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Spacer fabric supported flat-sheet membranes: A new era of flat-sheet membrane technology☆

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ABSTRACT

Current flat sheet MBR membranes are sandwich constructions containing at least 3 different layers. These membranes have no or only very backwash-ability and their envelope construction is a very labour-intensive multi-step operation.
In this paper an innovative single method for constructing a prior-to-art back-washable flat sheet membrane envelope is described. The key element of this concept is the use of a 3D spacer-fabric as a membrane support stucture. Spacer-textiles can be made by a knitting or weaving process and they are normally used for the construction of all kind of light-weight composite materials. They basically consist of two faces (their outer layers), which are connected with each other by a multitude of monofilament spacer yarns. As a result a solid three dimentional structure is obtained which contains three distinguishable layers: the two faces (each e.g. 0.5 mm thick), and a hollow space in between them formed by the monofilament spacer yarns. In our concept the hollow space of the spacer fabric is used as the permeate drainage channel, whereas its faces are used for membrane anchoring. The interesting spacer fabrics for use as a membrane support have a thickness in between 2 and 10 mm. In our manufacturing process both faces of the spacer-fabric are directly and simultaneously coated with membrane dope in a vertical set-up. The pore size of both membrane layers is controlled by a combined VIPS and LIPS process. A membrane envelope has been realized with 0.3 µm pores having a pure water permeability of 1500 l/hm^2 bar. A membrane adhesion test revealed that the membrane layers are attached well to the spacer fabric and can simply be back-washed with a TMP of 1 bar. Application tests showed that the critical flux of the IPC membrane is similar to a commercial MBR membrane type.

1. State-of-the-art submerged flat-sheet MBR technology

State-of-the-art submerged flat-sheet MBR technology consists of flat-sheet membranes which are fabricated to filtration panels. These are typically sandwich constructions with at least three separate layers. Two of them are pre-fabricated membrane layers, the others are permeate drainage layers which are sandwiched in between them. The used permeate drainage layers can be either coarse non-wovens (Abfall Abwasser Anlagentech A3) [1], spacer fabrics (Microdyn-Nadir), or solid plastic constructions. The latter ones are rendered a permeate drainage function by creating channels and/or openings directly by injection molding technique (Kubota, Toray) [2,3], or by machining the plastics after extrusion (Abfall Abwasser Anlagentech A3, Alfa Laval, Weise Water Systems) [1,4,5]. All layers of the sandwich are held together by gluing or laminating techniques over their entire surface or just at their edges. For sealing these sandwich composites their edges are glued, or all kind of welding techniques are being used. To conclude, the construction of closed membrane envelopes/membrane is a very labour-intensive operation.

Today the major features of flat-sheet MBR technology are their low fouling tendency and their high resistance against clogging, because they can be placed nicely at a pre-defined distance from each other (e.g. 6 mm). The disadvantages are their lower packing density (especially in the case of the 6 mm thick versions), the impossibility to backwash them and their sensitivity to breaking near the top side.

The limited possibility to backwash originates from both the membrane layers being used, and from the envelope construction. Most of the used membrane layers (almost all) are supported by non-woven type of support structures. A typical property of these membranes is poor adhesion to their support, nevertheless all measures that are taken to maximize it, like matching punctually the casting speed, the pore size and porosity of the non-woven with the membrane dope viscosity. Indeed, the backwash pressure for current flat-sheet MBR membranes and their panels has to be limited to 0.7 bar as a maximum. The second reason for the low backwash pressures of the membrane panels is the limited attachment between the two membrane layers, or between the layers and the drainage

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layers in between them. In some constructions there is no attachment at all, making them sensitive for being damaged by coarse air bubbling.

These properties hinder the competitiveness and prevalence of flat-sheet submerged MBR technology with hollow fiber/capillary technology for low pressure membrane techniques (MF and UF).

To summarize, the construction of current flat-sheet MBR membrane panels is a labour-intensive, multi-step operation. The membranes have only limited backwash-ability and membrane envelopes have limited mechanical strength. Both are matters for further improvement.

2. The IPC membrane concept and its construction

Having in mind the labour-intensiveness and the limited mechanical strength of existing flat-sheet membrane envelopes, we decided to develop an integrated concept using just one single support layer, which is coated on both sides with a membrane layer in one single step. The so obtained membrane envelope contains two adjacent membrane layers, which are partially inside the support, and a permeate channel in between them which is located completely inside the support. This concept is called “Integrated Permeate Channel” membrane concept (or IPC membrane concept).

The key elements to construct this prior-to-art back-washable flat-sheet membrane concept are the use of special developed spacer fabrics as a support structure, but also the fact that the membrane layers are directly coated on both sides of it.

2.1. Special developed spacer fabrics as support structure

Spacer fabric textiles are made by a knitting process and have their normal use in e.g. sports shoes, underwear, car seats, dashboards and medical mattresses. All these applications make use of their excellent breathability, cushioning and shock absorbing properties.

The key properties are their special construction and their high porosity making them very interesting for venting applications and for construction of all kind of light-weight composite materials.

A spacer fabric basically consists of two faces or outer layers, which are connected with each other by a multitude of monofilament “spacer” yarns. These spacer yarns keep the two outer layer at a certain pre-defined distance from each other (see Fig. 1).

These monofilaments can be present in a very high number (up to 100 monofilaments per cm^2), which make them almost inseparable hollow structures. The main reason for their inseparability is that the two outer layers are tied and fixed together by loops in the spacer monofilaments in these outer layer regions (see Figs. 2 and 3). In addition in these regions also multi-filament yarns are interwoven with the monofilaments spacer yarns (see Fig. 3) giving lead to an inseparable but still flexible material.

These multifilaments also help closing/opening the faces of the spacer fabric (see Figs. 4 and 5). As a result the spacer fabrics contain three distinguishable layers: two identical faces (each about 0.5 mm thick) and a hollow space in between them which is formed by the monofilament spacer yarns.

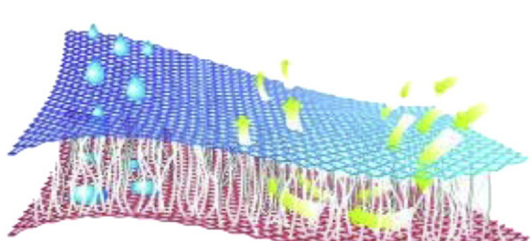

Fig. 1. Typical cross-section of a spacer fabric consisting of two outer layers connected with each other by monofilament spacer yarns.

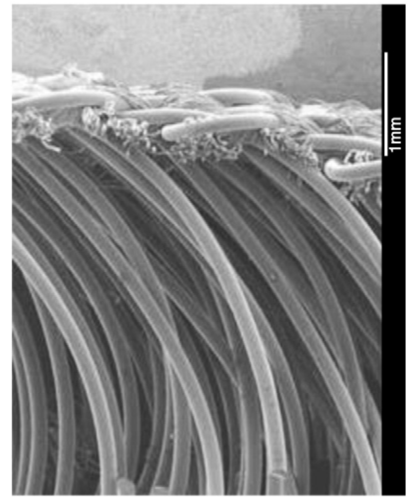

Fig. 2. Detailed view on the spacer yarns of a spacer fabric near to one of its outer layers.

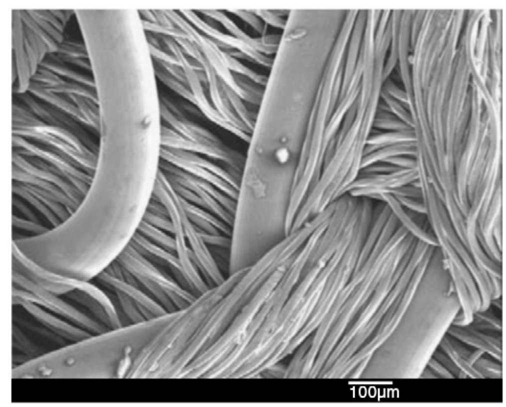

Fig. 3. Detailed view on the outer layers of a spacer fabric showing the interweave of the monofilaments spacer yarns with the multi-filament outer layer yarns.

The length of these spacer yarns determines the distance/height between the two outer layers. This can be between 1 and 100 mm, but it is believed that spacer fabrics with thicknesses between 1.5 and 5 mm are of most interest for being used as supports for membrane application. For our IPC concept the hollow space of the spacer fabric is intended to be used to constitute the integrated permeate channel, whereas the two face layers are used for membrane anchoring.

The existing spacer fabrics are not suitable as such. In order to make them suitable quite some properties had to be changed considerably.

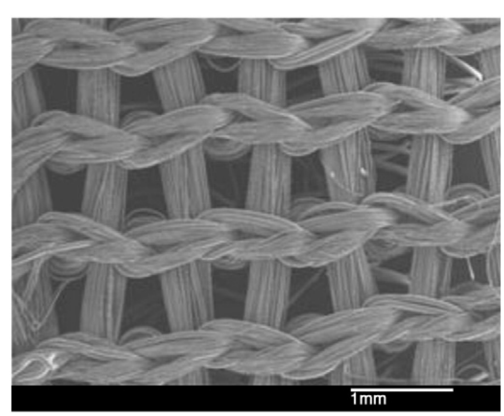

Fig. 4. Detailed view on the top surface of two different spacer fabrics showing the ability to close or open the outer layers by using different multi-filament yarns.