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Performance Study of Ceramic Filter Module in Recirculated Aquaculture System (RAS)

L Y Ng[1], C Y Ng[2]

[1]Centre for Environmental and Green Technology, Department of Chemical Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman, Jalan Sungai Long, Bandar Sungai Long, Cheras 43000 Kajang, Selangor, Malaysia.
[2]Department of Chemical & Petroleum Engineering, Faculty of Engineering, Technology and Built Environment, UCSI University (North Wing), Lot 12734, Jalan Choo Lip Kung, Taman Taynton View, 56000 Cheras, Kuala Lumpur, Malaysia.

E-mail: ngcy@ucsiuniversity.edu.my

Abstract. The growth of world population has led to significant increase in seafood demand over the world. Aquaculture has been widely accepted by many countries to increase the seafood production owing to the decline of natural seafood resources. The aquaculture productivity, however, is directly linked to the pond water quality. In this study, attempts were made to employ ceramic micro-filter to improve the pond water quality through filtration processes. There were two batches of filtration processes, short term (1 hour) and long term (48 hours). Significant improvements on real pond water quality were recorded through the short term microfiltration process, which reduced turbidity (96%), total suspended solids (TSS) (80%), biochemical oxygen demand (BOD) (72%), chemical oxygen demand (COD) (55%), ammonia (60%), nitrate (96%) and phosphorus (83%). The long term filtration process also showed high efficiency in the removal of solid particle and organic matters. The results showed that all of the parameters were successfully reduced to acceptable ranges (turbidity<80 NTU, TSS<400 mg/L, BOD<5 mg/L, COD<70 mg/L, phosphate<3 mg/L and ammonia<0.05 mg/L) for fish culturing activity. Based on current study, there was a drastic increase in nitrate content after 24 hours due to the nitrification process by regenerated bacteria in the filtered pond water. Current study showed that the microfiltration using ceramic micro-filter has high potential to be used in recirculating aquaculture system throughout the aquaculture activities in order to maintain the pond water quality, thus, increase the survival rate of cultured species.

1. Introduction

Aquaculture is important in providing food and generating income in many developing countries such as Thailand, India, China and Malaysia. Continuous growth of world population makes food scarcity a critical issue around the world. Malaysia government has foresighted the future prospect of aquaculture, thus, heavily promoting the aquaculture activities locally [1]. Fish farming, thus, has been blooming since a decade ago in Malaysia. The main challenge that farmers are facing now, however, is proper water quality control. To mitigate this problem, several methods and system have been introduced and attempted such as sedimentation control, probiotic treatment and treating the effluent by microalgae [2].

Filtration can be used to retain suspended solid matter from a liquid by passing the fluid through the pores of filter medium. The presence of suspended solids in the pond water is normally resulting from fish waste and uneaten food, which contribute to a portion of the oxygen demand and toxic ammonia in the farming system [2]. In addition, filtration process has low energy consumption, easy to be set up and economically feasible to be integrated into several separation processes [3]. Therefore, filtration could be a highly potential method to mitigate the water contamination problem in fish farming although it is still not widely adopted by aquaculture industry.

Water quality in the fish farming is one of the most complex solution as it consists of many controllable and un-controllable parameters. A poorly managed pond water is prone to the outbreak of diseases because of the blooming of bacterial and/or viruses in the water. One of the most common diseases in aquaculture farms is White Spot Syndrome Virus (WSSV) disease. Poorly managed pond water will encourage the replication of WSSV, which consequently lead to higher mortality rate during the farming cycle [4,5]. Parameters in aquaculture that require intensive monitoring and controlling including pond water pH, total suspended solids, salinity, ammonia, ammonium, nitrate, nitrite, heavy metals, temperature and dissolved oxygen content. The survival rate of cultured species can be increased if the parameters listed above are well-controlled within the acceptable limit. Filtration system using ceramic module, therefore, is proposed in this study to be integrated into the pond water system in order to improve and maintain the pond water quality.

Table 1. Optimum water parameters for freshwater aquaculture activity (catfish) [6]

Parameter	Optimum range
pH	pH 6 - 9
Turbidty	< 80 NTU
Total suspended solids (TSS)	< 500 mg/L
COD	< 70 mg/L
BOD	< 5 mg/L
Ammonia	< 0.05 mg/L
Nitrate	< 1 mg/L
Phosphate	< 3 mg/L

2. Materials and methods

Pond water was collected from a freshwater catfish pond during 60 culturing days and it is located at Hulu Langat province, Selangor, Malaysia. The water sample was stored in 2.5 L polyethylene bottles and kept at $4^{o}C$ prior to the experiments and water analyses. The pond water pH was collected and measured using Eutech pH700 (Thermo Fisher Scientific Inc. MA, USA). The Doulton ceramic filter (Southfield, United State) with an average pore size of 0.6 µm was selected to be used as the filter module in this study. The chemicals and reagents such as ammonia salicylate reagent powder pillows, nitra Ver5 nitrate reagent powder pillows, molydovanadate reagent, COD digestion solution and copper and iron standard solution were purchased from Hach (Colorado, United State).

The tested parameters were turbidity, total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total ammonia nitrogen (TAN), nitrate ($NO^{3-}N$), phosphate ($PO4^{3-}$) and heavy metal (Fe, Cu). All of the parameters were analyzed using Hach DR3900 spectrophotometer and following standard procedures (U. S. Environmental Protection Agency 1983). In the COD test, samples need to go through the digestion process using Hach DRB 200 digital reactor prior to the concentration reading by Hach DR3900 spectrophotometer. Perkin Elmer Analyst 400 Atomic Absorption Spectrometer (Ohio, United State) was used to analyze the heavy metal in all the samples.

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2.1. Calculation

The flux (L/m^2.min) of permeate can be calculated using the Equation (1):

$$Flux, J = \frac{V}{A.\Delta t} \quad (1)$$

where *V* is the volume of permeate collected (in unit L), *A* is surface area of filter (in unit m^2) and *Δt* is interval of time (minute). Normalized flux is a ratio of permeate flux to initial pure water flux (*J/Jo*), as shown in Equation (2), at similar operating pressure and temperature.

$$Normalize\ flux = \frac{Permeate\ \ flux}{Initial\ \ water\ \ flux} = \frac{J}{J_o} \quad (2)$$

Rejection of the tested parameters can be expressed in terms of percentage as shown in Equation (3):

$$Rejection, Rej\ (\%) = \left(1 - \frac{Cp}{Cf}\right) x100\% \quad (3)$$

where *Cp* and *Cf* represent the concentration of concerned components in permeate and feed streams, respectively.

2.2. Experimental setup

A recirculating aquaculture system (RAS) was set-up using a filtration module as shown in figure.1 The RAS was conducted at short and long term in this study. Filtration process using pure water was conducted for 15 minutes before the filtration of pond water samples. This is to ensure that the filter module is in good condition and also for the filter wetting purpose. The operating conditions for each of the experimental run are shown in table 2. A water pump (BLDC Pump DC-30A, 12V, Guangzhuo, China) was used to supply the desired pressure throughout this study. Permeated water sample was collected and recorded for an interval of 1 minute over an hour of filtration period for water flux calculation. The collected permeate was stored at 4^{o}C prior to the water analyses.

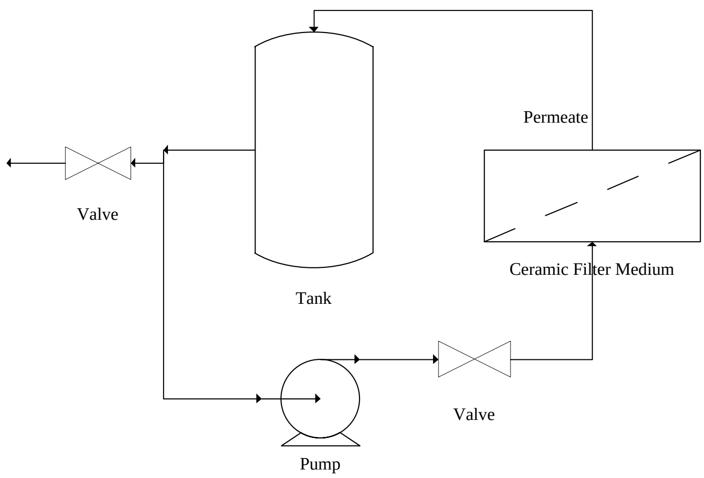

Figure 1. The schematic diagram of filtration system

Table 2. Parameters of each experimental run

Experiment set	Abbreviation	Filtration Time	Pressure (bar)	Temperature (^{o}C)
Short term (batch 1)	S.T1	1 hour	1	25
Short term (batch 2)	S.T2	1 hour	1.5	25
Long term	L.T	48 hours	1	25

For the long term filtration process, the permeate was returned to the pond water tank continuously for a duration of 48 hour. The pressure and temperature applied was same as the short term filtration set (S.T1). At the end of long term filtration process, the sample was sent for water analyses. The produced flux for all batches of filtration were evaluated and discussed. All the tested parameters for all batches were also compared and discussed.

3. Results and discussion

3.1 Flux decline

Figure.2 and figure.3 shows the normalized flux decline curves for experimental set S.T1 and S.T2, respectively. Similar normalized flux decline curves were observed for both batches of short term filtration processes. Normalized flux reduction, as much as 97%, were achieved for both S.T1 (6 min) and S.T2 (5 min) within a very short period of filtration time. The pond water sample is a complex mixture which consists of various components with a broad range of particle sizes and different properties. These factors may affect the performance of used ceramic filter. Ceramic filter with high porosity is highly susceptible to fouling during the starting of filtration process owing to the concentration of foulants onto the pores present on the ceramic filter, which led to a drastic decline of solution flux [7; 8]. This drastic flux decline can be observed in the normalized flux decline curves as plotted (figure.2 and figure.3).

Ceramic filter with an average pore size of 0.6μm encouraged the fouling phenomenon to be observed on the ceramic filter owing to a broad distribution of particle sizes in the pond water sample [9]. Ceramic filter used in this study can be categorized as microfiltration which restrict the passage of micro-sized or larger constituents through the filter pores. For instance, the constituents including TSS, dissolved solids, natural organic matter (NOM), inorganic matter, bacteria, proteins traces from uneaten food and feces and solid particles [10]. The presence of these components increased the fouling rate of ceramic filter module, thus, reduced the volume of permeate. Fouling mechanisms such as pore blocking and cake layer formation are the possible explanations for the reduced permeate as can be observed in this study. This, however, requires further experimental data in the future to verify the fouling mechanism observed on the ceramic filter. After 5 minutes of filtration, steady-state flux was achieved. This condition normally occurs when a cake layer with certain thickness covered and compacted on the surface of a filter [11; 12; 13]. Cake formation, thus, could be formed during these short term filtration processes using the ceramic filter in this study.

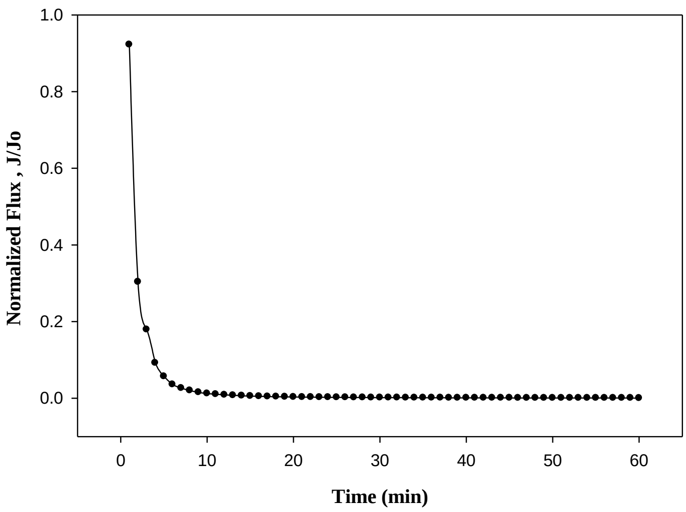

Figure 2. Flux decline of pond water for filtration set S.T1

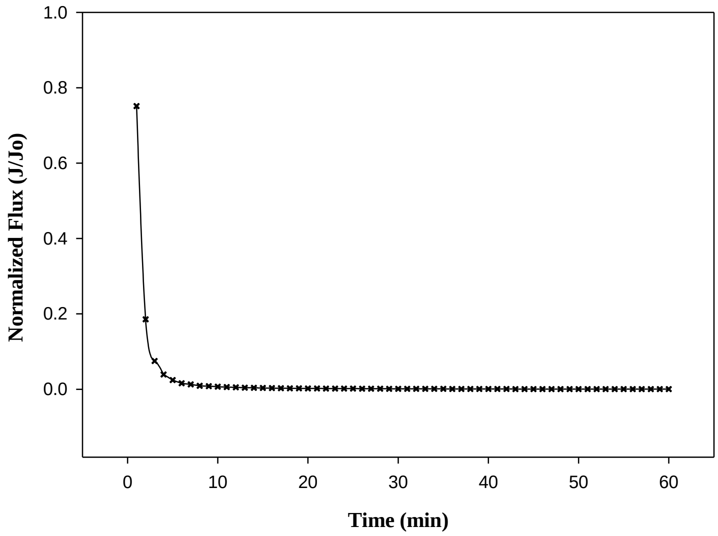

Figure 3. Flux decline of pond water for filtration set S.T2

3.2 Sample analyses
Performance and efficiency of ceramic filter in fish pond water treatment was evaluated through the water analyses. This study analyzed the water samples based on several parameters including pH, turbidity, TSS, BOD, COD, ammonia, nitrate, phosphate and heavy metals. The feed stream and permeate samples collected from the filtration processes (T.S1, T.S2 and L.T) were sent for water analyses. Range of water sample pH 5.0 – 6.50 was recorded for all the feed and permeate streams of S.T1 and S.T2. The results obtained is reasonable owing to the fact that a healthy freshwater fish culturing activity has to be conducted at pH values near to the neutral condition [14]. Extremely acidic or alkaline conditions are not suitable for freshwater fish farming, which might lead to lower survival rate of the cultured fish. Water pH, therefore, is one of the important parameters that need to be continuously monitored in aquaculture industry. Close monitoring of the pond water pH is one of the important practices that normally employed to minimize the stress in cultured species, thus, diseases and viruses infection [15].

The pond water or feed stream sample of each batch of filtration collected was sent for water analyses based on the parameters as mentioned earlier. Table 3 shows the water analysis results in feed streams for all filtration batches. Based on the analysis results, no heavy metals (copper and iron) elements were present in the pond water sample collected.

Table 3. Water analyses of feed stream for all batches of filtration process

Parameters	Value
pH	6.61 ± 0.00
Turbidity (NTU)	62.55 ± 1.35
TSS (mg/L)	1072.00 ± 0.30
BOD (mg/L)	4.71 ± 0.31
COD (mg/L)	128.67 ± 1.52
Ammonia (mg/L)	0.47 ± 0.05
Nitrate (mg/L)	1.15 ± 0.05
Phosphate (mg/L)	5.10 ± 0.10
Copper (mg/L)	n.a
Iron (mg/L)	n.a

Figure.4 illustrates the rejection percentages for all water parameters in S.T1 and S.T2 after the filtration process using ceramic filter. Turbidity and nitrate achieved higher rejection rate for both short term filtration processes in comparison to other parameters. Turbidity analysis showed 96.35 ± 0.08% and 97.24 ± 0.07% rejections for filtration set S.T1 and S.T2, respectively. For nitrate removal study, 94.50 ± 0.83% and 95.89 ± 0.84% retentions were recorded during the filtration set S.T1 and S.T2, respectively.

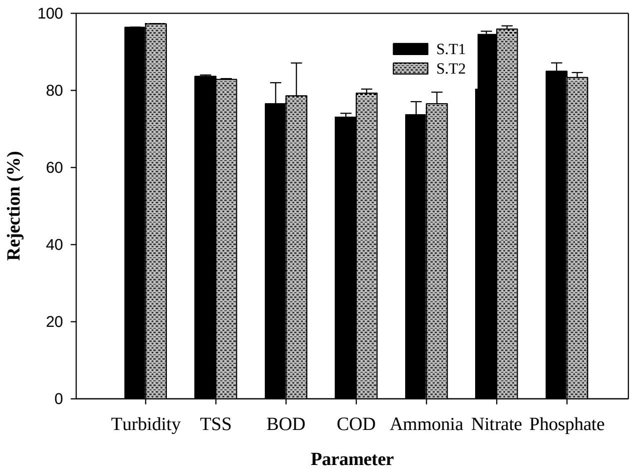

Figure 4. Rejection percentages for all water parameters in S.T1 and S.T2 after filtration process using ceramic filter

Above 80% of rejections were observed for TSS and phosphate for both S.T1 and S.T2 filtration sets. On the other hand, 73 – 80% of BOD, COD and ammonia were retained by ceramic filter during the short term filtration processes, S.T1 and S.T2. Pond water comprises various particles or compounds, which own broad ranges of particle sizes and different characteristics. Combination of several factors have contributed to the rejection results during the filtration processes using ceramic filter. Besides particle size distribution factor, ionic organic matters would attach to or combine with oppositely charged compounds forming larger particles that were restricted from passing through the ceramic filter [16]. The ionic compounds that were investigated in this study including ammonia ions, nitrate, phosphate and so forth. These particles are possible to be retained on the filter surface or deposited on the filter pore wall if their sizes are similar to or larger than the ceramic filter pores [9]. In this study, rejection of all of the water quality parameters were highly encouraging in which most of their rejections were above 70%.

Visualization of the water quality difference can be done based on figure.5, which illustrates the water quality after the filtration process using ceramic filter. The improvement can be verified based on the water color, odor and turbidity content. After the filtration treatment, turbidity and color of the water are clearly reduced. This observation, coincidently, can be confirmed by the results in figure.4, which shows that most of the foulants have been successfully retained by ceramic filter.

Figure 5. Quality of pond water before and after treatment using ceramic filter module

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3.3 Long term filtration

The operating condition for long term filtration process was fixed as stated in table 2. The initial permeate flux for the long term filtration was recorded as 1101.34 L/m^2.hr, while the permeate flux after 48 hours was reduced to 0.5580 L/m^2.hr. The reduction of permeate flux was 99.95 %. This revealed that a tremendous fouling had occurred during the long term filtration. This observation is reasonable as the filtration process in this study was carried out using a dead-end mode, which retain the water contaminants, thus, the build-up of the foulants within the ceramic module. Cake formation could be one of the fouling mechanism on the surface of ceramic filter after 48 hours of filtration process. Similar result was also reported by several researchers who performed the long term filtration in their study [10; 17; 18]. Pore blocking mechanism, however, could be the contributor to the drastic reduction in the permeate flux after 48 hours [19].

Figure. 6 shows the concentration of turbidity, TSS, COD and BOD from initial (0 hour) until the end (48 hours) of long term filtration process using ceramic filter medium. The water parameters were determined at 0, 6, 12, 24 and 48 hours of filtration. Concentration of TSS had dropped drastically from the initial until 6 hours of filtration, which was followed by gradual decline up to the end of the filtration. However, other parameters (turbidity, COD and BOD) had slowly declined from the beginning until the final stage of long term filtration process. This outcome disclosed that the ceramic filter medium is able to effectively remove the TSS from aquaculture pond water throughout the filtration process [8; 20]. Most of the suspended solids consist of inorganic matters and their particle sizes can reach up to 2 microns [20]. TSS particle sizes are much bigger in comparison to ceramic filter pores. Most of the TSS, thus, could be retained by the ceramic filter module. Turbidity measurement is an indicator of water quality based on the water clarity and estimated TSS in water [8]. In this study, turbidity of pond water reduced during the long term filtration along with reduced TSS content. Concentration of TSS, turbidity, COD and BOD parameters in this study were successfully reduced to the optimum water parameter ranges as shown in Table 1 [21].

The concentration of ammonia, nitrate and phosphate at various time intervals (at 0, 6, 12, 24 and 48 hours) during the long term filtration study were plotted in figure.7. A declining trend was shown by ammonia and phosphate parameters throughout the long term filtration. Nitrate analysis, however, showed different trend when compared to ammonia and phosphate contents for several intervals between 0 and 48 hours of the long term filtration process. This distinctive result is logical owing to the nitrification process in the water sample. In this study, ceramic filter medium with 0.6 µm average pore size is permeable to microorganism and bacteria [16; 4]. The presence of nitrifying bacteria converts the ammonia in permeate streams into nitrate through nitrification process when sufficient time was provided during the long term filtration using ceramic filter [3]. Consequently, the content of nitrate in pond water sample was increased after 12 hours of filtration. The decline of nitrate in the beginning of long term filtration process can be explained by the retention of nitrate by ceramic filter, which was verified through the short term filtrations that were conducted in this study. The nitrification process by bacteria in the initial stage of the long term filtration, in addition, may not be initiated as the growth of bacteria require longer duration before the nitrification process can become significant [15; 17]. After the long term filtration of pond water sample using ceramic filter, concentration of ammonia and phosphate were still within the optimum range for aquaculture activity. At 48 hours, nitrate concentration was 1.2 mg/L, which was slightly higher than the optimum limit ($<$ 1 mg/L). Continuous and sequential filtration system using a combination of ceramic filter media and ultrafiltration membrane may be suggested in the future to remove the excess nitrate content to further improve the pond water quality [22; 9]. Possibility of disease or virus infection on cultured fish can be further minimized thus higher survival rate by reducing the stress induced on the cultured species when the pond water quality can be properly managed through the ceramic filter.

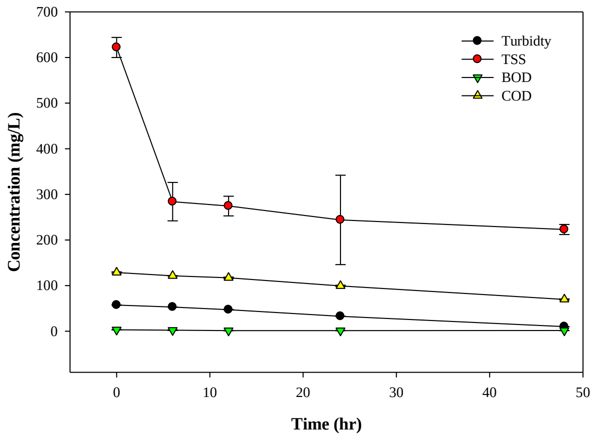


Figure 6. Interval results of turbidity, TSS, BOD and COD analyses between 0 and 48 hours of long term filtration process using ceramic filter.

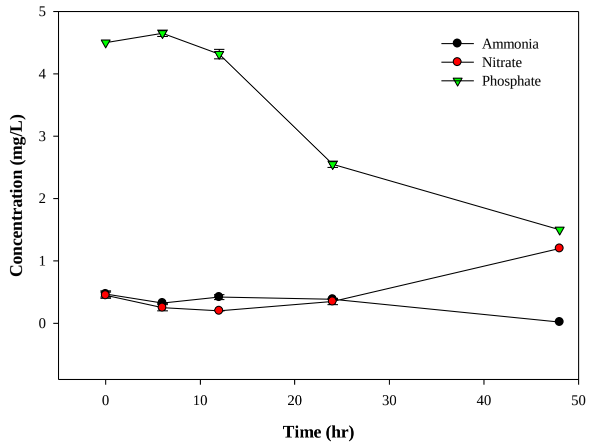
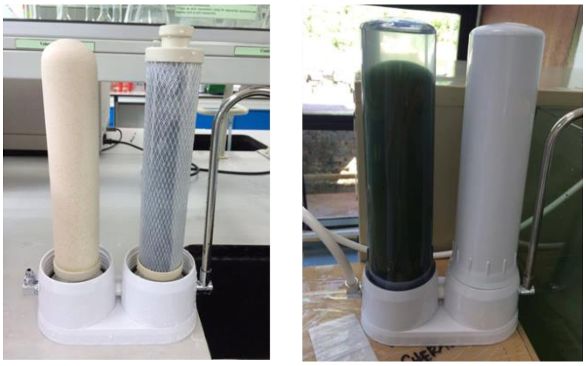


Figure 7. Interval results of ammonia, nitrate and phosphate analyses between 0 and 48 hours of long term filtration process using ceramic filter.

Figure. 8 illustrates the condition of ceramic filter medium used in this study before and after the filtration process using pond water. There was a significant distinction between fresh and used ceramic filter. Based on the observation, cake formation on the ceramic filter was one of the main mechanisms that contributed to the tremendous flux reduction as shown in figure.2 and figure.3. A thick layer of greenish cake consists of various kinds of foulants was coated on outer surface layer of the ceramic filter used during the study. Fish pond water, which consists of plenty of microalgae or fungus, acts as a medium to absorb CO_2 while provide O_2 to aquatic organisms through photosynthesis [23]. This is an important process to cultured-fish in ensuring a continuous supply of oxygen. Pond water is rich with various nutrients that encourages the growth of microalgae. The presence of microalgae in fish pond water is important in decomposing the organic matter in sediment while keeping the pond water clean [24]. Microalgae culturing could be one of the method to be used to manage and maintain the high quality of culture pond water [2; 25]. Excessive bloom of microalgae, however, can lead to high consumption of the pond water nutrients. When the nutrients in the pond water are depleted, large amount of dying microalgae and their decompositions may compete with the cultured fish for oxygen supply, which may reduce the fish survival rate. Relationship between the filtration flow rate and microalgae growth rate may need to be taken into consideration during a fish pond water filtration in order to maintain the presence of nutrients and quality of the pond water.



(a) (b)

Figure 8. Illustrations of ceramic filter (a) before and (b) after filtration process using fish farming pond water

Ceramic filter has been selected in this study as it can resist the bacterial attack better than polymeric materials. To study its feasibility in terms of economic perspective and performance reliability, ceramic filter in this work was cleaned after the long term filtration study. Clean water was used as a washing agent. 76.43% of flux recovery was successfully recorded by applying the washing on used ceramic filter medium after long term filtration (initial pure water flux was 1101.34 L/m^2.hr and water flux after cleaning was 841.75 L/m^2.hr). High flux recovery revealed that a great potential use of ceramic filter in aquaculture in which its performance can be further improved through periodical backwash and conducting the ceramic filter in a scale-up cross flow filtration system during a fish farming period [10; 26]. Implementation of a such filtration system, together with a periodical backwash step in aquaculture industry, can further minimize the water management cost and other chemical consumptions [27]. Based on its high flux recovery and good retention capability of undesired solutes, ceramic microfilter can be suggested to be integrated into a recirculating aquaculture system.

4. Conclusion

Performance of ceramic filter has been successfully evaluated in terms of flux decline and retention capability towards different water parameters such as turbidity, TSS, BOD, COD, ammonia, nitrate and phosphate using real pond water sample from a catfish farm. Deposition of the foulants onto the ceramic filter was one of the main factors that contributed to the flux reduction during the filtration of pond water. Pond water consists of various components that possess broad particle sizes and different properties. These components, thus, contributed to the high flux decline profiles as observed in this study. The mechanisms of fouling that dominated the filtration of pond water could be pore blockage and/or cake formation. Images of ceramic filter, before and after the filtration process, successfully demonstrated the retention of the foulants from the pond water.

All of the tested water parameters showed significant rejection after short term filtrations (S.T1 and S.T2), whereby the highest rejection was towards turbidity and nitrate at 97.84% and 95.89%, respectively. Meanwhile, rejection percentage for TSS, BOD, COD, phosphate and ammonia were between 73 to 80%. Based on the results, pond water quality has been successfully improved using ceramic filter module during the short term filtration processes. Significant results based on the water parameters also have been demonstrated during the long term filtration process. All of the tested parameters were successfully reduced to the optimum conditions for freshwater fish farming activity, excluding nitrate content. This could be explained by the nitrification of ammonia by the nitrifying bacteria after 12 hours. Sequential filtration system, by integrating microfiltration and ultrafiltration, is suggested for future investigation to further reduce the nitrate and microorganism content for pond water quality improvement.

Flux recovery, as high as 76.43%, was successfully obtained after the washing process done on the used ceramic filter. This result implies that the ceramic filter could be periodically backwashed in order to prolong its lifespan for continuous application in fish farming. A cross-flow filtration system can be suggested in future to maintain the quality of pond water while minimizing the build-up of the foulants on the ceramic filter. Chemically stable, good resistance towards bacterial-attack, recoverable water flux and effectiveness in retention capability towards various contaminants have suggested the ceramic filter to be further investigated in the future. This is as part of the effort to integrate the microfiltration into an aquaculture water management system for a sustainable development in that industry.

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