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# Modelling of particle deposition in a submerged membrane microfiltration system

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HIGHLIGHTS

- Experiments on permeate flux, and aeration rate on particle deposition
- Modelling of particle deposition in submerged membrane with flat sheet membrane.
- Relationship of cake resistance, permeate flux, particle deposition was derived.

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ABSTRACT

In this study, microfiltration of a concentrated suspension of kaolin clay was performed in an aerated tank with submerged flat sheet membranes. Particle deposition was correlated with cake resistance based on experimental results. The effects of air flow rate and permeate flux on transmembrane pressure (TMP) and on membrane resistance were studied. The experimental results show that the filtration resistance due to cake formation plays a dominant role in the total filtration resistance. An increase in permeate flux caused higher TMP development due to an increased amount of particle deposition. Conversely, an increase in air flow rate reduced TMP by detaching deposited layers back into suspension. The particle deposition under different filtration flux and air flow rates was correlated to establish an empirical formula. Based on the experimental results, a general relationship between the cake resistance, permeate flux and particle deposition was derived as $R_c = 1.01 \times 10^{12}\, J \cdot w_c$ that suggests that the cake resistance is proportional to the multiplication of flux and cake deposition. Moreover, the effect of air flow on cake porosity was observed to be more significant at low permeate flux.


## 1. Introduction

Submerged membrane systems (with air bubble scour system for membrane fouling/particle deposition reduction) are increasingly used in many industries for the purification and separation of particles from liquid. In such systems, the injected air bubbles not only prevent the deposition of particles on the membrane but also detach the deposited cake from the membrane surface and induce the continuous movement of the fibres [1]. Since the performance of the microfiltration (MF) is significantly affected by membrane fouling, a better understanding of the particle deposition mechanism in an air sparged membrane system could lead to better efficiency and minimum membrane fouling.

The application of air flow (air scour or air sparging) in submerged membrane systems is a popular hydrodynamic approach in controlling membrane fouling. The effect of air flow to enhance the membrane system performance has been reported in literature [2–6].

Laborie et al. [7] studied the effect of air injection into a feed stream that generates a gas/liquid two phase flow on the membrane surface to reduce particulate membrane fouling. They found that air injection enhanced the permeate flux in all experiments that used ultrafiltration (UF) hollow fibres to treat clay suspension. The results showed that the air injection clearly modified the cake structure, and appears to expand the cake. Cabassud et al. [1] also investigated the effect of applying air flow filter feed with hollow fibre UF. They linked the flux enhancement to hydrodynamic control i.e. the mixing and turbulence created by the air bubbles in the liquid phase. Significant increases in permeate flux have been reported, even at very low air flow rate, for all the concentrations studied. Guibert et al. [8] compared several new configurations of continuous aeration system in submerged UF systems to mitigate fouling. They observed the changed local aeration intensity and sequential aeration at different locations under hollow fibre membrane modules due to the new aeration configurations [8].

Significant development has been achieved in understanding the fouling of individual components such as bacteria, yeast, proteins and

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colloids in MF and UF [9,10]. Suspended solids are very often identified as the main foulant [11,12]. The significance of the submicron colloidal fraction in the suspended solids has been correlated with membrane fouling rates [13,14]. Ivanovic et al. [15] studied the role of submicron particles in membrane fouling with the modification of a submerged hollow fibre membrane reactor by introducing a flocculation zone below the aeration device of the membrane module. This caused the reduction of submicron particles from 8.2% to 6.9%. They reported that the reduction of submicron particles (colloids) adjacent to the membrane resulted in a better fouling control in a biofilm membrane reactor. Bouhabila et al. [16] observed that the supernatant of mixed liquor suspended solids (MLSS) had 20–30 times higher specific resistance than the sludge suspension, which highlights the high fouling propensity of soluble and colloidal fractions.

Many models have been developed to understand the membrane fouling mechanism or to predict the filtration flux during MF. During filtration of colloidal particles and macromolecules, the diffusion mass transport phenomenon was dominant, and concentration models were used to predict the concentration profile near the membrane surface and the pseudo-steady filtration flux [17]. When cake resistance contributed to most of the total membrane resistance, hydrodynamic models were used to describe the particle fouling and flux decline [9]. Cake resistance was found to be a major component during filtration of colloidal particles in a submerged membrane reactor tank. This is why, this study has focused on the characteristics of the cake and thus its resistance. The effects of operating conditions such as air flow and permeate flux rates on transmembrane pressure (TMP), particle deposition, and membrane filtration resistance were studied experimentally. The correlation of air flow rate with particle deposition and TMP was established at different permeate flux rates.

## 2. Cake characteristics

The transmembrane pressure ($\Delta P$) developed over the filtration period can be used to calculate the total filtration resistance ($R_t$) by applying Darcy's law [9].

$$J = \frac{\Delta P}{\mu R_t} = \frac{\Delta P}{\mu (R_c + R_m)} \tag{1}$$

The total membrane resistance ($R_t$) is the sum of the cake resistance ($R_c$) and clean membrane resistance ($R_m$). Resistance due to pore blocking is neglected because the diameter of particles used is greater than the membrane pore size. The cake resistance can be used to calculate the cake mass ($w_c$) as:

$$R_c = w_c \alpha_{av} \tag{2}$$

where $\alpha_{av}$ is an average specific membrane resistance which was determined by using known values of cake resistance ($R_c$) and particle deposition ($w_c$). The total membrane resistance ($R_t$) can be calculated from the $\Delta P$ that was determined experimentally. The clean membrane resistance ($R_m$) was obtained from experiment. The resistance due to pore clogging was assumed found to be negligible as the particle size is larger than the membrane pore size. Hence, the cake resistance ($R_c$) can be calculated by deducting the clean membrane resistance from the total membrane resistance. The particle deposition ($w_c$) was calculated by measuring the suspended solid concentration.

Based on the mass balance, the cake thickness ($L_c$) can be calculated as:

$$L_c = \frac{W_c}{\left(\rho_p (1-\varepsilon_c)\right)} \tag{3}$$

where $\rho_p$ is the density of particle, and $\varepsilon_c$ is the average cake porosity, which can be calculated from the Kozeny's equation [18]:

$$\alpha_{av} = \frac{180(1-\varepsilon_c)^2}{\left(\rho_p * d_p^2 * \varepsilon_c^3\right)} \tag{4}$$

where $d_p$ is the average diameter of the particles. The specific resistance is a function of $\varepsilon_c$ and $d_p$, and the cake resistance depends on the specific resistance (Eq. (2)).

The cake thickness can be calculated as:

$$L_c = \frac{R_c}{\alpha_{av} \rho_p (1-\varepsilon_c)}. \tag{5}$$

In this study, the cake layer thickness was first determined using cake mass, kaolin density and membrane effective area. Later this value was used to calculate cake porosity using Eq. (3).

## 3. Materials and method

Submerged microfiltration experiments were conducted using a flat sheet membrane (A1, Germany, pore size = 0.14 μm, poly-vinylidene fluoride). The membrane tank, which had a capacity of 12 L, was filled with kaolin clay suspension. The concentration of the kaolin clay suspension was 10 g/L of tap water. The kaolin clay concentration was kept high within the range of mixed liquid suspended solids in a membrane bioreactor. The particle sizes of kaolin based on the particle size distribution of D[v,0.9], D[v,0.5] and D[v,0.1] were 0.186 μm, 0.3 μm and 0.462 μm respectively (where D[v,0.9], D[v,0.5] and D[v,0.1] represent 90%, 50% and 10% respectively). The mean particle size is higher than the membrane pore (0.14 μm), so internal pore blocking was negligible and all particle deposition occurred on the membrane surface.

The flat sheet membrane (membrane area = 0.2 $m^2$) was submerged in the tank and air flow rates were continuously supplied from an air diffuser plate located at the bottom of the tank. The diameter of the bubbles was in the range of 2–4 mm. It is noted that the cake formation on a vertical membrane under low TMP is affected by gravity. But in this study, air flow (counter-gravity shear force) was continuously

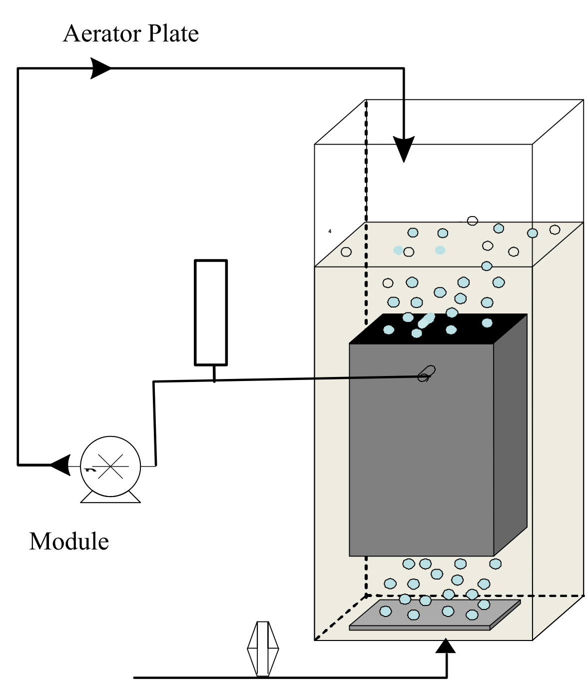


**Fig. 1.** Schematic diagram of experimental set-up.