Application of Powdered Activated Carbon to Reduce Fouling of Membrane in a Pilot-Scale Recirculating Aquaculture System

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Abstract

Recirculating aquaculture systems (RAS) are essential for the reduction in fresh water usage as well as the discharge of nutrients along with aquaculture effluents. A RAS consisted of an anoxic reactor, a membrane bioreactor (MBR) and a UV-disinfection unit was used to process 10,000 L/day of aquaculture effluent provided high quality treated water for recirculation to a Barramundi fish culture. However, the rate of fouling of membrane in the MBR was around 1.47 kPa/day. In order to reduce the rate of fouling, 500 mg of powdered activated carbon (PAC) per litre of MBR volume was introduced which decreased the rate of fouling to 0.90 kPa/day, while maintaining the treated effluent quality.

Keywords: Denitrification, fouling, Membrane bioreactor (MBR), Powdered activated carbon (PAC), Recirculating aquaculture system (RAS), Transmembrane pressure (TMP)

Introduction

As the needs to combat the ever-increasing problems of excessive demands on capture fisheries coupled with the diminishing number of species due to over-exploitation, the aquaculture industry is expected to alleviate some pressure in the near future. However, the challenges brought about by human population growth and competition for water, land and natural resources forces the aquaculture industry to maximise the productivity and minimise the water usage. Both these criteria could be met if efficient recirculating aquaculture systems (RAS) were brought into practice. A RAS could theoretically eliminate the daily water exchange required in an aquaculture farm by treating the effluent for recirculation (Gutierrez-Wing and Malone, 2006; Avnimelech, 2006; Lucas and Southgate, 2003).

The effluent should be treated to remove the water quality parameters such as total ammonia (NH_3/NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), chemical oxygen demand (COD), biological oxygen demand (BOD), suspended solids (SS), turbidity and microorganisms such as bacteria and viruses. An effective RAS system that consisted of an anoxic reactor followed by a membrane bioreactor (MBR) and a UV disinfecting unit could treat the aquaculture effluent and provide significant reductions in the water quality parameters that have been mentioned above. However, one major problem of this system would be the fouling of membrane in the MBR.

Fouling is the coating of the membrane surface or blocking of the pores with a solid or gelatinous material (cake), which creates a barrier through which the treated effluent (permeate) must pass. Thus, the effective pore size distribution of the membrane is reduced. The net effect of blockage is to reduce the permeate flux passing through the membrane. There are three major categories of membrane fouling: Inorganic fouling, organic fouling and microbiological fouling. Most inorganic fouling occurs due to scale-forming dissolved solids such as calcium. The most common inorganic fouling problems can be dealt with by appropriate pre-treatment. Organic foulants have a natural affinity for the membrane surface. Due to this affinity, organic foulants such as oils, wet out the membrane spreading directly onto the membrane surface. Organic fouling may be cleaned with a detergent or caustic soda. Biological foulants are aerobic and anaerobic living materials such as bacteria, fungus, algae, and the extra-cellular polymeric substances (EPS) and metabolic wastes they generate.

Microbes literally grow into massive quantities that effectively block flow through the membrane surface. Cellulose acetate membranes may support microbiological growth while the polyamide type does not. However, both types are subject to fouling by microorganisms. This can be controlled in cellulose acetate membranes by chlorination of the feed water. Fungus tends to grow in areas such as silica-phosphate gel, which provides both protection from flow and food for additional growth.

The aim of this study is to elucidate the effectiveness of powdered activated carbon (PAC) as a means to mitigate the fouling of membrane in a RAS. PAC could adsorb dissolved organic substances and the EPS, which are the major components that cause fouling the membrane in a MBR. Also the cake that forms on the membrane surface would have large porosity in the presence of PAC.

Materials and Methods

The RAS system comprises of a fish tank (2,500 L) that was used to raise Barramundi fish and a treatment system including an anoxic reactor (1,000 L), MBR (1,000 L) and a UV-disinfection unit to treat the aquaculture effluent in order to recirculate the treated effluent back to the fish tank (Figure 1). The effluent from the fish tank was flowing to a sump through the drainpipe. A pump was dividing the flow into two streams, one returned back to the fish tank through water sprayers and the other stream was passed to the bottom of the anoxic reactor. Brown sugar solution was allowed to drip into the anoxic reactor to adjust the carbon to nitrogen ratio in the anoxic reactor to 4:1 by weight. The overflow from anoxic reactor was allowed into the MBR. The MBR was aerated by perforated air pipe that is placed inside the MBR (at the bottom).

A suction pump was used to obtain permeate from the MBR which was passed through a UV disinfectant unit to kill the microorganisms that pass through the membrane pores. The micro-filtration membrane in the MBR supplied by Kolon Industry Inc., South Korea was capable of treating 10,000 L per day and made of polypropylene (Figure 2). Specifications of the membrane are given in Table 1.

Two sets of experiments were conducted using the system to study the rate of fouling with and without the addition of PAC into the MBR. The experiment that was conducted with PAC used 500 mg of PAC for every litre of MBR volume. The transmembrane pressure (TMP) was measured at the suction side (or permeate) of the membrane everyday to calculate the rate of fouling of membrane. Water quality parameters such as NH_4^+, NO_3^-, No_2^-, turbidity and pH were measured in the fish tank, MBR and the treated effluent to evaluate the performance of the RAS.

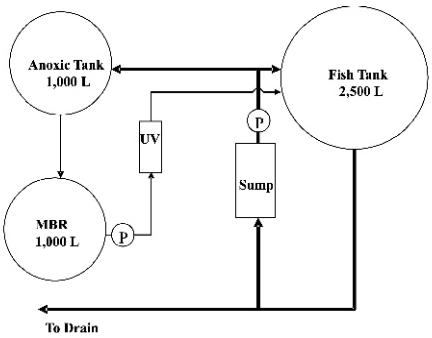

Figure 1. *Schematic of the RAS*

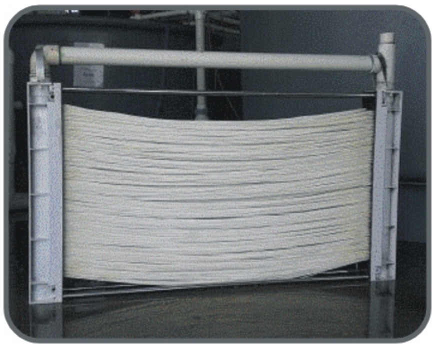

Figure 2. *Micro-filtration membrane used in the MBR of the RAS*

Table 1 Specifications of micro-filtration membrane

Parameters	Description
Module type	Cleanfil-S20
Type of membrane	Braid-Reinforced Hollow Fiber
Material of coating layer	Polysulfone, Polyethersulfone, PVDF
Coating thickness	0.05~0.1 mm
Outer diameter	2 mm
Inner diameter	0.8 mm
Pore size	0.3 μm
Dimensions of the module (L x W x D)	1184x105x628 (mm)
Area of membrane	20 m2
Flux	20~25 LMH
Manufacturer	Kolon Industry Inc., Yongin City, Kyunggi-Do, South Korea

Results and Discussion

The non-PAC run began with very low start up TMP of 2 kPa and increased up to 24 kPa over a period of 15 days (Figure 3). However, the run with PAC started with 1 kPa of TMP and increased up to 28 kPa over period of 30 days. Thus the rate of increase of TMP was 1.47 and 0.90 kPa/day for non-PAC and PAC runs respectively. The membrane was operated for an intermittent suction period of 3 hours followed by a relaxation period of 5 minutes. A small-scale RAS processing 40 L/d of aquaculture effluent coming from a similar Barramundi culture tank showed a rate of increase of TMP of around 0.48 kPa/day at a C:N ratio of 4:1 (Pulefou *et al.,* 2008). The operation of the membrane in that system was an intermittent suction period of 12 minutes followed by a relaxation period of 3 minutes. Thus, it could be seen clearly that shorter time interval between consecutive relaxation periods could reduce the rate of fouling significantly. However, in large scale operations, this time interval should be chosen carefully in order to extend the life period of pumps.

Membrane resistance to permeate flow was measured on the clean membrane after each run to see the effectiveness of PAC in reducing the irreversible resistance. Generally, the resistance to permeate flow is contributed by three different components: (i) intrinsic membrane resistance, R_m; (ii) cake resistance, R_c and (iii) irreversible resistance due to pore blocking, R_f. Thus, the total resistance, R_t can begiven by:

$$R_t = R_m + R_c + R_f \quad (1)$$

Once the membrane is cleaned after each run, the resistance should be due to R_m and R_f as the cake layer would have been removed from the surface of the membrane. Thus, if clean water is passed through the membrane at different flow rates and corresponding TMP is measured, the resistance due to Rm and Rf (=Rt) could be computed by using the following equation:

$$J = TMP/(\square R_t) \quad (2)$$

Where J is the flux through the membrane. It can be seen from Figure 4 that the addition of PAC has reduced the fouling due to pore blocking to a very good extent. This can be attributed to the absorption of organic substances and EPS by PAC, which are the major components of pore blocking. However it should be noted that the cleaning of non-PAC and PAC runs were carried out after 16 and 11 days respectively and the PAC run that was used evaluate the irreversible resistance was different to the PAC run that is used to discuss all other results.

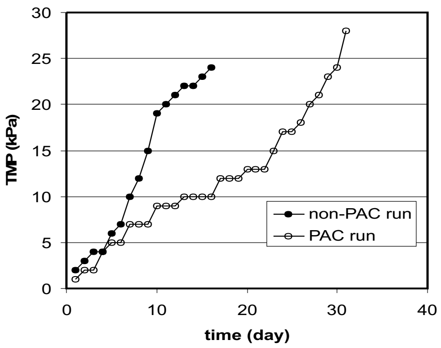

Figure 3. *Increase in TMP with time in both non-PAC and PAC runs*

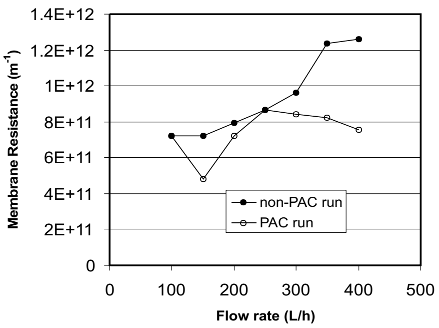

Figure 4. *Combined resistances due to membrane and irreversible fouling ($R_m + R_f$) in both non-PAC and PAC runs.*

The average turbidity in the MBR during the non-PAC run was around 839 NTU and which was reduced to 0.34 NTU in the permeate providing a turbidity removal of 99.96% (Figure 5). Similarly, during the PAC run, the turbidity in the MBR and the permeate were 1000 NTU and 0.13 NTU, respectively providing a turbidity removal of 99.99%. Thus, both non-PAC and PAC runs yielded very high quality permeate in terms of turbidity. The non-PAC run maintained the nitrate, nitrite ammonia levels in the fish tank between 8 and 20 mg/L, 0 and 3 mg/L and 0.1 to 0.6 mg/L, respectively (Figure 6). During this time, the permeate from the MBR contained 11 to 21 mg/L of nitrate, 0 to 2 mg/L of nitrite and 0 mg/L of ammonia. This shows that the RAS was functioning as required for the Barramundi culture to grow at desirable rate.

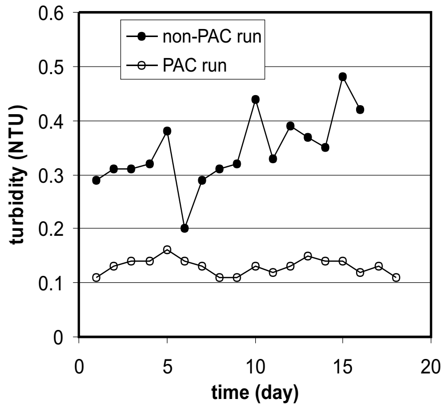

Figure 5. *Turbidity of the permeate from the MBR in both non-PAC and PAC runs*

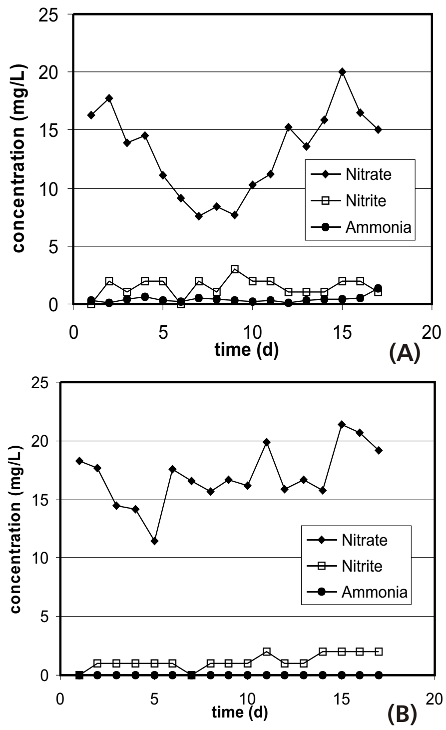

Figure 6.*Concentration of nitrogen species during the non-PAC run (a) Fish tank (b) Permeate from the MBR*

Conclusions

An efficient recirculating aquaculture system (RAS) comprising of an anoxic reactor, membrane bioreactor and a UV-disinfectant unit was used to culture Barramundi fish by treating 10,000 L of aquaculture effluent continuously. The system maintained low levels of nitrate (<20 mg/L), nitrite (<3 mg/L) and ammonia (<0.6 mg/L) in the fish tank. The permeate from the membrane that was recirculated to the fish tank contained <21 mg/L of nitrate, <2 mg/L of nitrite and 0 mg/L of ammonia. The membrane in the MBR required cleaning due to fouling after 16 days. Cleaning of membrane initiated when the TMP reached around 25 to 30 kPa. However, when PAC was introduced into the MBR at 500 mg per litre of MBR volume, cleaning of membrane needed only after 31 days of operation. Calculations showed that PAC reduced irreversible resistance, which could be attributed to the adsorption of dissolved organic substances and EPS by PAC

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