Domestic wastewater treatment by a submerged MBR (membrane bio-reactor) with enhanced air sparging

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Abstract The air sparging technique has been recognised as an effective way to control membrane fouling. However, its application to a submerged MBR (Membrane Bio-Reactor) has not yet been reported. This paper deals with the performances of air sparging on a submerged MBR for wastewater treatment. Two kinds of air sparging techniques were used respectively. First, air is injected into the membrane tube channels so that mixed liquor can circulate in the bioreactor (air-lift mode). Second, a periodic air-jet into the membrane tube is introduced (air-jet mode). Their applicability was evaluated with a series of lab-scale experiments using domestic wastewater. The flux increased from 23 to 33 $lm^{-2}h^{-1}$ (43% enhancement) when air was injected for the air-lift module. But further increase of flux was not observed as the gas flow increased. The $R_c/(R_c+R_f)$, ratio of cake resistance (R_c) to sum of R_c and R_f (internal fouling resistance), was 23%, indicating that the R_c is not the predominant resistance unlike other MBR studies. It showed that the cake layer was removed sufficiently due to the air injection. Thus, an increase of air flow could not affect the flux performance. The air-jet module suffered from a clogging problem with accumulated sludge inside the lumen. Because the air-jet module has characteristics of dead end filtration, a periodic air-jet was not enough to blast all the accumulated sludge out. But flux was greater than in the air-lift module if the clogging was prevented by an appropriate cleaning regime such as periodical backwashing.

Keywords Activated sludge; air sparging; fouling; membrane; submerged MBR

Introduction

The membrane bioreactor (MBR) technology has been subject to keen interest, rapid development and extensive application to the wastewater industry in the last 5–10 years, since the process offers many advantages over conventional wastewater treatment methods. However, the principal limitation of this process lies in the membrane fouling mainly associated with the formation of cake deposition on the membrane surface, thus limiting the permeate flux. Membrane fouling leads to frequent membrane cleaning and/or replacement, increasing operating costs.

Various attempts have been made to control membrane fouling in MBR processes. The most recent studies of enhanced mass transfer in membrane processes have been concerned with the two-phase gas-liquid flow (Cui *et al*., 2001). Flux improvement by air injection to produce "slug flow" has been practically demonstrated in studies on hollow fibre membranes based on bentonite particles (Cabassaud *et al*., 1997), and tubular membranes employing dextran (Ghosh and Cui, 1999). Little information, however, is available for the two-phase flow of the submerged MBR.

Results are reported for two-phase flow in a submerged MBR system for wastewater treatment. Two air-injection configurations for the submerged MBR were studied: intermittent air-jetting into a module sealed at one end (air-jet mode), and conventional air lift allowing circulation of the mixed liquor in the bioreactor (air-lift mode). The applicability of each was evaluated with a series of lab-scale experiments using domestic wastewater.

Material and methods

The pilot plant comprised a perspex bioreactor with a working volume of 0.06 m^3 and two tubular type membrane modules (Figure 1), both operated in-to-out. The air jet frequency for the submerged unit was 1/2 sec^{-1}. The transmembrane pressure (TMP) was applied by using a head of water, and was kept at around 3.4 and 7.1 kPa for the submerged and side-stream units respectively. The membranes used were polyethersulfone with a nominal pore size of 0.2 μm.

Screened and settled primary effluents from Cranfield University wastewater treatment plant were supplied to the system. MLSS concentration analysis was carried out in accordance with *Standard Methods* (APHA *et al*., 1995). COD analysis was carried out in accordance with a US EPA approved method using a Hach Laboratory Method 8000 (Spectrophotometer Model DR/2010).

Results and discussions

Air-lift module

The two-phase flow patterns depend on the air-injection ratio (ε) defined as $\varepsilon = Q_g/(Q_g + Q_l)$; Q_g and Q_l are the superficial gas and liquid flow rate respectively, both of them being calculated as if each phase was circulating alone in a tube. Flow pattern is classified according to the value of ε (Cabassaud *et al*., 2001); a bubble-flow ($\varepsilon < 0.2$) where air bubbles are dispersed in the liquid phase. For intermediate values of ε ($0.2 < \varepsilon < 0.9$), a slug-flow consisting of gas and liquid slugs are observed. For an annular flow ($\varepsilon > 0.9$), a continuous gaseous phase flows in the centre of the pipe. It is well known that slug-flow is the most efficient regime for significant enhancement of flux (Mercier *et al*., 1997).

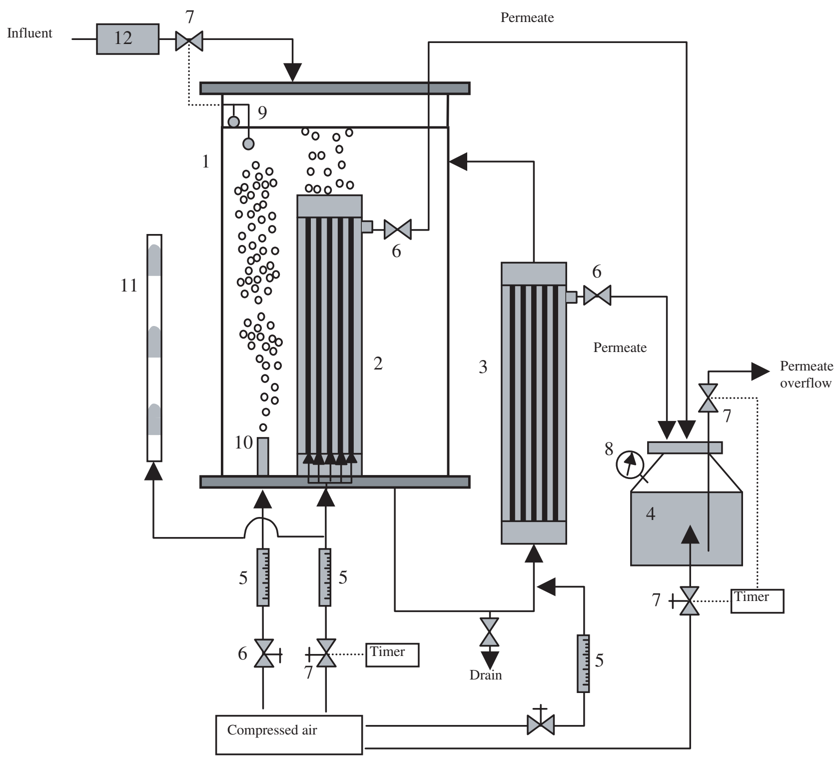

Figure 1 Schematic diagram of the experimental set-up for the submerged MBR; (1) bioreactor, (2) air jet module, (3) air lift module, (4) pressurised backwashing tank, (5) flow meter, (6) adjustment valve, (7) solenoid valve, (8) pressure gauge, (9) level sensor, (10) diffuser, (11) visualization tube, (12) prefilter

Flux enhancement for the filtration of activated sludge suspension (MLSS concentration = 3,200 mg/l) was observed when air was injected (Figure 2). Flux increased from 23 to 33 $lm^{-2}h^{-1}$ (43% enhancement of flux). The enhancement could be provided by the wall shear caused by two-phase flow and turbulence caused by the falling film in the bubbling wake. But further increase of flux was not observed as the gas flow increased. It should be noted that the flux did not increase as the flow pattern had changed from bubble to slug flow regime ($\varepsilon > 0.2$). However, most other research showed that flux enhancement for the slug flow regime is much greater than for the bubble flow. For example, for the membrane filtration of biologically treated wastewater, the flux was increasing continuously as the flow pattern had been changed from bubble to slug flow regime (Vera *et al.*, 2000).

This phenomenon, no further flux increase as the gas flow ratio increases, is presumably related to the irreversible internal fouling such as pore blocking and pore narrowing. The predominant flux limiting factor may be attributed to an internal fouling rather than to the cake layer on the membrane surface. Because a flow with low ε value was good enough to remove the cake layer, further increase of air flow had no more benefit for flux enhancement. On the other hand, an irreversible internal fouling cannot be affected by the air flow rate and thus, further increase of flux was not observed. To verify the fouling phenomenon a series of resistance was calculated. According to the resistance-in-series model the permeate flux (J) took the following form (Chang and Lee, 1998); $J = \Delta P_T/(\eta \cdot R_t) = \Delta P_T/h(R_m+R_c+R_f)$, where J is permeate flux, ΔP_T is transmembrane pressure (kg $m^{-1}s^{-2}$), h is permeate viscosity (kg $m^{-1}s^{-1}$), R_T is total resistance (m^{-1}), R_m is membrane resistance (m^{-1}), R_c is cake layer resistance, and R_f is internal fouling resistance (m^{-1}).

Resistance values for each membrane are calculated using the data from flux and clean water flux (Table 1). The cake resistance (R_c) is relatively small, and the internal fouling resistance (R_f) was greater than R_c. The R_c/R_T ratio shows that only 8% of the total resistance was attributed to the cake layer. The $R_c/(R_c+R_f)$ ratio indicates that only 23% of resistance causing flux decline resulted from the cake layer. However, most studies about membrane fouling in MBR processes showed that R_c is always much greater than R_f (Chang *et al.*, 2001a; Chang *et al.*, 2001b; Kim *et al.*, 2001). This phenomenon clearly indicates that most cake layers on the membrane surface have been removed by the air flow, and thus R_f acted as the predominant resistance. Consequently, air-injection clearly improves flux performance of the submerged MBR process by eliminating part of the cake layer.

Figure 3 shows the long-term operation over 37 days for the air-lift module. It shows the effect of backwashing and air sparging on flux. While backwashing and air sparging were performed simultaneously (indicated as a+b in Figure 3), flux exhibited a steady state value (30~32 $lm^{-2}h^{-1}$). During the backwashing only mode (b in Figure 3) flux decreased to ~22 $lm^{-2}h^{-1}$, indicating that a 30% decline in flux was due to stopping of air injection.

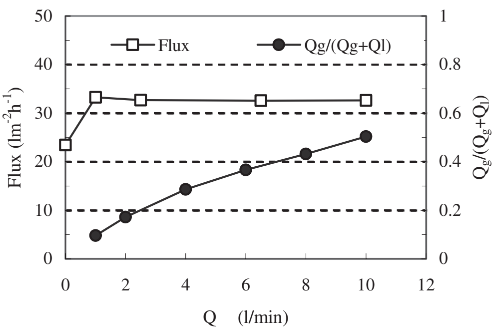

Figure 2 Flux decline as a function of air flow-rate for the air-lift module during filtration of mixed liquor of activated sludge

Table 1 A series of resistance values for the air-lift and air-jet modules

	Resistances ($10^{11} \times m^{-1}$)				Cake resistance ratio (%)	
	R_m	R_c	R_f	R_T	R_c/R_T	$R_c/(R_c+R_f)$
Air-lift module*	5.1	0.6	2.0	7.7	8	23
Air-jet module**	7.7	53	2.7	63.4	84	95
Air-jet module***	3.0	$R_c + R_f = 1.5$		4.5	–	–

* 37 days of operation with and without backwashing
** 10 days operation without backwashing (clogging)
*** 13 days of operation with backwashing (no clogging); R_c and R_f cannot be distinguished because membrane was torn after 13 days of operation

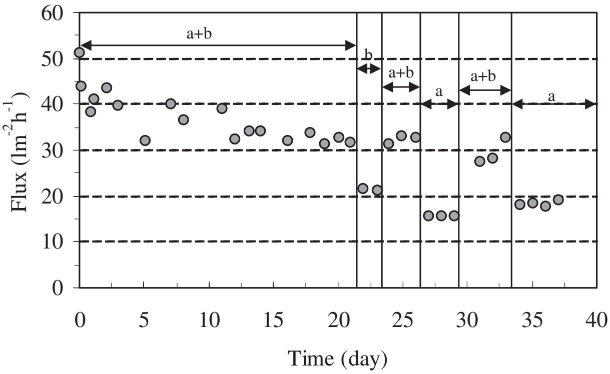

Figure 3 Effect of backwashing and air-injection on flux performance of the air-lift module; (a) air only, (b) backwashing only, (a+b) air and backwashing together

Stable flux for the air sparging only mode (a in Figure 3) was 17~20 $lm^{-2}h^{-1}$. It seems that the effect of backwashing on flux is slightly greater than the effect of air sparging. However, considering that the backwashing is carried out so frequently (2 min backwashing per 30 min operation), the air sparging effect on flux is relatively great.

As with other MBR studies, COD removal is high (>93%) for all the period of operation (Figure 4). Permeate COD ranged from 4 to 20 mg/l. The substantial variation in influent COD load had little adverse effect on organic removal rates. Since the soluble part of the influent COD was around 22%, most organic load came from suspended solids (SS) in the influent. But a relatively great fluctuation in influent SS also does not affect permeate quality.

Air-jet module

Figure 5 shows the flux decline as a function of operation time for the air-jet module with

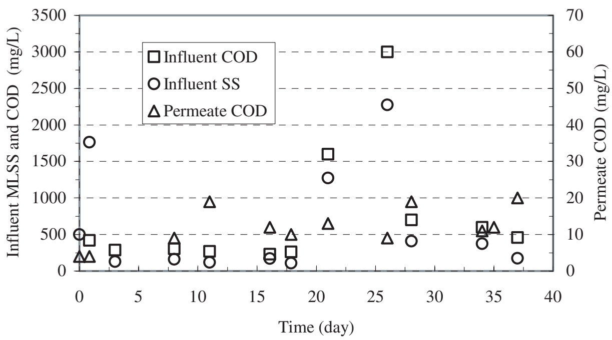

Figure 4 Variation of permeate COD for the air-lift module in accordance with the fluctuation of influent COD and MLSS

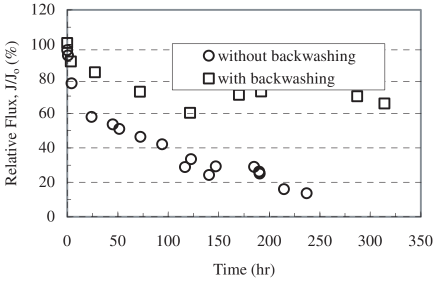

Figure 5 Effect of backwashing on flux performance for the air-jet module

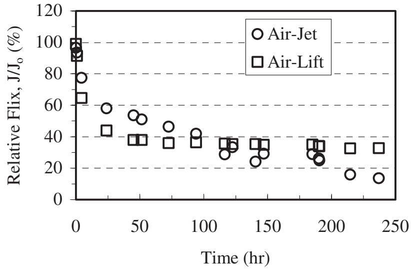

Figure 6 Comparison of flux decline between air-jet and air-lift module

and without backwashing. To compensate for the difference in initial water flux between both modes a relative flux (J/J_o) was used to compare flux performances; J is flux and J_o is the initial water flux. For the non-backwashing mode, it showed a rapid flux decline at the initial stage. The flux reduced continuously, and finally reached 0 after 250 hours of operation. The membrane module was dismantled and taken out from the bioreactor to find out what had made the flux decline continuously. An investigation inside the membrane module showed that there was complete clogging with the sludge on the lumen side. MLSS concentration (3,500~3,800 mg/L) is not high enough to explain the clogging problem. The air-jet (flow rate = 5 l/min, pressure = 13 psi, pulsation frequency = 0.5 sec^{-1}) seems to be insufficient to blast out all of the accumulated sludge. An increased air pressure (25 psi) and air flow rate (10 l/min) with same pulsation frequency did not solve this problem.

The clogging phenomenon seems to be inherent because the air-jet module is a sort of dead-end filtration. The concentrated sludge resulting from liquid permeation is able to accumulate inside the lumen unless a proper cleaning regime is carried out. The effect of periodical back-washing using the permeate solution (2 min/30 min) on prevention of sludge clogging is shown also in Figure 5. Cleaning with backwashing significantly prevented the clogging and improved the flux. However, further work is needed in optimising start-up and operating conditions to ameliorate the clogging problems encountered with the air-jet module.

Figure 6 shows the comparison of flux decline between the air-jet and air-lift modules. All experimental conditions were the same for both modes except for the air injection mode: air pressure = 13 psi, air flow-rate = 5 l/min and same mixed liquor of biomass. Relative flux (J/J_o) for the air-jet module was greater than that of the air-lift module until 100 hr. Whilst the flux for the air-lift mode exhibited a steady state value, the flux of the air-jet mode decreased continuously, indicating that clogging inside the air-jet module had been developing. After 100 hr of operation for flux for the air-jet module was less than that for the air-lift module.

It is interesting to notice that the air-jet module can exhibit a better flux performance than the air-lift module if the clogging is controlled using a proper cleaning regime. It is well known that the pressure inisde an air-jet membrane channel fluctuates with response to the air-jet pulsation (Maranges and Fonade, 1997). The pressure variations inside the channel caused by air pulsation can induce a beneficial effect on the flux, i.e., a periodical decrease of pressure creates back-transport of permeates which then helps to dislodge the cake layer. This pressure variation effect as well as the turbulence caused by two-phase flow can make the air-jet mode show a better flux performance than the air-lift mode.

Conclusions

To apply and verify the two-phase flow technique to the submerged MBR system, two types of module (air-jet and air-lift) were developed. If the clogging problem in the air-jet module can be overcome using an appropriate backwashing protocol, a greater flux can be expected from this configuration. The air-lift module demonstrated a higher flux than the conventional submerged MBR system. Both configurations thus offer promise for MBR applications.

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