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Chemical-free and carbon neutral membrane based emergency water supply system

Amila Abeynayaka [1)], Thuy Nguyen [1)], Chettiyappan Visvanathan [1,*)] and Prapan Ariyamethee [2)]

1) Environmental Engineering and Management Program, School of Environment, Resources and Development, Asian Institute of Technology, P.O. Box 4, Klong Luang, Pathumthani 12120, Thailand.
*e-mail: visu@ait.ac.th

2) Liquid Purification Engineering International Co., Ltd., Thailand.

Abstract

Membrane based potable water treatment unit (PWTU) was operated with different types of surface water sources. The treatment unit is designed to operate without electricity which suites in emergency situations and rural water supply where the electricity is not abundant. The PWTU consists of a polyvinylidene fluoride (PVDF) hollow fiber membrane module (200 kDa molecular weight cutoff) and a hand pump to develop trans-membrane pressure (TMP). Capacity of the system, physical, biological and chemical water quality parameters of raw waters and treated waters were analyzed. Membrane fouling patterns and cleaning procedures were observed under different surface water conditions. Removal efficiencies of different fractions of natural organic matter (NOM) were determined. The PWTU was operated with a selected community and feedback was taken to prepare operational and maintenance manuals to guide the system operators in real situation. Suitable operational and maintenance methods such as membrane cleaning were identified. Treated water satisfies the chemical, physical and most of the biological water quality parameters of drinking water standards.

Keywords: Emergency water supply, Membrane filtration, Natural organic matter, Membrane fouling, Human powered

1. Introduction

In 2008, 137 natural disasters and 174 anthropogenic disasters were reported, while Asia suffered the most in terms of the number of lives lost (Rudolf, 2009). In 2009 there were 27 million displaced people due to conflicts alone (Nina et al., 2009). The number is much higher including the natural disasters. As well as food, shelter, and medical aid, providing clean water is usually one of the highest priorities in the event of an emergency (Reed & Shaw, 1995). Onsite water treatment solution has increasingly being considered as a strategy to cope with prolonging disaster recovery sessions and has reached to a certain development. When the raw water sources are taken from drinking water sources such as rainwater and ground water extracted from wells, the water treatment generally consist only disinfection. However, obtaining water from surface, open or unknown sources requires a certain treatment process before it is used for drinking purposes. Most popular water treatment methods are based on coagulation (Garsadi et al, 2008; Dorea, 2008) and sand filtration (Dorea et al., 2006), bio-sand filtration (Elliott et al., 2008) or membrane filtration (Butler, 2009, McBean, 2009, and

Park et al. 2009). Adverse effects from disasters generally limit the access of chemicals and electricity for operating water treatment systems. Hence, electricity and chemicals requirements can be considered as the important factors which restrict the application of these systems in emergencies.

Microfiltration (MF) is a low pressure membrane filtration processes that have growing interest in drinking water treatment. Naturally, the low pressure demand of microfiltration made it flexible in selecting the driving force sources. For example, hollow fiber microfiltration has been used in the Sky Hydrant unit with the driving force created by about one meter of gravity head (Butler, 2009).

Disaster situations can lead to a fact that facilities such as electricity or chemicals are limited while human power can be abundant, especially in the case of internally displaced people gathered together at one place such as in camps. The same condition can be found in the rural areas without electricity. This condition induced to an idea of using human power to drive the membrane based water treatment system. In this study an actual scale potable water treatment system (PWTU) consist of a polyvinylidene fluoride (PVDF) hollow fiber membrane module and a hand pump to reach necessary pressure was operated and evaluated. This PWTU was operated with water from two different types of surface water sources including a surface water collection pond and a river. It was evaluated the performance of the system in terms of capacity and treated water quality, operation and maintenance, and membrane fouling. Finally a questioner survey was conducted to get feedback from operators.

2. Materials and methods

2.1. PVDF hollow fiber membrane system

A dead-end outside-in hollow fiber MF [200 kDa MWCO (molecular weight cut off); 3.4 m^2 surface area] made of PVDF and a rotating hand pump were used as the most important units of the system. Pretreatment consisted of a bar screen and a cloth-bag filter with the pore size of 45µm. The schematic diagram of PWTU and the actual system are given in Fig. 1 and Fig. 2 respectively. For operation, surface water was poured through the coarse screen, cloth screen and then stored in the feed tank. From here, the feed water was then pumped by the hand pump through the membrane, and the filtrate was collected and stored in the filtrate tank.

The PWTU was designed to operate with human power of users by rotating the hand pump. However for the convenience in operating the system during the study period, the hand pump was connected to a electrically powered motor to rotate. This motor was able to switch on and off automatically following a program set up via an electrical controller system. In this study, the motor was set to work for a cyclical operation of 10 min on and 15 min off. To simulate the actual operating conditions, the system was operated only 16 hours of the day; the remaining hours (8 hours in night time) were kept rest.

Draining of the concentrate in membrane housing was conducted once in a day after finishing 16 hours of operation. Filtrate flux and TMP were measured 3 times per day at 8 hour intervals. The system was operated until the TMP reached 50 kPa and then chemical cleaning was performed. The filtrate flux was kept at 16.88 $L/m^2/h$ during the operating 10 minutes. This gives an average flux of 6.75 $L/m^2/h$ for the operated 16 hours in a day. With this operating condition the system was able to provide 350-380 L/day of treated water.

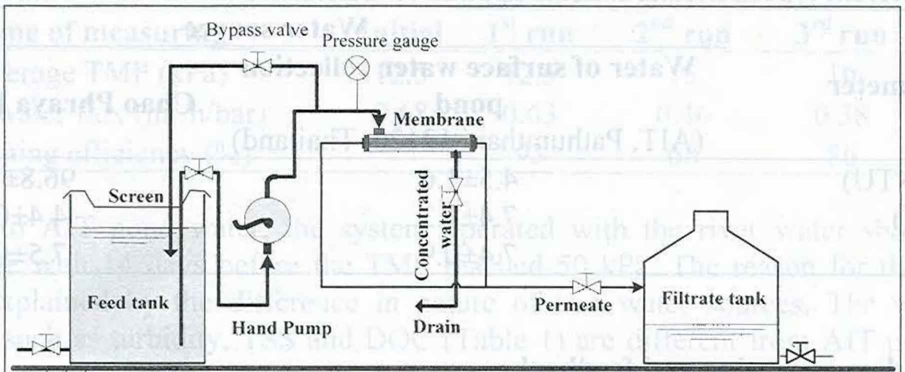
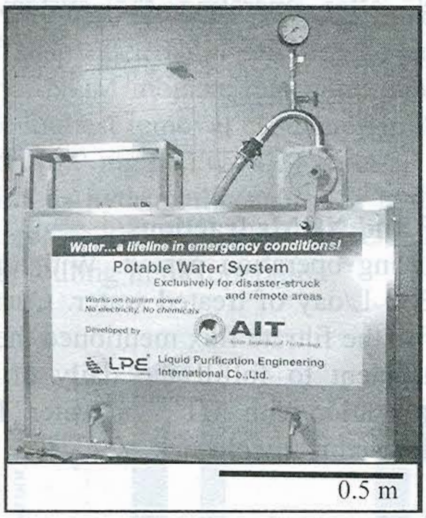
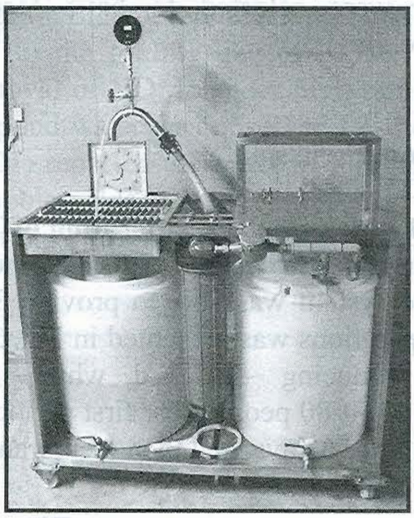


Fig. 1. Schematic diagram of the PWTU



(a) Front



(b) Rear

Fig. 2. Actual PWTU

Once the maximum TMP reached 50 kPa, the filter was detached from the system and chemically cleaned according to the following procedure. After rinsing by treated water, the filter was immersed into the 0.03% NaOCl cleaning solution for 8 hours, then rinsed again by the treated water and re-installed into the system as in the beginning. The system was then operated with tap water to measure the efficiency of the chemical cleaning each time. Before changing the feed water from AIT pond water to river water, a special cleaning with HCl (pH=2), 0.03% NaOCl solution (pH=11, adjusted with NaOH) subsequently was applied to get the initial pure water flux.

2.2. Different feed water sources and analytical methods

The system was operated with two types of feed water from a surface water collection pond and a river (Table 1). Turbidity was measured by a HATCH turbidimeter (2100N). Samples were filtered through 0.45 µm pore size filter paper and then DOC was determined by a Shimadzu TOC analyzer. Most probable number (MPN) method was used to measure total coliform and fecal coliform (APHA, 2005). To find the effects NOMs from different surface waters on membrane fouling, DOC fractionation was performed using XAD-8 and XAD-4 resins (Kennedy et al. 2005).

Table 1: Different types of water sources applied in the study

Parameter	Water source	
	Water of surface water collection pond (AIT, Pathumthani 12120, Thailand)	Chao Phraya River
Turbidity (NTU)	4.5±1.6	96.8±7.5
DOC (mg/L)	7.4±1.3	4.4±0.5
pH	7.4±0.9	7.5±0.9

2.3. Actual demonstration and feedback

In order to get the feedback about the operation of the HFMF system and prepare the operation manual, the system was operated manually with 32 people in AIT community. Three different age groups including 10-20, 21-55 and 56-70 years old with different nationalities were selected to have feedback after operating the system through a questionnaire.

3. Results and discussion

3.1. Treated water capacity, alteration of TMP and NOMs fractions

A filtrate flux of 6.75 $L/m^2.h$ was obtained during operation period. With this operating condition the system was able to provide 350-380 L/day of treated water. Change of TMP during the operations was presented in Fig. 3. With the filtrate flux mentioned the system was capable of producing ~380 L/d, which is sufficient to fulfill the daily drinking water requirement of 50-80 people. For first period of operation with AIT pond water, TMP reached up to 51 kPa after 6 days, and then membrane was chemically cleaned.

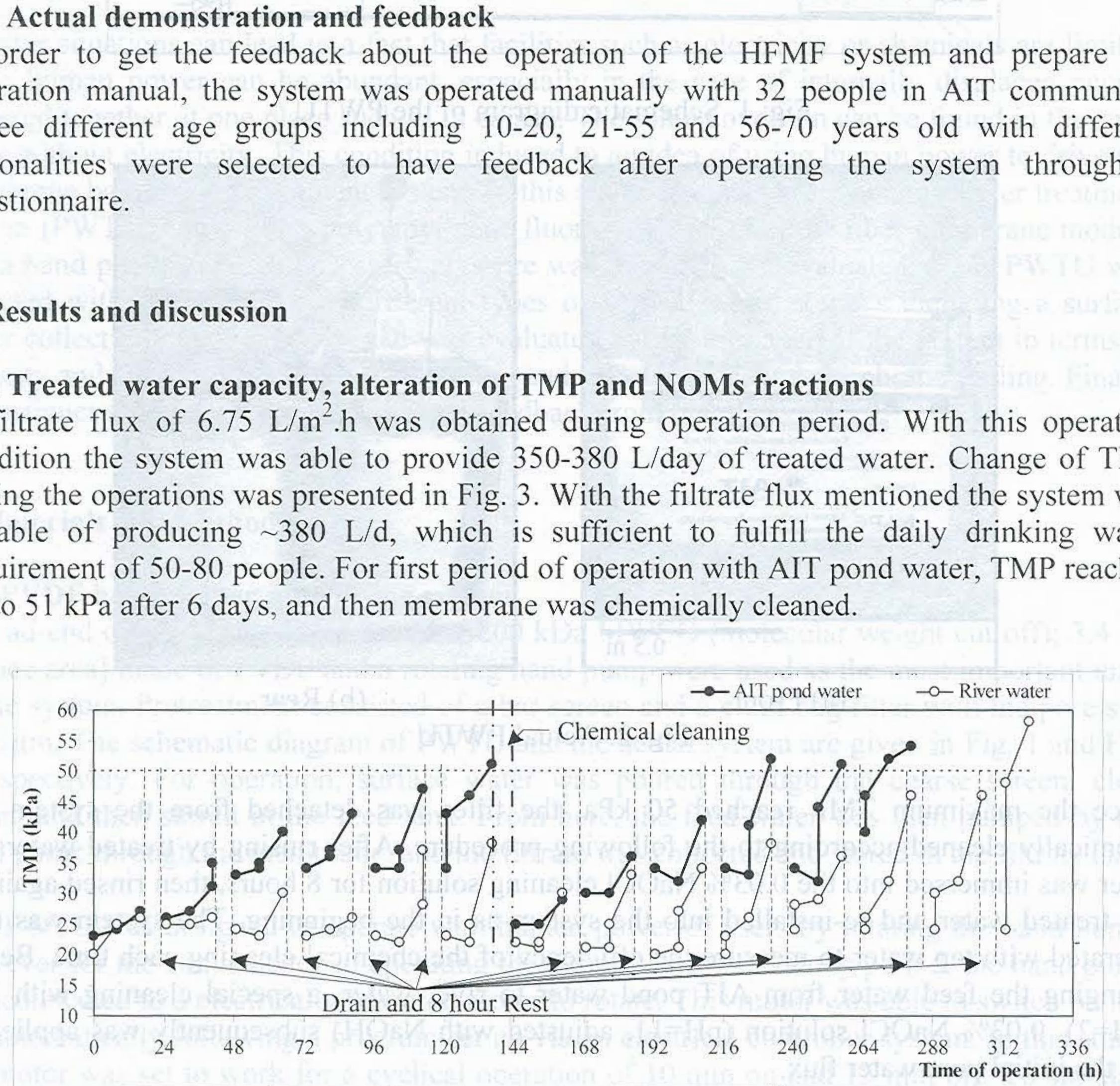


Fig. 3. Corresponding max TMP of the system operated with AIT pond and river water

Efficiencies of chemical cleaning were presented in Table 2. Compared to the initial pure water flux, the flux recovery was 93% after the 1st run. However, the efficiency was reduced significantly, up to 56% after the 3rd run. The reason for this trend could be the accumulation of inorganic foulants on the surface of the membrane while NaOCl is particularly used for removing only the biofoulants. The 100% flux recovery obtained by applying NaOH and HCl with NaOCl. NaOH and HCl solution are capable of removing inorganic and organic foulants. Hence, it is suggested to use this method when the relevant chemicals are available.

Table 2: Changes of chemical cleaning efficiency by operating period

Time of measuring	Initial	1st run	2nd run	3rd run	4th run
Average TMP (kPa)	12.5	12.5	15	16	13
Pure water flux (m^3/h/bar)	0.68	0.63	0.46	0.38	0.68
Cleaning efficiency (%)		93	68	56	100

Compared to AIT pond water, the system operated with the river water shows a longer filtration life with 14 days before the TMP reached 50 kPa. The reason for this difference could be explained by the difference in nature of two water sources. The water quality parameters such as turbidity, TSS and DOC (Table 1) are different from AIT pond water to river water. However there was no much difference in percentage distribution of three DOC fractions in both feed waters. Hydrophobic, hydrophilic and transphilic DOC fractions of AIT pond water was 47, 42 and 11% respectively, while in the river water; 47, 44 and 9% respectively. Yet the membrane fouling pattern under two types of waters is different. The river water with high turbidity prolongs the operation time before reaching 50 kPa. Hence the presence of suspended solid affected adversely to the fouling due to NOM. The removal efficiencies of NOM indicate that minimum removal of NOMs under high turbid conditions (Fig. 4). The highest removal efficiency in AIT pond water was observed for the hydrophilic DOC fraction (0.9 mg/L; Fig. 4). Fan et al. (2001) reported the order of fouling potential of NOM fraction as hydrophilic neutral > hydrophobic acids > transphilic acids > hydrophilic charged. Therefore, the hydrophilic DOC fraction in AIT pond water could be the major cause of membrane fouling in the operation.

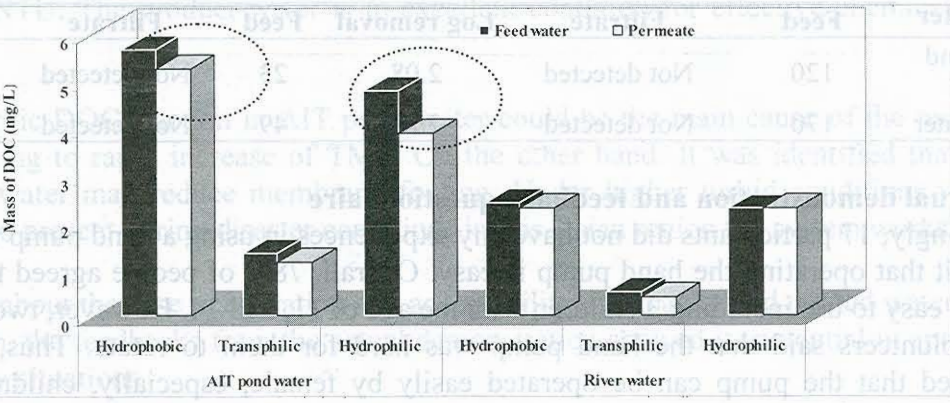


Fig. 4. Comparison of DOC fractions removal from AIT pond water and river water

Interestingly, there was no significant elimination of DOC fractions from the river water about. It has been suggested that inorganic particles can affect the fouling behaviors of organic substances (Zularisam et al. 2006). The presence of inorganic particles such as clay minerals in the river water created a significant competition between NOM and inorganic particles to adsorb onto the membrane surface or in the pores. Therefore, the high turbidity content in the river water could reduce membrane fouling by forming a barrier between NOMs and membrane. That could be the reason for the longer filtration life of the system when it worked with the river water compared to with the pond water. Hence under higher turbid conditions which is more likely to present during disaster conditions in this Asian region the system works well.

3.2. Treated water quality

Turbidity and micro-particles removal

Turbidity removals with both types of waters were above the drinking water quality standards of potable water. With the pond water, turbidity was removed up to 96% and the average turbidity in treated water was about 0.18 NTU and stable. For the river water with 96.8±7.5 NTU, a slight increase of turbidity in treated water was observed. The average of that was 0.56 NTU and removal efficiency was 99.4%. In brief, the system could treat the surface water to good condition for successful disinfection, because of a turbidity of less than 1 NTU (Twort et al. 2000).

Total coliform and fecal coliform removal

Amount of total coliform and fecal coliform found in the pond water, river water and product waters is presented in Table 3. PWTU was capable of complete removal of both total and fecal coliform presented in both types of water. The PVDF membrane having 200 MWCO is capable of removing bacteria by simple size rejection. However there are possibilities of growing pathogenic bacteria in the filtrate line or in storage containers. Moreover pathogenic viruses which are smaller than membrane pore may escape through the membrane. Hence post disinfection measures have to be taken for further safety. The treated water quality with low turbidity provides excellent conditions for the further disinfection with chlorine compounds such as $Ca(OCl)_2$.

Table 3: Total coliform and fecal coliform removal

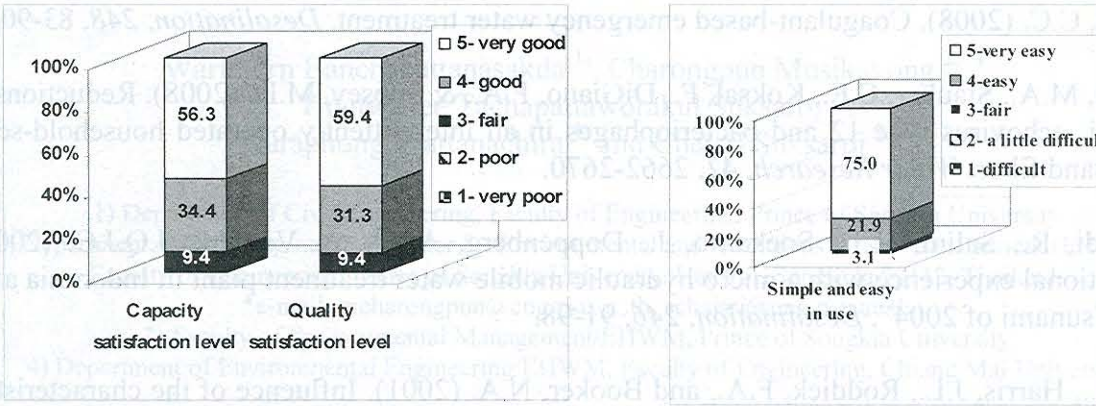
Type of feed water	Total coliform (MPN/100mL)			Fecal coliform (MPN/100mL)		
	Feed	Filtrate	Log removal	Feed	Filtrate	Log removal
AIT pond water	120	Not detected	2.08	23	Not detected	1.36
River water	170	Not detected	2.23	49	Not detected	1.69

3.3. Actual demonstration and feedback questionnaire

Interestingly, 17 participants did not have any experiences in using a hand pump but 15 out of them felt that operating the hand pump is easy. Overall, 78% of people agreed that the hand pump is easy to use including 3 children with the age of 11, and 14. However, two out of three elder volunteers said that the hand pump was hard for them to rotate. Thus, it could be concluded that the pump can be operated easily by female, especially, children yet some difficulties for elder people.

In emergency situations, quantity of treated water is generally considered as important. All volunteers were asked to rank their satisfaction level for the treated water. About 56% considered the capacity from the system was very good (Fig.5a). Most remaining participants believed the system could produce a good quantity of treated water whereas 9.4% thought that the capacity is fair. Water quality was also evaluated by physical observation. About 60% people ranked the treated water as a very good quality and 31% felt the water had a good quality. The fair level was given by 3.1%. The overall consideration about the simplicity and ease of the system in operation was taken into the final question. The "very easy" option was selected at the highest level of 75%, followed by the "easy" option with 22% (Fig. 5b).

There were several lessons and valuable suggestions given by the participants during the actual demonstration which help to improve the system and the operation manual. One of major suggestion was reducing the footprint of the system, so that it will be easier in handling and transporting the system.



(a) Capacity and quality satisfaction (b) Ranking for simplicity and ease

Fig. 5 Actual operation feedback

4. Conclusions

The system is capable of producing 350-380 L/d of potable water, which is sufficient to supply drinking water for a small community with 50-80 people. The system can provide bacterial pathogen free water. The system can treat the surface waters up to the turbidity of 0.18 - 0.56 NTU. The product water is in excellent condition for effective chemical further disinfection.

The hydrophilic DOC fraction in AIT pond water could be the main cause of the membrane fouling, leading to rapid increase of TMP. On the other hand, It was identified that higher turbid river water may reduce membrane fouling. Under higher turbid conditions which is more likely to present during disaster conditions in this Asian region the system works well.

Considering about the ease in operation and acceptability of capacity and treated water quality of the system, the feedbacks from the actual demonstration showed its potential in application in emergency situations.

5. Acknowledgement

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