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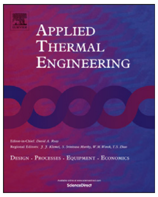

Sludge components and their fouling properties in a submerged micro-membrane filtration system

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HIGHLIGHTS

- Membrane filtration process includes two stages.
- Increased air intensity has little effect on the supernatant filtration process.
- Filtration flux of suspended solid and active sludge increase with air intensity.
- The synergistic effects are evaluated for the multi-stage filtration process.
- Supernatant plays an important role during the initial filtration process.

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ABSTRACT

The fouling characteristics of microfiltration (MF) membranes were investigated with active sludge in a membrane bioreactor (MBR). The active sludge was separated into the suspended solids and the supernatant. The filtration through MF membranes of the active sludge and each component were investigated using an experimental submerged filtration system. The suspended solids were found to be the main factor causing the membrane fouling and flow resistance. The whole filtration process was divided into two stages according to the Hermia blocking law, with each stage corresponding to a specific fouling mechanism. These divisions were used to analyse the filtration of each component of the active sludge for different air flow rates. Increases in the air intensity had little effect on the supernatant filtration but increased the filtration rate of the suspended solids and the active sludge. The synergistic effects were analysed to describe the multiple stages in the filtration process. The synergistic effects between the supernatant and the suspended solids promoted the membrane fouling. The supernatant had a great effect on the fouling during the initial filtration process.

1. Introduction

Membrane bioreactors (MBR) are widely used in wastewater treatment. MBR systems allow complete physical retention of the bacterial flocks and virtually all the suspended solids within the bioreactor. The MBR has many advantages over conventional wastewater treatment approaches, including a smaller footprint and smaller reactor requirements, high effluent quality, good disinfection capability, higher volumetric loading and less sludge production [1]. However, the MBR filtration performance inevitably decreases with filtration time. This is due to the deposition of soluble and particulate materials onto and into the membrane, which is attributed to interactions between the active sludge components and the membrane. This major drawback has been investigated since early MBR systems are designed but is still one of the most challenging issues blocking further MBR development [2].

Many studies have attempted to quantify the membrane fouling caused by each fraction of active sludge. Active sludge can be divided into two parts: the suspended solids and the supernatant. The supernatant can also be divided into the colloids and the solutes. Wisniewski et al. reported that the solutes played a major role in membrane fouling in the MBR process [3]. Defrance et al. reported that suspended solids caused the greatest amount of fouling among the sludge fractions [4]. Bouhabila et al. reported that colloids were the main contributors to membrane fouling [5]. Le-Clech et al. compared results obtained from 13 different studies

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where the relative contributions of each fraction were calculated. The contribution of the supernatant (soluble and colloids) to the membrane fouling varied from 17% to 81%. These wide discrepancies were thought to be caused by the different operating conditions and biological states of the suspension [6]. However, most of the experiments neglected the coupling or synergistic effects which may occur due to interactions among different components of the biomass [6]. The whole filtration process should be analysed to identify changes during membrane fouling. Also, many of the experimental schemes used dead-end filtration systems instead of submerged filtration systems which are frequently used in practical applications.

In this study, microfiltration (MF) membranes were used in a submerged filtration system with the fouling characteristics assessed using active sludge from a local MBR plant. The roles of the different components of the active sludge in the whole filtration process were investigated. The process was divided into stages to analyse all the parts of the whole filtration process for different air flow rates. The permeability was calculated for each stage and the synergistic effects were used to describe the multi-stage filtration process.

2. Materials and methods

2.1. Experimental system and analysis

A schematic of the submerged membrane filtration system is shown in Fig. 1. The system consisted of a feed tank, an aerator, a membrane chamber, a filtrate collection vessel, an electronic balance and a PC. The filter membrane was fixed on the membrane chamber module with a filtration area of 1.77 cm^2. The filtration pressure was supplied by a water head of about 7.5 kPa (a 77 cm high water column below the membrane). The operating temperature was kept at 20 °C. The filtrate weight was measured using the electronic balance and recorded by the PC. Compressed air was injected into the suspension tank through an exchangeable injector head and the air flow rate was controlled by a valve. The filtration of the MBR mixed liquor was measured at three different air flow rates of 0.0 L/min, 1.0 L/min and 2.0 L/min.

2.2. Membranes and foulants

A mixed cellulose esters membrane (HAWG04700, Millipore) was used as the filtration membrane in the experiments. The membrane had a 0.45 μm pore size, 150 μm thickness and 79% porosity. The membrane was hydrophilic and made from biologically inert materials of cellulose acetate and cellulose nitrate. Prior to use, the membrane was immersed in de-ionized water for 24 h to remove soluble impurities and additives from the fabrication process. The waste active sludge was acquired from a wastewater treatment plant in Beijing. The active sludge is separated into the suspended solids and the supernatant using gravitational sedimentation of the active sludge mixed liquor for 4 h. The suspended solids and the supernatant were diluted in de-ionized water to the same concentrations as in the active sludge to prepare a solid-only liquor and supernatant-only liquor. These two liquors were also filtrated to compare with the original active sludge.

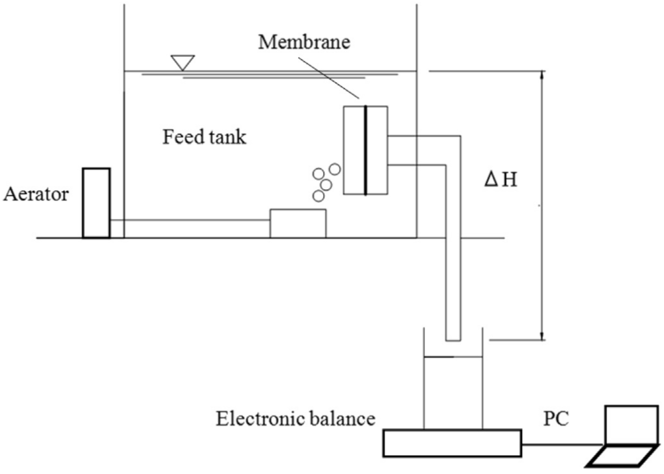

Fig. 1. Schematic diagram of the MBR filtration system.

2.3. Membrane fouling model

At the beginning of the membrane filtration process, the membrane surface is not fully covered by foulant particles. The main cause of membrane fouling during this period is the interactions between the particles and the unpolluted membrane surface. As the filtration process continues, the membrane surface becomes fully covered with foulant particles and the main cause of the membrane fouling is the interactions between the particles. Thus, the filtration process can be divided into two stages. A filtration model is developed for each stage to describe the filtration process and entire membrane fouling process.

Deposition of particles inside the pores or on membrane surface leads to fouling of the membrane. This phenomenon can be mechanically described by four models. The first standard blocking model assumes that the particles deposit inside the membrane which constricts the pores and reduces the permeability. The second complete blocking model assumes that the particles block pore entrances and prevent flow. The third intermediate blocking model assumes that some particles are responsible for pore blocking and the rest accumulate on top of the other deposited particles. The fourth cake filtration model applies when particles accumulate on the membrane surface as a permeable cake of increasing thickness that adds resistance to the flow. These mechanical concepts are used to introduce the so-called “blocking laws” which are one of the most common models for fouling mechanisms [7].

In the complete blocking model [8], each pore at the membrane surface is assumed to be blocked by one foulant particle. For this condition, the filtrate volume is proportional to the blocking area. The particles in the MBR mixed liquor are usually larger than the pores in the microfiltration membrane [9], thus, the complete blocking model was chosen to describe the first stage of the filtration process. In the cake filtration model [10], the foulant particles attached to the membrane surface develops into a regular cake layer. The cake layer has its own structure and filtering ability. These two filtration models can be combined into the following differential equation:

$$\frac{d^2t}{dV^2} = k\left(\frac{dt}{dV}\right)^n \tag{1}$$

$n = 2$: complete blocking model
$n = 0$: cake filtration model

where t is the filtration time (s) and V is the filtrate volume (m^3).

For the complete blocking model, Eq. (1) reduces to:

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