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Assessment of using hollow fibre microfiltration in treating lake water

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ABSTRACT

The main objective of this study was to determine the reliability of using microfiltration system which is composed of a coagulant such as ferric chloride (pretreatment substance) and hollow fibre membrane as filtering medium for improving water quality. In this study, raw water samples were collected from a lake located at the Faculty of Engineering, Universiti Putra Malaysia. The experiments were carried out in three stages: the first stage used distilled water, the second stage used lake water stored in a tank and the third stage used lake water stored in the tank and mixed with ferric chloride as coagulant. A storage tank and a separation tank were used; the storage tank is used to store water pumped from the lake (used in the second stage) while in the third stage, the stored water in tank was used for pretreatment or coagulation with optimum dosage of ferric chloride (determined from jar test). The experimental results show that the flux obtained from second and third stages was low. For lake water stage, the best flux was found to be 4.97 $l/m^2/h$. The distilled water stage shows that shaft rotational speed of peristaltic pump was one of the factors affecting the flux. Therefore, a pump shaft rotational speed of 7 rpm was chosen based on flux and suction pressure. The experimental results show the ability of microfiltration using hollow fibre membrane together with ferric chloride as coagulant to produce treated water with 97% turbidity removal and 85% removal of total suspended solids (TSS). For treated raw water, it is found that the removals of TSS were ranged from 71.7 to 91.6% when alum was used as a coagulant while the TSS removals were ranged from 74.4 to 89.20% when ferric chloride was used as a coagulant. In this study, it is found that the optimum dosages of ferric chloride and alum were 4 and 20 mg/l, respectively. Although the percentage removal of TSS is slightly higher when alum is used as a coagulant compared with using ferric chloride, it is recommended to

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use ferric chloride as a coagulant due to its economical and health advantages. Furthermore, ferric chloride can be used in wide range of pH values while alum can only be effective when pH value around 7.

Keywords: Lake water; Treatment; Coagulation; Microfiltration

1. Introduction

In Malaysia and due to intensive development, the problem of river water quality deterioration is worsening. River as a natural water source is unpolluted but after human use, the water becomes discoloured. River water quality deterioration is synonymous with development and it is the result of pollution from both point and non-point sources. From data compiled by the Department of Environment, Malaysia, overall pollution trend shows slow but steady deterioration in the water quality of rivers in Malaysia and of 116 rivers, only 36% are rated as clean rivers and 64% are polluted. In terms of heavy metal contamination, 55 rivers have been found to exceed the maximum limit of 0.001 mg/l for cadmium, 44 rivers exceeded the iron limit of 1.00 mg/l, 36 rivers exceeded the lead limit of 0.01 mg/l and 24 rivers exceeded the mercury limit of 0.0001 mg/l. The main sources of organic water pollution are domestic and industrial sewage, effluent from palm oil mills, rubber factories and animal husbandry. Mining operations, housing and road development, logging and clearing of forest are major causes of high concentration of suspended sediment in downstream stretches of rivers. In several urban and industrial areas, organic pollution of water has resulted in environmental problems and adversely affected aquatic lives. In the Klang Valley alone, an estimated 50–60 tons of wastes end up in the river system daily [1]. Based on the above situation, water sources other than river should be considered. Natural lakes and manmade lakes are an important source of water supply.

Conventional drinking water treatment processes for typical water treatment plant condition was evaluated to determine their effectiveness in removing antibiotics. Experiments were conducted using synthetic solutions prepared by spiking both distilled/deionized water and Missouri River water. Sorption on activated carbon, reverse osmosis and oxidation with chlorine and ozone under typical plant conditions were all shown to be effective in removing the antibiotics [2].

Continuous water quality measurements of storm run off into a single road inlet at two experimental catchments in Belgrade, Yugoslavia and Lund, Sweden, were carried out. Both sites were equipped with similar instrumentation for measurements of overland flow, turbidity, pH, conductivity and temperature. The results of their study indicate that the antecedent dry weather period length has only a minor effect upon road sediments washoff, but it has an influence upon conductivity. Suspended solids from first flush were found in a limited number of storm events [3].

The microbial contamination cannot be assessed by measurements of turbidity at drinking water plants. This is because the presence of colloids in water creates interferences with the nephelometric response. Thus, there is a need for a more relevant, simple and fast indicator for microbial contamination detection in water, especially in the perspective of climate change with the increase in heavy rainfall events [4].

A gravel wetland system was used to treat run-off from parking lot, and based on the results, the system showed satisfactory treatment efficiency for total suspended solids (TSS) (more than 70%) and total zinc (almost 60%). Average treatment efficiency for chemical oxygen demand (COD) was 50%, while 35–45% for nutrient such as total nitrogen and phosphorus. Overall, the system was able to treat 30–60% of inflow and improved the water quality standard of outflow to one or two levels higher [5].

Due to defects in the quality of treated water from conventional methods in some regions of China, the performance of ultrafiltration (UF) membranes in treating raw water from Binxian Reservoir (China) was investigated. It was found that using coagulation before ultrafiltration increased permeates flux and retarded membrane flux decline [6]. Also, results showed that membrane permeate flux in a coagulation/UF process was higher than that in coagulation-sand filtration-UF process with raw water of medium turbidity. Ultrafiltration provided effective turbidity removal. Iron, manganese and aluminium were removed completely. The UF membrane also perfectly removed all coliform bacteria. The reduction of total organic carbon (TOC) was satisfactory. The quality of the produced water is complied with China's drinking water guidelines [6].

The increasing role of pressure-driven membrane processes in drinking water treatment was highlighted [7]. The major uses of membrane processes in the US include desalting, disinfection by-product control, disinfection, clarification and removal of synthetic and inorganic chemicals. Membranes are also furthering capabilities to purify wastewater for indirect potable reuse. Also, it is increasingly being used for filtering backwash water from conventional water treatment [7].

Integrated membrane systems consist of nanofiltration (NF) and low-pressure reverse osmosis membrane, RO processes were used to treat surface water in order to produce drinking water [8]. In terms of hydraulic performances both pretreatments: ultrafiltration and clarification were found to be effective to control RO fouling. Despite UF reduces the silt density index (SDI) well below the maximum advised by the membrane manufacturer, a slight fouling occurred on the RO membranes at high flux. Organic material plays a role in membrane fouling, and therefore reducing SDI may not guarantee a low fouling rate of the RO membranes [8].

The performance of pilot scale hybrid process to produce drinking water from river water was studied [9]. The plant was consisted of ozonation and membrane filtration, followed by activated carbon filtration. The main objectives were to determine the effect of ozone on the filtration and fouling behaviour of ceramic microfiltration and ultrafiltration membranes with pore sizes of 0.1 gm and 20 kD as well as on the quality of the water produced. The results showed that a certain ozone concentration in the permeate was required to maintain stable and high permeate fluxes during microfiltration and ultrafiltration of river water without backflushing. For the used membranes, results showed that a minimum concentration of 0.05 mg/l of ozone in the permeate was needed. Furthermore, as the ozone dosage was increased, permeate fluxes rose to the values of pure water permeability depending on ozone doses. Ultrafiltration of the river water with the addition of ozone achieved a yield of 99% without reducing membrane permeability while obviating the need for membrane backflushing. The hybrid proposed treatment can reduce the concentration of the organic components in the water, determined as TOC, chemical oxygen demand as permanganate demand (COD), adsorbable organic halogens and spectral absorption coefficient (SAC_{254}), to values under the respective determination limit. Moreover, the hybrid proposed treatment could eliminate completely the coliform bacteria, *Escherichia coli*, *Pseudomonas aeruginosa*, Clostridia and faecal streptococci, which were sometimes present in the treated river water [9].

The theory of fouling dynamics in cross-flow membrane filtration was compared with ultrafiltration experiments with suspensions of 0.12 μm silica colloids [10]. It has been experimentally verified that colloidal fouling in cross-flow filtration is a dynamic process from non-equilibrium to equilibrium and that the steady state flux is the limiting flux [10].

In this study, lake water from the lake located at the Faculty of Engineering, Universiti Putra Malaysia was treated using microfiltration process and ferric chloride as a coagulant.

2. Material and methods

2.1. Description of the microfiltration system

In this study, the components of the microfiltration system are shown in Fig. 1. The system is composed of a centrifugal pump, one-way valves, polyvinyl chloride (PVC) pipes, storage tank with electric motor and mixer, separation tank, hollow fibre membrane, air diffuser, pressure gauge, peristaltic pump and a tank to collect the treated water. The centrifugal pump is used to pump water from the lake to the microfiltration system. A storage tank with 49.0 cm wide, 47.5 cm long and 32 cm deep is used to store the pumped water from the lake before treatment. Also, the tank contains mixer which continuously mix the water in order to avoid sedimentation. The mixer is used to mix alum with water in the storage tank. It also prevents colloidal particles from settling at tank base. In the separation tank, separation process takes place through hollow fibre membrane. The separation tank is exactly similar in size to the storage tank. PVC pipe is used to convey water to the microfiltration system. The peristaltic pump used with the system can be operated with a range of shaft rotational speed from 1 to 100 rpm under a range of temperature from 0 to 40°C. This type of peristaltic pump is suitable to suck filtered water through the hollow fibre membrane in small quantity. Hollow fibre membrane module is used to filter the lake water, and the effluent is collected from two opening located at left and right sides. The membrane has outer diameter of 0.37 mm, inner diameter of 0.25 mm, range of pore size between 1.8 and 2.7 μm, 3,964 membrane strands and effective area of 3.09 m. The microfiltration system was fed with water from a lake located at the Faculty of Engineering, Universiti Putra Malaysia. Samples from the lake water were taken to the laboratory for water quality analysis.

2.2. Operation of the microfiltration system

The experiments are implemented in 3 stages, in the first stage, the experiments were run using distilled water, while in second stage, the experiments were run using water pumped from the lake and stored in the tank. Finally and in the third stage, the experiments were run using the water in the storage tank mixed with ferric chloride as coagulant. Distilled water is

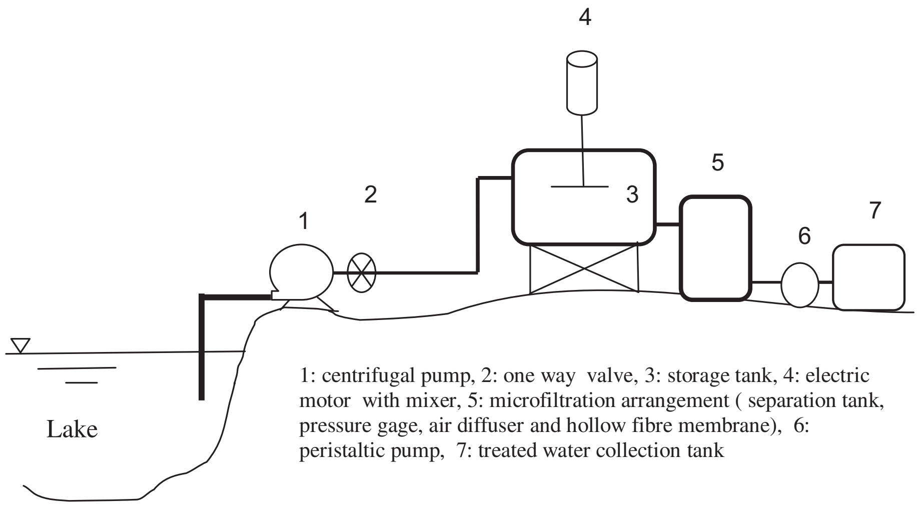

Fig. 1. Schematic diagram for the microfiltration system used in the study.
Notes: (1) centrifugal pump, (2) one-way valve, (3) storage tank, (4) electric motor with mixer, (5) microfiltration arrangement (separation tank, pressure gage, air diffuser and hollow fibre membrane), (6) peristaltic pump, (7) treated water collection tank.

used to obtain the correct flux value and tests were carried out with different pump shaft rotational speeds. Time allocated for the experiments was 3 h, and all data were recorded. After that, values of the flow rate, *Q* and flux, *J* were calculated from the data. After the value of flow rate (*Q*), flux (*J*) and pump shaft rotational speed were determined, the experiments were carried out. A pump speed of 7 rpm was selected for the first time, and effluent was collected every 24 h. The value of pressure and the effluent volume was recorded. Furthermore, the values of flow rate and flux were calculated and their performances were compared. Also, the percentage removal was determined. Before running this stage, the optimum coagulant dosage used in the coagulation process was determined using jar test. Similar to the pervious experiments, the volume of the filtered water and the value of pressure were recorded, respectively, in order to obtain the value of flow rate and flux. For jar test, 500 ml samples were mixed at high rotational speed of the apparatus (100 rpm). The primary coagulant was added simultaneously to each beaker and mixing continued for 1 min. The speed was reduced to 40 rpm for 10 min. Time of appearance of the floc and its size (use sample floc sizes chart supplied) was observed. The stirrer stopped and the floc allowed to settle for 20 min (avoid convection currents). pH and turbidity of the supernatant were determined, and special care was taken so that the collected samples were free from floating and settled floc. The above steps were repeated for six different coagulant dosages. In this study, the coagulant used was ferric chloride with a range of dosage between 2 and 12 mg/l. The tested parameters in the water samples before and after filtration are colour (Pt-Co), COD in mg/l, turbidity in NTU, TSS in mg/l, pH, temperature, dissolved oxygen (DO) in mg/l, alkalinity (mg as $CaCO_3$/l). For each parameter, comparison was made between water sample before and after filtration. Impact of coagulation on lake water with ferric chloride is studied in order to test its effectiveness as a coagulant.

3. Results and discussion

A daily monitoring for selected water quality parameters was conducted in the laboratory using water samples collected from the lake, storage tank after adding ferric chloride as a coagulant and finally from the effluent. The tested parameters are pH, temperature, TSS, turbidity, colour, DO, COD and alkalinity. The laboratory tests are useful to assess the

Table 1
Characteristics of lake water

Parameter	Value range
pH	6.51–7.67
Temperature	26.5–33.8
Alkalinity (mg $CaCO_3/l$)	31.5–40.0
Turbidity (NTU)	4.14–14.98
Colour (Pt-Co)	57–341
TSS (mg/l)	42.5–75.6
COD (mg $CaCO_3/l$)	96–160

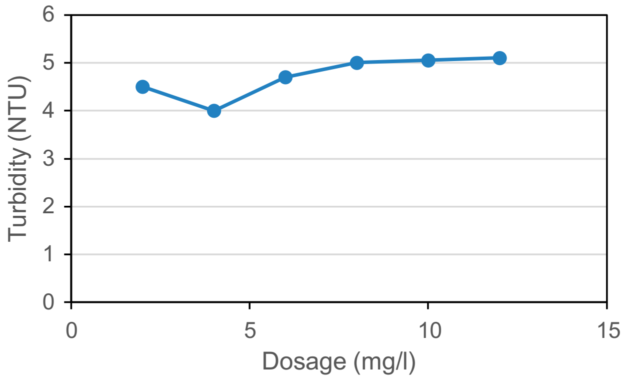

Fig. 2. Results of jar test using ferric chloride as a coagulant.

efficiency of ferric chloride as a coagulant and hollow fibre membrane as a microfilter. Table 1 shows the quality of lake water samples.

3.1. Jar test using ferric chloride

In this study, the optimum dosage of ferric chloride was determined using jar test. As shown in Fig. 2, the optimum dosage of ferric chloride as a coagulant was found to be 4 mg/l. This dosage reduced the turbidity of the lake water to a minimum value of 4 NTU. From the above finding, a dosage of 4 mg/l of ferric chloride is recommended to be used for the coagulation process for the lake water treatment.

3.2. Comparison of flux and suction pressure with time

Flux obtained from microfiltration is affected by suction pressure, effluent volume, membrane area and flow rate. Also, the flux is affected by the flow being used, and generally, there are two types of flow, namely cross-flow and direct flow. Cross-flow is able to reduce the formation of cake layer which will cause fouling of the membrane, so this type of flow gives higher flux value compared with direct flow. When the cake layer is formed, suction pressure becomes higher and more energy is needed to suck water through membrane pores. Initially, the flux value was high and then it became low, and finally, it became constant with the time. The flux unit is l/m^2/h.

3.3. Microfiltration using distilled water

Values of the flux for distilled water were determined experimentally using selected shaft rotational speeds for the peristaltic pump, and the speed values were 1, 5, and 7 rpm. The variations of peristaltic pump rotational shaft speed, suction pressure and flux are shown in Figs. 3–6. Fig. 3 shows that when the peristaltic pump shaft rotational speed was high, the flux value was high too. For pump shaft speed of 1 rpm, the flux was measured at left side of the hollow fibre membrane module after operation time of 10 min and it found to be 0.505 l/m^2/h. For the same operation time (10 min) but for peristaltic pump shaft speed of 5 rpm, the value of flux was increased to 3.625 l/m^2/h. For peristaltic pump shaft rotational speed of 1 rpm and after operation time of 10 min, the value of flux at left side of the membrane module was 0.505 l/m^2/h while the value of the flux at the right side is higher by 7.2% and equal to 0.544 l/m^2/h. For a particular pump shaft

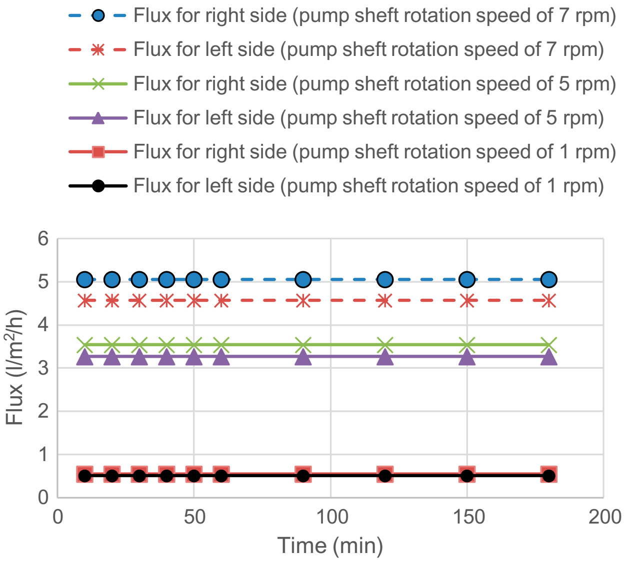

Fig. 3. Flux values at left side and right side of the membrane module for different peristaltic pump shaft rotational speed.

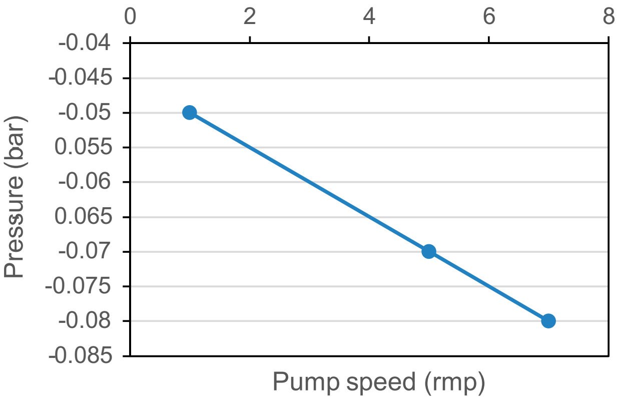

Fig. 4. Variation of pressure with different peristaltic pump shaft rotational speed using distilled water.

rotational speed, the initial and final values of the flux are not changed at left side of the module for 3-h operation time and same result also obtained at the right side of the module. This is because the content of solids in distilled water is almost nil, and therefore, no cake layer formed on the membrane surface. Figs. 4 and 5 show that higher pump shaft rotational speed gives higher suction pressure and higher value of flux. Suction pressure (Fig. 5) increases linearly from 0.05 bar for shaft rotational speed of 1 rpm to 0.08 bar for shaft rotational speed of 7 rpm where values of flux were 0.525 and 4.810 l/m^2/h, respectively. Increase in suction pressure will increase the filtration rate through the membrane surface and this was resulted in a higher flux value (Fig. 6).

3.4. Microfiltration using raw water

Cross-flow microfiltration process for lake water treatment was operated using fixed peristaltic pump rotational speed of 7 rpm. By comparing the performance of left side and right side of the membrane module (Fig. 7), it is found that the flux value for left side is slightly lower than that at the right side. The minimum flux and maximum flux at the left side of the module were 4.146 and 4.664 l/m^2/h, respectively, while the minimum flux and maximum flux at the right side of the module were 4.729 and 4.276 l/m^2/h, respectively.

This is in evidence that flux at the left side of the membrane module is lower than that at the right side. Fig. 8 shows that flux of the module declines with time. According to the fouling theory of microfiltration [10], the decline in flux is attributed to the formation of a dynamic or secondary membrane on the top of primary membrane (hollow fibre membrane). Fig. 9

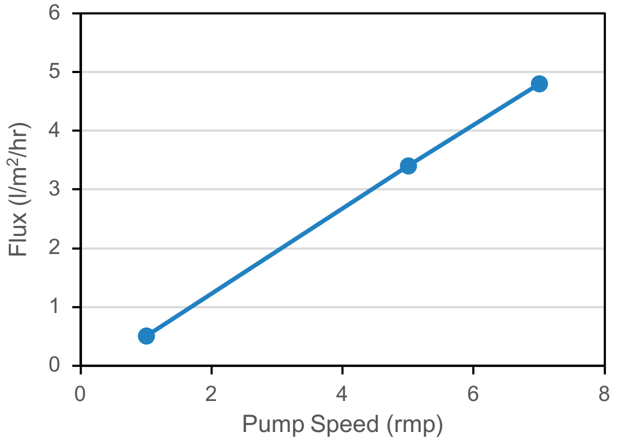

Fig. 5. Variation of flux with peristaltic shaft rotational speed using distilled water.

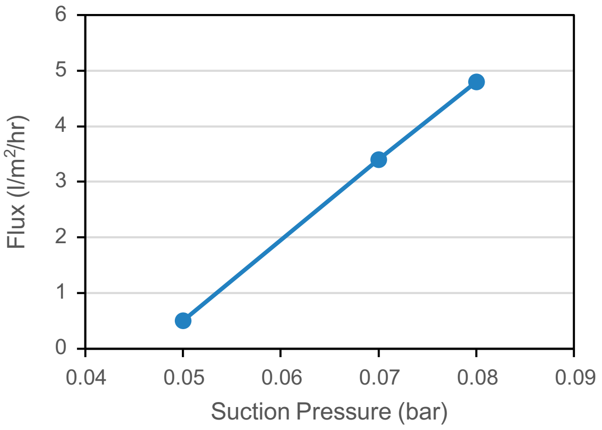

Fig. 6. Variation of flux with the suction pressure.

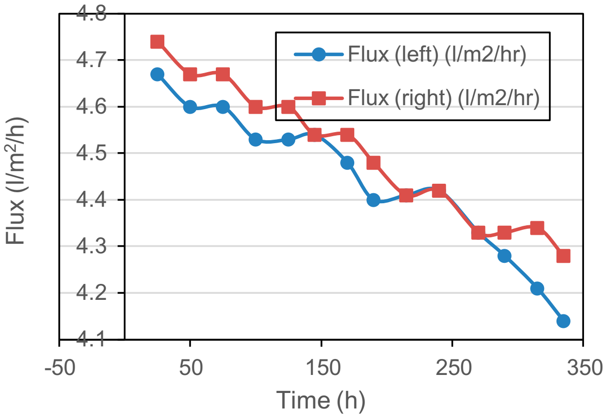

Fig. 7. Variation of flux at left side and that at right side of the membrane module with time using lake water.

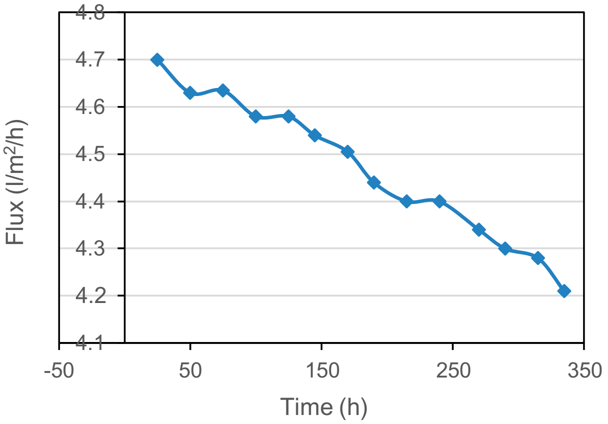

Fig. 8. Variation of flux with time using lake water.

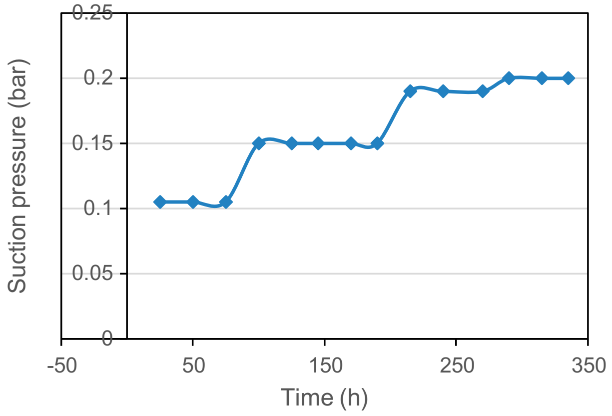

Fig. 9. Variation of suction pressure with time using lake water.

shows that the suction pressure increased gradually with the time. For a starting suction pressure of 0.1 bar, the membrane needs 288 h to reach a suction pressure of 0.2 bar. There was a sudden increase in the suction pressure between 72–96 h and 192–216 h. This is because the turbidity removal during these time intervals was resulted in more deposition of the particles on the membrane surface.

Results from laboratory tests revealed that pH value for lake water was not constant. Fig. 10 shows that the lowest pH value was 6.51 while the highest value was 7.20. The rapid mixing in the storage tank increases the concentration of DO in the water and this resulted in an increase in the pH value. Aeration process increases the concentration of DO in water; thus, high pH values were recorded in the effluent. Therefore, there is a relationship between the pH and DO concentrations in lake water. Besides that aeration can be used as an alternative solution for neutralizing lake water when the acidity of the water is high.

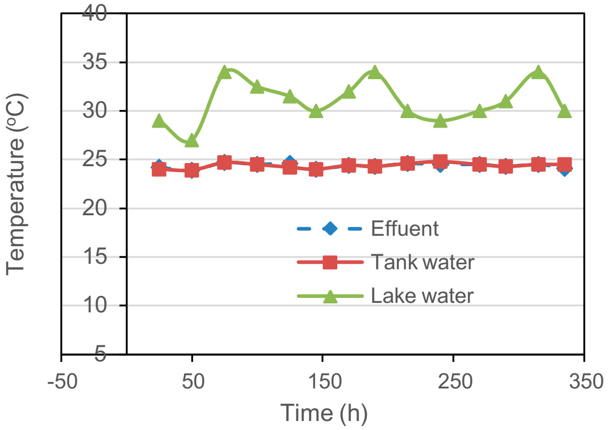

Fig. 11. Variation of temperature with time for lake water.

Fig. 11 shows the variation of temperature with time for lake water, water in the storage tank and effluent. The temperature of the lake water was the highest compared with the temperature of water in storage tank and temperature of the effluent. This is attributed to the fact that lake water is absorbing heat from sunlight and this justifies the high variation in lake water temperature with time. Lake water was pumped to the storage tank which is located inside air-conditioned laboratory and this causes a drop in water temperature. This justifies why the temperature of the water in the storage tank and effluent temperature was almost the same.

Fig. 12 shows the variation in the alkalinity with time for lake water, water in the storage tank and effluent. The lowest value of the alkalinity was found in the lake water compared with the other two. Also,

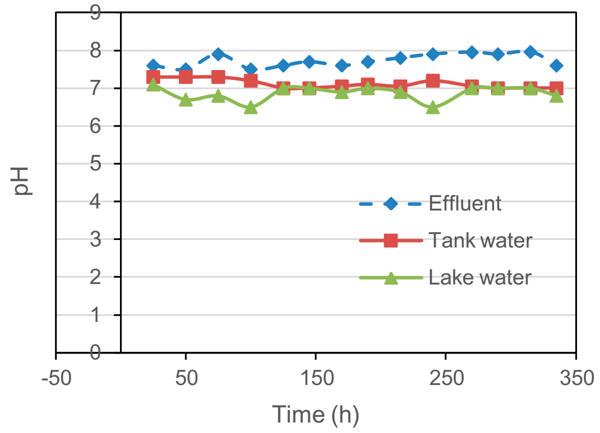

Fig. 10. Variation of pH with time for lake water.

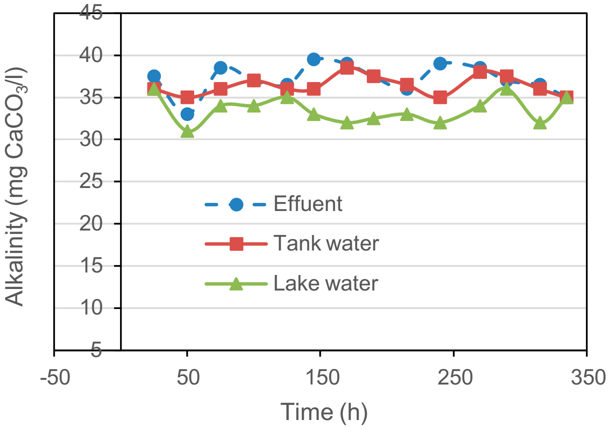

Fig. 12. Variation in the alkalinity with time.

result of the laboratory tests shows that the alkalinity of the above three did not change much and it was in the range of 30–40 mg of CaCo$_3$/l. It is found that there was a relationship between pH and alkalinity of lake water. When the pH of lake water was high, the alkalinity of the water was high too. For lake water, water in storage tank and effluent, the measured values of their pH were within range of 4.5–8.3. Therefore, their alkalinity can be related to the existence of carbonates. Usually, the bicarbonates are converted to carbonates in the above range of pH.

Fig. 13 shows the variation of turbidity with time for lake water, water in the tank and effluent. The turbidity of lake water was generally high, but after the lake water was pumped to the storage tank, some of the suspended solids were settled at the bottom of the tank and this made the turbidity of water in the storage tank to be low.

Fig. 14 shows the variation of colour with time for lake water, water in the tank and effluent. It is shown that the value of measured colour of lake water was higher than the value of the colour for water stored in the tank. Although rapid mixing was continuous in the tank, sedimentation was occurred and this contributed to reduce the value of measured colour for stored water in the tank. The microfiltration using hollow fibre membrane was able to reduce the value of effluent colour to a range of 12–51 Pt-Co.

Fig. 15 shows the variation of TSS with time for lake water, water in storage tank and effluent. The TSS of the water in storage tank was slightly lower than the TSS of lake water, and this is attributed to sedimentation occurred in the storage tank. The variation in TSS of water in the tank follows almost the same trend of TSS variation for lake water. After

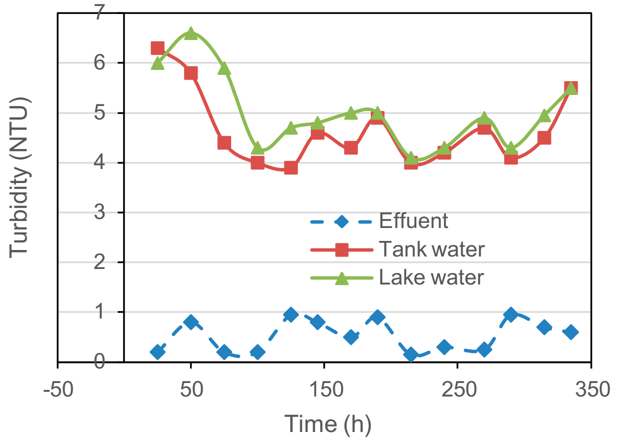

Fig. 13. Variation of turbidity with time for lake water, water in the tank and effluent.

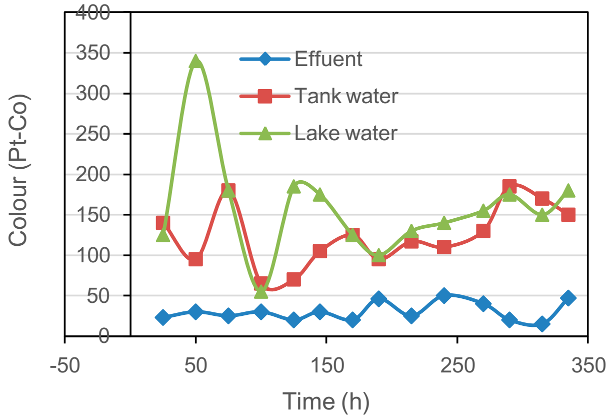

Fig. 14. Variation of colour with time for lake water, water in storage tank and effluent.

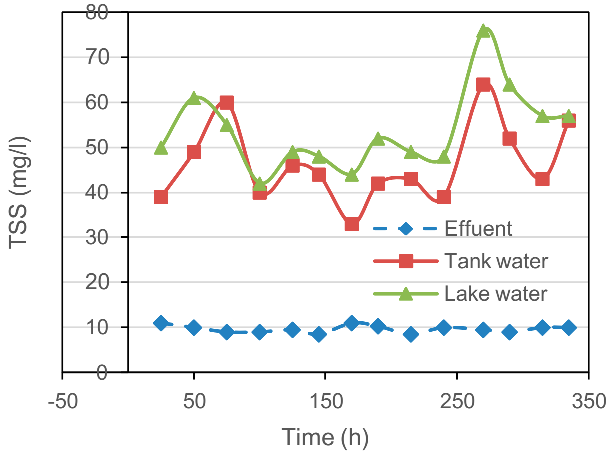

Fig. 15. Variation of TSS with time for lake water, water in the tank and effluent.

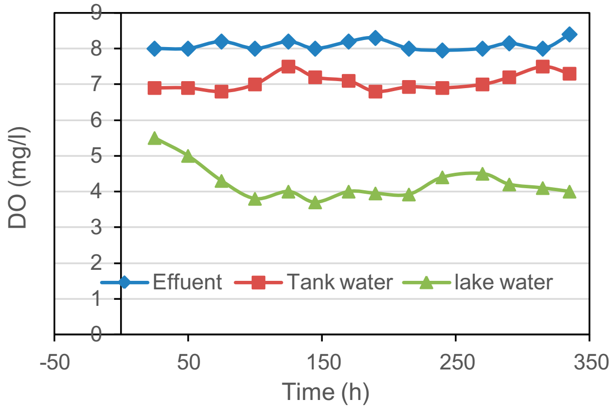

Fig. 16. Variation of DO with time for lake water, water in the tank and effluent.

microfiltration, it is found that the value of TSS was reduced to about 10 mg/l. The TSS and turbidity of water are related to each other.

Fig. 16 shows the variation of DO with time for lake water, water in the tank and effluent. The highest concentration of DO was found in the tested samples obtained from the effluent and this was followed by the concentration of DO in water stored in the tank, while the lowest concentration of DO was found in the lake water. Water in the storage tank was subjected to mixing and this increased the DO concentration in water. Consequently, the filtration tank also provides additional oxygen since the aerator running continuously during period of the experiments and this makes the filtrated water to have the highest concentration of DO compared to the lake water.

Fig. 17 shows the variation of COD with time for lake water, water in the tank and effluent. The concentration of COD in water stored in the tank was lower than COD concentration of water in the lake water. This is because the rapid mixing in storage tank provides more DO which increases the rate of chemical reactions. Fig. 18 shows the variation of COD removal with time. The concentration of COD in the lake water was fluctuating (range of change in COD concentration was found to be 96–160 mg/l) and this made the COD concentration in the effluent fluctuating too. Thus, the microfiltration process is not very effective in removing the COD from lake water and other alternatives such as adding coagulant may be considered to increase the removal.

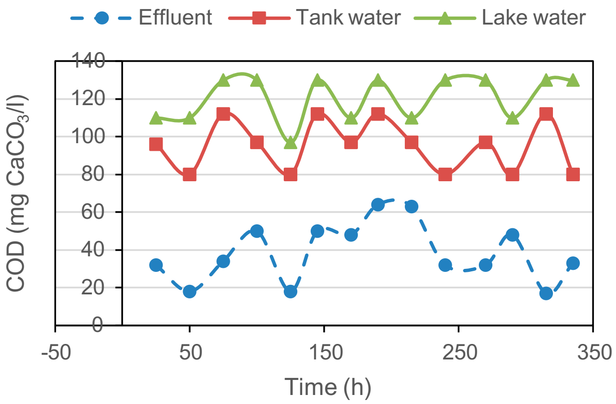

Fig. 17. Variation of COD concentration with time for lake water, water in the tank and lake water.

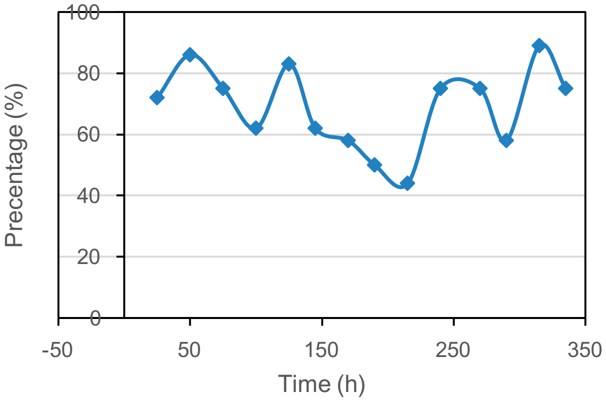

Fig. 18. Variation of percentage removal of COD with time.

3.5. Microfiltration using raw water with ferric chloride

Cross-flow microfiltration process for raw water with ferric chloride was operated using a fixed speed of 7 rpm for the peristaltic pump shaft. Fig. 19 shows the comparison between the flux at the left side of the membrane module and at the right side of the membrane module. Also, it shows that the flux at the left side of the module was lower than that at the right side. The highest and lowest fluxes at the left side of the module were found to be 4.664 and 4.172 $\mathrm{l/m^2/h}$, respectively. While the highest and lowest fluxes at right side of the module were found to be 4.768 and 4.332 $\mathrm{l/m^2/h}$, respectively. Fig. 19 shows that the slope for flux at the left side of the module was more constant compared with the slope of the flux at the right side of the module. So, the flux at left side of the module was more stable than the flux at the right side of the module and became more constant between 240 and 336 h.

The variation of the pressure with time is shown in Fig. 20. The pressure was found to be 0.09 bar at

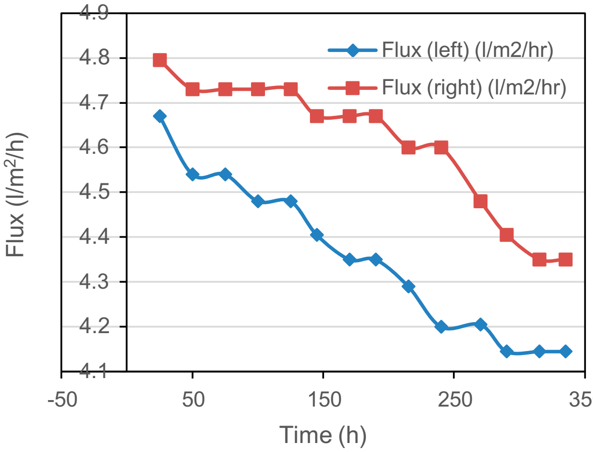

Fig. 19. Variation of the flux at the left and right sides of the module using lake water with ferric chloride.

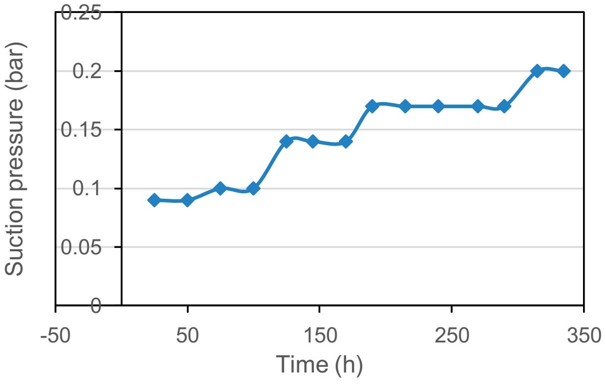

Fig. 20. Variation of suction pressure with time for lake mixed with ferric chloride.

24 h but it increased to 0.20 bar after 336 h. This is because the area of the membrane is large, and the formation rate of the cake layer on the membrane surface was slow. It was observed that there was a sudden increase in the suction pressure on the time interval between 96 and 120 h and also another increase on the time interval between 168 and 192 h. This is because the turbidity was increased between these time intervals, and as a result, more particles deposited on the membrane surface.

Fig. 21 shows the variation of the flux obtained from the microfiltration module with time. The feed water to the hollow fibre membrane module was pumped from the lake to the storage tank and mixed with ferric chloride as a coagulant. Data presented in Fig. 21 show that the flux declined with time. According to the fouling theory of microfiltration, the decline in flux is attributed to the formation of a dynamic or secondary membrane on the top of the primary membrane (hollow fibre membrane).

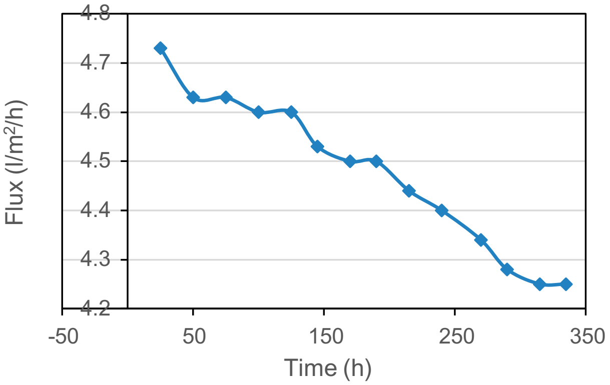

Fig. 21. Variation membrane flux with time using water in the storage tank mixed with ferric chloride.

Fig. 22 shows the variation of pH with time for the lake water, water in the tank mixed with ferric chloride and effluent. Generally, it is observed that the values of pH for both effluent and water in the tank mixed with ferric chloride were lower than the pH values of the lake water. The main reason which made the pH of the water in the storage tank lower than that of the lake water was the acidic action of ferric chloride added to the water as a coagulant. However, aeration used with the microfiltration process made the effluent pH different from the pH of the lake water and the pH of the water in the storage tank.

The temperature of water is a very important parameter because it affects the chemical reactions, reaction rate and environment of the aquatic life and suitability of the water usage. Factors such as weather and room condition affect water temperature. As shown in Fig. 23, the temperature of the lake water was the highest and it was followed by the

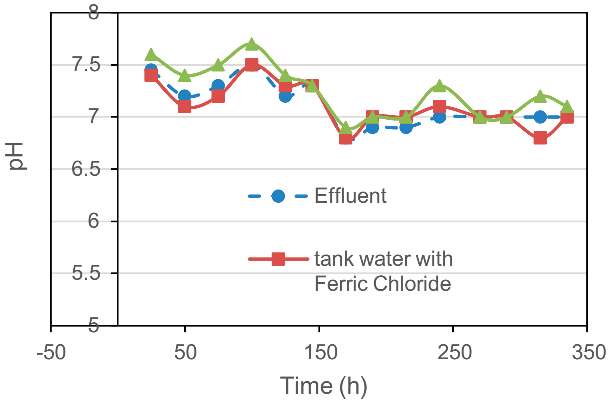

Fig. 22. Variation of the pH with time for lake water, water in the tank mixed with ferric chloride and effluent.

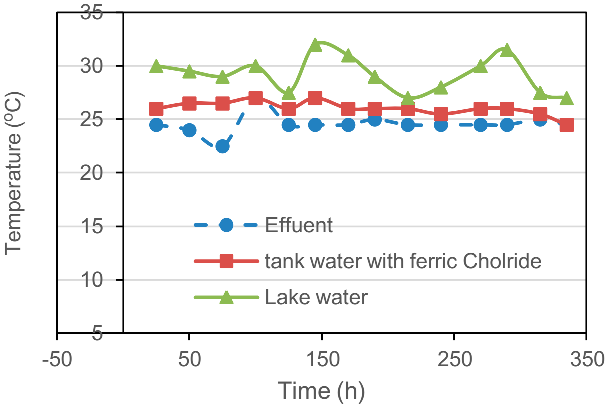

Fig. 23. Variation of temperature with time for lake water, water in the tank mixed with ferric chloride and effluent.

temperature of the water in the tank mixed with ferric chloride while the temperature of the effluent was the lowest one. The temperature of the lake water depends on the weather, and it is affected by the surrounding environment. Thus, the variation in the temperature of the lake water is high. The temperature in the laboratory was affected by the air conditioning; therefore, the temperature of the effluent and the temperature of the water in the tank mixed with ferric chloride were consistent and found to be lower than the temperature of the lake water.

Alkalinity of water is a measure of its capacity to neutralize acids, in other words, to absorb hydrogen ions without a significant change in pH. Fig. 24 shows the variation of the alkalinity of the lake water, water in the tank mixed with ferric chloride and effluent. The alkalinity of the lake water was the highest among the other two (water in the tank mixed with ferric chloride and the effluent). However, alkalinity of the effluent was lower than the alkalinity of both the lake water and the water in the tank mixed with ferric chloride. It is found that there is a relationship between the pH and alkalinity of water in the tank mixed with ferric chloride. The ferric chloride lowers the pH of the water in the storage tank and this contributes to lower its alkalinity.

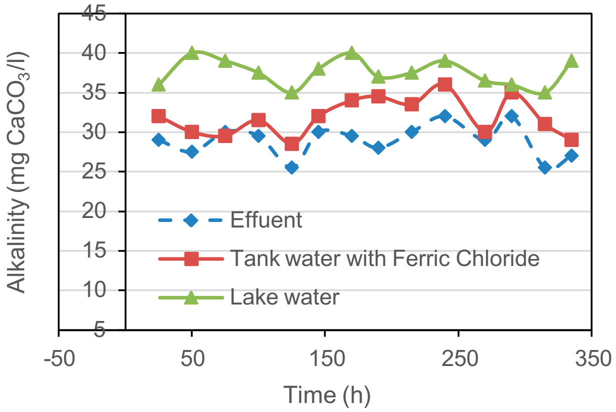

Fig. 24. Variation of alkalinity with time for lake water, water in the tank mixed with ferric chloride and effluent.

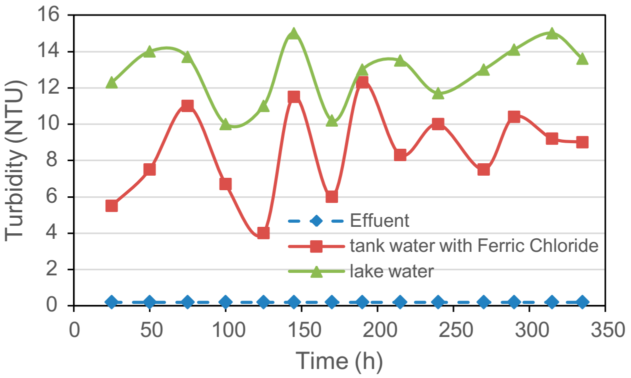

Fig. 25. Variation of turbidity with time for lake water, water in the tank mixed with ferric chloride and effluent.

Fig. 25 shows that the variation of turbidity with time for the lake water, the water in the tank mixed with ferric chloride and effluent. It is found that the turbidity of the lake water was high and this is attributed to the fact that the lake water is affected by the quality of the run-off discharged to the lake. For this reason, coagulation using ferric chloride did not result in constant turbidity values. After the microfiltration process, the turbidity of the effluent was almost constant. The percentage removal of turbidity from the lake water was 98% as shown in Fig. 26. This proves that microfiltration together with the use of ferric chloride in the coagulant is efficient in removing the turbidity of the lake water.

Data from laboratory tests show that the variation of colour for water in the tank mixed with ferric chloride is affected by the colour of lake water. After ferric chloride was added to the water in storage tank, the colour of the water became brownish. The hollow fibre membrane is able to reduce water colour, so the effluent colour was much lower than the colour of the feed water. Besides, the hollow fibre membrane is also able to reduce the quantity of suspended solids including removal of ferric ions in the treated water and this made the colour of effluent low after treatment. Fig. 27 shows that after 168 h, the colour of the effluent becomes almost constant and further reduced after 288 h, so the microfiltration process required more time to produce treated water with minimum colour.

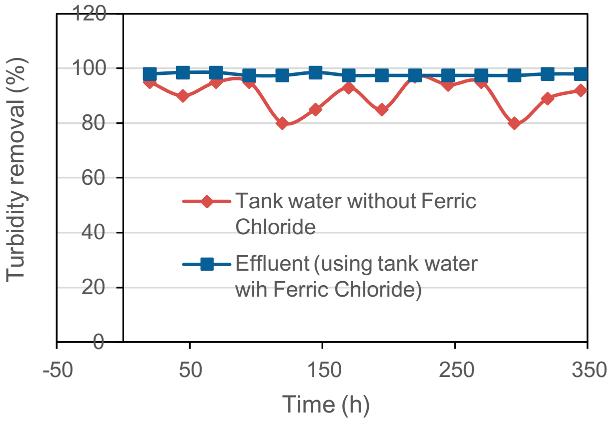

Fig. 26. Variation of turbidity removal with time.

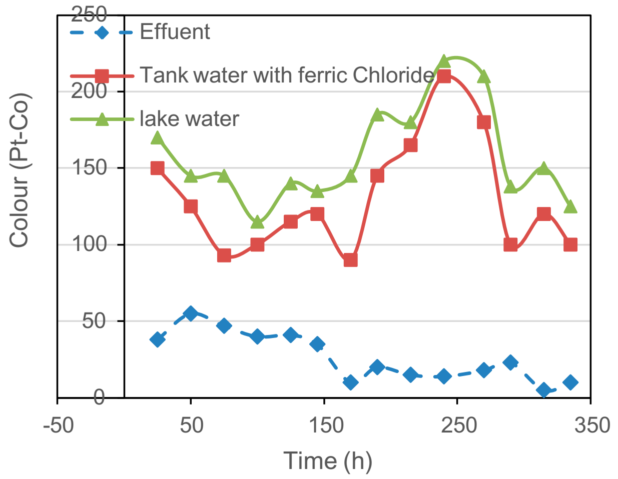

Fig. 27. Variation of colour with time for lake water, water in the tank mixed with ferric chloride and effluent.

Suspended solids in water may consist of inorganic particles or immiscible liquids and it commonly related to turbidity. So, high concentration of suspended solids in water results in high turbidity. Fig. 28 shows that the TSS concentration in the lake water was within the range of 60–75 mg/l. Laboratory tests showed that the variation in turbidity, pH and TSS of lake water was high. Therefore, coagulation by mixing ferric chloride with the water in storage tank was found not that effective in removing colloidal particles and reducing the concentration of TSS to lower than 10 mg/l. But the concentration of TSS in the storage tank without adding ferric chloride (coagulant) was higher compared with the TSS concentration when ferric chloride (coagulant) was added. This can be related to the fact that mixing ferric chloride with water in the storage tank was resulted in sedimentation of larger formed flocs and this made its concentration lower. The microfiltration process was efficient in removing residue in the storage tank since TSS of the effluent was reduced to the acceptable level (lower than 10 mg/l), and it was noticed that the removal of TSS became stable after 48 h.

DO is important because the end products of chemical and biochemical reactions in an anaerobic system often produces aesthetically displeasing colour, tastes and odours in water. The quantity of DO depends on reactions, atmospheric pressure, temperature, depth and dissolved salt in water. When DO concentration drops below the equilibrium value, the net movement of oxygen will be from atmosphere into the water and this is called reaeration. The difference between the equilibrium concentration and the actual concentration is called the DO deficit and it is described mathematically by:

$$D = C_s - C \tag{1}$$

where D is the DO deficit, C_s is the equilibrium concentration and C is the actual concentration.

Fig. 29 shows the variation of DO concentration with time for lake water, water in the tank mixed with ferric chloride and effluent. Rapid mixing and aeration increase DO concentration in water. Laboratory tests showed that the lake water had the lowest DO concentration while the DO concentration in the storage tank with mixing and adding ferric chloride was higher. Finally, the highest DO concentration was found in the effluent. This confirms that the aeration used with microfiltration added more DO to water compared to the rapid mixing used in the storage tank.

Fig. 30 shows that lowest DO deficit was found in the effluent than in the storage tank when the stored water mixed with ferric chloride while the lake water was found with maximum DO deficit. DO concentration in

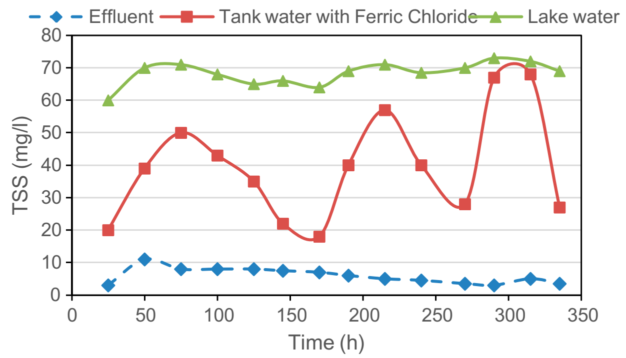

Fig. 28. Variation of TSS with time for lake water, water in the tank mixed with ferric chloride and effluent.

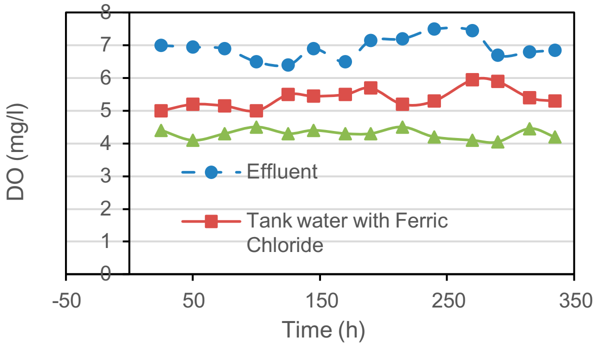

Fig. 29. Variation of DO concentration with time for lake water, water in tank mixed with ferric chloride and effluent.

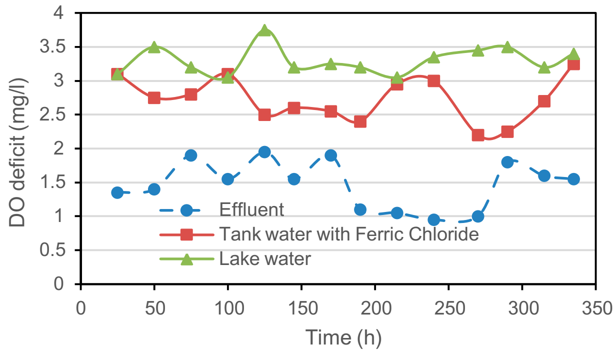

Fig. 30. Variation of DO deficit with time for lake water, water mixed with ferric chloride and effluent.

the lake water was found to be below saturated level, but rapid mixing and aeration increased the DO concentrations and made it close to the equilibrium concentration. The DO deficit is roughly calculated because it is difficult to determine the exact equilibrium DO concentration for a particular temperature.

COD is widely used to characterize the organic strength of wastewaters and pollution of natural waters. The test measures the amount of oxygen required for chemical oxidation of organic matter in a water sample. The variation of COD with time for lake water, water in the tank and effluent is shown in Fig. 31. The concentration of COD for the lake water was varied from 95 to 160 mg/l, and it showed that the lake water was slightly polluted. When the lake water was stored in the tank and mixed with ferric chloride, the COD concentration became 80–144 mg/l after 48 h. But the COD concentration reduced between 32 and 64 mg/l after the microfiltration process. This shows that coagulation and microfiltration processes are able to reduce the concentration of COD in lake water. Fig. 32 shows the variation in percentage reduction of COD with time for the water mixed with ferric chloride while Fig. 33 shows the variation in percentage reduction of COD with time for both lake water and water in the tank mixed with ferric chloride.

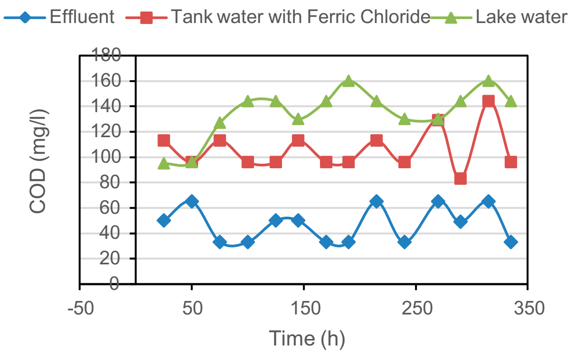

Fig. 31. Variation of COD concentration with time for lake water, water mixed with ferric chloride and effluent.

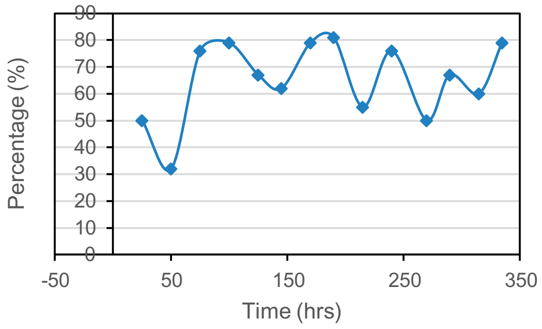

Fig. 32. Percentage reduction of COD with time for water in the tank mixed with ferric chloride.

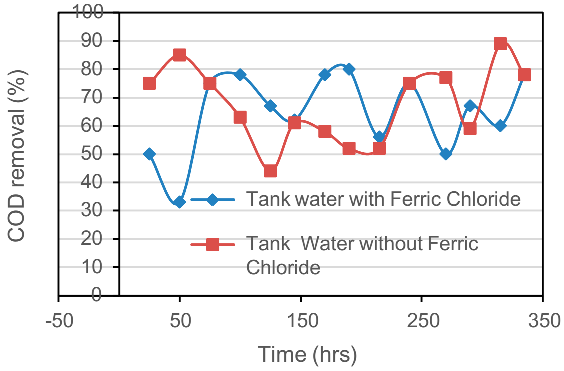

Fig. 33. Percentage reduction of COD for lake water and water in the tank mixed with ferric chloride.

3.6. *Testing the effectiveness of alum and ferric chloride as coagulants*

Fig. 34 shows the reduction of TSS in lake water mixed with alum as a coagulant. The reduction in TSS is slightly higher when the alum was used compared with using ferric chloride. The percentage reduction in TSS is found between 71.7 and 91.6% when alum was used as a coagulant while the percentage reduction in TSS was found between 74.4 and 89.2% when ferric chloride was used. This is because the formation of flocs using alum as coagulation is higher compared with the formation of flocs using ferric chloride as a coagulant. But from cost and health point of view, ferric chloride is recommended since optimum required dosage is found to be 4 mg/l while the dosage of alum needed was found fivefold and equal to 20 mg/l. Furthermore, ferric chloride can be used in

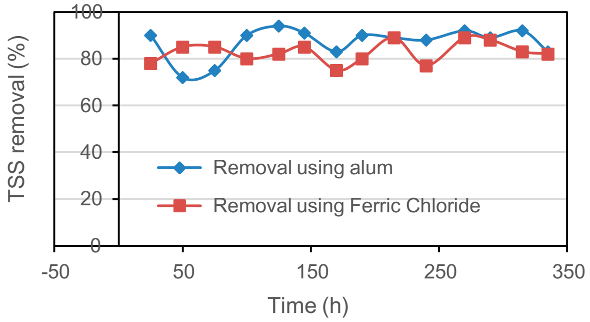

Fig. 34. TSS reduction using alum and ferric chloride.

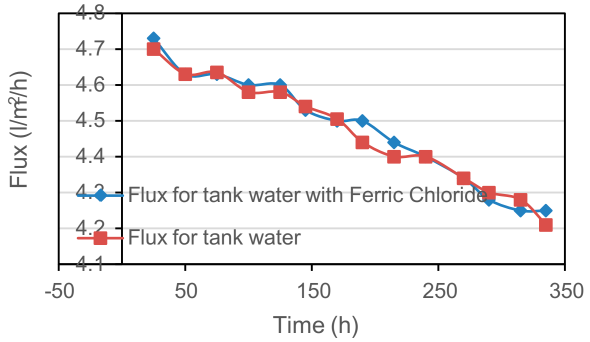

Fig. 35. Comparison between the flux obtained from treated lake with and without using ferric chloride as a coagulant.

wide range of pH while the alum is only effective when the pH value is equal to 7.

3.7. Comparison between flux of treated lake with and without using ferric chloride

Fig. 35 shows that the flux obtained from treating the lake water without using any coagulant is slightly lower than the flux obtained from using 4 mg/l of ferric chloride as a coagulant. This can be attributed to the formation of larger flocs during the coagulation process which resulted in clogging the membrane pores and reduce both membrane effective area and the flux.

4. Conclusions

In this study, coagulation (using ferric chloride) combined with microfiltration was used to treat lake water pumped from a lake located at the Faculty of Engineering, Universiti Putra Malaysia. From jar test, the optimum coagulation dosage using ferric chloride was found to be 4 mg/l. It is found that pH value of the water samples decreased after coagulation. This is attributed to acidic affect of the ferric chloride. The pH value of the lake water before coagulation was found to be 7.8, and it became 6.4 after coagulation (reduced by about 22%). Also, the alkalinity of the effluent was dropped, and the range of alkalinity for the samples taken from the effluent was found to be 25–40 mg/l. On average, the turbidity removal by microfiltration without coagulation was 88% but the removal was increased to 98% when combined microfiltration and coagulation was used. Almost same results were obtained for TSS removal. Due to aeration, the concentration of DO in the effluent ranges from 4.3 to 8.2 mg/l. The removal of COD was found almost the same with and without using ferric chloride as coagulant, and the removal ranges from 43 to 88%. The percentage removal of TSS using alum and ferric chloride was found almost the same and only 3% increment in the removal of TSS was observed when alum is used as a coagulant. This confirms the effectiveness of using ferric chloride as a coagulant compared with alum. Furthermore, ferric chloride can be used in wide range of pH while alum is only effective when the pH value equal to 7.

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