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Evaluation of fouling formation and evolution on hollow fibre membrane: Effects of ageing and chemical exposure on biofoulant

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ABSTRACT

Bio-deposition and biofouling, a major challenge for membrane filtration, is still not fully understood due to its complex structure and intricate evolution with time and chemical environment. In this work, diluted sludge from an anaerobic bioreactor with low mixed liquor suspended solid (MLSS) concentration was filtered for 3.5 h to form initial fouling layers which were then exposed to various solution environments for 17 h. Apart from monitoring the hydraulic resistance of membrane fouling, a real time direct observation (DO) technique was applied to monitor the change of thickness in the fouling layer. The cohesion and adhesion of different fouling layer were investigated by monitoring the transmembrane pressure (TMP) and thickness change after applying relaxation (cessation of filtration) and backwash. It was found that TMPs and resistances of the aged fouling layers increased significantly after 17 h filtration. All the aged fouling layers exhibited lower compressibility as a result of more soluble microbial products (SMP) and extracellular polymeric substances (EPS) excretion, biofilm growth. From *in situ* imaging, the fouling on the membrane surface appeared to be inhomogeneous from the inner (lumen) surface outwards. During long term filtration of fouling layer with Milli-Q water, direct observation (DO) results indicated the reorganization of the fouling layer in terms of peeling, rolling over and re-depositing on the membrane surface, resulting into more compressed fouling layers with higher resistances. Confocal Laser Scanning Microscopy (CLSM) analysis of aged fouling layers also indicated that the dead/total ratio of microorganisms was not uniform and increased gradually from the bottom to the top of the fouling layers.

1. Introduction

The development of biofouling and biofilm is one of the key fouling mechanisms in membrane fouling (Baker and Dudley, 1998). However, there is still a lack of detailed study of such phenomena, including fundamental mechanisms of biofilm development and biofilm structure information.

Fouling is commonly monitored by the transmembrane pressure (TMP), flux profiles and the corresponding fouling

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resistance calculated by Darcy's law. This only provides bulk membrane fouling information. In the past few decades, a number of non-invasive techniques have been developed to provide in-situ real-time monitoring of the membrane process (Chen et al., 2004). Direct Observation (DO), as a non-invasive, *in situ* optical technique, allows a real time observation of the particle deposition and removal on membrane surface in addition to fouling layer structure (such as thickness, density and homogeneity) (Marselina et al., 2009; Mendret et al., 2007; Wang et al., 2005). By using the DO technique, the development of foulant layer under different hydraulic conditions, such as cross flow velocity and back pulsing, has been investigated (Wang et al., 2005). Ye et al. (Ye et al., 2011) observed the change in cake height, composition and structure during the multi-cycle filtration-backwash process. Currently, the application of DO for membrane fouling study mainly focuses on model solutions such as bentonite, protein, alginate and model cell yeast solution. Its application for elucidating more complex biofouling development is still very limited. Subramani and Hoek applied the DO techniques to investigate the initial deposition of microbial cell on membrane surface (Subramani and Hoek, 2008). Biofouling develops from the initial bio-deposition into biofilm with increasing cell growth and EPS produced by the system. This forms a tangled matrix on the membrane surface which is difficult to remove. Biological activity, nutrient stress and chemical stress can significantly influence biofouling (Matin et al., 2011; Subramani and Hoek, 2008; Tansel et al., 2006). But detailed studies of biofoulant development from its initial deposition to biofilm formation and corresponding structural change under nutrient and chemical stress are rarely reported.

In addition to the structural information, adhesion and cohesion strengths of the biofilms are other essential factors to understand the mechanisms of fouling attachment and detachment, and to optimize fouling mitigation. There are limited studies focussing on such properties of biofilm during membrane fouling. The strengths of biofilm on other type of material surface have been previously investigated and reported in literature. Tensile force and shear force have been used to investigate the biofilm adhesion strength (Ohashi and Harada, 1996), and the micro-cantilever method has been applied to measure cohesion strength (Poppele and Hozalski, 2003).

More recently, confocal laser scanning microscopy (CLSM), along with cell staining and image analysis technique, was applied for ex-situ characterization of the fouling layer at the end of the filtration. Such techniques provide further detailed fouling structure information including the porosity of fouling layer (Sun et al., 2011; Yun et al., 2006), the spatial distributions of both porosities and the biovolumes of membrane fouling (Lee et al., 2007). With different specific stains, CLSM can also provide the estimated amounts of living and dead microorganism and organic substances such as EPS, SMP and biopolymer clusters (BPCs) (Sun et al., 2011; Yun et al., 2006).

The aim of this study is to investigate the evolution of fouling layer from simple microorganism deposition to a living biofilm and detachment dynamics in real time with freshly deposited and aged biomass foulants. The particular fouling behaviours and biomass evolution under nutrient or chemical shock loads or toxic substances exposure were also investigated. In addition to monitoring the basic hydraulic fouling resistances, DO technology was used to monitor the development of biofouling layer in real time with their corresponding structural information. By applying relaxation/backwash, and observing the corresponding TMP and fouling layer thicknesses, the cohesion and adhesion of the foulant layers were explored. CLSM analysis was incorporated at the end of filtration to provide detailed insight on the evolution of biofouling.

2. Materials and methods

2.1. DO filtration system

Fig. 1 shows the layout of DO filtration set-up, which comprised of a transparent membrane cell, a microscope, a video camera, a feed tank, two peristaltic pumps, a pulse dampener, a balance, a pressure transducer and a computer.

The details of transparent membrane cell and filtration system can be found elsewhere (Ye et al., 2011). A digital video camera (Sony, HDR-XR550E) was attached to the microscope for recording. The membrane cell was set up vertically, where the mounted hollow fibre was sealed at the bottom, and the permeate exited from the top. Polyvinylidene fluoride (PVDF) hollow fibre membranes (OD/ID 1300/650 μm, average pore size of 0.04 μm) from Evoqua Water Technologies, Australia, with a length of 15.5 cm were used in the study.

Feed was circulated by a peristaltic pump (Masterflex, L/S pump) at a cross flow velocity (CFV) of 15 mm/s. The solution in the feed tank was continuously stirred with a magnetic stirrer to ensure homogeneity. The permeate flux was controlled by another peristaltic pump. The balance and the pressure transducer (Labom, CB 1020) were connected to the computer to measure the mass of the permeate flux and permeate pressure respectively. All values were recorded in real time with Labview7.2 data acquisition software.

2.2. Filtration procedure

The filtration procedure can be divided into two stages, as indicated in Fig. 2. The first step is the formation of initial fresh biomass foulant layer. The second step is the exposure of the foulant layer to a variety of chemical solutions under

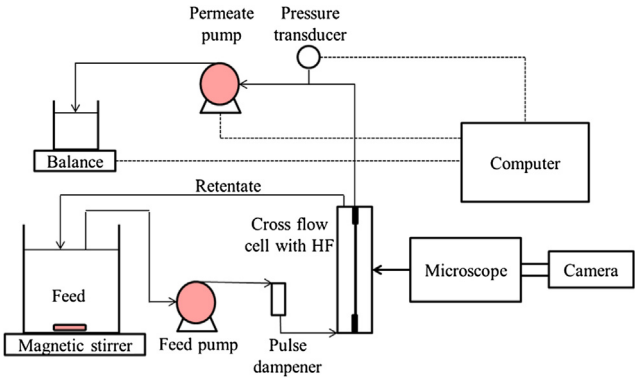

Fig. 1 – Schematic of the direct observation set-up.