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A novel eductor-based MBR for the treatment of domestic wastewater

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ABSTRACT

A novel aeration device has been developed that combines the mechanism of a venturi aerator with the flow multiplier effect of an eductor used for pump driven mixing. The performance of this novel eductor was evaluated in a flat-sheet immersed MBR and compared with the same MBR equipped with a conventional diffuser for the treatment of domestic wastewater. The eductor showed a higher rate of oxygen transfer both in clean and wastewater compared to the diffuser. The α value with the eductor (0.91) was also found to be more than that of the diffuser (0.75). Higher recirculation rate through the eductor resulted in a higher mixing/turbulance inside the MBR tank and thus alleviated membrane fouling significantly compared to the diffuser. The performance of the MBR in terms of organics removal was also found to be higher with the eductor than the diffuser. The eductor could have significant potential as a combined aerator and mixer in the field of wastewater treatment by MBR.

1. Introduction

Membrane bioreactors (MBR) are an increasingly preferred option for treating municipal wastewater and in some instances are designated as best available technology. MBRs achieve water with an excellent effluent quality for water reuse or recycling (Yang et al., 2006; Judd, 2008; Wang et al., 2008). It has numerous advantages over the conventional activated sludge process (CASP), i.e., more constant permeate quality, independent control of solid and hydraulic retention times, operation at higher mixed liquor suspended solids (MLSS) etc (Judd, 2008). MBR process have full-scale applications in a number of areas including industrial wastewater treatment, municipal wastewater, landfill leachate treatment, domestic water reuse and drinking water reclamation (Oron and Bick, 2000; Galil et al., 2003; Oron et al., 2004; Sthal et al., 2004; Bick et al., 2005). Experts suggest that MBRs may be a key to global water sustainability. Increased use of membranes is expected to continue well into the future (Shannon et al., 2008; Metcalf and Eddy, 2003).

In spite of having many advantages the MBR suffers from some drawbacks. The main drawback of the MBR systems is the high operating cost associated with membrane fouling control (Judd, 2011). For example, Yoon et al., 2004 estimated a cost in the range of ~4000–6000$/year with the MBR operated with >14 g/L of MLSS at a volumetric flow rate of 1000 m^3/day. Further in another literature, the total energy consumption of the treated wastewater in a MBR was reported to be 0.53 kWh/m^3 (Rachmani, 2013).

Air-scouring, which formed back-transport, detaching particles from membrane surface into bulk solution, found to be the most effective method of preventing the formation of cake layer (Ueda et al., 1997; Bouhabila et al., 1998; Chang and Judd, 2002). However, air-scouring had no effect on the cake removal beyond the critical value of the air flow rate (Ueda et al., 1997; Hong et al., 2002).

Most of the previous studies for membrane fouling control were concentrated on the optimization of the standard aeration demand (SADm) and superficial air and liquid velocities along the surface of the membrane and the aeration had been done mostly with the different types of air pumps (e.g., compressor, blower etc) which bubbled air in the MBR through different types of diffusers (Ueda et al., 1997; Ivanovic and Leiknes, 2008; Chang and Fane, 2001; Chua et al., 2002).

In another study by Park et al. (2005), a Venturi nozzle was used to aerate the membrane-coupled high-performance compact reactor (MHCR), and was reported to have significant improvement in terms of membrane fouling control and the overall performance of the MBR over the other conventional MBRs.

Since the overall mixing (influent, biomass and the air) in the reactor and the shearing forces of both the liquid and the air along the membrane surface are the major factors contributing towards

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the overall performance of the MBR (Naundorf et al., 1985; Chang and Fane, 2000; Ducom et al., 2002), we chose to use a patented novel eductor-based air injector (US7,731,163B2) with features not found in Park's study. This eductor also works with the Venturi principle but differs in that when the liquid is injected into the device, it not only draws the air from the atmosphere but also drags the surrounding liquid inside to the point of the air injector, resulting in the formation of a huge jet mixture of liquid and air. As a result, the device mixes the liquor, biomass and the air and generates high liquid and air velocities next to the membrane. This study examines the performance of such a submerged flat-sheet MBR coupled to a Venturi-eductor to treat real municipal wastewater both in terms of fouling prevention and nutrient removal.

2. Materials and methods

2.1. Experimental setup

The schematic diagrams of the experimental set up have been shown in Fig. 1a, b c. The MBR tank was rectangular in shape and was made up of transparent polyacrylic sheet with an effective volume of 75 L (0; Fig. 1a). A flat-sheet membrane module (Fig. 1b, Microdyn Nadir, Biocel Lab) of 0.34 $m^2$of membrane surface area with an average 0.04 μm of pore size (1; Fig. 1a) was immersed inside the tank. The membrane unit was equipped with an in-built diffuser (2; Fig. 1a, position relative to module shown in Fig. 1c) to aerate the membrane with compressed air supplied by a compressor (3; Fig. 1a). The rate of air flow and the inlet air pressure were measured by a rotameter (Platon NG series) (4a; Fig. 1a) and a pressure gauge (5; Fig. 1a) respectively. A peristaltic pump (Masterflex Easyload II BT100-2J, 77200-60) (6; Fig. 1a) draws permeate and provides back-washing to the membrane unit of the MBR. The pump speed was controlled by a frequency controller (Shenzhen Encom electric technologies Co., Ltd, ENC, EDS 800 series) (7a; Fig. 1a). The treated permeate was stored in a 15 L volume permeate storage tank (8; Fig. 1a). Liquid flow rotameters (Platon NG series) (4b and 4c; Fig. 1a) were connected to the line of the permeate/backwashing tube to measure the permeate and the back-washing flow respectively. A pressure transducer (−1 to +1 bar; Fox Con USA, CSPT-300F) (9; Fig. 1a) was installed which continuously measured the transmembrane pressure (TMP) and was connected to the computer (10; Fig. 1a) via a data interfacing device (ADAM 4017) (11; Fig. 1a). A dissolved oxygen (DO) meter (YSI Environmental) (12; Fig. 1a) was immersed in the tank which continuously monitored the DO concentration in the reactor. The domestic wastewater was supplied from the nearby caravans of SdeBoqer Campus of Ben-Gurion University of the Negev, Israel, and was pumped into a settling tank placed on the roof of the laboratory. The wastewater passed through another sedimentation tank and was stored in a feed tank (13; Fig. 1a) and then finally flowed into the MBR by gravity through a float switch (14; Fig. 1a) which kept the liquid volume inside the tank constant. No fine screen was necessary after the two settling tanks given the low level of TSS in the feed tank. The characteristics of the wastewater in the feed tank are given in Table 1. A thermostat (Haqos aquarium) (15; Fig. 1a) was also immersed in the reactor to maintain the reactor's temperature at 26 ± 2 °C throughout the experiment. During the eductor mode of operation the in-built diffuser was replaced with an eductor (16; Fig. 1a) whose exit was attached to a tube perforated along its length with 1 mm holes and closed at its far end (17; Fig. 1a).

A liquid jet was formed by feeding mixed liquor into the eductor with a centrifugal pump (Pan World, 250PS-3) (18; Fig. 1a) whose speed was controlled by another frequency converter (7b; Fig. 1a) (same model as above). The rate of mixed liquor recirculation was measured with ultrasonic sensors (Dalian Hipeak, UIL-100M-S2) (19; Fig. 1a) which were connected to a digital display unit (UIL-100M-S2) (20a; Fig. 1a). A pressure gauge (21; Fig. 1a) was installed at the mixed liquor recirculation path to measure the inlet pressure of the mixed liquor into the eductor. Ambient air was pulled into the liquid jet through an air inlet tube (22; Fig. 1a) due to the local pressure drop at the throat of the eductor. The atmospheric air suction rate was measured by a hot wire probe anemometer (GMH-Honsberg, Labo-FG-I00500K100PS) (23; Fig. 1a) connected to a digital display device (20b; Fig. 1a) (BEST Electrical and Automation).

The mixing eductor used for the air injector was a nominal ¼ inch eductor (Spraying SystemsCo., Wheaton, USA) (Fig. 2a). The external diameter, orifice internal diameter, and the length of the eductor was 32 mm, 5 mm and 76 mm respectively. The eductor was modified (as per the guidelines of the patent) with a polypropylene tube (external diameter of 6 mm and internal diameter of 3.5 mm) inserted into the eductor to serve as an air inlet. The outlet of the air inlet tube inside the eductor was at the center of the throat of the eductor, (7.5 mm in length, 15 mm internal diameter) at an angle of 45° (Fig. 2b). The company specification for the eductor's performance in terms of mixing (without air inlet) has been given in Table 2.

It is clear from the table that the resulting total flow rate through the eductor was many-fold higher than the inlet flow to the eductor.

The perforated tube mounted at the exit mouth of the eductor and mounted horizontally near the bottom of the tank was baffled to distribute the ejected mixture of the liquid and the bubbles uniformly across the width of the membrane at its bottom edge (Fig. 3). The perforated distribution tube was placed beneath the flat sheet membrane module just below the position of the diffuser tube which was removed in order to conduct the comparative study between the performance of the diffuser and the eductor under the same operating conditions.

2.1.1. Operation of the MBR

Since this was a comparative study between the performance of the diffuser and the eductor, the experimental conditions were kept nearly same for both the cases. The activated sludge was collected from the municipal wastewater treatment plant from Yeroham, Israel. The activated sludge was poured inside the MBR and was acclimated with a constant permeation-backwashing mode of operation (10 min permeation and 30 s back-wash) at 12 h of hydraulic residence time (HRT) with 5 LPM of aeration through the diffuser. The back-washing was done at a flow rate of 150 ml/min. The acclimatization was carried out over a period of one month. When a steady state COD reduction (>90%) was obtained over a period of 7 days we considered the completion of acclimatization.

After the completion of the acclimatization of the reactor, the further experiments were started. The experimental protocol was divided into two main segments, namely, (1) operation with the in-built diffuser and (2) operation with the eductor; to have a clear idea of the differences in the performances between these two. The specific studies at each of the above mentioned segments included (i) aeration and oxygenation study, (ii) membrane fouling rate study (iii) wastewater treatment efficiency study and (iv) study of the energy consumption by both the eductor and the diffuser. The aeration and oxygenation studies were further divided into 3 segments namely (a) study of the rate of air drawn through the eductor at different mixed liquor recirculation flow near the surface (5 cm water depth) and at a depth of 40 cm (this was a specific study only for the eductor mode of operation), (b) the oxygen transfer rate study (in clean water and wastewater) with both the eductor and the diffuser, and (c) the study of the DO profiles at different