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Investigation of Novel Methods of Reducing Membrane Fouling

Introduction

Wastewater is a form of water resource. By reusing wastewater, it can significantly reduce the demand for water supply. Membrane bioreactor (MBR) is an effective and economic water treatment process to produce usable water from wastewater. The advantages offered by the MBR over conventional treatment have been reviewed (Stephenson *et al.,* 2000). Unlike conventional water treatment, membrane bioreactor can help to cut down carbon footprint by maintaining a high concentration of biological suspension to be filtered off to produce clean water in a membrane bioreactor (Chang *et al.,* 2002). An increased rate of nitrification, which is required to inhibit production of sulfide and other particles which might cause the quality of the water in the membrane bioreactor to further deteriorate, can also be achieved because a large amount of slow-growing autotrophs, which can supply nutrients, can be kept in an aeration tank after treatment (Chiemchaisri and Yamamoto, 1993; Fan *et al*., 1996; Kishino *et al*., 1996; Nah *et al*., 2000).

The flux rate, which means rate of water uptake in membrane bioreactor, is directly proportional to driving pressure and inversely proportional to membrane fouling. However, membrane fouling in membrane bioreactor is a prominent problem because it is very common in membrane bioreactor and reduces flux rate significantly. As soon as the membrane surface comes into contact with the biological suspension, the solid particles will be deposited on the membrane surface. A similar effect will be achieved if solid particles are absorbed into the membrane pores (Chang *et al*., 2002). Either way, flux rate decreases significantly.

In order to reduce membrane fouling in a submerged membrane bioreactor, aeration is introduced. By providing aeration, it helps to maintain the solids in suspension, come into contact with the membrane surface and knock solid particles on membrane surface off, effectively removing fouling (Dufresne *et al.,* 1997). However, having aeration as the solution to membrane fouling might not be feasible in the long run because energy consumption for aeration is still one of the major operating costs for all MBRs in common use (Zhang *et al*., 2011). Hence there is a need to explore other means of reducing membrane fouling to increase water flux rate.

Objectives

To increase water flux rate by

(i) Determining the optimal length of individual hollow fibre in a membrane module consisting of membranes with a total membrane length of 90 cm.

(ii) Determining the optimal method of reducing membrane fouling in membrane bioreactor systems among aeration, use of a plastic board to reduce particles, use of a motor, mechanical cleaning using a self-designed wiping system and a hybrid system which combines mechanical cleaning with the use of a plastic board.

Hypotheses

(i) For a total membrane length of 90cm, individual hollow fibres with length of 20-30cm will give the highest flux rate.

(ii) Mechanical cleaning will be the best method for reducing membrane fouling, giving the highest flux rate.

Materials and Methods

The hollow fibre membranes (Toray, HFM Type), air pump (Super precision 18000) and vacuum pump (Rocker 300) were provided by Singapore Membrane Technology Centre.

Methods

The overview of the project can be summarized in figure 1, as shown below.

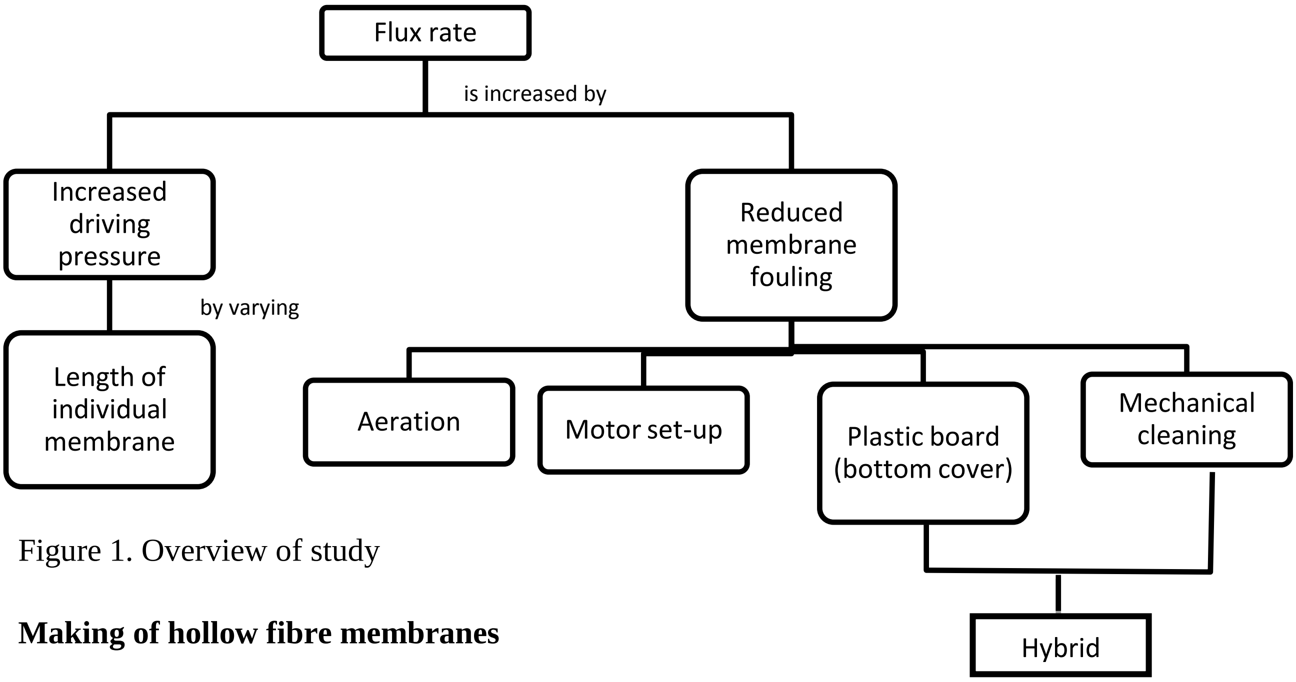

Figure 1. Overview of study

Making of hollow fibre membranes

The tubing was cut and a hollow fibre membrane was inserted into the tubing. Glue was applied at one end of tubing. Glue was also applied at the other end of the membrane.

Figure 2. Hollow fibre membrane

Experimental set-up

For all experiments, the apparatus was set up as shown in figure 3. A mass of 160g of bentonite was mixed with 40 litres of water to simulate wastewater. The hollow fiber membrane module was placed into the tank. The eexperimental set-up to be studied was run for 30 minutes and filtered water obtained after 30 minutes was collected in the vacuum chamber and weighed. Triplicates were conducted. The greater the mass of water, the greater is the flux rate and the more effective is the membrane module.

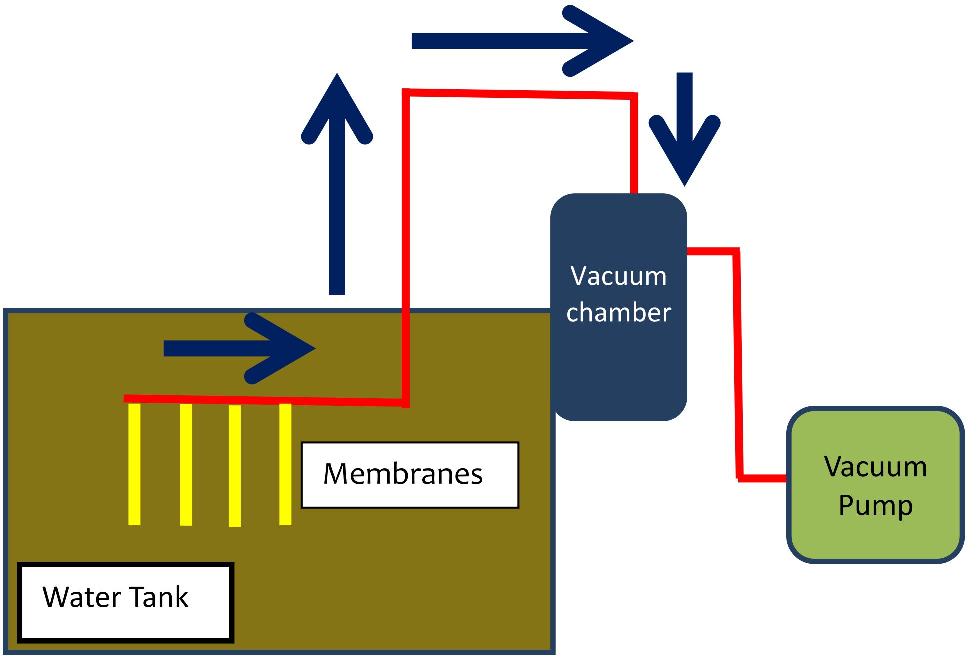

Figure 3. Experimental set-up to determine flux rate

Experiment to determine the optimum length of individual hollow fibre membranes
Hollow fibre membranes of various individual lengths, 45cm, 30cm, 22.5cm and 15cm, which adds up to a total length of 90cm, were made. The set-up (as shown in figure 3) was run for 30 minutes and the water collected weighed.

Experiments to determine the optimum method of reducing membrane fouling

The following methods to reduce fouling were studied:

1. Aeration

Hollow fibre membranes were placed in an enclosure (plastic bottle) and concentrated bubbling was provided by the air pump. The air bubbles will knock off the particles deposited on the hollow fibre membranes, thus reducing fouling.

Figure 4. Set-up for aeration

2. Use of a plastic board to reduce particles

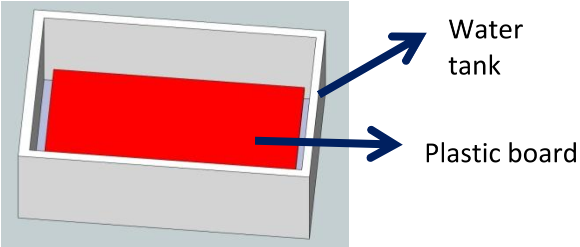

Figure 5. Use of a plastic board as a bottom cover

A plastic board was submerged into the tank. Along the way, it will trap particles in the suspension to the bottom of tank. By doing so, there will be lesser particles in the suspension, reducing the number of particles deposited on the membrane. Thus, fouling is reduced.

3. Mechanical cleaning using a self-designed wiping system

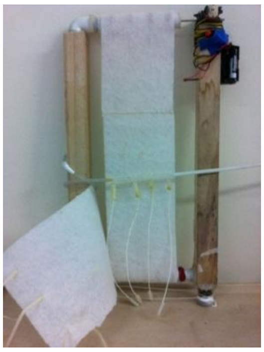

Figure 6. Self-designed wiping system

The fouling on the membrane is mechanically wiped off by a rotating oil filter powered by a motor at 36 rpm. As the oil filter brushes against the membranes, foulants on the surface of the membrane will be wiped off mechanically.

The details of the design of the wiping system are shown on appendices, page 9.

4. Use of a motor

Figure 7. Motor used to reduce fouling

A motor (Tamiya 6-speed gearbox H.E) was used to vibrate the hollow fibre membranes at 42 rpm. The particles deposited on the membranes will be shaken off by the vibrations, reducing fouling.

5. Hybrid system

The mechanical cleaning and use of a bottom cover methods are combined to reduce fouling.

Results and Discussion

Determination of the optimal length of individual hollow fibre membranes

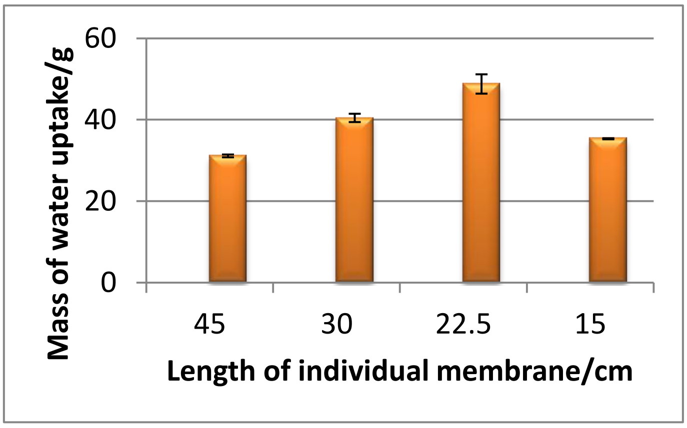

Figure 8. Mass of water uptake by membrane of various individual lengths

In this experiment, the total length of membranes were kept constant at 90 cm. The following membrane modules were studied: 2x45 cm, 3x30 cm, 4x 22.5 cm and 6x15 cm. The membrane module which is made up of 4 X 22.5cm hollow fiber membranes shows the highest water uptake. Thus, optimum length of individual hollow fibre membrane was determined to be 22.5 cm.

As the length of individual membrane increases, the driving pressure in the membranes decreases. This reduces rate of water uptake. Similarly, as the horizontal length of membrane module increases, the driving pressure also decreases. This also reduces rate of water uptake. Figure 8 shows that the membrane module made up of 4 X 22.5cm has the best combination of both horizontal and individual membrane length, resulting in the highest driving pressure and flux rate.

Experiments to determine the optimum method of reducing membrane fouling

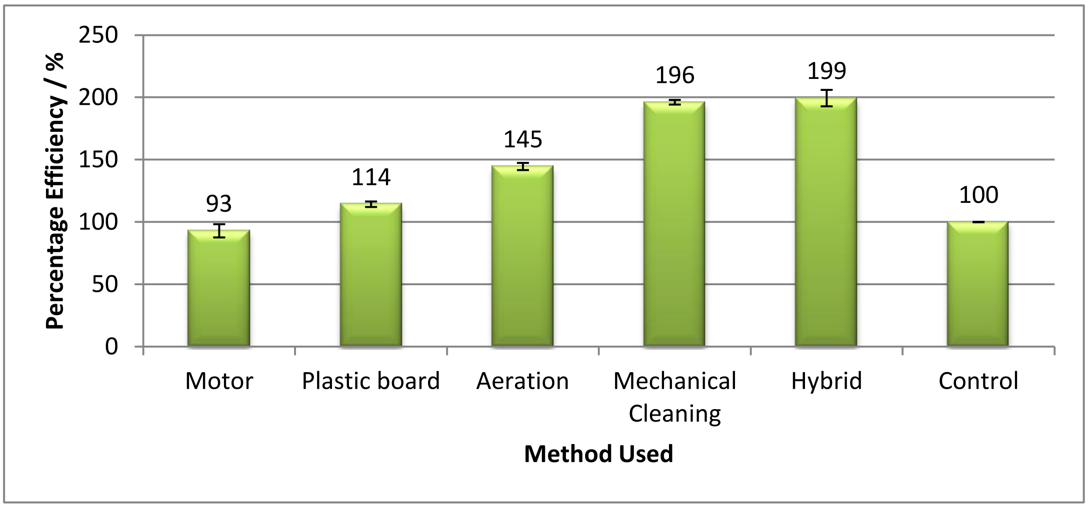

Figure 9. Percentage efficiency of various methods of reducing fouling with respect to control

Figure 9 shows that except for the use of a motor, the rest of the methods resulted in a greater water uptake and hence greater efficiency, due to membrane fouling being reduced. Mechanical cleaning using the self-designed wiping system and the hybrid (self-designed wiping system with plastic board) resulted in greatest rate of water uptake, with the percentage efficiency almost doubled that of the control. Detailed analysis of the use of each method in reducing fouling is discussed below.

Motor

The use of the motor setup to cause the membrane module to vibrate and shake off fouling was not useful in reducing membrane fouling. A percentage efficiency of 93 % was observed as compared to the control. The lower percentage efficiency is likely due to the lack of the power of the motor used. Hence it was unable to cause the membranes to vibrate hard enough to shake the foulants off the membrane, rendering this method ineffective.

Aeration

The aeration set-up shows a higher rate of water uptake than the control set-up, with a percentage efficiency of 145% with respect to control. Use of aeration traps the air bubbles in the enclosure, increasing the rate of collision between the hollow fiber membranes and the air bubbles. Thus, rate at which foulants are being knocked off the hollow fiber membrane is more rapid. This increases the rate of water uptake significantly. However, this aeration set-up may not be feasible in the real world as the energy consumed for aeration has been reported to be approximately a high percentage of 38% of total power consumption (Zhang *et al*., 2011). Thus, methods which consume less energy and reduce aeration will be favored and more feasible.

Use of plastic board to reduce particles

The placement of a plastic board sheet at the bottom of the tank was useful in reducing the number of particles in the water of the tank, resulting in a higher rate of water uptake due to a reduction in membrane fouling. By placing the plastic board in the water, large insoluble bentonite particles are trapped between the plastic board and the bottom of the tank, resulting in a reduction in the number of particles in the area of the tank where the membranes are situated. As total number of foulants exposed to the membrane decreases, the fouling of the membranes is reduced, resulting in an increased rate of water uptake. This method does not require any electrical energy and can be easily implemented in conjunction with other methods of fouling control, making it a viable method of fouling control.

Mechanical cleaning with the use of self-designed wiping system

The use of the mechanical cleaning device (self-designed wiping system) brings about a much higher rate of water uptake, as compared to that of the control set-up. The device makes use of a rotating oil filter powered by a motor. The membrane module was secured and sandwiched between two pieces of oil filter (appendices, page 9). Once the motor was turned on, one of the oil filters would roll and brush past the membranes, thus cleaning the foulants off the membranes mechanically. This system would thus help to ensure that the fouling generated during microfiltration does not build up, and pores along the membrane module are not blocked, resulting in a higher rate of clean water uptake significantly due to the increased efficiency in the process of microfiltration.

Figure 10. Control (without mechanical cleaning) – fouling observed

Figure 11. With mechanical cleaning using the self-designed wiping system– no fouling observed

Hybrid system

The hybrid system did not have a significant increase in flux rate as compared to the mechanical cleaning method. This could be due to the relatively short experiment duration (30 minutes), which did not allow for the strengths of the hybrid system to be adequately displayed.

However the use of a hybrid system has its merits, as the bottom cover can reduce the number of particles in the tank, enabling the frequency of cleaning of the wiping system to be reduced, allowing for even greater maintenance costs reductions. The use of a plastic board is not likely to increase operation costs significantly as no energy is required for the addition of the bottom cover, allowing this method to be more advantageous than just the mechanical cleaning method.

Conclusions

The membrane module which is made up of 4 X 22.5cm hollow fiber membranes shows the highest water uptake. Thus the optimum length of the individual membrane fibre is determined to be 22.5cm.

The use of the motor setup was not useful in reducing membrane fouling, resulting in a lower rate of water uptake. Mechanical cleaning and hybrid result in greatest water uptake as compared to the rest of methods. The method of mechanical cleaning using our self-designed wiping system can be applied to membrane bioreactors today using flat sheet membranes. The use of it is extremely simple. All the user has to do is to turn on the motor of the wiping system, which will cause the oil filter to move and rotate. As the oil filter brushes against the membranes, foulants on the surface of the membrane are wiped off mechanically. The oil filter is also self-cleaning. Foulants that gather on the oil filter will dissolve back into the water present in the oil filter, which acts as a sponge. The contaminated water in the oil filter is then squeezed out of the oil filter after it emerges out of the water's surface due to the tension present in the oil filter at the PVC tube at the top of the product. This causes all foulants that have been removed from the membrane to be also removed from the oil filter, causing the oil filter to be self-cleaning, potentially reducing maintenance costs. In addition, compared to the aeration system which uses 500W, the self-designed wiping system is more energy efficient as it only consumes 0.028W of electricity.

The self-designed wiping system has the potential to be commercialized and used in membrane bioreactor systems to reduce fouling.

References

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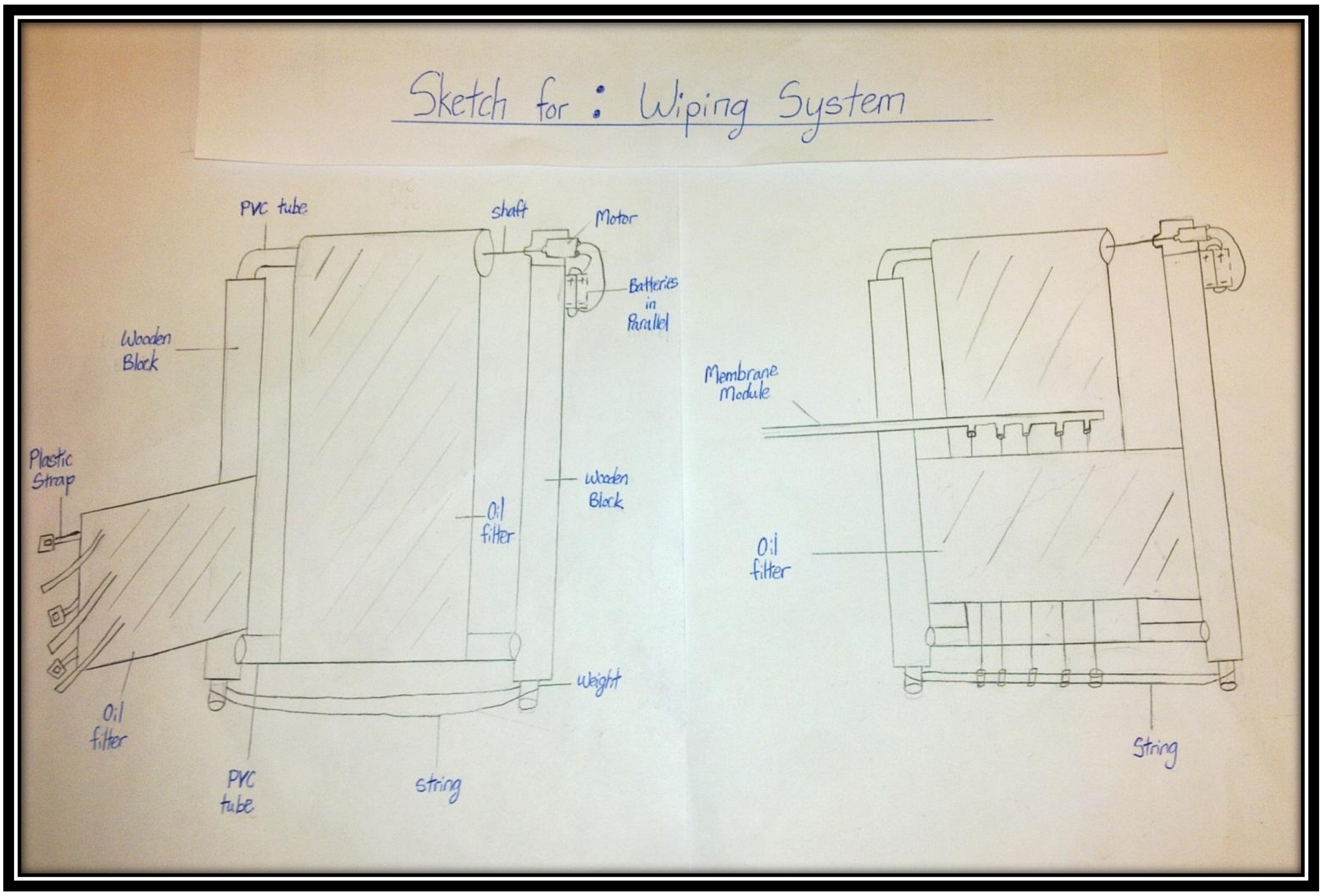
Appendices

1) Sketch for Self-designed wiping system for mechanical cleaning



2) Use of mechanical cleaning (self-designed wiping system)