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Influence of supporting media in suspension on membrane fouling reduction in submerged membrane bioreactor (SMBR)

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ABSTRACT

In this study, the SMBR was compared in terms of membrane fouling with and without the addition of suspended medium in the membrane reactor. The effectiveness of medium in suspension in submerged membrane bioreactor (SMBR) was evaluated at different filtration flux. The SMBR was operated at a flux of 5–30 L/m^2 h (corresponding hydraulic retention time of 10–1.7 h) with and without suspended medium. The suspended medium used in this study was granular activated carbon (GAC; particle size 300–600 mm) at air scouring (aeration) rates of 0.5–1.5 $m^3 m^{-2}$ membrane area h^{-1}. At higher aeration rate of 1.5 m^3/m^2 membrane area h, the effect of flux on membrane resistance was found to be negligible. The reduction of aeration rate from 1.5 to 1.0 $m^3 m^{-2}$ membrane area h^{-1} resulted in a sudden rise of TMP. The addition of suspended medium prevented a sudden rise of TMP (total membrane resistance reduced from 51×10^{11} to 20×10^{11} m^{-1}). The organic removal efficiency remained high irrespective of flux. The molecular weight distribution (MWD) and excitation emission matrix (EEM) analysis of SMBR effluent showed a range of organic (composed of amino acids, biopolymers, humics and fulvic acids type substances) removed by the GAC both by scouring and adsorption mechanisms.

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1. Introduction

Industrial applications of MBR prove its interest in wastewater treatment, due to its ability in completely removing solids (micro-organism included), its superior removal of nutrient and organic matter, high loading rate capabilities, low sludge production and small footprint. This makes the MBR particularly suitable when water reuse is envisaged.

The major challenge in the membrane filtration systems is the control of membrane fouling and its minimization during operation. There is a pressing need to minimise the fouling potential and/or develop a simple method to measure and predict the fouling potential of wastewater. Membrane fouling can be either reversible or irreversible. Membrane fouling can be divided into three scales of fouling [1,2]: (i) sludging (sludge accumulation) on the membrane surface [2], which can be avoided by inducing sufficient local shear stresses (aeration). (ii) Irreversible fouling due to physico-chemical interactions (adsorption) of soluble compounds onto the membrane surface which can be cleaned only by chemical(s) [3]; (iii) the development of a biofilm due to an accumulation of cells, extracellular polymeric substances (EPS) and soluble microbial product (SMP) on the membrane surface. The presence of EPS and SMP in the mixed liquor of MBR is the main cause of the progressive membrane fouling [4]. Long term experiments, without membrane cleaning, are always marked by an exponential rise in transmembrane pressure (TMP) as membrane fouling becomes increasingly severe.

Several researchers have explained the accumulation of fouling compounds on and within the membrane material [3,5]. EPS represent the total fraction of biopolymers (the soluble ones (SMP) and those that are bound to flocs). These EPS and SMP are mainly composed of proteins and polysaccharides, nucleic acids, lipids and other polymeric compounds. EPS and SMP are considered to be the most important irreversible membrane foulants. This required chemical cleaning of membrane which ultimately decreases the membrane life time and increases the cost of maintenance. Recently, researchers have also described the role of the thin biological deposits on the membrane surface and their influence on fouling rate in terms of their own biological activities and their mechanical properties, such as compressibility [6].

It is commonly accepted that air bubbling close to the membrane is one of the most efficient means of minimizing reversible fouling and ensuring sustainable operation [7,8]. Bubbling induces local shear stress, which controls fouling and creates a favourable hydraulic distribution throughout the fibre network [9]. Membrane aeration forms an important part of the operating cost of the MBR [10,11] and it is important to optimise the membrane aeration.

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But because of the presence of irreversible interactions between soluble compounds or bacteria and membrane material, membrane fouling cannot be controlled only by aeration. It is then important to define procedure to reduce the concentration of these compounds at the membrane surface and in solution. Incorporation of supporting media/adsorbents may be relevant to scour some of the foulant on the membrane surface and capture some of the fouling-causing substances prior to their contact with membrane material. An addition of adsorbents into the biological treatment tank removes a majority of soluble organic compounds that cause irreversible membrane fouling [12–15]. Adsorption of EPS on PAC was studied during the operation of submerged hybrid PAC-MBR [16].

This paper targets the use of granular activated carbon (GAC) to improve the process efficiency by increasing the permeate flux without the need to increase aeration rate to reduce the irreversible membrane fouling. Previous work had concentrated on the addition of powder activated carbon (PAC) [12,14] mainly to achieve additional removal of organic matter thereby also reducing the membrane fouling. In this study, GAC was used instead of PAC. GAC as a suspended medium was rarely (or not) used in previous studies. In this study, the performance of SMBR were compared with and without the addition of GAC as suspended medium through the evaluation of the effectiveness of the suspended medium as adsorbent and scouring media to remove organic matter that causes membrane.

Extracellular polymeric substances (EPS) and soluble microbial products (SMP) are major factors for fouling. Selective elimination of those substances from the system and/or deposited membrane is a key on the success of membrane fouling control. Literature reported that an addition of activated carbon (AC) resulted lower fouling [12–16]. Most researchers including Lesage et al. [15] stated that the soluble organics were adsorbed on AC but the organic removal was measured in terms of surrogate parameters. Understanding the nature of and range of organics in fouling both in absence and presence of AC is vital for its application. This paper used two simple but robust analytical techniques (i) size exclusion chromatography and (ii) fluorescence spectroscopy (excitation emission matrix) to identify and quantify a wide range of organics in SMBR and fouling. The excitation emission matrix (EEM) enabled us to identify a wide range of organics (humics, fulvics, BOD_5, extracellular polymers, proteins and their precursors). The EEM spectra identified key differences in fouling when running before and after GAC. This enabled us to understand what types of organics were selectively removed when GAC was applied and why less fouling occurred when applying GAC.

2. Materials and methods

The schematic diagram of submerged membrane bioreactor (SMBR) used in this study is shown in Fig. 1. A flat sheet membrane module with an area of 0.2 m^2 made of polyvinylidene fluoride (PVDF) was used in this study. The average pore size of the membrane was 0.14 μm. Air flow rate in the range of 0.5–1.5 $m^3/(m^2$ membrane area h) was applied to produce shear stress on the membrane surface. The spacing between the membrane panels is about 1.1 cm. The range of aeration rate used in this study was between 0.5 and 1.5 m^3/m^2 h. This range of aeration rate used is very common in MBR even though it is low. A number of studies have been done on the effect of aeration rate on membrane fouling [17,18]. They state that after a critical rate of aeration there is no effect of aeration on membrane flux. The critical aeration rates that have been reported were in the range of 0.0048–0.010 $m^3\,m^{-2}\,s^{-1}$ (for MLSS concentrations varying form 2–10 $g\,L^{-1}$ and flux of 10–20 $L\,m^{-2}\,h^{-1}$). The aeration rate those used in our present study was between 0.0023 and 0.0069 $m^3\,m^{-2}\,s^{-1}$ which falls in the range of values reported in previous literature. Here the aeration rate velocity is the aeration intensity which is defined as the air flow/unit floor area in Nm^3 air per m^2 cross-section per unit time, rather than specific aeration demand (Nm^3 air per m^2 membrane area per unit time). The effective volume of the reactor was 10 L.

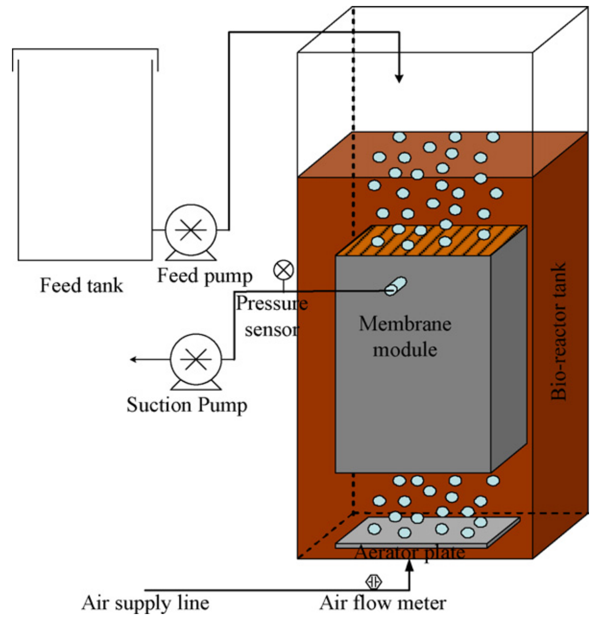

Fig. 1. Laboratory scale membrane bioreactor.

The choice of PVDF membrane for the flat sheet module was due to its higher water permeation rates, its resistance to high and low pH and its ability to withstand strong oxidising agent such as sodium hypochlorite during membrane cleaning. The pore size (0.14 μm) of the membrane classifies it as a microfilter and it can retain almost all the biomass including the isolated micro organisms. The membrane module contained 8 flat sheets connected together at an interval of 12 mm. Each sheet acts as a single membrane module. The membrane filtration process was from outside to inside, without any relaxation or back-wash procedure. Permeate was pumped out using a peristaltic pump at a constant flux. A pressure transducer with online data acquisition was used to monitor the transmembrane pressure (TMP) every 5 mins.

At the beginning, the MBR was seeded with 3 L of mixed liquor (sludge) obtained from a domestic sewage treatment plant. After seeding, the bioreactor was continuously fed with a synthetic feed consisting of ethanol (as an organic source) and mineral salts containing nitrogen and phosphorus (as nutrients) in the ratio of COD:N:P ratio equal to 150:5:1 with an organic load of 1.5 kg COD $m^{-3}\,d^{-1}$. This COD:N:P ratio represents that of domestic wastewater. As the aim of the research was to understand the change in fouling behaviour at different hydraulic retention times (HRT) and aeration rates, the organic loading rate was kept constant. The average sludge retention time (SRT) was 20 days and total suspended solid (TSS) concentration was in the range of 5–6 g/L. TSS concentration was maintained by wasting excess sludge (5%, v/v) every day and diluting it by adding a similar amount of wastewater (irrespective of HRT). The pH of the mixed liquor was monitored daily and remained between 6.5 and 7.6.

The concentrations of the feed were continuously re-evaluated based on the HRT to keep a constant organic loading rate (OLR) based on the following formula.

$$C_v = \frac{C_s \times Q}{V} \quad (2.1)$$

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