane types, this standpoint yielded a new cleaning methodology based on 'Maintenance Cleaning in Air'.

This MC in Air is carried out once a week or two weeks with considerably less chemicals compared to the classical recovery cleaning techniques. Overall the MC in Air procedures has lead to a more stable process operation. Further optimisation of the procedures at Beverwijk yielded even better results with intermittent MC in Air back flushing with warm water/permeate, by some 10 to 15°C above the normal process temperature.

The year 2002 also saw the beginning of advanced automation of several pilots, both for the membranes and the process control, the latter was in foresight of larger practical installations. The dynamics of the MBR system varies tremendously from that of a conventional installation and little was known about the performance of high-tech measurement devices in the higher sludge concentrations. In co-operation with Endress+Hauser, Dr. Lange and Danfoss various measurement devices were tested for reliability, reproducibility and accuracy and numerous processes were automated.

The new membrane tank at Hilversum (photo: Solis).

MBR Hilversum

At the Hilversum STP, an MBR pilot was envisaged to help the design process for the full-scale installation Hilversum, and several goals were specified. Firstly, to see if the pilot could generate knowledge directly related to an improved full-scale design, to establish if the required effluent discharge criteria of MTR for nitrogen and phosphorus could be achieved and to give an idea of the chemicals needed, and finally, to gain the practical experience of running an MBR for at that time an unknown technique within DWR.

In essence the pilot system is as follows. A Huber pretreatment on raw influent via a 0.5 mm fine screen, a plug flow biology and a sludge water separation via a separate Kubota membrane filtration tank. The company Solis supplied the membrane system with 150 flat sheets with a surface area of 0.8 m^2 and a maximum RWF of 5 m^3/h.

The pilot installation was commissioned in November 2002 and is expected to remain in operation on location WWTP Hilversum until July 2007. Unfortunately, start-up problems forced a rebuild in 2003, and by the end of 2004 the system had undergone further rebuilds to optimize to smaller membrane tanks. The coming months will see changes in the cleaning of the fine-screens and a methanol dosing system will be installed. Eventually, a small man-made lake will be installed after the system to further investigate the effects of permeate on surface waters, in relation to algae growth and ground water infiltration characteristics.

Reflecting on the results so far, a number of items spring out. The pretreatment with fine screens is most problematic. Blockage through fat, hair and toilet paper causes the necessity for intensive and frequent cleaning. The future design takes into account these factors and is foreseen with hot water and high pressure cleaning facilities. An interesting fact is that the screenings (paper), makes up approximately 25% of the sludge production that can be further dewatered to some 35% DS.

The achievement of MTR quality effluent (TN < 2.2 mg N/l and TP < 0.15 mg P/l) is not easy, even with sodium acetate dosing the discharge criteria remained difficult. At the same time it was seen that due to the release of biologically bound P in the post denitrification it was not possible to achieve the P discharge criteria, but is believed with the future use of methanol as C-source for denitrification the P release shall no longer occur. A complicated factor for MTR discharge is the presences of humic acid in permeate and the relevant bound phosphorus and nitrogen. For this reason alone is the MTR discharge criterion almost impossible to reach.

One item that stood out was the effortless functionality of the Kubota membrane system, this has built up trust within the DWR organisation for membranes and has increased the knowledge of the operational aspects of membrane technology.

The sludge production of the pilot installation, including the 'paper production' was much lower than in conventional systems. It is believed that due to the relatively large membrane tank with continuous aeration, mineralisation of the sludge occurred. The reduction in the membrane tank size from 12 m^3 to 3 m^3 at the end of 2004 confirmed this observation. The sludge production without chemical addition rose considerably and proved advantageous for the phosphorus removal and for the formation of humic acid.

Through the decrease in size of the membrane tank the Kubota principle of circulation of sludge in the membrane tank has been abandoned. Sludge and air, required for the dynamic scouring of the membrane however, remains turbulent as in the old situation.

MBR Maasbommel

In 2002 the Water Board Rivierenland, together with Royal Haskoning and STOWA, started a two-year research project concerning the applicability of MBR and continuous sand filtration for the treatment of municipal wastewater[4].

On the wastewater treatment plant Maasbommel, a MBR with an organic loading of 650 p.e. (136 g TOD) and a hydraulic capacity of 20 m^3/h was operated parallel to the existing WWTP. Two full-scale continuous sand filters were installed downstream of the secondary clarifiers to polish the effluent of the existing WWTP at a total hydraulic capacity of 120 m^3/h. The performance of the two alternatives was compared on the following aspects.

MTR quality

The results of the research project concluded that for both configurations it was difficult to comply with the yearly average MTR effluent standards for nitrogen and phosphate[5]. During conditions of RWF, the contact time of the MBR was reduced and process conditions deteriorated (especially for denitrification). As for the removal of heavy metals, compared to conventional treatment both configurations displayed no advantage.

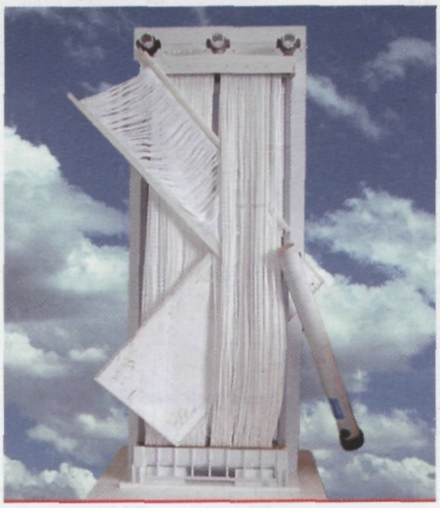
The same applied to the removal of herbicides and pesticides. For the purpose of desinfection (as determined using the bacterial level and E. coli) performance of the MBR was superior. Based on the chemical analyses of several endocrine disruptors, the conventional system with sand filters and the MBR yielded comparable effluent qualities. Both systems achieved removal efficiencies of 95% for bisfenol A, estron and ß-oestradiol. The oestrogene potential of the effluent (determined using a bioassay) was about 60% lower for the MBR as compared to the sand filter effluent.

Performance

Technical process stability was comparable for the two alternatives. Achieving a stable effluent quality for nitrogen and phosphate was easier for the sand filters than for the MBR. Especially under rainwater flow conditions the effluent quality of the sand filters was stable while that of the MBR is more vulnerable to influent flow variations. Optimisation of the process configuration and process control would lead to improvements in this respect. When membrane cleaning was completely automated, required operator attention was equal for both configurations. Another problematic aspect was the process measurement and control in low concentration ranges around the MTR effluent standards. Current instrumentation is too inaccurate in these ranges to be reliably used as input for process control. For future design purposes this will require additional attention.

Epilogue

Looking back at the last five years we must assess our current position and consolidate the knowledge we have acquired. 'MBR Beverwijk' as a trigger still lingers on in the thoughts of many foreign and domestic end users, and the Dutch contribution to the successful



Module types of Kubota, Mitsubishi, X-Flow and Zenon.

development of the MBR-technology has been widely recognised and applauded.

The MBR hype associated with Beverwijk has found a solid form in the realisation of the demonstration plant MBR Varsseveld; many aspects of numerous Beverwijk pilots have been combined into this demonstration system. The possibility to interchange membranes has been addressed, removal of cassettes has been eliminated, cleaning procedures have been made totally flexible and integrated, the biological system has been fine tuned to the membrane configuration, and the pre-treatment has been exhaustive and final in the removal of unwanted debris able to hinder the performance of the membranes. Understandably, all these items are being addressed in the research and development programme.

At the time of writing this article MBR Varsseveld has been in operation for some four months. Already the fruits of the MBR Beverwijk experience are being harvested: the flexibility in the chemical cleaning procedure was essential as the wastewater feed from Varsseveld contains substantially more fat than at Beverwijk, the biological configuration is already yielding MTR values for total nitrogen, and total phosphorus will follow. The pre-treatment has been intensively tested to yield better quality influent suitable for the membranes, here, off the shelf technologies have proved inadequate and the devices have required serious modification to achieve a debris free feed stream. The membranes have been made maintenance friendly with easy inspection and overall accessibility.

From the pilot research project described in this article, much knowledge has been gained. Knowledge however, only becomes 'real' once it has been proven under various conditions, on several systems, and lastly has been scaled up to a viable full-scale installation. The lessons of the first phase experiences will have to be tested in full-scale, with Varsseveld the next phase has been entered. ¶

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Samenvatting

Het MBR-onderzoek dat sinds 2000 plaatsvond op de rioolwaterzuivering Beverwijk, heeft tot positieve inzichten geleid over de toepasbaarheid van de MBR-technologie voor het Nederlandse afvalwater. Het onderzoek stimuleerde de ontwikkeling van de MBR-technologie wereldwijd. Het onderzoek leidde bovendien tot fundamentele wijzigingen in de procesvoering van een mebraanbioreactor, in het bijzonder op het gebied van chemische reiniging en procesbesturing en automatisering. In 2002 zijn pilotonderzoeken gestart op de rioolwaterzuiveringen Hilversum en Maasbommel. Hierbij was de aandacht met name gericht op de haalbaarheid van de MTR-norm voor het effluent. Met het onderzoek op de rwzi's van Beverwijk, Hilversum en Maasbommel is hiermee de eerste fase van de ontwikkeling van de membraanbioreactor in Nederland afgerond.