Pilot Scale Investigation of Microfiltration Performance and Reuse Potential for Water and Wastewater

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Abstract

Membrane filtration is currently gaining popularity in water and wastewater reuse applications. Several studies have been carried out using lab scale experiments, which provided short-term data and limited practical information for membrane applications. Hence, this study was conducted in a pilot-scale unit using a 0.1 μm hollow fiber microfiltration membrane. Three different types of feed water– surface water, surface water with added kaolin clay and treated wastewater– were used in order to investigate the long-term stability effect and the reliability of each feed water for direct reuse applications. The results showed that inorganic fouling or suspended solids such as clay have less effect on the stability of membrane filtration. Therefore, for microfiltration, inorganic matter is not the major fouling agents, which mechanical cleaning or backwashing could be used successfully for fouling control. Organic fouling is the significant cause for reducing flux, which is the limiting factor for microfiltration. Proper pretreatment is needed for the feed water, which contains a high amount of organic contents. In all experimental runs high quality filtrate was obtained and it did not depend on the feed water quality. Turbidity and total organic carbon (TOC) could be maintained for all kinds of feed water at 0.04-0.45 NTU and 3.8-10.6 ppm respectively. This would be reliable and satisfactory water quality requirement for reuse.

Key words: microfiltration (MF); membrane flux; transmembrane pressure (TMP); water reuse

INTRODUCTION

Asian industrialization has caused rapid population growth and urbanization, leading to increasing demand for potable water, which consequently increases the volume of wastewater generated. The reuse of wastewater is a way offers one possible sustainable and economical solution to the problem. Reuse of wastewater will produce economic benefits because of the reduction in the cost of potable water and the cost of sewage disposal charges. Moreover, pollution in receiving bodies will be abated. Between 60 and 80 percent of industrial water demand is for cooling processes, and this does not require water quality to be as high as that of domestic water supply (Visvanathan and Cippe, 2000). This represents a real potential for reuse and recycling of treated wastewater.

The conventional approach to accomplishing the reuse of wastewater is by treatment schemes such as multimedia filtration, carbon adsorption and ozonation. However, these conventional technologies face certain difficulties, such as the cost of chemicals, space requirement, operational problems, unstable water quality produced due to load fluctuations, etc. (Parameshwaran and Visvanathan, 1998). Therefore an effective way to reuse wastewater needs to be developed.

Membrane filtration is one of the techniques used for the solid-liquid separation and is currently gaining popularity in water and wastewater reuse. Christensen *et al.* (1981) found that ultrafiltration has a significant potential for domestic and industrial water reuse. Bhattacharya *et al.* (1978) showed that the recycled ultrafiltrate from laundry and shower wastewater could be used as non-potable water. Adham *et al.* (1996) illustrated that lower membrane costs, simplicity of operation, and development of higher flux membranes with low fouling potentials have made possible a multitude of applications for this technology. These indicate that membrane filtration has high potential for water and wastewater reuse both in terms of technical and economical feasibility.

Currently, most membrane research has involved lab-scale experiments. Cartwright (1994) has recommended that the pilot unit should be operated on the side stream for at least 30 days. This length of time was necessary to provide sufficient information for membrane stability, long-term membrane fouling and data for engineering scale-up. Therefore, this research was run as a pilot-scale experiment for long-term operation to study the stability effect of the system and to investigate the reliability of the permeate water quality for reuse from different types of feed waters.

MATERIALS AND METHODS

Feed Water

This experimental research was divided into two phases. Three different types of feed water were used. The first phase of the research focused on water reuse, where the feed water used came from the Asian Institute of Technology (AIT) canal, which is a part of the general canal system of Thailand. The water quality in the canal depends very much on the rainfall pattern. During the peak rainy season, extremely turbid water is expected in these canals. Therefore the experiments were also conducted with higher particle concentration by adding kaolin clay to study the effect of particle concentration on feed water. The second phase addressed wastewater reuse, in which AIT-treated wastewater was used as feed water to investigate the potential for wastewater reuse. Table 1 shows the characteristics of this feed water. Kaolin clay was added to the surface water, which generated 40-90 NTU of turbidity and 30-110 mg/L of suspended solids.

Table 1. Feed Water Characteristics

Parameter	Unit	Surface Water	Treated Wastewater
1. pH	-	7.8-8.2	8.1-8.4
2. Temperature	°C	28-30	30-31.5
3. Turbidity	NTU	3-25	16-25
4. TSS	mg/L	15-20	20-45
5. Color	Pt-Co	3-5	8-20
6. COD	mg/L	15-50	70-135
7. BOD	mg/L	<6	20-40
8. TOC	mg/L	4.1-7.7	18-27
9. Hardness	mg/L	80-100	110-130
10. Chlorophyll a	μg/L	10-12	80-135
11. Fe	mg/L	0.02-0.09	0.02-0.13
12. Mn	mg/L	0.07-0.15	0.09-0.23
13. Fecal Coliform	CFU/ml	15	8

Experimental Set-Up

Figure 1 shows the schematic diagram of the pilot-scale experimental set-up. This system consisted of feed water, pre-filter, feed tank, microfiltration membrane module, chlorine tank, back wash tank, air compressor, PVC ball valve, diaphragm valve, feed pump and back wash pump. The system was automatically controlled by a programmable logic controller (PLC). The pre-filter used for this pilot unit was a disk pre-filter with 200 μm pore size.

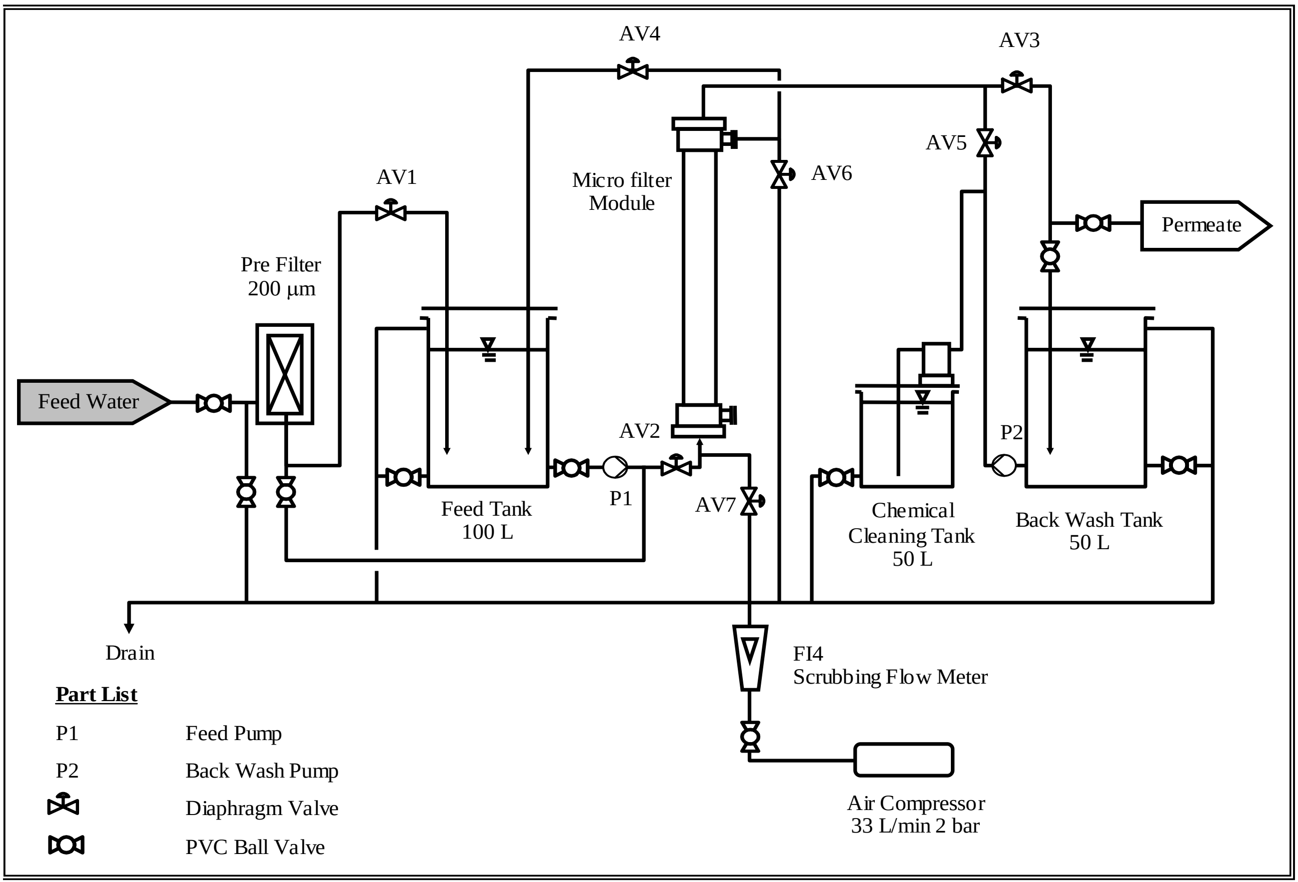

Fig1. Schematic diagram of pilot-scale experiment

Membrane Module and Operation

A hollow-fiber microfiltration outside-in configuration made of a polyvinylidene fluoride (PVDF) module was used in this study. The microfiltration membrane (Microza MF USV-3003 module, manufactured by Asahi Chemical Industry Co., Ltd in Japan) had average pore sizes of 0.1 µm and surface area of 7 m^2, enabling efficient and precise separation and removal of suspended substances, colloids and bacteria from the feed water. Filtration time, backwashing time and flushing time were set for 30 min, 30 seconds and 30 seconds respectively.

Membrane backwashing was conducted with permeate water with 3 ppm of NaClO, combined with air scrubbing. The feed flow rate was fixed for 1,500 L/h, while the constant permeate flux was obtained at three different rates of 480 L/h, 600 L/h and 720 L/h. Each experiment was stopped when the feed pressure level reached 1.5-2.0 kg/cm^2, at which level chemical cleaning was required.

RESULTS AND DISCUSSION

Effect of Feed Water Type

Two types of experiments were used to compare the effect of feed water type. The first experiment studied long-term effects; the results are shown in Fig 2. The running time for treated wastewater was 45 h, which was less than that for both surface water and surface water with added kaolin clay. The surface water was low in suspended solids (3-20 mg/L of TSS) and organic content (15-50 mg/L of COD). The membrane system at 600 L/h or 86 L/h.m^2 permeate flux could be run for 210 hours, at which point feed pressure reached 28 psi, after which chemical cleaning was required. The second run was surface water with added kaolin clay, the TSS of which was within the range 50-110 mg/L, while the organic content was the same as that of the surface water. The membrane system could be run for 130 hours. The third run was the treated wastewater, which had high organic content (80-120 mg/L of COD), and TSS was 30-45 mg/L. Feed pressure of the treated wastewater increased quickly, and the system could be run for only 45 hours. These results show that fouling by organic matter is a more significant issue for microfiltration systems than suspended solids or inorganic content such as clay. Therefore, proper pretreatment is needed for the feed water that contains high amounts of organic content.

The second experiment was short-term investigation, measuring permeate flow reduction with time in a cycle of filtration. Three types of feed water were compared in order to study how flux declined for each feed-water. As shown in Fig 3, only a small difference (17-25 %) in flow reduction was found in surface water and surface water with added Kaolin clay, but a big difference (58 %) was observed in the treated wastewater. The possible explanation was that surface water with added Kaolin clay had higher suspended solids than surface water alone, but organic matters were the same. So that kaolin clay possibly caused particle or inorganic fouling, in which the particle size was in the range of 0.1-4.0 µm, while membrane unit pore size is 0.1 µm. Therefore, there was a small difference in flow reduction for surface water and surface water with added Kaolin clay because of lesser amount of internal clogging or adsorptive fouling. The treated wastewater was high in both organic matter and suspended solids, which means that the potential for cake formation and

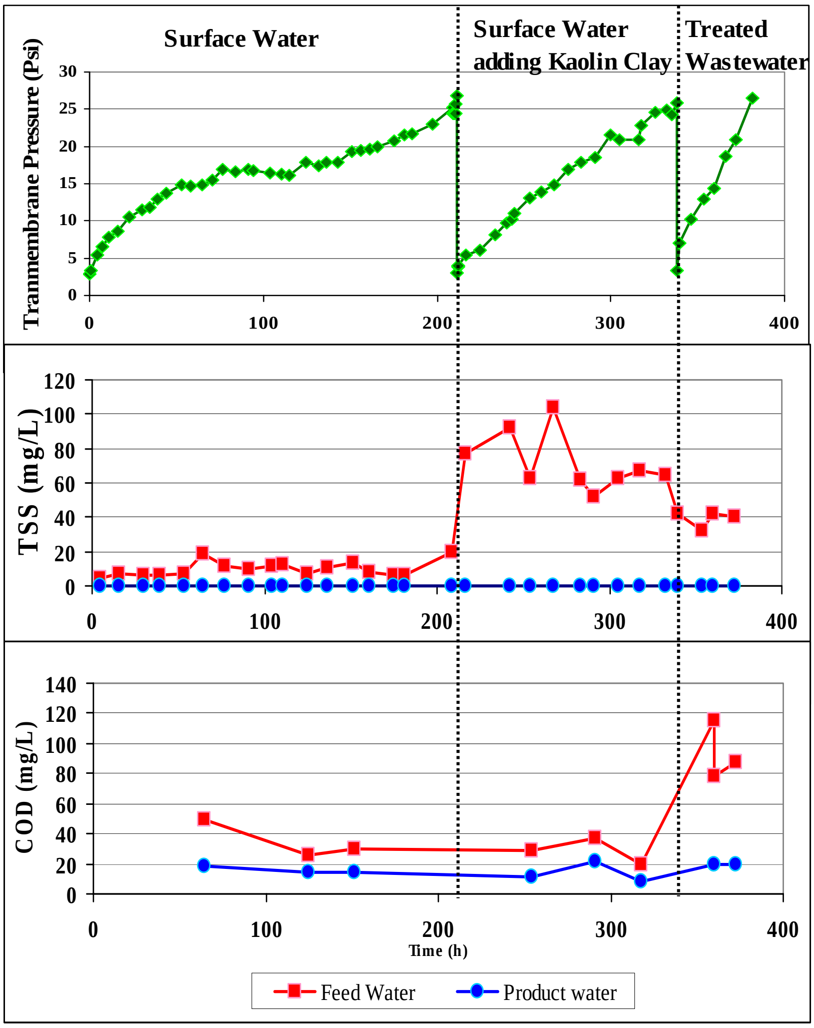

Fig 2. Effect of feed water type on long term running, initial permeate flux = 86 L/h.m^2 or 600 L/h

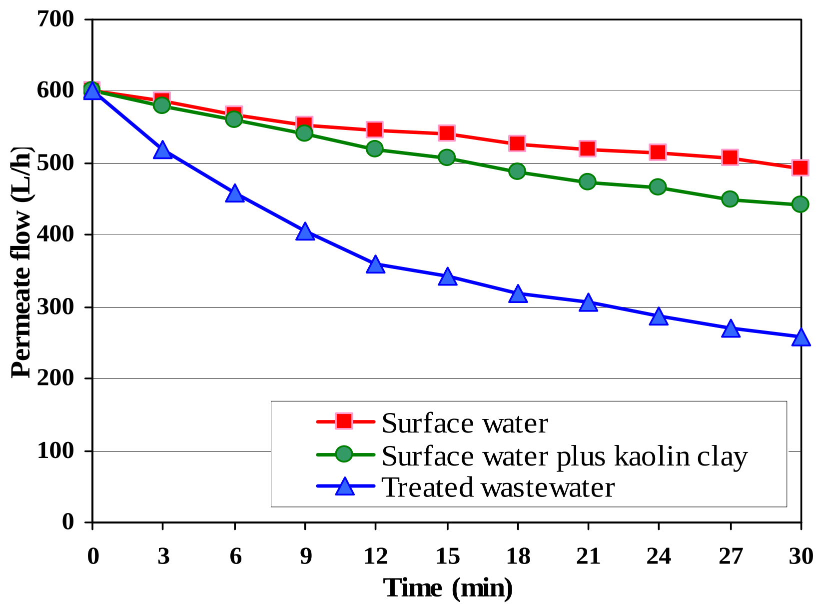

Fig 3. Permeate flow reduction in a filtration cycle for three feed water types at 600 L/h of initial permeate flow

adsorptive fouling is high. Therefore, the flow reduction in the filtration cycle of treated wastewater is the highest. These results show that for the treated wastewater, a shorter filtration time is required before the periodic backflushing in order to prolong running hours. Hence, backflushing or mechanical cleaning and filtration time are significant factors for membrane stability, for which the experimental results are shown in the following sections.

Fouling and Mechanical Cleaning Effect

In order to identify the air scrubbing rate for better mechanical cleaning effects, the experimental runs were conducted at different feed rates and air scrubbing rates. Figure 4 shows that when air scrubbing was 1,000 L/h at 0.35 bar, the feed pressure increased rapidly, and reached 26 psi at 180 hours. While using 1,600 L/h or 0.75 bar of air scrubbing, the feed pressure was gradually increased and reached 26 psi after 470 hours or 19 days. The system could be improved more than 160 % when air scrubbing was increased from 1,000 L/h to 1,600 L/h. It shows that for this kind of water, which was high in suspended materials but low in organic contents, just a simple pretreatment such as a disk pre-filter and proper mechanical cleaning condition was good enough to prolong the running of the system for the feed water.

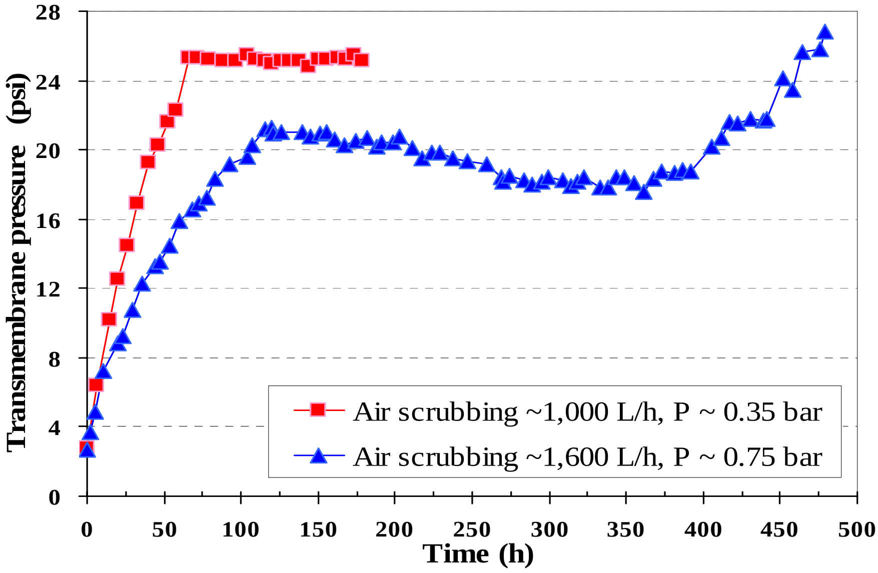

Fig 4. Air scrubbing effect on surface water at 480 L/h of initial permeate flow

To investigate the effect of mechanical cleaning on fouling by organic and inorganic matter, surface water with added kaolin clay and treated wastewater were used. Both feed types were run at an air scrubbing flow rate of 2,000 L/h, or 1.5 bar pressure, and were compared with surface water at 1,600 L/h of air scrubbing or 0.75 bar pressure. Figure 5 shows that even with the high levels of suspended solid in the surface water with added kaolin clay running; the system could be prolonged just by increasing the air scrubbing volume. However, for treated wastewater with high organic content, the system could not be run as long as others, even by using higher air scrubbing. It seems that suspended solids are not the major cause of fouling, and could be successfully

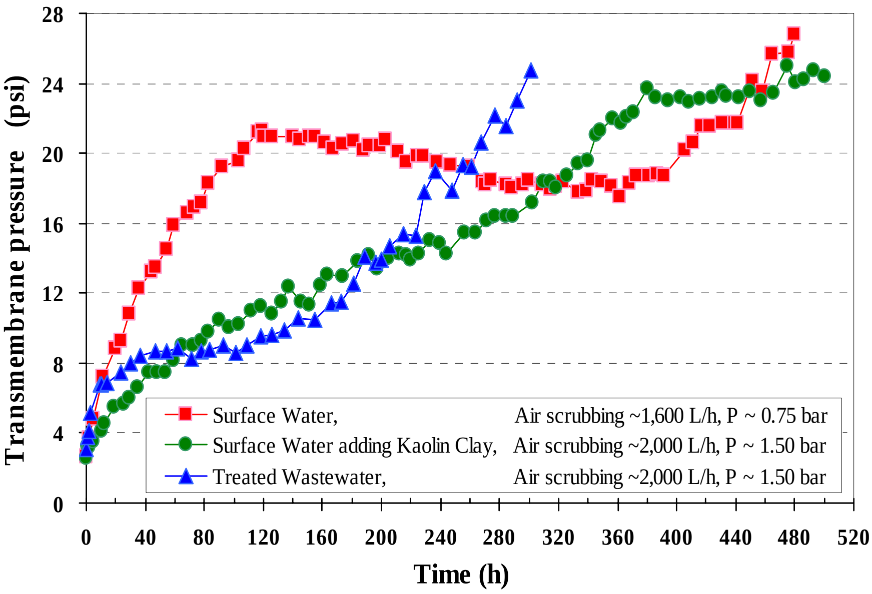

Fig 5. Air scrubbing effect on different feed water

controlled using mechanical cleaning or backwashing.

Long-term Stability

During the filtration process, the concentration of foulant materials accumulated on the membrane surface decreases the permeate flow decreases. For maintaining the permeate flow constant, adjustment of the valves was required. In these experiments, differences in transmembrane pressure before and after backwashing step were investigated. Recordings of TMP were taken every six hours by adjusting the valves to maintain constant permeate flow before and after backwashing. To prevent membrane failure, this microfiltration pilot unit was automatically cut off when the feed pressure was equal to or higher than 28 psi. Figure 6 depicts the TMP levels initially rising in a ‘zig-zag’ curve. This is because when the feed pressure was less than 28 psi, the valve could be adjusted for maintaining constant permeate flow and recording the pressure before and after backwashing. In case that the constant permeate flow could not be controlled before backwashing by manually adjusting valves, only transmembrane pressure after backwashing was measured.

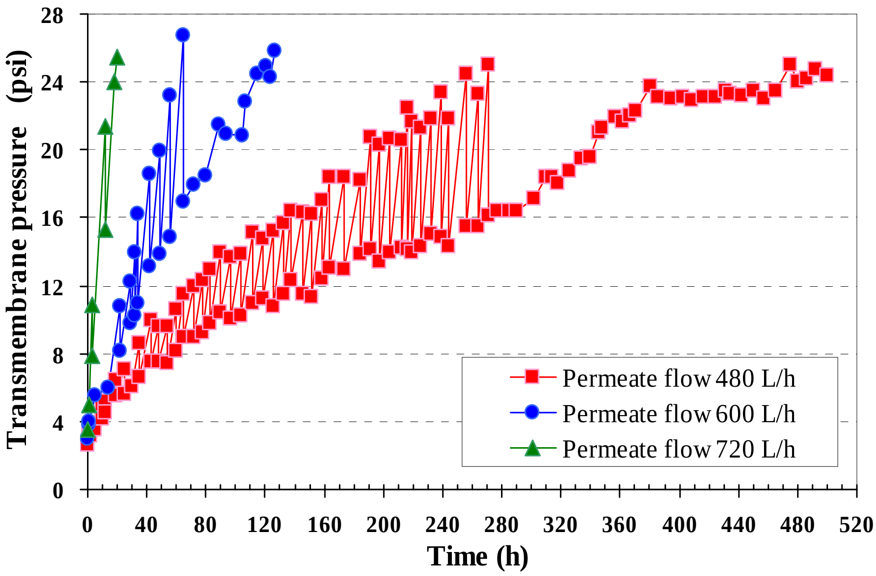

Fig 6. Long-term stability in various permeate flow for surface water with added Kaolin clay

This shows that the difference of TMP before and after backwashing increased with time in all the permeate flow rates. This is because some of the fouling material could not be removed completely from the membrane by backwashing and accumulation over a period of time, caused increasing transmembrane pressure over time. At a certain TMP value, (28 psi for this system) chemical cleaning was required.

Even the system was run with high amount of particle materials in surface water with added kaolin clay, the stability of this system is quite effective. It could be run for 500.5 h or 21 days at a permeate flow of 480 L/h or 70 L/h.m^2. The running hours reduced sharply to 127 and 19.5 h when permeate flows were 600 L/h and 720 L/h respectively. The results showed that higher water production by increasing permeate flux is not a realistic alternative because of the high pressure driven through the membrane and high fouling occurring as the critical flux concept.

For the treated wastewater, there was a rapid decrease in permeate flow when compared to surface water and surface water with added Kaolin clay. The treated wastewater is high in both organic matters and suspended solids, which leads to high levels of fouling, and rapid flow reduction. In addition, inappropriate processes such as longer filtration time and smaller volume of air scrubbing could increase the likelihood of mechanical and chemical fouling. Therefore, different filtration time experiments were conducted to investigate the effect of filtration time. As presented in Fig 7, the initial TMP was almost the same in both experiments. For a permeate flow of 600 L/h, with running times of 15 minutes and 30 minutes, the filtration times were 48.5 hours and 74 hours respectively. Running times improved when the filtration time was reduced from 30 minutes to 15 minutes, at which time the improved percentage of 600 L/h permeate flow was 70.1 %. These show that long term stability of membrane system did not depend on only permeate flow but also filtration time.

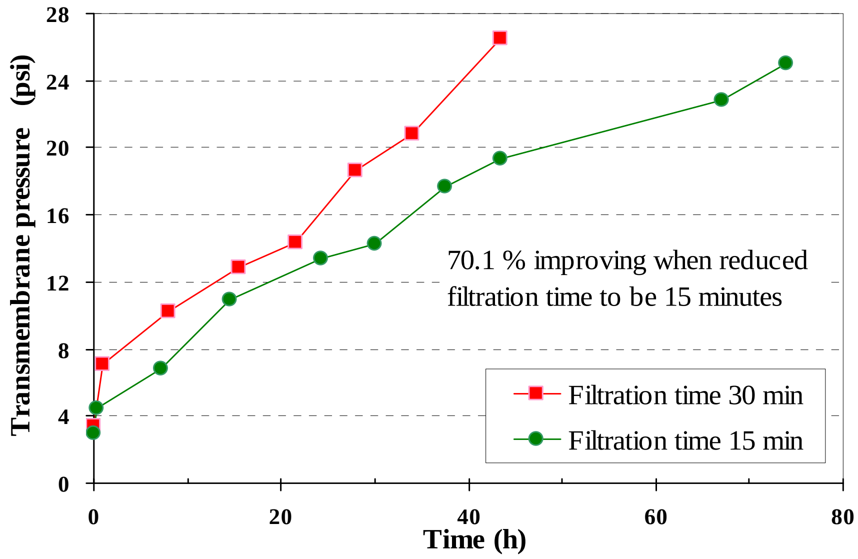

Fig 7. Long-term investigation of variation in filtration times for treated wastewater at the permeate flow rate at 600 L/h

Reliability of Water Quality

The long-term reliability of the system was evaluated for use of all types of feed water. High permeate water quality could be obtained the reliability of which does not depend on feed water quality for this system. Surface water turbidity and suspended solid varied between 3-25 NTU and 15-20 mg/L respectively. For surface water with added Kaolin clay, turbidity and suspended solid varied between 40-90 NTU and 30-110 mg/L, and for treated wastewater, it varied between 16-25 NTU and 20-45 mg/L. Although there was wide variance of turbidity and suspended solids of feed water, the permeate turbidity was still very low (0.05-0.45 NTU) throughout the duration of all experiments. The results for permeate turbidity levels were also related to suspended solids, which were not detected. These results show that the system has a good potential to handle high turbidity and suspended solids loading without any effect on permeate water quality, as presented in Fig 2. The COD of surface water and surface water with added kaolin clay was 15-50 mg/L while TOC was 4.1-7.7 mg/L. For treated wastewater, COD was 70-135 mg/L while TOC was 18-27 mg/L. The permeate COD and TOC were maintained at 7-30 mg/L and 3.8-10.6 mg/L, even for treated wastewater with high levels of organic matter. Some organic matter present in dissolved form could not be removed by microfiltration. Hence, microfiltration alone was shown to be effective for the removal of particles, but ineffective for the removal of organic materials.

Water and Wastewater Reuse Potential

Six parameters are critical to permeate water quality reuse: pH, BOD_5, turbidity, TSS, fecal coliform and Cl_2 residue. Comparisons between MF permeate water quality and that required for normal reuse is shown in Table 2. The results show that water produced using the microfiltration membrane can satisfy the water quality requirements for reuse.

Table 2 Comparisons of MF permeate water quality and water quality required for reuse

Parameters	Unit	Water quality requirement for reuse*	MF permeate of	
			surface water	Treated wastewater
1. pH	-	6-9	7.7-8.1	8.0-8.3
2. BOD_5	mg/L	<10	<2	<2
3. Turbidity	NTU	<2	0.05-0.45	0.05-0.45
4. TSS	mg/L	<30	ND	ND
5. Fecal Coliform	CFU/ml	0	0	0
6. Cl_2 residual	mg/L	<1	<0.1	<0.8

* *Source: Asano, (1998)*

CONCLUSIONS

The long-term pilot-scale experiment on microfiltration membrane reveals the following results: Organic fouling is the most significant factor in the decline of flux, which is the limiting factor for microfiltration selection. Proper pre-treatment is needed for feed water that contains high organic contents. Fouling by inorganic matter or by suspended solids such as clay does not have much effect on the stability of membrane filtration. Therefore, for microfiltration, suspended solids are not a major cause of fouling, and could be successfully controlled using mechanical cleaning or backwashing. For treated wastewater, the flux-reduction rate in a filtration cycle was apparent, while the reduction for both surface water and surface water with added kaolin clay was smaller. Wastewater treatment should be run for a shorter filtration time in order to prolong running times. The stability of this system was quite effective for surface water and highly effective for suspended solids in surface water with added kaolin clay, which could be run for 500.5 or 21 days at permeate flux 70 L/h.m^2.

The water produced using the microfiltration membrane can satisfy the water quality requirements for reuse. High quality permeate can be obtained, the reliability of which does not depend on the feed water quality. Although feed water might have a wide range of turbidity and suspended solids, the permeate turbidity remained very low (0.05-0.45 NTU) throughout the duration of all the experiments. The levels of permeate suspended solid were also very low, no suspended solids could be detected. The permeate COD and TOC were maintained at 7-30 mg/L and 3.8-10.6 mg/L, respectively, even for high levels of organic matter in treated wastewater. Some organic matter, which was in dissolved material form, could not be removed by microfiltration.

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