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Anaerobic membrane bioreactors for treating waste activated sludge: Short term membrane fouling characterization and control tests

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ABSTRACT

There is limited information on the impact of sludge characteristics, membrane type and operation parameters on membrane fouling under anaerobic conditions. This paper examined filtration characteristics of anaerobic sludges with solids concentration between 6 and 33 g/L and the interaction with negatively and neutral charged membranes at various fluxes within the subcritical region. The study employed a short term filtration protocol using a bench-scale tubular ultra-filtration membrane operated at a cross-flow velocity of 1 m/s and under constant pressure. The results showed that the effects of anaerobic sludge concentration and membrane surface charge on membrane fouling were a function of the operating flux. Their impact on fouling was found to be minimal at the lower fluxes (8 LMH) however detrimental at higher fluxes (30 LMH). Further study on impact of anaerobic sludge composition on membrane fouling indicated that the decline in membrane performance at the higher subcritical fluxes was associated mainly with the colloidal fraction when the suspended solids concentrations were less than 20 g/L whereas at higher concentrations both the solids and colloidal fractions contributed to development of the fouling layer. Integration of a relaxation cycle and addition of cationic polymer were found to be effective in controlling anaerobic membrane fouling.

1. Background

There is an increasing interest in wastewater treatment technologies that are sustainable with low energy requirements, and the ability to produce by-products of value, while generating minimal quantities of residual streams. Anaerobic processes are known to offer these benefits as the energy input associated with providing oxygen is not required, methane and nutrients are generated as a process byproduct, and sludge production is less than that produced by aerobic processes. However conventional anaerobic processes typically require large bioreactor volumes to accommodate the slow growth rates of methanogenic bacteria. The integration of membranes with anaerobic bioreactors has the potential to substantially reduce bioreactor volumes by facilitating the decoupling of HRT and SRT. The operation of the bioreactors at relatively shorter HRTs and longer SRTs can achieve reduced bioreactor volume, while attaining higher organic loading and good process performance.

The design of anaerobic membrane bioreactors (AnMBRs) requires information on the performance of membranes under anaerobic conditions. Relatively extensive studies of the application of AnMBR for municipal wastewater treatment have evaluated the effects of membrane properties [1–4], sludge properties [5–7] and operational and environmental conditions [8–13] on permeate flux. Permeate flux is one of the most important parameters that determine the economic viability of anaerobic membrane bioreactors. Elevated fluxes allow for smaller membrane surface areas for a given hydraulic treatment capacity. However membrane fouling typically increases with flux and hence membranes are typically operated below a critical flux region to minimize fouling [14]. Berube et al. [15] conducted a comprehensive review to identify the parameters governing permeate flux in an anaerobic membrane bioreactors treating low strength municipal wastewaters. Their survey indicated that the optimal membrane system for an AnMBR treating low strength wastewater consisted of an organic, hydrophilic, and negatively charged membrane with a pore size of approximately 0.1 μm.

On the other hand very few studies have been conducted on AnMBR systems for treating high strength particulate wastewater [16,2,18–20]. Most of this work was preliminary in nature hence very limited evaluations were carried out to assess the effect of membrane type, membrane operating condition and sludge characteristics on membrane fouling. Most of the membrane configurations used for these applications were external, tubular ultra-filtration membranes. Traditionally fouling control in tubular membranes has been achieved by increasing the cross-flow

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velocity (CFV). Increasing CFV in the case of AnMBR operation has been reported to cause shear effects on the anaerobic biomass and subsequent reduction of digester performance [21,17,20]. It has been proposed that mechanical stress due to excessive pumping could potentially destroy the close relationship that is necessary for inter-species hydrogen transfer [21]. Hence strategies to minimize the decline in flux without excessive CFV need to be explored.

The overall objective of this study was to understand membrane fouling in AnMBRs treating high strength particulate wastewater and suggest strategies to minimize fouling. The specific objectives included evaluating the impacts of sludge concentration and composition, membrane surface charge type, membrane flux and filtration time on membrane fouling. Further, the potential of relaxed operation in tubular membranes and the addition of cationic polymers to the anaerobic sludge as strategies to minimize membrane fouling were investigated.

2. Materials and methods

A bench scale membrane apparatus was assembled to conduct short term filtration tests under controlled conditions. A schematic of the bench scale membrane setup is shown in Fig. 1. The bench scale system consisted of three 50 L tanks that were employed to hold the anaerobically digested waste activated sludge, clean water and backwash solutions respectively, a 30 cm long by 2.5 cm diameter horizontally mounted negative (ABCOR®-FEG™ PLUS MODULE: 10-HFP-276-PVI) and neutral (ABCOR®-FEG™ PLUS MODULE: 10-HFM-276-PVI) charged KOCH tubular ultra-filtration membrane with a molecular weight cutoff 100,000 Da, a centrifugal pump to re-circulate the feed continuously through the loop and a peristaltic permeate suction pump. Both membranes were made of polyvinylidene fluoride (PVDF) material and had similar operating ranges. The membrane module was operated at room temperature with a constant cross flow velocity (CFV) that was adjusted by regulating the flow from the centrifugal pump. The membrane feed, concentrate and permeate pressures were recorded using a digital pressure gage. The permeate flow rate was recorded using a balance and stopwatch and the temperature was monitored using a mercury thermometer. The concentrate from the loop and the permeate were returned constantly to the feed tank to keep the feed volume and composition constant.

The research described in this paper was conducted in a series of experiments. In the initial testing critical fluxes were determined with one sludge type. The critical flux after its initial introduction [22] has become a widely accepted parameter for assessing the fouling behavior and comparing different operating conditions [23]. In this study the critical flux data was used to establish the range of fluxes that would be assessed in subsequent testing. Short term filtration tests were then carried out to assess the influence of anaerobically digested sludge solids concentration, membrane surface charge, membrane flux and filtration time on membrane fouling under controlled conditions. Subsequently, short term bench scale studies were conducted to identify the sludge fractions that were responsible for fouling. Finally, the use of relaxed operation and polymer addition to control membrane fouling were evaluated.

The critical flux was determined by operating the tubular membrane operation in constant flux mode. The bench scale membrane setup was modified to allow constant flux operation by connecting a pump on the permeate side of the membrane to create a suction that generated a prescribed flux. Fig. 2a and b depict a classical pressurized tubular setup operating with constant pressure and the modified setup to operate with constant flux respectively. During constant flux operation: the feed was pumped through the membrane at a constant rate to keep a constant cross flow velocity (CFV), and the suction pump connected on the permeate side was set to deliver a constant flux. In order to deliver the required flux, over a range of filtration resistance conditions, P_p changed and it was monitored over time.

The critical flux was determined by the flux step method [23]. The flux step method involved increasing the permeate flux in steps for a fixed duration and monitoring the TMP at each flux value. This is expected to result in a linear relationship between TMP and flux within the sub-critical flux region and an exponential increase in TMP indicating rapid accumulation of foulants at fluxes beyond the critical flux value. For each flux step, the increment in flux was 4 L per meter square per hour (LMH). The duration of the test was 30 min and this was followed by a 2 min relaxation time to eliminate built up of reversible foulants before the next flux value was implemented. The test was conducted with the neutral and negatively charged membranes using a relatively dilute feed (solids concentration of approximately 6 g TS/L) that consisted of digested anaerobic sludge from a pilot AnMBR that was digesting waste activated sludge (WAS) and operated in parallel.

Once the critical flux was established the impact of key sludge properties and operating factors on membrane fouling was examined systematically following a 2^4 factorial experiment. The main factors consisted of solids concentration (approximately 6 and 18 g/L of TS), permeate flux (lower and upper end of the sub-critical flux range) and membrane surface charge type (neutral vs. negatively charged). In addition, to assess whether conditions varied with the duration of short term membrane operation, data was collected at two different filtration times (30 and 120 min) resulting in a total of 16 experimental runs. A few of the experiments were conducted with a virgin membrane while most of the runs were conducted with previously-used membranes. In these latter cases, the membrane was backwashed with water for 20 min and a clean water TMP measurement was obtained for the first series of experiments to assess change in membrane condition. The measurement showed the clean water permeability of used membranes was reduced by 15%. However no difference in clean water permeability was observed with repeated use of the membranes. In this case the clean water permeability that was measured after backwashing remained on average at 830 ± 34 LMH/bar.

The contribution of colloidal and suspended solids to the reduction of permeation flux was investigated in tests that employed filtered sludge fractions (cake and supernatant) under similar operating conditions. For this purpose 20 L anaerobically digested sludges were obtained from pilot scale anaerobic membrane

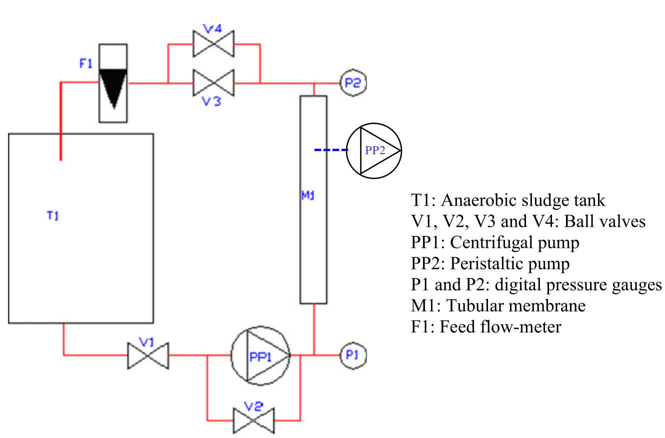

Fig. 1. Schematics of bench scale membrane setup.