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Optimisation of the geometry of a polymeric Multibore® ultrafiltration membrane and its operational advantages over standard single bore fibres

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ABSTRACT

The main advantage of inge Water Technologies' Multibore® membrane geometry lies in the extreme durability of the membrane. Membrane breakage is virtually impossible, which gives it a real competitive edge over single bore membrane systems. One of the drawbacks was that the Multibore® took up more volume in comparison to seven single bore membranes, which led to a higher m^2 price of the membrane as well as a lower packing density in a module. Further optimisations have now addressed these points so that the Multibore® is not only a much tougher membrane with an optimum microorganism rejection; now it can also achieve a higher packing density without any additional costs in comparison to single bore membranes.

Keywords: Membrane; Multibore®; Ultrafiltration; Membrane geometry; Single bore; Membrane production

1. Introduction

Ultra- and Microfiltration can nowadays be considered as the treatment of choice for many applications ranging from drinking water production to waste water reclamation. The main advantage of these technologies lies in the quality of the treated water, which is independent of the feed water characteristics. Furthermore the membrane based solutions normally have a low energy impact as well as low chemical consumption needs. The most standard form of the membranes used for these water applications is a hollow fibre or capillary. These membranes can achieve a high packing density, and so they are able to treat large flows of water on a relatively small footprint. One of the main drawbacks that plant operators have to contend with is the occurrence of fibre breakages [1,2]. Fibre breakage means that a plant operator has to perform frequent integrity tests, and repair the damaged fibres in regular intervals. A significant improvement to this standard hollow fibre technology was introduced to the market in 2001 when the German membrane manufacturer inge GmbH started producing the Multibore® membrane, which combines seven capillaries into one fibre. This membrane had the advantage of being much stronger than a single bore fibre, which enabled inge to give their customers a unique membrane guarantee: if membrane damage were to occur, the module would be repaired or replaced at inge's costs.

Among the benefits of the Multibore® technology, apart from its robustness, are the high pH tolerance, high permeability and high virus rejection rate which makes it an ideal membrane for various applications including, for example, sea water pre-treatment [3]. A drawback of the Multibore® membrane was the material costs involved in the manufacturing of the membrane. The membrane that was introduced to the market in 2001 had a geometry which was less than ideal, which meant that per m^2 of membrane area, more PES and other ingredients

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had to be used. This article describes the optimisation of the geometry of the Multibore® membrane and the benefits that this optimisation brings.

2. Methods

The Multibore® membranes are produced in a diffusion induced phase separation (DIPS) process [4,5]. This means that the base materials of the membrane together with additives are dissolved in a solvent, which is diffused out of the nascent membrane by means of a non-solvent. The controlled diffusion enables the pore sizes and pore lengths to be optimised. The main polymer material used in the Multibore® membranes is a Polyethersulphone (PES). This material is ideal for ultrafiltration membranes, since the pore formation can be controlled properly so that the resulting membrane retains viruses to a very high degree. The resulting membrane is also more hydrophilic than for example PVDF. Furthermore, the material is compatible to the entire pH spectrum from 1 to 13 which enables fast removal of scale deposits at low pH, as well as a virtually complete cleaning ability from organic substances at high pH. PES also has good oxidant tolerance, with the maximum allowable exposure to chlorine, for example, far exceeding usual exposures encountered in membrane plants [6,7].

Other polymers mixed in the dope formula for the production of the Multibore® membranes are used to enhance features such as pore shape, density and length, anti-fouling characteristics, as well as strength and elasticity.

These characteristics are further optimised by choosing carefully the composition of the lumen (which forms the inside skin of the membranes), all temperatures, pressures, viscosities and other parameters that influence membrane formation. Standard characteristics that are measured include permeability of pure water through the membrane, tensile strength tests which measure break and elongation up to break, and pore size determination by means of liquid–liquid porometry [8], molecular weight cut off (MWCO) as well as MS2 phage rejection tests (the latter performed at independent renowned institutes).

3. Results and discussion

3.1. History and improvement

When inge started the production of Multibore® membranes, the production parameters were similar with few minor alterations from well-known single bore membranes. These early Multibore® as well as single bore membranes had, for the time, good membrane characteristics. The first Multibore® membranes produced looked like the membrane in Fig. 1.

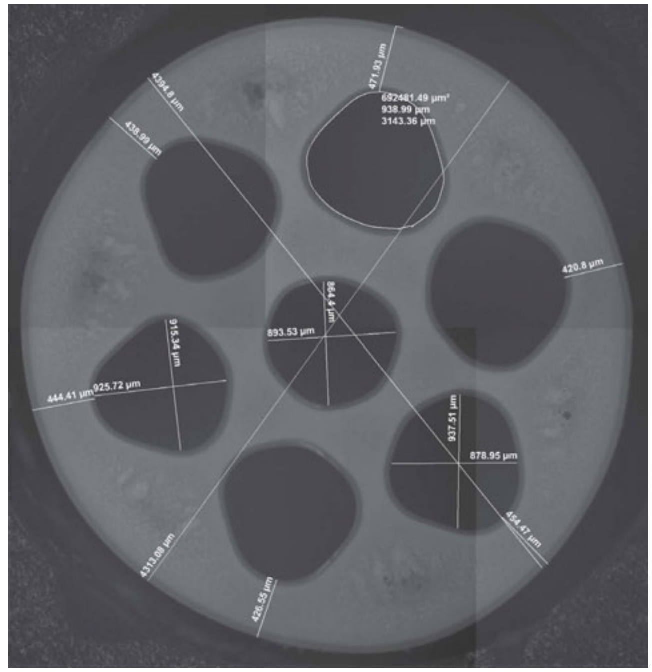

Fig. 1. Example of first Multibore® membrane.

The membrane permeability was typically around 550 l m^{-2} h^{-1} bar^{-1}. This was similar to single bore ultrafiltration membranes at that time, with similar pore-sizes. It was obvious though that the geometry was not yet optimised in a number of ways.

Most striking is the shape of the membranes. Whereas the inner capillary is relatively well rounded, the outer ones display a pear-shape. This shape means that the distance from the 'base of the pear' to the 'tip of the pear' is larger than that of a round capillary. This means that the outer diameter of the entire fibre is larger than with round capillaries. It should be noted though that the shape of the capillary has no influence on membrane characteristics or fouling and cleaning behaviour. Another obvious point is the wall thickness, measured from the 'tip' to the outside of the fibre. This wall thickness is the main criterion for the extreme strength of the membrane. Clearly a minimum of wall thickness must exist before this Multibore® membrane reaches its full advantage in terms of strength and durability. Internal production rules always have stipulated a minimum wall thickness of 300 µm, although differences between spinning heads meant that some membranes had to have slightly thicker wall thicknesses, as can be seen in Fig. 1. The 300 µm ensures that the membranes display a burst pressure which is in excess of 12 bar. A third important characteristic is the distance between the capillaries (between the six outer capillaries as well as between the inner and outer capillaries). There clearly needs to be a certain minimum, so that the water from this capillary can easily transport away (and vice versa in a backwash).

Although it was easy to see why the Multibore® should be optimised in terms of geometry, the exact way to do this was not as straight forward. Extensive optimisation work was carried out on an experimental membrane spinning machine, whereby various ideas were tested. Changes to the dope and lumen formulations, air gaps, spinning speed, the process temperatures as well as other process characteristics were combined until finally the Multibore, which can be seen in Fig. 2, was obtained.

Visually this membrane is already much more appealing due to the round capillaries; what's more important though is the reduction in the outer fibre diameter. The outer diameter has been reduced from around 4.3 mm (4.2–4.4 mm) to a maximum diameter of 4.0 mm (3.9–4.0). This reduction has been achieved mainly by eliminating the pear-shape capillaries, as well as a more consistent wall thickness between all produced membranes. The Multibore® membranes are fabricated in one process step, which means that one spinning head produces the equivalent of seven single bore membranes. All spinning heads are fabricated by a fine-machine manufacturer which has very narrow tolerances. The spinning heads are precision instruments, which is necessary in order to obtain membranes with consistent membrane geometries.

The advantage of a smaller outer diameter is apparent from the following graph (Fig. 3) in which the packing density of single bore membranes (a standard 0.8 mm capillary with 1.4 mm outer diameter is used) is compared to Multibore® membranes (standard 0.9 mm capillary). The packing density for the former Multibore® with the pear shaped capillaries was about 20% lower than that of a standard single bore membrane. When the outer diameter reaches about 3.92 mm, there is no difference in possible packing density between single bore and Multibore® membranes. This is more or less the situation with the current Multibore®.

A further benefit is in terms of membrane production costs. Over the last 10 y the industry has seen falling prices for membranes, which has forced the industry to reduce production costs. From Fig. 3 we can see a line which estimates the volume of polymer material, and consequently dope solution needed in comparison to single bore membranes. The first 4.3 mm Multibore® used about 20% more polymers and solvents in production compared to a single bore. Now with the improved geometry, the Multibore® actually uses slightly less material for the same amount of surface area.

The Multibore® that inge supplies for most water applications has an inner capillary size of 0.9 mm diameter. The formation of these capillary membranes with 0.9 mm capillaries uses about 26% more lumen (fluid to form capillaries) than a membrane with 0.8 mm capillaries. In addition, an estimated 13% more dope solution is used in order to form a Multibore® with 0.9 mm capillaries in comparison to a Multibore® with 0.8 mm capillaries. Clearly these are cost factors which need to be taken into account. The packing density, however, is also greatly affected by the fibre diameter: a smaller diameter fibre can achieve higher packing densities (Fig. 4). However, the reduction of the inner capillary size is not something that inge considers changing for standard applications as the benefit of the larger bore is significant for some applications. The pressure loss during filtration as well as backwashing is significantly reduced,

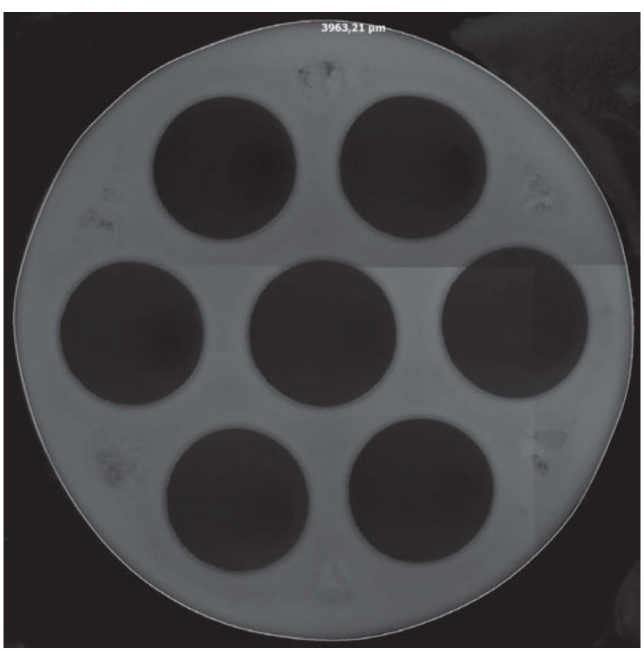

Fig. 2. Current Multibore®.

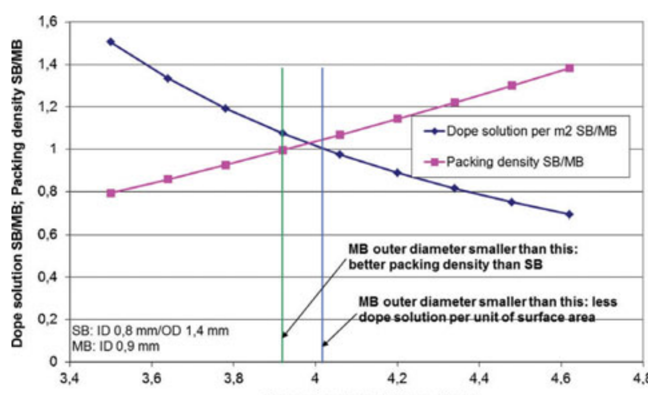

Fig. 3. comparisons of packing density and material costs for Multibore® and single bore membranes.

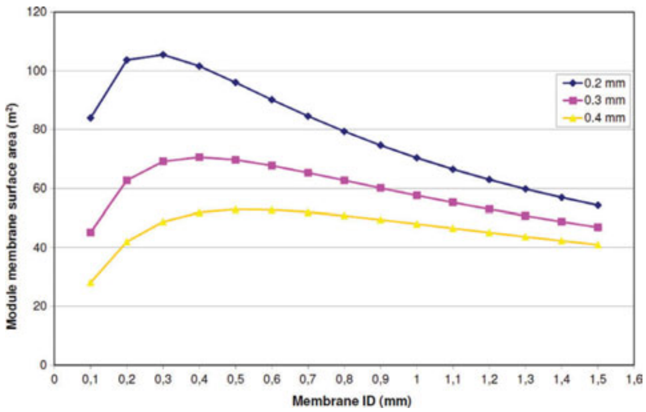

Fig. 4. Packing density comparison with various capillary diameters and different thicknesses between capillaries.

which leads to a much more equal flux distribution over the length of the membrane. This low pressure loss eliminates uneven cake layer formation and consequently improves the membrane's backwash-ability.

The improvements to the Multibore® described above have led to the possibility of increasing the membrane surface area in the dizzer® range of modules that inge markets. The largest module was the dizzer5000®, which had 45 m² of membrane area until 2006. This module was rebranded as dizzer5000plus®, in 2007 at which point the module contained 50 m². In order to include the latest geometry optimisations achieved on the Multibore® membrane, in 2009 the module was rebranded again to dizzer® XL 0.9 MB 60 and with the same module (same materials and dimensions) was able to contain 60 m². Clearly this has a large benefit in terms of compactness of a membrane installation as well as total installation costs.

Already the proprietary system that inge markets as the T-Rack® system [9], is extremely compact in comparison to more conventional rack designs. In this system the end-caps that are usually needed on both entrance and exit sides of the modules are integrated in the system headers. This makes the system ultra compact (as can be seen in Fig. 5) with a possible footprint reduction of 50%, while simultaneously saving substantial rack building costs per module. As an additional benefit, the volumes in the headers are reduced which means that less water and chemicals are needed for chemically enhanced backwashes. The increased packing density in the dizzer® modules and the subsequent reduction of the necessary number of modules to be installed leads to an extra 20% reduction in footprint.

During the optimisations of the membrane geometry, other characteristics have also been improved. The virus and bacteria rejections, as measured at independent institutes, have been found to be exceeding the necessary standards for ultrafiltration membranes. During spike testing of MS2 phages in a very low turbidity feed water (<0,2 NTU) our standard large scale module, the dizzer® XL 0.9 MB 60 with 60 m² of active membrane area, achieved full rejection of all dosed MS2 phages, which gave a theoretical log reduction value (LRV) of more than 5.7 log. Smaller modules are tested regularly as well under laboratory conditions including ultra-pure water. Here LRV's in excess of 5 log for MS2 are consistently measured (a 4 log reduction of viruses is a common criteria asked for by drinking water customers). Test in accordance to ASTM F 838-05 [10] showed a LRV of 9.7 log for the very small *Pseudomonas diminuta*. These excellent rejection characteristics have been achieved despite the fact that the membrane permeability has increased drastically to about 1000 l m^{-2} h^{-1} bar^{-1}. These permeability and rejection improvements were due to narrowing the pore size distribution as well as optimising the pore length.

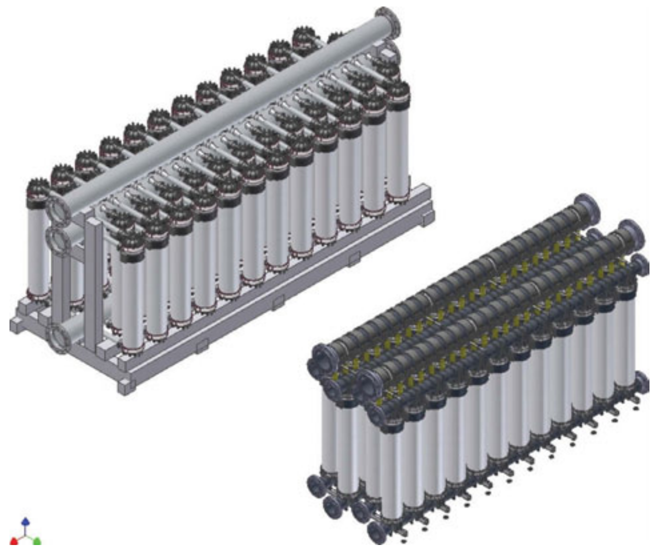

Fig. 5. Comparison conventional rack with T-Rack®.

Due to the success with the 0.9 mm Multibore® membrane, a further product was introduced in 2009, the 1.5 mm Multibore® (*see* Fig. 6), which also benefits from the perfectly round capillaries. For applications with very high amounts of solids in the feed water, or were a (small) cross-flow or bypass stream would be beneficial, the standard smaller capillary sizes of 0.8 mm is too small and leads to a significant cake-layer build-up. The cake-layer reduces the effective capillary size which means that a larger pressure loss is found over the length of the membranes. The large scale module made with these thicker membranes, the dizzer® XL 1.5 MB 40, achieves 40 m² of surface area, which is a large increase in comparison to the 30 m² modules that was obtained with a single bore 1.5 mm fibre.

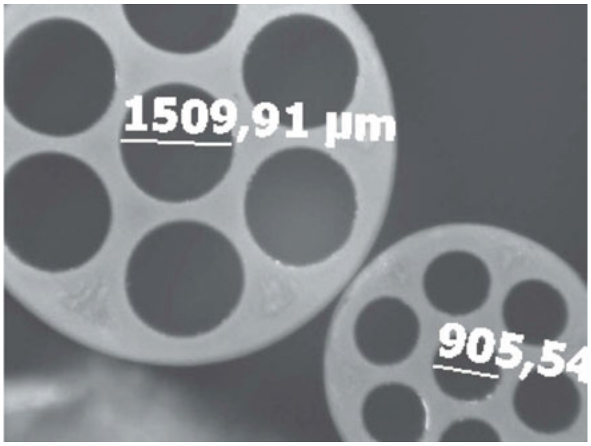

Fig. 6. Size comparison between a 0.9 and a 1.5 mm Multibore® membrane.

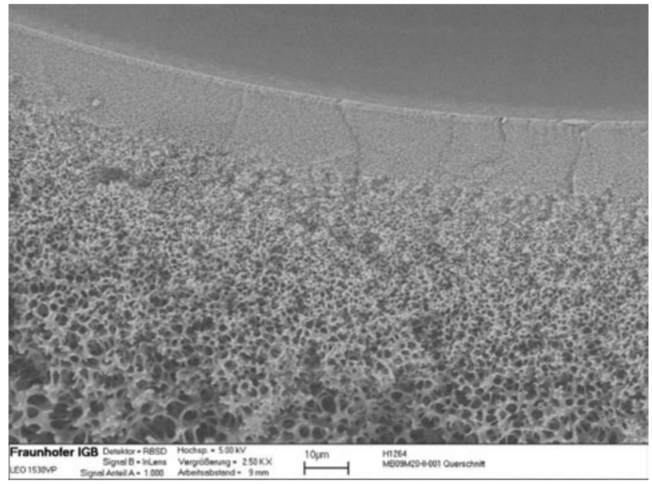

Fig. 8. Close-up of skin layer on inside of a Multibore® capillary.

3.2. Further improvement possibilities

As explained above, the ability of the foam structure to transport water without a significant pressure loss is a prerequisite for the Multibore® to function properly. If the pressure loss is too high, the inner capillary will get dirtier over time since the backwash flow reaching this capillary will be reduced, leading to a loss of membrane permeability. Furthermore, when the inner capillary gets fouled, the other capillaries will have to work harder at a higher flux which consequently will have an impact on these capillaries. The following photos show the inner structure of the Multibore® membrane. Fig. 7 is a raster electron microscopic image which depicts the area between three capillaries.

The dense porous layer around the capillaries can be seen in stark contrast to the very open inner structure. The large pores in the middle of these flow paths are in the range of 10 µm. This compares to pores in the thin skin layer (close-up in Fig. 8), of around 20 nm. The 500 fold increase in pore size allows for water flow which has virtually no impact on the measured pressure drop in the membrane. Of course there is a limit to the thickness of this inter-capillary distance, and this is exactly the aim of the following optimisations: to reduce this distance so that the outer diameter is even smaller, without getting water flow transport problems. Experiments with Multibores® in which the permeability was measured with and without the inner capillary (by blocking-off the inner capillary) with various inter-capillary distances have shown that the minimum distance between the inner and the outer capillaries is around 150 µm. This means there is still scope for a further optimisation step, which could lead to another increase in packing density.

Fig. 7. Area between three capillaries in a Multibore®.

4. Conclusions

The Multibore® membrane has been optimised in a number of ways. From an optical point of view the capillaries have evolved from pear shaped to completely round. This has enabled the reduction of the outer diameter of the Multibore® membrane, which has led to two important benefits. The first is the reduction in material costs per m² of membrane area, since less material is needed in order to produce the membrane. The second benefit is the possibility of increasing the surface area in a module. This has enabled the dizzer® modules to contain more surface area then before and the large scale module from inge (the dizzer® XL 0.9 MB 60) now contains 60 m². Other characteristics have been improved, such as the permeability, which, in combination with excellent virus and particle removal gives the

Multibore® ultafiltration membrane unique advantages in the membrane market.

Acknowledgements

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References

[1] I.H. Huisman and K. Williams, Autopsy and failure analysis of ultrafiltration membranes from a waste-water treatment system, Desalination, 165, (2004) 161–164.

[2] A.J. Gijsbertsen-Abrahamse, E.R. Cornelissen and J.A.H.M. Hoffman, Fiber failure frequency and causes of hollow fiber integrity loss, Desalination, 194 (2006) 251–258.

[3] D. Gille and W. Czolkoss, Ultrafiltration with Multibore membranes as seawater pre-treatment. Desalination, 182 (2005) 301–307.

[4] I. Cabasso, E. Klein and J.K. Smith, Polysulfone Hollow Fibers. I. Spinning and Properties, J. Appl. Polym. Sci., 20 (1976) 2377–2394.

[5] M. Mulder, Basic Principles of Membrane Technology, Kluwer, Dordrecht, 1996.

[6] G. Pearce, Manufacturer's Comparison: part 2. Filtr. Sep., 44(3) (2007) 35–37.

[7] C. Maletzko, PESU Membranes in municipal water treatment applications, Desalin. Water Reuse, 19(3) (2009) 22–26.

[8] S. Munari, A. Bottino and P. Moretti, Permporometric study on ultrafiltration membranes, J. Membr. Sci., 41 (1989) 69–81.

[9] W. Ding, R. Gimbel and S. Panglisch, Application of CFD in Membrane Technology, 8th Aachener Tagung Wasser und Membranen, **W18** (2009) 1–10.

[10] ASTM. (2005). Standard Test Method for Determining Bacterial Retention of Membrane Filters Utilized for Liquid Filtration. ASTM F 838-05.