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Membrane fouling characterization in membrane-based septic tank

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ABSTRACT

Septic tank is a conventional on-site wastewater disposal system providing only primary treatment (settlement of solids), while offering little biological degradation. To further improve the quality of treated water, the conventional septic tank can be modified by the introduction of membrane module capable of effective rejection of suspended solids as well as associated particulate organic matter. However, membrane fouling by partially-treated water can be considered as one of the major limitations of the membrane-based septic tank (MBST) system. The present study was carried out in a pilot-scale MBST by using flat-sheet woven fiber microfiltration (WFMF) membrane modules. WFMF membrane module having 1 m^2 effective filtration area was submerged in septic tank of 4 m^3 working volume and operated at different fluxes to investigate the fouling frequency and effects of cleaning protocols. It was found that the physical cleaning protocol was effective in removing cake as well as partial pore blocking resistance without requiring chemical cleaning. On the other hand, after each operation cycle, the irreversible fouling of membrane increased.

Keywords: Woven fiber microfiltration; Septic tank; Membrane module; Membrane fouling; Irreversible fouling

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1. Introduction

As water scarcity situation is becoming worse, reuse of water is becoming more attractive [1]. More than a billion people in the world do not have access to potable water [2,3]. Almost 40% of the world population lives under water scarcity and is expected to increase to 60% by 2025 [4]. The need for sustainably managing the water resources is becoming a necessity [5]. In fact, the environment is repeatedly experiencing high stress related to scarce or non-existent wastewater treatment systems. To effectively handle this problem, decentralization of wastewater treatment is increasingly accepted as a suitable and sustainable solution [6]. Decentralized wastewater treatment has recently gained much attention in wastewater management for

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water reclamation due to its build-as-you-need principle. It is cheap enough in terms of construction, maintenance, and operation. It can be applied not only for low-income countries, but also in areas of sparse population [7]. Decentralized wastewater management is economically and technically more efficient then centralized approach [8–10]. The less comparative cost is due to minor sewer lines and simpler technology [11]. Among the technologies used for on-site or decentralized wastewater treatment, anaerobic processes are becoming more popular because of their capability in reducing the organic matter from municipal and industrial wastewaters [12].

Septic tank is the system that allows the on-site treatment for wastewater at a residence, cluster of residences, or small commercial units [13]. The quiescent condition inside the tank allows the portions of suspended solids to settle, floatable solids to rise up and provides residence time for biological activity [14]. The first reported application for the domestic use of septic tank was in France in 1860, which was a "box" located between the house and the cesspool-trapped excrement, which reduced the solids and generated clean water that entered to the soil more quickly [15]. Conventional septic systems consisting of a septic tank followed by a soil absorption system are the preferred on-site wastewater disposal system because they are inexpensive to install and require minimum maintenance [16]. When properly installed in suitable soils, they can provide an adequate level of wastewater treatment for many years. However, the septic tank in a conventional on-site wastewater disposal system provides only primary treatment. This means that the soil absorption field receives a significant load of suspended solids, organic matter, and nutrients. Not only are the suspended solids potentially high in harmful bacteria and pathogens, they also clog up the pores of the native receiving soil, thereby eventually causing the system to fail [15].

Increased water scarcity and stringent water quality legislation are enhancing the wide use of the membrane-based treatment systems. Such technologies have frequently been rejected in the past because of high capital costs [17]. With advanced technology and cost reductions, membrane systems are now capable of decontaminating wastewater efficiently [18,19]. A major limitation in the extensive application of membrane filtration for wastewater treatment is the fast decline of the permeation of flux or rapid rise in transmembrane pressure (TMP) with time due to membrane fouling [20]. Indeed, fouling has many negative effects on the membrane system resulting in the high capital costs associated with membrane module replacement and operating costs associated with routine membrane cleaning. To prevent or reduce membrane fouling, several research studies have focused on modification and development of membrane materials [21]. Interest in anaerobic membrane technologies for decentralized wastewater treatment has grown rapidly during the past few years. The objective of the current study was to monitor the behavior of flat-sheet woven fiber microfiltration (WFMF) membrane modules in anaerobic conditions for decentralized wastewater treatment and also, the optimization of the system at different flow rates.

2. Materials and methods

The present study was carried out in a full-scale membrane-based septic tank (MBST) having approximately $4\,\text{m}^3$ capacity by using WFMF module with characteristics reported in Table 1. WFMF membrane module was submerged in septic tank (Fig. 1) and operated at different fluxes to investigate the fouling frequency and effects of cleaning protocols. Permeate was withdrawn using a peristaltic pump, and the permeate flow rate and TMP were continuously recorded.

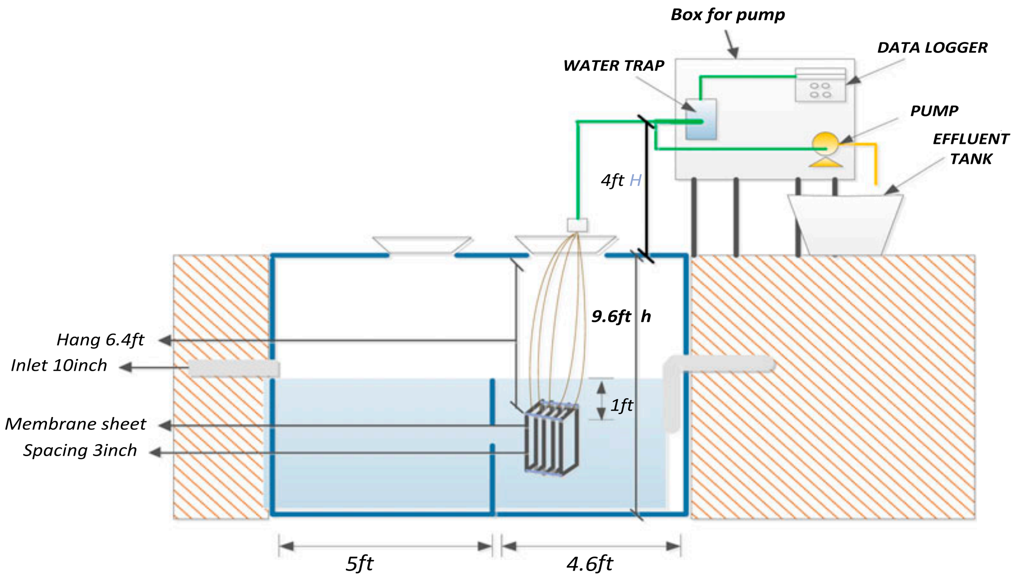
2.1. Maintenance and cleaning of the membrane module

During the membrane modules maintenance, the operation was stopped when TMP reached $-80\,\text{kPa}$. At this point, the module was disconnected from the pump and pressure gauge. Manhole (cover) of septic tank along with module was lifted using steel rods (Fig. 2) for cleaning purposes.

Before physical cleaning, the total hydraulic resistance (R_t) was measured using deionized (DI) water. Membrane modules were washed by spraying tap water and brushing to remove the deposited solids. After physical cleaning, R_m+R_p was determined prior to the chemical cleaning step. Lastly, the membrane

Table 1
Woven fiber microfiltration (WFMF) specifications

Item	Specifications
Membrane type	Dead-end mode, outside-in, flat sheet
Number of membrane modules	5
Filter	2 sheets (fixed) + 1 spacer between the 2 flat sheets
Material	Polyester
Pore size	1–3 μm
Effective size: L × W	$38 \times 28 = 1{,}024\ \text{cm}^2$
Total membrane area	$\frac{5\times2\times1024}{10000} = 1.00\text{m}^2$



H = Height of surface to three way socket (pressure gauge connects)
h = Distance between ground level and water surface

Fig. 1. Immersed MBST system.

Fig. 2. Membrane module along with manhole cover.

modules were chemically cleaned using NaOCl (0.03% w/v) for 6 h, followed by DI filtration for 30 min. Lastly, the intrinsic membrane resistance (R_m) was measured with DI water. Pore blocking resistance (R_p) and cake layer resistance (R_c) were determined using formulas: $R_p = (R_m + R_p) - R_m$ and $R_c = R_t - (R_m + R_p)$. After the completion of cleaning procedure, the membrane module was kept in a clean dry condition for the next filtration run.

3. Results and discussion

3.1. Treatment performance of MBST

MBST treatment performance was determined in terms of chemical oxygen demand (COD), total suspended solids (TSS), ammonium nitrogen (NH_4^+–N) and *Escherichia coli* (*E. coli*) concentrations, and removal efficiencies. Table 2 presents the treatment performance parameters along with the national environmental quality standards (NEQS), Pakistan for sewer line effluent discharge of wastewater. The COD, TSS, and NH_4^+–N removal efficiencies of about 60% were achieved and the effluent concentrations were below the required NEQS with the MBST. These results infer that the MBST satisfies the secondary treatment requirements and any further effluent treatment with either leachate fields or subsurface beds is not required. Moreover, above 99% fecal coliform/total coliform removal suggests that the treated water can be reused locally for horticulture and landscaping.

Table 2
Treatment performance of MBST

Parameters	Units	Influent	Effluent	Removal (%)	NEQS
COD	mg/L	200 ± 25	75 ± 10	50–65	150
TSS	mg/L	320 ± 50	160 ± 50	50–60	400
Fecal coliform/ total coliform	Cfu/ 100 ml	20,000 ± 5,000	10 ± 5	99–99.9	
NH_4^+–N	mg/L	30 ± 5	15 ± 5	40–60	40
pH		7.0 ± 0.5			6.0–10.0
Temperature	℃	25 ± 5			40

3.2. Fouling characteristics of MBST

Membrane fouling was evaluated with the help of TMP profile obtained during membrane filtration. In this study, TMP was monitored under four different fluxes of 2, 5, 8, and 11 L/m^{2}h (LMH) and the filtration operation was stopped when TMP reached 80 kPa. At this stage, the membrane module was taken out of operation for physical and chemical membrane cleaning, meanwhile, performing the membrane resistance analysis to determine total resistance (R_t), cake resistance (R_c), pore-blocking resistance (R_p), and intrinsic membrane resistance (R_m). TMP profiles of the four phases of MBST are shown in Figs. 3 and 4.

At 2 LMH, the MBST system operated continuously for 23 days over which the TMP reached 70 kPa as shown in Fig. 3. During this stage of initial operation, the rate of TMP increase was very low, which cannot be considered as an optimum.

At the end of each filtration run, a significant increase in hydraulic resistance was observed as TMP reached 80 kPa under suction pressure. On the other hand, as operational cycles increase, the irreversible fouling of the membrane increases as shown in Fig. 4. It was found that after each successive operation cycle, the TMP profile trend starts from higher value than the previous due to irreversible fouling. Chemical cleaning was not practiced after the completion of first phase (2 LMH) because membrane module deformation occurred. After continuous operation of 65 days and nine operational cycles, the irreversible fouling increased up to 20% of the overall fouling trend. Moreover, the average filtration durations at 5, 8, and 11 LMH were found to be 8, 7, and 5 days, respectively, which show that flux of 8 LMH is optimum, keeping in view, considerable time for module cleaning procedure and sustainable flux operation. The resistance-in-series model was applied to evaluate the fouling characteristics. The membrane resistance analyses are summarized in Table 3 which represents the resistance values for R_m, R_p, R_c, and R_t after replicate experimental measurements.

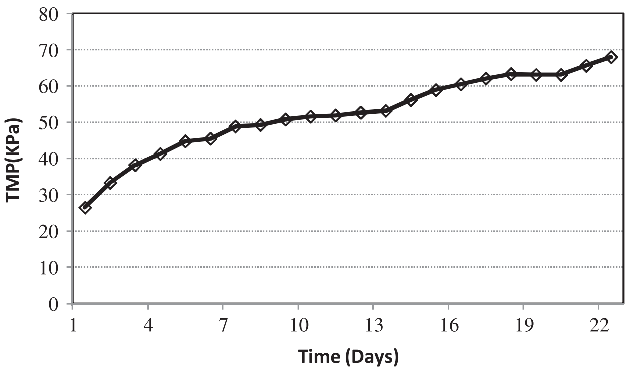


Fig. 3. TMP profile at flux operation of 2 LMH irreversible fouling trend.

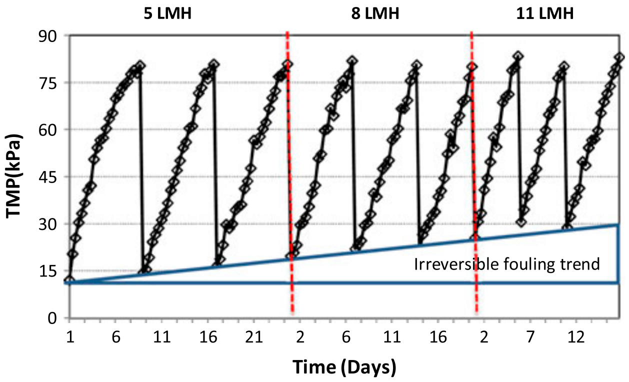


Fig. 4. TMP profile at different flux operations of 5, 8, and 11 LMH.

It was found that the R_p and R_c values increased among consecutive runs under the operational fluxes i.e. 5, 8, and 11 LMH, which indicates that the physical cleaning after each cycle was partially effective in restoring the membrane permeability and removing the fouling irreversibility. The R_c/R_t and R_p/R_t were mostly within the range of 47–57 and 37–44%, respectively, depicting that the cake layer contribution to the total hydraulic resistance was greater compared with pore-blocking resistance.

The chemical cleaning protocol was discontinued after the two LMH runs because the membrane sheet began to detach from the membrane module frame as the binding material between frame and membrane sheet got removed. Deformation of membrane module due to chemical cleaning suggests that the chemical reagent (NaOCl) used for these membrane modules was not suitable.

Table 3
Resistance analysis of membrane modules at different fluxes

Resistances		5 LMH	8 LMH	11 LMH
R_m ($\times10^{12}$ m^{-1})		0.80	0.80	0.80
R_p ($\times10^{12}$ m^{-1})	Run 1	1.65	2.38	3.59
	Run 2	2.40	3.40	3.91
	Run 3	3.61	4.13	4.50
R_c ($\times10^{12}$ m^{-1})	Run 1	2.42	2.86	3.65
	Run 2	2.68	3.86	4.39
	Run 3	3.70	4.60	4.84
R_t ($\times10^{12}$ m^{-1}) Average		7.80	8.41	9.06
R_c/R_t (%)		53.3	56.6	47.3
R_p/R_t (%)		36.9	43.1	43.9

4. Conclusion

The MBST was able to satisfactorily treat wastewater at source and no further wastewater treatment was required to satisfy the NEQS. Effluent of the MBST can be reused for horticulture, landscaping, and any other nonpotable purposes. At the end of each filtration run, significant increase in hydraulic resistance was observed as TMP reached 80 kPa under suction pressure. However, the average filtration durations at 5, 8, and 11 LMH were found to be 8, 7, and 4 days, respectively, which shows that flux of 8 LMH can be optimum, keeping in view, considerable time for module physical cleaning (brushing, washing, and drying) as well as sustainable flux operation. As operational cycles increased, the irreversible fouling of the membrane enhanced. After each successive operational cycle, TMP profile trend started from a higher value of pressure than the previous one at an average increase of 2% in irreversible fouling. Further studies on MBST may include investigation of sustainable and effective chemical cleaning procedure for minimizing irreversible fouling of membranes as well as maintaining the integrity of membrane module itself. Moreover, the design of membrane module with greater filtration area per given tank volume should also be investigated in the MBST.

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