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Resupply initiated

A fast and reliable approach to benchmark low pressure hollow fibre filtration membranes for water purification

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ABSTRACT

In this study a benchmark protocol for low pressure hollow fibre membranes was developed and evaluated. The benchmark approach involved three main steps: first a systematic membrane characterisation, then a short-term bench-scale testing evaluated by a scoring system, and finally a long-term full scale performance comparison. Four different hollow fibre membranes were characterized with respect to electrical charge, hydrophobicity, surface morphology et al. All hollow fibre membranes and two types of water (river water and secondary effluent) were used in a controlled filtration protocol. The performance of these membranes were evaluated according to the scoring system which included the effect of fouling (TMP development), hydraulic permeability recovery, and membrane chemical cleaning under both moderate and high fluxes. A key result of this study is that the overall performance of the membranes in long-term can be qualitatively predicted using a short-term bench scale test and a scoring system. The benchmark of membranes in the full scale tests showed results comparable to the results obtained in bench-scale. Detailed comparison of the scores from bench and full scale tests highlights some challenges in applying such approach in practice. The study found very limited relationship between membrane characteristics and filtration performance. It was observed that some membrane characteristics influence fouling at the beginning of fouling formation, but the effects were reduced over time as the membrane underwent more intense fouling and several cleaning cycles.

1. Introduction

With significant growing demand for low pressure membranes in water treatment (microfiltration, MF, and ultrafiltration UF), the water industry and membrane manufacturers have been pursuing a variety of methods addressing selection, comparison and evaluation of the suitability of UF membranes for filtration of different waters and of filtration configurations [1–3].

In practice, the selection of membranes in the water industry depends on the experience of the designer, and the process needs to pass through certain objective and subjective evaluation procedures. Typically a number of membrane candidates are selected from a database when particular water types are targeted. This is then followed by small bench-scale tests for comparing fouling intensity when membranes are operated under similar or individually optimised conditions. After such comparisons, the selected membranes are then benchmarked in pilot scale tests for a more realistic long-term evaluation. This procedure is clearly time consuming and requires infrastructure and significant resources. Therefore, either due to the complexity of the challenge or due to the lack of standardization, the authors have not been able to identify approved standards or applicable guidelines for the evaluation and selection of UF membranes for solving a specific water treatment problem. Facing numerous existing membrane brands globally and continuous addition of new products every year, a fast and fairly accurate pre-selection of suitable membranes entails significant potential to save time and resources.

Membrane selection can to some extent be facilitated by experienced desk work identifying the key membrane properties together with module design. Several studies have already been conducted and there are some general approaches. For instance, Filloux et al. [4] summarized that the membrane material, hydrophobicity, pore size and pore size distribution play important roles in determining performance. That is in agreement with previous studies [5]. Another important parameter is the membrane roughness which is used to describe the average surface topology of a membrane. It is generally believed that a rough surface may be more easily fouled partly because roughness

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Table 1
List of membranes used in this study including nominal properties as presented in the accompanying specification datasheets.

Description	Membrane A	Membrane B	Membrane C	Membrane D
Material*	PVDF	PESM	PESM	PVDF
Pore size (μm)*	0.03	0.03	0.02	0.1
Nominal MWCO (kDa)*	100	150	100	–
Total membrane area in bench-scale module (x 10^{-3} m^2)	3.27	3.58	3.56	3.77
Pure water permeability @ 20 °C (LMH/bar)	351	707	1000	1320
Flow Configuration	Outside-in	Outside-in	Inside-Out	Outside-in

* According to the manufacturers specifications. The different membranes were subsequently characterized as individual fibers and potted in miniature-modules to allow for flexible and more accessible configuration.

simply increases the available surface area and directly affects properties like zeta potential that can also influence fouling rates [6]. However, a systematic and thorough understanding of the correlation between membrane character and performance has not been represented. As one membrane can be characterized on a number of levels and by various methods, and provided no single parameter alone dictates the fouling behavior, the overall robustness of the membrane selection is undoubtedly a compromise of all factors involved [7]. The complexity will further increase when considering seasonal variables or differing feed water qualities.

For such reasons, it is necessary to conduct reliable and representative early filtration tests. Bench-scale tests have been widely used in research, e.g. Huang et al. [8] suggested a particular ultrafiltration setup to fulfil this kind of requirement, which has also been used in other fouling studies [9]. By comparing filtration performance results created in such a setup and assisted by a pilot UF unit, Nguyen et al. [10] confirmed that membrane performance evaluation at bench scale is in accordance with that obtained on pilot scale. By using a unified membrane fouling index (UMFI), the authors were able to quantify fouling intensity for different membranes. However, these benchmarks have focused on fouling rate and classification of reversible and irreversible fouling for research purpose. In practice, more parameters besides just fouling rate should be included in evaluating membrane performance. Here we understand membrane performance as the performance of membrane and module under certain operating scenarios, such as pure water permeability during filtration, permeability recovery after backwash, chemical resistance during clean-in-place (CIP), mechanical strength in air scouring, and so on. From a module perspective it could include specific energy consumption, module integrity, et al.

The objectives of the present work are:

(1) To develop a fast (less than two weeks) and reliable membrane pre-selection procedure based on a designed test protocol and a quantified scoring system which includes fouling increase rate, permeability recovery, membrane integrity, et al.
(2) To further validate/justify the scoring system by comparing the predictions to existing full scale data, and figure out the challenges when such scouring system is used in practice.

In this study, we evaluate four different hollow fibre membranes by filtering river water and secondary effluent from a municipal wastewater treatment plant, both located in Jutland (Denmark). We focus on a three-step qualification model; firstly a careful membrane characterisation to evaluate the property and configuration characteristics; then a relatively short bench-scale fouling study (less than two weeks) which in line with a scoring system identifies the membranes most likely to be suitable for the application; and finally a long-term full scale study used primarily to validate the bench-scale approach and figure out the challenges in scaling up. The bench-scale scoring system is based on a combined calculation taking the TMP development, hydraulic permeability recovery, required membrane cleaning intervals and varying fluxes into account.

2. Material and methods

2.1. Materials

2.1.1. Membranes

In this study four different types of membranes have been used, three of which are capillary UF membranes with a nominal MWCO in the range 100–150 kDa, while one is a MF membrane with a nominal pore size of 0.1 μm. The fibers were acquired directly from the manufacturers. Membranes were made from either polyvinylidene fluoride, PVDF (membranes A and D), or modified polyethersulfone, PESM (membrane B and C). Membranes A, B and D are configured as outside-in membranes, while membrane C conversely is inside-out. The overall list of the membranes can be found in Table 1. For more information about the membrane structure and properties, see Section 3.

2.1.2. Bench-scale filtration modules

To ensure a close to equal filtration area in all of the membranes, small modules were constructed to contain close to 33–38 cm² of available filtration area. The module is made of transparent polyvinyl chloride (PVC) tube with connections. The module is 20 cm in length and one cm in diameter. The fibers were firstly cut in an appropriate length exceeding that of the module, then aligned in the small plastic tubing and carefully potted using epoxy potting glue. At the one end, the fibers were end-sealed with potting agent, while the other end served as the permeate collection, i.e., the fibers were protruding through the potting. An opening in the side of the module allowed for feed water circulation and air-scouring (for outside-in configuration). The procedure varies a bit depending on the fiber nature and susceptibility towards curing and drying but in general terms the procedure is the same. Integrity test was conducted using compressed air to exclude modules with any leakage or fiber breakage. The modules were then stored in 500 ppm sodium bisulphate solution (SBS) to prevent bacteria multiplication before used in coming tests. Before use, all membranes were chemically deconditioned and permeability was quantified by filtering clean water (RO water) at 20 °C. Only the modules within a range of ± 10% average clean water permeability were used in further tests.

2.2. Membrane characterization

2.2.1. Membrane Pretreatment

For characterization all membrane fibres were pretreated by washing in EtOH for 2 h at RT and 100 rpm on a mechanical shaker and then equilibrated in Milli-Q water for 24 h. Afterwards, the samples were stored in a 0.01 M NaN3 solution in Milli-Q water.