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Combined effect of air and mechanical scouring of membranes for fouling reduction in submerged membrane reactor

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ABSTRACT

This study investigated the combined effect of air flow and use of granular support medium in suspension in a submerged membrane reactor to reduce membrane fouling. Lower membrane fouling and a slower rise in transmembrane pressure (TMP) were noticed when a higher air flow rate was used for membrane scouring. Further fouling reduction was achieved by adding a granular medium in the reactor. The results showed that in the absence of the granular medium, when air flow was tripled (from 600 to 1800 L/h/m^2), the TMP development was decreased by 60%. TMP further dropped to 85% with the addition of granular medium (for the same air flow rate). The doubling of the air flow rate (from 600 to 1200 L/h/m^2), without granular medium, led to a 32% reduction in TMP development at 10 L/m^2.h. The same result was obtained at a lower air flow rate of 600 L/h/m^2 with the granular medium. This result shows that the same reduction of TMP can be obtained by adding granular medium instead of doubling air flow rate. Therefore adding granular medium in the suspension (mechanical scouring) with air flow (air scouring) could be a sustainable alternative to applying high air flow in submerged membrane systems.

1. Introduction

Although membrane filtration have several advantages over conventional treatment process, its wider application has been constrained by membrane fouling due to particle deposition and intrusion of macromolecules, colloids and particles onto and into the micro-porous membrane [1]. Fouling causes a significant increase in hydraulic resistance which leads to permeate flux decline or a rise in transmembrane pressure (TMP) when the membrane process is operated under constant-TMP or constant-flux conditions, respectively. Frequent membrane cleaning is thus required. It significantly increases the energy consumption leading to higher operating costs.

Several approaches have been applied to mitigate membrane fouling. The injection of air into the feed stream (air scouring) has been found to be an effective means of mitigating the adverse effect on filtration flux [2]. In a submerged membrane system, when air is injected through an air distributor into a stationary feed, air bubbles are formed and the buoyancy forces associated with the bubbles keep the suspension in motion [3]. The air bubbles also scour the membrane surface detaching the deposited cake layer thus reducing fouling. Air scouring poses less of a risk to membrane surfaces compared to chemical agents. Ueda et al. [4] stated from their detailed experimental study that air flow was a significant factor governing filtration conditions. They found reductions in fouling by augmenting air flow rates or aeration intensity. Various other methods such as vortex generation on corrugated membrane surface [5], development of new membrane materials [6], new design of membrane module [7,8], modification of feed flow pattern [9], incorporation of in-situ or ex-situ cleaning regimes for membrane units [10] and the addition of organic or inorganic additives [11,12], have been used to reduce membrane fouling and enhance filtration flux.

One of the most common strategies to reduce and control sludging/fouling in a submerged membrane bio-reactor (MBR) is to provide aeration (air scouring) close to the membrane surface. This induces local shear stress, which controls fouling and creates a favourable hydraulic distribution throughout the membrane surface [13]. Membrane aeration forms an important part of the operating cost of the MBR [3,14] and it is important to optimise the membrane aeration process. It is commonly accepted that air bubbling close to the membrane is one of the most efficient means of minimizing fouling and ensuring sustainable operation [15,16].

Basu and Huck [17] also examined the impact of a support material on an integrated bio-filter membrane system and found that the fouling of the support medium system was at least two times slower than the non-support system. Here support medium refers to the external agents such as granular activated carbon (GAC) or anthracite placed in a known quantity in suspension in the submerged membrane bioreactor. Krause et al. [18,19], Siembida et al. [20] and Johir et al. [21] used mechanical cleaning of membranes by introducing granular material into the submerged membrane reactor. The granular medium resulted in

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the enhancement of scouring of the membrane surface. Aryal et al. [22] also reported the influence of anthracite granules in submerged microfiltration. They observed that the presence of anthracite in suspension reduced TMP and flux declines by two to three folds. Thus, these results indicate that introducing of granular medium in suspension, has a significant role in controlling fouling. However, to date, there has been no literature that investigated the relative effect of granular medium in suspension (for mechanical scouring) and air flow (air scouring) when they are used together. This study highlights the relative merits of these two factors through detailed experiments conducted under different operating parameters.

2. Theory

In filtration systems, it is observed that the flux declines from an initial value to reach a steady value over time. Therefore, permeate flux can be expressed as a function of resistance (Darcy's law):

$$J = \frac{\Delta P}{\mu[R_m + R_c]} \tag{1}$$

where J is the permeate flux ($L/m^2.h$), μ is the viscosity (Pa.s), ΔP is the trans-membrane pressure (kPa), R_m and R_c (m^{-1}) are resistances of the clean membrane and cake layer deposited on the membrane surface.

In this study, the cake is assumed to be incompressible, and the particles are deposited on the successive layers of cake. It is also assumed that each deposited layer has the same permeability as the preceding and subsequent layers. As the membrane resistance remains constant this makes the permeate flux exclusively dependent upon R_c, the cake resistance, if all other filtration conditions remain the same. It highlights that if the membrane fouling can be kept minimum, the permeate flux can be increased. Therefore Eq. 1 can be modified as:

$$J = \frac{\Delta P(t)}{\mu[R_m + r_c M(t)]} \tag{2}$$

In the above equation, r_c (m/g) is the flow resistance per unit mass of solid or the specific cake layer resistance. M(t) (g/m^2) is the amount of solids deposited on membrane surface as a function of time.

In order to calculate ΔP(t) using Eq. 2, it is essential to know the amount of particles deposited on the membrane surface as a function of time. This can be determined by measuring the concentration of solids as a function of time. The mass deposited on the membrane surface as a function of time can then be calculated from the equation below:

$$M(t) = v(t)\frac{c_o - c_t}{A} \tag{3}$$

where, V(t) (m^3) is the volume as a function of time, A (m^2) is the membrane area, C_0 and C_t (g/m^3) are concentrations of suspension at initial and time t. The filtrate was recirculated back into the suspension tank in order to maintain a constant volume of suspension.

3. Materials and methods

Submerged microfiltration experiments were carried out using a flat sheet membrane (Fig. 1). The flat sheet membrane used in this study was supplied by the A3 Company and had a nominal pore size of 0.14 μm and an effective membrane area of 0.2 m^2. The membrane consisted of eight flat sheets separated from each other with a gap of 12 mm. The reactor tank with a volume of 12 L was filled with a suspension of kaolin clay (Sigma, USA). Kaolin is a naturally occurring white clay which may be generally described as an Aluminium silicate hydroxide.

The membrane was submerged in a reactor. An air distributor plate was used to produce air bubbles at different air flow rates. The air flow was controlled by an air flow metre. The bubbles of size between 2 to 4 mm in diameter (considered as a large bubble) were used in this study.

The membrane filtration mode of operation is from outside to inside where the permeate is forced through the membrane by suction pressure. A peristaltic pump was used to extract the permeate at a constant permeate flux. The suction pressure was monitored online by a pressure transducer installed between the suction pump and a membrane module. The pressure transducer was connected to a data acquisition system for logging the suction pressure of the system. No back wash was applied during the experimental period.

The size of the kaolin clay particles (used to prepare the suspension) varied between 0.2 to 4 μm and the mean particle size was 2.10 μm, which was larger than the membrane pore size. The density of clay was 2760 kg/m^3. The unimodel particle size distribution is presented in Fig. 2. The D[v,0.9], D[v,0.5] and D[v,0.1] were 3.91 μm, 2.10 μm and 1.61 μm respectively (where D[v,0.9], D[v,0.5] and D [v,0.1] represent the 90%, 50% and 10% of the volume distribution below the given value respectively). The kaolin clay suspension was prepared by mixing predetermined amount of kaolin clay in the tap water. The concentration of the kaolin clay suspension was 10 g/L which is similar in range to the mixed liquor suspended solid (biomass) concentration in the membrane bioreactor (used in wastewater treatment application). The tap water had a minimal amount of suspended solids of less than 5 mg/L.

The membrane was tested for its hydraulic resistance prior to each experiment. Prior to each experiment, the membrane was cleaned with tap water and placed on a shaker operated at 120 rpm for an hour. Finally the membrane was submerged in a chemical solution (3% w/w sodium hypochlorite) for 3 h. The clean water permeate flux was measured at the beginning of each test in order to ensure

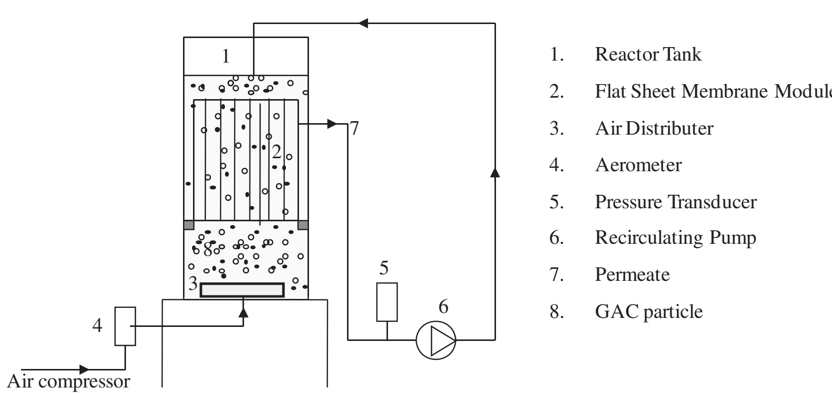

Fig. 1. Schematic diagram of experimental set-up.