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Resistance analysis for enhanced wastewater membrane filtration

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Abstract

This study investigated enhancement techniques for synthetic wastewater filtration in a membrane bioreactor (MBR) at mixed liquor suspended solids concentrations (MLSS) of 12–18 g/L. Air sparging (AS), backflushing (BF) and a combined application of both (AS + BF) were applied to increase permeate flux compared to the conventional application (NON). Scanning electron microscope (SEM) measurements of cake thickness served for evaluating cleaning effectiveness and as input data for some of the model calculations. AS + BF showed the lowest overall resistance, and thus the highest permeate yield, for about 2 weeks of observation. The contribution of fouling resistance, cake resistance and membrane resistance to the overall resistance was evaluated, based on experimental data. Air sparging significantly lowered cake thickness and consequently cake resistance. The experimental cake resistance and the model resistances were compared. A model based on the measured cake thickness and literature values for the specific surface area proved most successful. Finally, a relationship between the backflush resistance and the permeate flow resistance was observed.

Keywords: Resistance; Wastewater; Cake thickness; Air sparging; Backflush resistance

1. Introduction

Major research efforts in recent years have been aimed at overcoming the drawbacks of membrane fouling. For microfiltration, a variety of operation techniques are available: changes in cross-flow velocity (CFV), implantation of turbulence promoters, backflushing (BF) or backpulsing, pulsatile flow, rotation of flat sheet membranes, application of electrical and ultrasonic fields, and air sparging (AS) [1]. In industrial membrane applications, chemical cleaning is used periodically to restore flux. However, to reduce the frequency of chemical cleaning and thereby "down times" of the system and consumption of chemical cleaning agents, it is beneficial to apply enhancement techniques such as AS and BF. In this study, chemical cleaning was only performed in between test series. Tests during which no additional means to recover flux was used between cleanings, are referred to as non-enhanced or conventional operation (NON).

Flux enhancement through AS has been used since the late 1980s and applied commercially for inside-out and outside-in filtration. Both options have advantages and disadvantages. For outside-in filtration, coarse air bubbling provides CFV and shear stress in membrane bioreactors. This process is used in a number of commercial applications. Advantages are easy use and low maintenance costs; its chief disadvantage is the limited effect the air bubbles have in preventing fouling development on the membrane surface. The application of AS inside of membrane channels for inside-out filtration is commercially less common due to membrane surface area restrictions for these module types. However, the advantage of this method lies in the direct accessibility of the membrane surface to the air bubbles which can suppress particle deposition [2]. If air is injected into a tube which transports water, depending on the ratio of gas to liquid volume flow, the interface of this two-phase flow follows a variety of flow patterns. Through the dimensionless air injection ratio r (r = superficial gas velocity/(superficial gas velocity + superficial liquid velocity)), sometimes called the "void fraction" of the pipe, the flow pattern can be predicted. The increase of air injection ratio r creates for vertical pipes bubble flow ($0 < r < 0.2$), slug flow ($0.2 < r < 0.9$) and, finally, annular

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flow ($0.9 < r < 1.0$) [3]. For flux enhancement, slug flow is the most effective at disrupting the concentration polarization layer and maintaining stable permeate fluxes over longer time periods [4]. The experimental setup for this paper provided both air sparging (AS) and the very common option of backflusing (BF) to minimize fouling. Both techniques were applied separately and simultaneously.

As Bowen et al. [5] described, four fouling mechanisms are usually distinguished in microfiltration. (A) Complete pore blocking; (B) standard blocking; (C) intermediate blocking; (D) cake filtration. In practice usually all four mechanisms contribute to flux decline in different amounts. Air sparging is especially successful in fighting the build up of cake layers (external fouling). To overcome pore plugging (internal fouling), air sparging is less practical, but backflushing can partially tackle this problem. To overcome both internal and external fouling, a combination of both techniques was investigated in this research.

In this study special emphasis was placed on the cake resistance, which is a major contributor to the overall fouling in most wastewater microfiltration applications. The cake can act as an additional filter or secondary membrane, catching smaller particles and it undergoes a compaction process with ongoing time. Cake formation, together with other fouling mechanisms, can finally exceed the membrane resistance [6]. Several theoretical models for estimating cake resistance in wastewater microfiltration were evaluated by means of experimental data from conventional filtration. Those results allowed a comparison of the improvements achieved with AS and/or BF as discussed below.

2. Materials and methods

2.1. Membrane bioreactor setup

For experimental setup of the membrane bioreactor (MBR), an activated sludge tank with a capacity of 60–80 L was used (see Fig. 1). For this study, activated sludge was generated by inoculating synthetic wastewater with activated sludge from the local sewage treatment plant. The synthetic wastewater feed was glucose-based and contained high concentrations of the three basic elements carbon (C), nitrogen (N) and phosphorus (P) along with other compounds. For more details see Psoch and Schiewer [7]. A thermostat maintained the reactor temperature between 14 and 24 °C. The sludge retention time was maintained at 35 days by withdrawing about 2 L of sludge every day. The hydraulic residence time varied depending on the permeate flux.

The experiments were carried out with two vertical membrane modules, which were deployed in parallel. Each membrane module (Microdyn-Nadir) consisted of three polypropylene membrane tubes (pore size 0.2 μm) in a plastic housing of 0.75 m length. The diameter of the tubes was 5.5 mm, yielding a membrane surface area of 0.036 m^2 per module. Applied transmembrane pressures (TMPs) were between 100 and 200 kPa (1–2 bar). Cross flow velocities (CFV) of the water within the

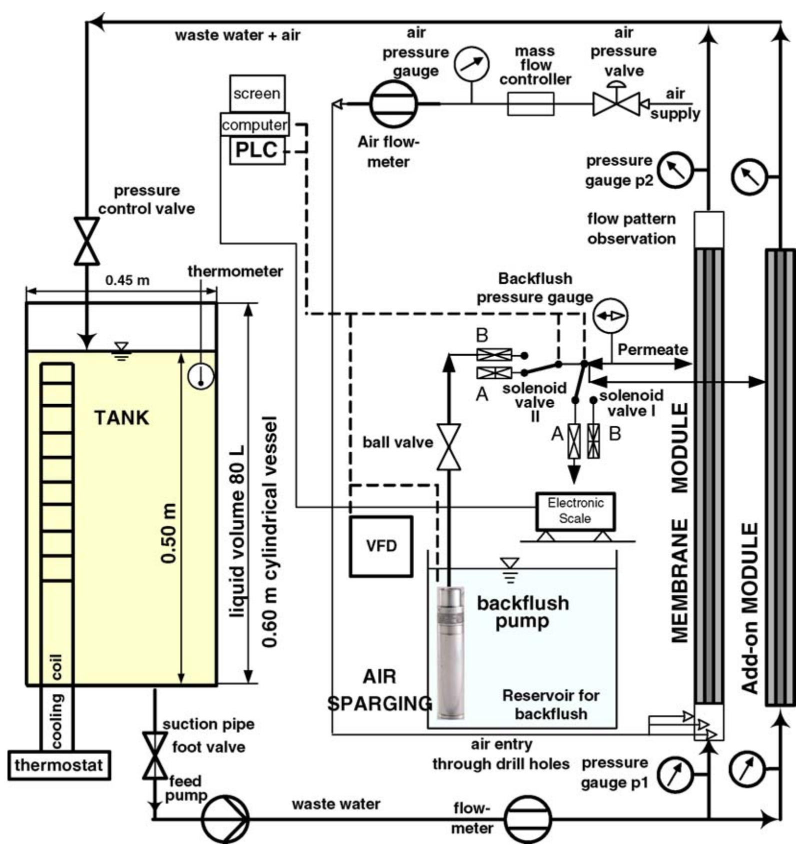

Fig. 1. Experimental setup schematic.