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Low-cost spiral membrane for improving effluent quality of septictank

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ABSTRACT

In recent years, three-chamber septic tank is gaining its popularity in developing countries as a decentralized treatment system for domestic wastewater. However, effluent discharged from a septic tank is not suitable to meet the standard limits for domestic wastewater. Because of which, it is necessary to enhance septic tank performance to get better quality in terms of wastewater treatment. This study applied a new membrane configuration called "spiral woven fiber microfiltration membrane" (SWFM) module dipped into the last chamber of a septic tank. Wastewater from a canteen in Ho Chi Minh City University of Technology area was used as the main source of waste in this study. Membrane fouling and treated effluent quality were investigated at various filtration fluxes. The results showed that the fouling rates of the SWFM conducted in this study were 1.96, 4.68, and 6.55 kPa/d for fluxes of 2, 4, and 6 L/m^2 h, respectively. The treated effluent from membrane-based septic tank complied with the current Vietnam effluent standard for domestic wastewater (column B). The removal efficiencies of suspended solids (SS), total kjeldahl nitrogen (TKN), total phosphorus (TP), chemical oxygen demand (COD), and coliforms of the upgraded system were much better than those in conventional septic tanks. At all fluxes, the removal efficiencies of SS, COD, and coliforms were 85–92%, 14–38%, and 68–99%, respectively. Though, nitrogen and phosphate removal efficiency was not effective in this process (anaerobic treatment system), under 10% but the treated water is definitely ideal for irrigation of parks, gardens, or grass golf. In conclusion, the SWFM is a potential low-cost membrane application for upgrading a septic tank to improve its effluent for water reuse purposes.

Keywords: Septic tank; Spiral woven fiber microfiltration (SWFM); Membrane fouling; Flux

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1. Introduction

Due to continual rise in population density, rapid industrial growth, and urbanization in Ho Chi Minh City (HCMC), domestic wastewater have caused many serious and controversial problems affecting the public and environmental health, and local economic activities. One of the serious problems that HCMC is facing is water sanitation due to excessive disposal of untreated wastewater from both domestic and industrial sectors. At present, approximately 75–80% of private houses in HCMC are equipped with septic tanks designed as the conventional styles (two-chamber or three-chamber septic tank). Moreover, many poor communities, whose low income, are challenging barriers for the city in the improvement of wastewater treatment systems and management of domestic wastewater discharge. Waterborne diseases such as dengue, filariasis, malaria, yellow fever, and trypanosomiasis have not solved completely yet.

In recent years, advanced technology breakthroughs have brought great advantages to wastewater treatment [1,2]. Particularly, the membrane processes comparing to other treatment technologies such as the conventional activated sludge process (ASP) [3], advanced oxidation processes (AOPs) [2] include a small footprint, low-cost application, and less discharged sludge production through maintaining a high biomass concentration in the bioreactor [4]. Moreover, these technologies require specific condition operation, wastewater properties and system maintenance. Basically, membranes applied to water and wastewater treatment is a material with specific pore size that allows some specific physical or chemical components to pass through it. Membrane itself has to be made useful and must then be configured in such a way to allow water filtration through it. For the key membrane processes identified, pressure is applied to force water through membrane. Furthermore, membrane bioreactor (MBR) can control wide variation of influent characteristics so that the reuse of treated effluent is possible for non-potable purposes due to high treatment efficiency. In terms of nitrification, the increased rate can be achieved by retaining a large amount of slow-growing nitrifying autotrophs in the aeration tank of the MBR. However, the widespread application of the MBR process is constrained by the high capital, maintenance, and operating costs [4]. In order to solve all of those obstacles in an effort not only to minimize the capital cost, but also to have high efficiency of wastewater treatment, an innovation must be figured, designed, and planned in such a way, which has practical application potential in reality.

In this study, low-cost microfiltration membrane materials such as woven polyesters were investigated for its performance in wastewater treatment and long-term operation by a simple continuous process. Spiral woven fiber microfiltration membrane (SWFM) in this study has been recommended as a suitable solution for low-income communities to upgrade septic tanks with economic and convenient operational procedures not requiring high level technical skills with robust properties and flexibility.

2. Materials and methods

2.1. Experimental setup

The schematic diagram of the SWFM system is shown in Fig. 1. Membrane was made from polyester material with pore size of 1–3 μm (Table 1). The installation of full-scale SWFM system consists of the connection between membrane module and peristaltic pump by plastic pipelines. A digital pressure gage was installed on the pipeline in the middle of peristaltic pump and membrane module to record the transmembrane pressure (TMP) changes during operation. The cylindrical stainless steel tube coverage was constructed to hold the spiral membrane module from moving during the operation in a septic tank with dimension of 25–38 cm as diameter (*D*) and height (*H*), respectively. The cylindrical coverage frame and spiral core were made from stainless steel. Microfiltration membrane with length of 46 cm was wrapped inside the spiral core to create the spiral membrane module (Fig. 2). A spiral core made from stainless

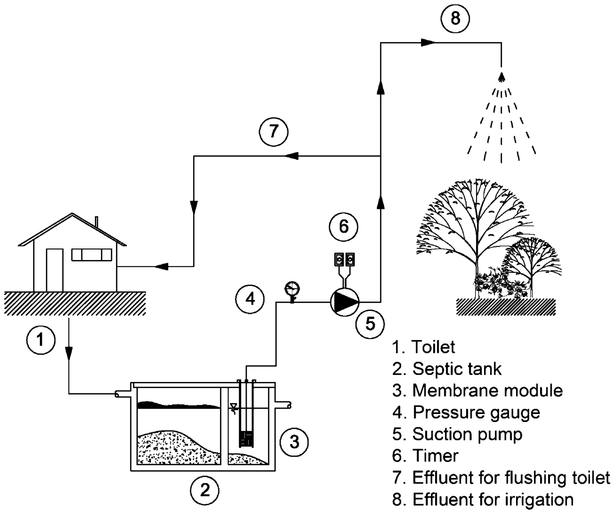

Fig. 1. Schematic diagram of application of SWFM system in a household.

Table 1
Specification of SWFM

Item	Characteristics
Membrane type	Dead-end, outside-in, spiral
Material	Polyester
Pore size	1–3 μm
Total area	0.969 m^2
Operational pressure	<80 kPa

Fig. 2. Configuration of SWFM module.

steel was fitted inside the cylindrical coverage and membrane was wrapped around this steel frame. The membrane module hung in the third chamber of the septic tank, was covered by steel bars which were specifically designed for this module. The module was immersed in the septic tank until distance between the water surface and the top of module was observed at approximately 10 cm.

2.2. Operating conditions

Based on the flow rate of domestic wastewater (240 L/d) entering into septic tank, and the module projected area of approximately 1 m^2, the process was setup to investigate optimal flux for SWFM system operation by operating at fluxes of 2, 4, 6 L/m^2 h. Membrane module mode was controlled for 8 min run and 2 min idle by adjusting time controller equipped with the suction pump. The different TMP was recorded two times per day (8 am and 2 pm). Membrane was considered as completely fouled and changed to new flux mode when TMP values recorded on the pressure gage was close to 80 kPa. Then the operation was stopped and whole module was taken out of the septic tank for physical and chemical cleaning procedure.

2.3. Cleaning method

In practice, resistance of membrane has to be considered as one of the problems in maintenance and operation for long-term operation [5,6]. Cleaning strategies have been carefully evaluated in this experiment to figure out the appropriate method to remove clogging factors which force the resistance to keep increasing [7]. Both physical and chemical cleaning methods were applied when TMP of system reached approximately to maximum working pressure of membrane (i.e. −80 kPa).

Firstly, after taken out of the septic tank, membrane was carefully moved out of the coverage and the surface was merely brushed as physical method to remove thin biofilm layer. In comparison to back-flush mode, physical removal efficiency was of 1–3 times higher [8]. This method was found out to be more cost-efficient as well as energy-efficient than others.

Chemical cleaning applied to remove fouled materials in membrane pores had higher removal efficiency, i.e. more than 80% as compared to physical cleaning. The chemical cleaning was expected not only to clean the membrane, but also to turn TMP back to initial TMP value. Factors affecting the membrane fouling included: membrane, biomass, colloids, soluble matters, and operation conditions. Pore size of microfiltration membrane in this study was around 1–3 μm so that it was too small for bigger flocs passing. The cake layer on membrane surface formed by biomass accumulation leads to the increase in membrane resistance. This cake layer can be removed by physical cleaning (i.e. brushing on the surface of membrane only). However, the deposition of colloids and soluble matters inside membrane pores is really hard to remove by applying physical method alone. This study followed the chemical cleaning methods recommended by suppliers, where the membranes were immerged in the 0.03% NaOCl solution for 8 h, and carefully brushed membrane with tap water again before measuring the membrane resistance to determine the cleaning membrane efficiency. Membrane cleaning studies on anaerobic systems have generally indicated that a combination of caustic and acid washes is required to remove organic and inorganic foulants [9]. Membrane resistances were measured after each cleaning period to determine the contribution from the various components of membrane fouling.

2.4. Analysis

Analysis of the results was made to evaluate the effective treatment of upgrading septic tank by applying a spiral membrane module. Influent and permeate of membrane system were analyzed for parameters such as pH (Eutech pH 5+ meter), chemical oxygen demand (COD), suspended solids (SS), total kjeldahl nitrogen (TKN), and total phosphorus (TP, colorimetric with stannous chloride—$SnCl_2$). These parameter analyses were carried out in accordance with standard methods. Total coliforms were analyzed using the IDEXX Quanti-Tray 2000.

3. Results and discussion

3.1. Fouling characteristic of spiral membrane system

The variation of TMP during operation is shown in Fig. 3. At flux 6 L/m^2 h in nine days run (day 0–9), the TMP value increased gradually in the first four days. Then a rapid increase rate in TMP was observed as the TMP increase in 70 kPa after nine days of operation. At flux of 4 L/m^2 h, SWFM system ran for 14 d with the highest TMP of 70 kPa. The increase rate in TMP at this flux was observed more steady and slower than at flux 6 L/m^2 h. In addition, Fig. 3 indicates flux 2 L/m^2 h could be considered as an optimum flux for real operation, as the membrane fouling rate can be greatly ameliorated by operating at low flux. Obviously, in the first 19 d, the TMP value reached only 35 kPa, and in the next five days, the TMP slightly increased higher than previous days. Thereafter, in the following days, the TMP increased to the same level as originally seen. A rapid increase in TMP at flux 2 L/m^2 h was observed when the TMP increased to nearly 70 kPa in 34 d at which membrane fouling rate was faster and the membrane needed chemical cleaning for further experiment.

These results show that membrane fouling follows a three-stage pattern as mentioned in the study [10]. Under subcritical flux conditions the initial variation in TMP is mainly due to membrane adsorption soluble organics and clogging by colloidal substances. At flux 6 L/m^2 h, the membrane fouling rate was very fast (dTMP/dt = 6.55 kPa/d) during this period and filtration operation could not be maintained for a long time. As the filtrating operation proceeded, more soluble organic substances and fine colloids were adsorbed in the membrane pores or deposited on the membrane surface.

Therefore, membrane fouling became rapid in the 6th–9th day period and the fouling rate of dTMP/dt increased to 6.55 kPa/d. The similar phenomenon occurred in the flux mode of 4 L/m^2 h operating in 14 d. At flux 4 L/m^2 h the fouling rate is more slow (dTMP/dt = 4.68 kPa/d) because the membrane system was operating at lower flux rate. After measuring the membrane resistance, it was apparently explained that at low flux the membrane seemed to be accelerated more soluble organic substances than others. The total resistance at 2 L/m^2 h flux was also the highest. Based on the fouling rate and the wastewater treatment capacity, flux of less than 4 L/m^2 h is highly recommended as the suitable flux for the spiral membrane-based septic tank in practice.

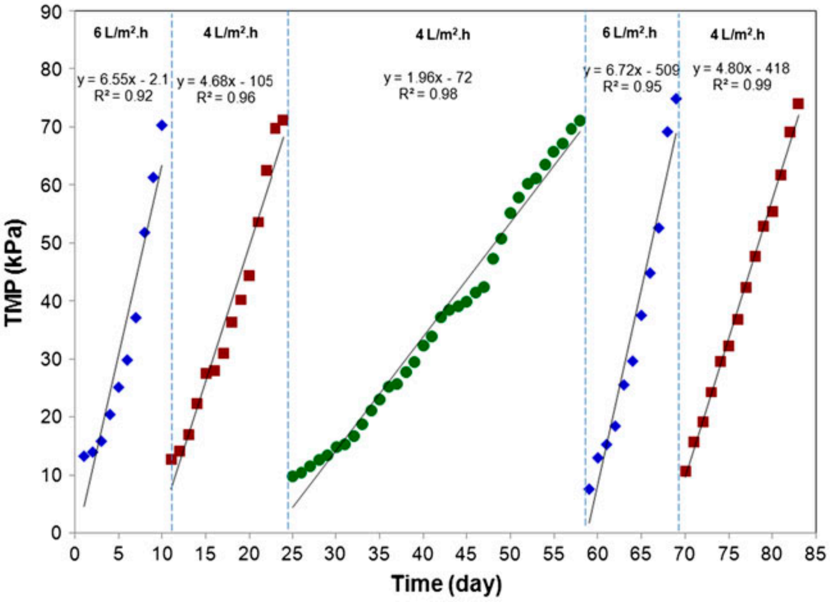

Fig. 3. Evolution of TMP profile of SWFM (LMH: L/m^2 h).

Table 2
Treatment performance (Day 1–83)

	COD			SS		
Flux, L/m^2 h	Influent, mg/L	Permeate[a], mg/L	Efficiency, %	Influent, mg/L	Permeate[a], mg/L	Efficiency, %
2	83 ± 30	30 ± 6	70–75	50 ± 8	3 ± 1	85–92
4	116 ± 39	91 ± 14	20–25	55 ± 7	4 ± 2	85–95
6	130 ± 15	71 ± 10	30–35	52 ± 5	5 ± 2	85–95

[a] Permeate: treated water after passing through membrane.

3.2. Treatment performances

During the operations of each flux, pH in the septic tank fluctuated in range of 7.1—8.6. This range of pH was in the optimum pH range for anaerobic process (6.5—8.5). As presented in Table 2, highest COD removal of 70–75% was at flux 2 L/m^2 h and COD concentrations of treated water were ranging from 24 to 36 mg/L. Otherwise, the removal efficiency of COD at flux 4 and 6 L/m^2 h were increased from 20 to 25 mg/L and 30 to 35 mg/L, respectively. The substantial COD variation of influent had greatly affected the removal efficiency. The average SS in membrane permeate of 5 mg/L was observed. There was no significant difference in total coliform removal at all fluxes and results were greater than 75% at all times, except a small portion of pathogens were eliminated in the septic tank. In terms of SS removal, there was a significant difference between influent and effluent for each flux. Table 2 shows that at all fluxes, the average amount of SS in influent and effluent were 50–55 and 3–5 (mg/L), respectively. The removal efficiency of SS at all fluxes was ranging from 85 to 95%. These results indicate that the spiral membrane in one hand would be efficient in SS reduction due to small pore size and configuration. On the other hand, the removal efficiency of nitrogen and phosphorus were not significant in this anaerobic membrane process (less than 5 and 10% for TP and TKN, respectively).

It can be explained based on the fact that membrane pore size did not have much effect on total coliforms treatment, probably due to the formation of a secondary membrane (biofilm cake layer). As most of the filtration resistance in a membrane arises from the formed cake layer, it is reasonable to expect this layer, rather than the spiral membrane structure, to be responsible for the coliform rejection.

3.3. Membrane area required for a household septic tank

This membrane module can be applied for all houses, apartments, and office buildings, etc. However, this study suggests a design for a typical house with maximum of five people, with the average daily wastewater to be about 200 L/capita d, where the toilet flushing and cleaning to be of 70 L/capita d. Thus, the amount of wastewater per day was calculated to be:

$$70\ \text{L/capita day} \times 5\ \text{persons} = 350\ \text{L/d} = 14.6\ \text{L/h}$$

According to the research result, the flux 4 L/m^2 h was selected as the optimal flux with the total surface area of membrane of 3.6 m^2 (~4 m^2). The membrane cost estimated for a household application is approximately $20. The total capital cost consisting of membrane, pump, pipelines, and connection factors is about $250. Maintenance cost for the system is about $10 per year. This could be the reasonable price for a typical household in developing countries.

4. Conclusions

Based on the research results, some concluding remarks are withdrawn as follows:

- Upgrading a septic tank by inserting a SWFM in its third chamber is considered to be an appropriate sanitation solution for low-cost decentralized wastewater treatment system in HCMC.
- The sustainable flux for SWFM was less than 4 L/m^2 h to control fouling in practice.
- Membrane fouling in the membrane-based septic tank was caused by the cake layer formation. The fouling can be removed by solar drying and brushing, which can achieve flux recovery of 90–95%.
- Further study is needed to prolong the membrane filtration period or fouling control of this membrane-based septic tank.

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