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Fouling in membrane bioreactors with various concentrations of dead cells

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ABSTRACT

The effects of sludge viability on process performance and membrane fouling in a membrane bioreactor were investigated. A laboratory-scale submerged membrane bioreactor (SMBR) containing a flat-sheet microfiltration membrane was used at various percentages of living cellular flocs and dead cells. The effect of live to dead cells ratio on the extracellular polymeric substances (EPS) concentration was also studied. The proportion of dead cells affected the type of EPS in the mixed liquor as well as hydrophobicity of activated sludge. Tightly bound EPS (TB-EPS) mitigated membrane fouling, whereas loosely bound EPS (LB-EPS) caused severe membrane fouling. The results show that the content of TB-EPS and LB-EPS increases with dead cells portion. Furthermore, the ratio of TB-EPS to LB-EPS was presented as an important parameter in MBR performance. It was showed that this ratio is a good representative of flocculability of activated sludge and fouling intensity. Compared to the live cells, the dead cells had lower hydrophobicity and induced membrane fouling so that membrane permeability of the viable activated sludge was twice of the dead cell culture. The potential of zone settling velocity (ZSV) to be considered as a key parameter in MBR operation was also reported.

1. Introduction

Fouling is a major obstacle for scaling up membrane bioreactors (MBRs) in wastewater treatment plants [31,36]. Solid retention time (SRT) has the greatest impact on MBR fouling over a range of operating parameters and affects sludge properties regarding viability, extracellular polymeric substances (EPS) content, soluble microbial products (SMP), floc size and settling characteristics [35].

Either in bound or soluble/colloidal form, EPS are believed to be the dominant cause of membrane fouling in MBRs [7,19]. EPS act as glue and bind cells together, and this affects the main activated sludge properties such as flocculating and settling characteristics. Many studies have investigated the role of EPS in bioflocculation and sludge settleability [10,35,49,64]. Several factors influence EPS concentration such as wastewater characteristics, intermittent feeding, sludge age and loading rate, mixed liquor suspended solids (MLSS) concentration and microbial growth phase [5,57,58,61]. Additional factors including toxic materials, mechanical stress, irregular sludge wastage or shifts in the oxygen supply increase EPS formation and cause changes in cell viability and membrane fouling propensity [20,33,70]. Moreover, several attempts have been made to correlate flux with MLSS concentration, floc size, sludge rheology [6,14] and soluble EPS concentration [38]. Yet, owing to the complexity of the biological systems and differences in applied experimental and analytical methods, these studies sometimes appear to be inconsistent and even contradictory.

In spite of numerous technical publications on membrane fouling and EPS, few studies have addressed the role of cell viability on EPS concentration and sludge properties, and hence on membrane fouling propensity. It has been claimed that increasing the SRT could enhance the development of slow growing microorganisms since they are able to consume the macro-molecules as substrates and produce less biopolymer [43]. But unfortunately, the study of microbial viability as a way to better understanding EPS formation and membrane fouling has not been adequately researched. However, SRT as a representative of sludge age and cells viability has taken sufficient place in the literature. Despite extensive investigations on influence of SRT on membrane fouling, their results are very contradictory. Few articles report serious fouling in long SRTs [34,66], other studies showed the inverse effect of SRT on fouling propensity [1,2,19]. A direct study of cell death and membrane fouling could explain this disagreement. As mentioned above, EPS is essential to sludge floc formation, but excessive EPS in the form of loosely bound extracellular polymeric substances (LB-EPS) may deteriorate cell attachment and weaken the flocs' structure. These properties could be affected by cell viability. Furthermore, sludge morphology varies significantly with the percentage of living cells; this entails changes in sludge floc size and results in the development of different predominant microbial communities, which could have a variety of effects on membrane fouling [1,46]. Little information is available to distinguish between the proportions of loosely and tightly bound EPS (TB-EPS), released by sludge with different cell viability, and their effects on the surface properties of biomass and hence membrane fouling. This work aimed to study fouling properties as a function of activated sludge viability

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and clarify the effect of different types of EPS on sludge properties in MBR systems.

2. Materials and methods

2.1. Experimental setup

The sludge filtration test was conducted in a 1.5 L stirred cell (Heidolph, MR3001K, Germany) using a 0.45-μm flat-sheet cellulose ester membrane filter (ME25, Whatman, Germany) submerged in a bioreactor (Fig. 1). The membrane surface was rinsed with air at a flow rate of 1 L/min. For each run, the stirred cell was filled with 1 L of one of the seven samples described in following section and a constant vacuum of 0.6 bar was applied for filtration by a vacuum pump. The total permeate volume was measured at ambient temperature under normal air pressure after 5 h of filtration.

2.2. Experimental procedure

The sample of activated sludge was obtained from a laboratory unit that works continuously to provide with the necessary fresh activated sludge acclimated with oily pollutants in various researches conducted in our laboratory. The composition of the synthetic influent for this unit has been shown in Table 1. The SRT of laboratory unit had been adjusted to 15 days. For preparing the dead cell mixture a thermal treatment, was conducted, which inactivates cellular enzymes and changes the osmotic pressure of the cells, allowing toxic materials entering them [17]. Dead cells were obtained by autoclaving a sample of activated sludge at 120 °C for 10 min. To study the effects of dead cells on membrane fouling, samples with various proportions of dead cells were prepared by mixing live activated sludge with the autoclaved sample. The proportions of dead cells were 0, 20, 40, 50, 60, 80, and 100%. The final MLSS concentration of each sample was adjusted at 14000 mg/L by dilution with water. The samples were then transferred to stirred cell for fouling examination.

2.3. Analytical methods

2.3.1. Sludge filterability

The dewatering ability of the sludge suspension was determined using the filterability test as described by Wisniewski and Gasmask [65]. The filterability of the suspension is estimated by submerged filtration of a 1 L sample in a stirred cell. To minimize the deposition of particles during experiments, the cell was equipped with a magnetic stirring rod that induced tangential stresses near the membrane surface. Furthermore, air scouring on the surface of the membrane prevented cake formation. The permeate volume was measured as an indicator of sludge filterability.

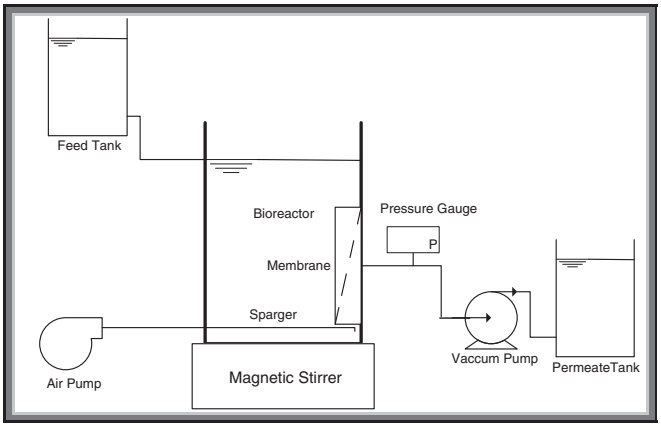

Fig. 1. Schematic diagram of experimental setup.

Table 1
Composition of synthetic influent.

Component	Concentration (mg/l)
Hydrocarbons (C_{13}, C_{16} , C_{22})	1000
$(NH_4)_2SO_4$	670
$(NH_4)H_2PO_4$	40
K_2HPO_4	100
KH_2PO_4	1000
$MgSO_4.7H_2O$	40
CH_3COONa	5000

2.3.2. Membrane filtration resistances

Membrane resistance was evaluated by the resistance-in series model based on Darcy's law as follows:

$$R_t = R_m + R_P + R_C = \Delta P / (\mu \times J). \quad (1)$$

Where ΔP is the trans-membrane pressure gradient (N/m^2), μ the viscosity of the permeate (Pa × s), and J the permeation flux (m/s). In this equation the total membrane resistance (R_t), consists of inherent membrane resistance (R_m), pore fouling resistance (R_p), and resistances due to sludge films (R_c).

The experimental procedure to get each resistance value was reported by Meng et al. [45] described briefly here as following. The resistance of membrane (R_m) was estimated by measuring the water flux of distilled water and the value of total resistance (R_t) was evaluated by the final flux of sludge wastewater microfiltration. Then the membrane surface was rinsed by distilled water and a sponge to remove the cake layer deposited on membrane surface. Following the cleaning of membrane surface, the distilled water flux was measured to get the resistance of $M = R_m + R_p$. The cake resistance (R_c) obtained from R_t and M, and the pore blocking resistance (R_p) was calculated from M and R_m.

2.3.3. EPS extraction and analysis

EPS could be divided into soluble and non-soluble portions. Soluble portion is considered as LB-EPS which is identical with SMP [35]. Several methods have been used to extract extracellular polymers from bacterial cultures; these include ammonium hydroxide extraction [59], sodium hydroxide extraction [60], ethylenediaminetetraacetic acid (EDTA) extraction [50], ultrasonication [25], high-speed centrifugation [53] and extracting by boiling or autoclaving [24]. The present study used formaldehyde and sodium hydroxide for EPS extraction as performed by Liu and Fang [40]. This method was selected due to its higher yield of EPS.

A sludge suspension was first agitated via vortex at room temperature for 5 min and then dewatered by centrifuging in a 10 mL test tube at 3500 rpm for 10 min (Hettich, Universal 320, Germany). The supernatant contained loosely bound EPS (LB-EPS), which were collected for analyses including determination of the protein extracellular polymeric substance (EPS_P) and of the polysaccharide-based extracellular polymeric substance (EPS_C) (Solution No.1). After the extraction of LB-EPS, the sludge was pelleted and resuspended in 5 mL of 8.5% NaCl and 0.22% formaldehyde and was shaken for 1 min. Next, 5 mL of 0.5% NaOH was added to the solution and it was shaken for another minute (solution No.2). Both solutions No.1 and No.2 were then centrifuged at 10000 rpm for 15 min to separate the remaining suspended materials. The solutions were then filtered through filter paper (0.45 μm) and the amount of TB-EPS and LB-EPS in the filtrate was determined. Both the LB-EPS and TB-EPS extractions were analyzed for protein and polysaccharide contents. The EPS_P were analyzed by a UV/VIS spectrophotometer (WTW, SpectroFlex 6600, Germany)