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Surface water treatment using microfiltration for drinking water production in Egypt

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ABSTRACT

Coagulation, flocculation, sedimentation, filtration and disinfection are the widely applied systems for surface water treatment in Egypt. Due to the deterioration of surface water quality and limitation of available land, microfiltration (MF) and ultrafiltration (UF) processes became promising alternatives for conventional surface water treatment. The objective of this paper was studying the performance of full-scale PALL MF system under different raw surface water quality. In addition, the effects of raw water conditioning using alum and powdered activated carbon (PAC) on MF performance in terms of permeate flux and treated water quality was also studied. MF permeate flux decreased with the increase of natural organic matter (NOM) concentration in raw water. MF permeate flux decreased after 20 min of operation from 85 lmh to 77, 70 and 48 lmh at total organic carbon (TOC) concentration of 5, 8 and 15 mg/L, respectively. Addition of coagulant (alum) to raw water significantly improved the MF performance in terms of TOC removal and permeates flux. The TOC removal increased from 25% at zero alum dose to 50% at alum dose of 10 mg/L. The permeate flux increased from 77 lmh at zero alum dose to 95 lmh at alum dose of 10 mg/L. Use of PAC with MF significantly improved the MF performance in terms of TOC removal and permeate flux. After 20 min of the MF operation, permeate flux increased from 75 lmh at zero PAC dose to 80 lmh at 100 mg/L PAC dose. Use of MF coupled with PAC/alum for surface water treatment achieved high effluent quality and significantly improved the TOC removal.

Keywords: Drinking water; Flux; Egypt; Membrane; Microfiltration; PALL; Surface water

1. Introduction

Conventional surface water treatment systems are widely used in Egypt. Typically coagulation, flocculation, sedimentation, filtration and chlorine disinfection processes are used in conventional surface water treatment plant (SWTP) [1]. Due to the industrial, domestic and farming activities, raw surface water quality is deteriorated [2]. The deterioration of water quality is a great challenge for conventional surface water treatment for drinking water production [3]. The conventional surface water treatment offers a limited efficiency for removal of natural organic matter (NOM) [4], synthetic organic compounds (SOCs) and disinfection byproducts (DBPs) removals [5–8]. Achieving high removal of protozoan parasites is also a challenge while using conventional surface water treatment plant [9].

The presence of NOM in the raw surface water sources and its removal in the water treatment plant is the major concern for environmental engineers [10]. NOM in the aquatic environment consists of a wide variety of organic compounds

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that are produced from the decomposition of plants, animal and human residues [11]. It causes adverse aesthetic qualities such as color, taste and odor [12]. In addition, NOM is considered to be a precursor for carcinogenic disinfection byproducts that could be produced during chlorination [13,14].

Due to the increase of pollution load in the surface water streams, microfiltration (MF) and ultrafiltration (UF) are increasingly being considered as alternatives to the conventional surface water treatment processes [15,16]. Compared with the conventional surface water treatment processes, membrane filtration offers several advantages such as no need for chemical agents, good quality of the produced water, less sludge production, compact processes and easy automation [1,17]. MF and UF membranes can effectively remove particulate contaminants, including protozoan parasites such as Cryptosporidium. However, membranes cannot effectively remove dissolved NOM, SOCs and compounds responsible for taste, odor and color [18,19]. Coupling of MF and UF membranes with coagulation or adsorption could effectively improve the processes [20].

The objective of this paper was studying the performance of full-scale PALL MF system under different raw surface water quality (turbidity and NOM). In addition the effects of raw water conditioning using alum and powdered activated carbon (PAC) on MF performance in terms of permeate flux and treated water quality was also studied.

2. Materials and methods

2.1. Pilot plant unit and procedures

All the experiments were conducted using PALL MF pilot plant. The membrane module type and materials are hollow fiber and polyvinylidene diflouride (PVDF), respectively. The membrane pore size is 0.1 micron. Details of the PALL membrane characteristics are presented in Table 1.

The PALL MF pilot plant was installed at SWTP near Mansura city, Dakahlia Governorate, Egypt. The water treatment plant is operated by Dakahlia Company for water and wastewater. The pilot plant was connected with coagulation tank (rapid mix tank) of the SWTP. Fig. 1 shows the process flow diagram of the MF pilot plant that was used in this study.

2.2. Raw water characteristics

Raw water was abstracted from the Damietta branch of the Nile River near Mansura city, Dakahlia Governorate, Egypt. The raw water characteristics are summarized in Table 2.

Kaolin and humic acid were added to the raw water to adjust the turbidity and total organic carbon (TOC) to the required concentration in the raw water.

2.3. Analytical methods

Total coliforms and fecal coliforms measurements were conducted at the National Research Center according to Standard Methods for the Examination of Water and Wastewater of American Public Health Association [21].

Table 1
Characteristics of PALL microfiltration membrane

Membrane material	PVDF
Pore size, μm	0.1
Fiber outer/inner diameter, mm	1.3/0.7
Active filter area	538 ft^2–50 m^2
Module size	6″ diameter x 79″ long
Housing	PVC or ABS
Gasket	EPDM
Type of filtration	Dead-end
Potting material	Silicone epoxy or urethane
Type of pressure	Outside-inside

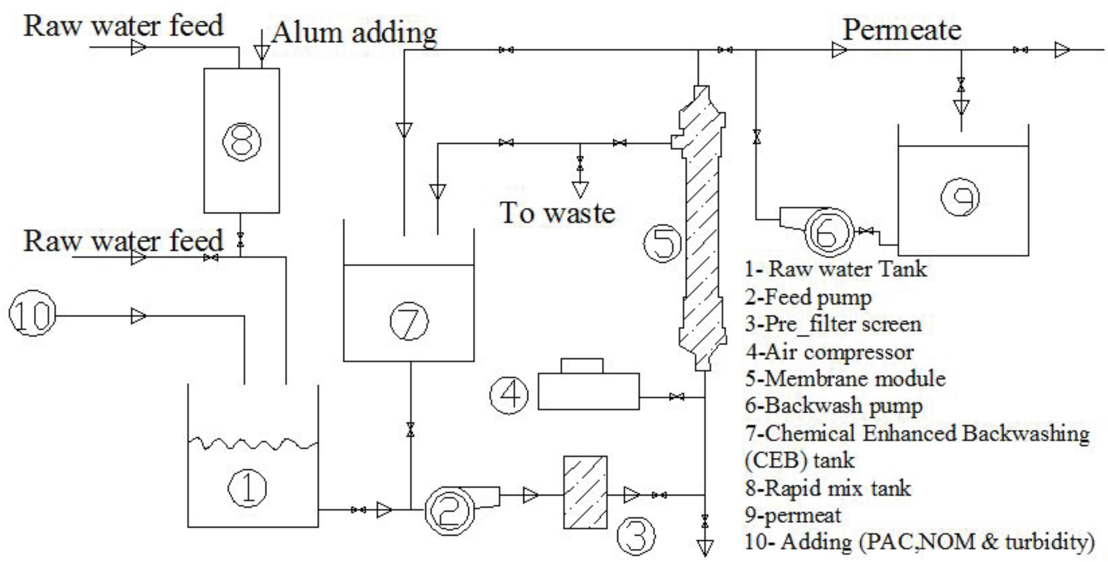

Fig. 1. Process flow diagram of the PALL microfiltration pilot plant.

UV254 was measured using UV spectrophotometer. Turbidity meter model 2100 C (Hach Company, USA) was used for turbidity measurement. Membrane flux, transmembrane pressure (TMP), flow rate, temperature, time were measured by the pilot instruments and monitored online on the pilot plant SCADA system. Fouling rates for the membrane performance were calculated as rate of permeability decline, expressed as normalized flux divided by the TMP (lmh/bar). Commercial PAC adsorbent was purchased from Hangzhou Ruijiang Chemical Co., Ltd. (China).

3. Results and discussion

3.1. Effect of raw turbidity on the MF membrane performance

To study the effect of raw water turbidity on the PALL MF membrane, initial turbidity on the raw water was varied in the range of 10–40 NTU. Raw water without chemical conditioning was used to feed the MF membrane. The system was operated at initial flux of 78 lmh. As shown in Fig. 2, MF permeate flux after 20 min of operation decreased from 78 lmh to 58, 48 and 40 lmh at turbidity of 10, 20 and 40 NTU, respectively.

The decrease of the permeate flux with the increase of the raw water turbidity could be ascribed to the external fouling developed by solid accumulation on the membarne surface [1,17,22]. The external fouling could be removed by the hydraulic backwashing; however, increase of hydraulic backwash frequency could decrease the MF recovery [1].

In terms of the effluent quality, the permeate turbidity was 0.1 NTU which is complying with the local and international regulations.

Table 2
Raw water characteristics

Parameters	Average value
Temperature (°C)	25 ± 4
Turbidity (NTU)	10 ± 3
TOC (mg/L)	6 ± 2
UV254 (1/cm)	0.150 ± 0.03
Fecal coliforms (MPN/100 mL)	200 ± 30
Total coliforms (MPN/100 mL)	$4 \times 10^4 \pm 10{,}000$

MPN – most probable number.

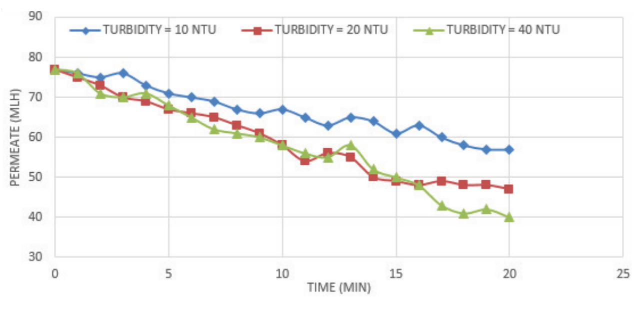

Fig. 2. Effect of initial turbidity on the MF membrane performance in terms of permeate flux.

3.2. Effect of natural organic matter on the MF membrane performance

In order to study the effect of raw water NOM on the PALL MF membrane, NOM in the form of humic acids was added to the feed water. The NOM was measured in terms of TOC. Fig. 3 shows the relation between the membrane flux and the TOC concentration. As shown in the figure, permeate TOC concentrations were 3.14, 5.4 and 8.2 mg/L at raw water TOC concentrations of 4.2, 7.3 and 15.3 mg/L, respectively. The TOC removal efficiencies were in the range of 25%–46%. Increasing TOC removal at high raw water TOC concentration could be ascribed to the blockage of membrane pore that restricting the molecules to pass through the membrane pores [15]. Due to the organics accumulation on the membrane surface, permeate flux decreased with the increase of the raw water TOC concentration. As shown in Fig. 3, permeate flux decreased after 20 min of operation from 85 lmh to 77, 70 and 48 lmh at TOC concentration of 5, 8 and 15 mg/L, respectively. The results show that presence of TOC has a great impact on the development of membrane fouling. This agrees well with the previous reported studies in the literature [15,23–25].

As shown in Fig. 4, hydraulic backwash every 20 min was not able to restore the permeate flux to the initial conditions. Initial flux decreased from 106 to 60 lmh after 20 h operation; hence chemical enhanced backwashing (CEB) frequency should be increased. The declining of initial flux after hydraulic backwashing at high NOM could be ascribed to the type of fouling that could be caused by the NOM. Charge interaction, adsorptive behaviors and diffusive particle transport are reported as the NOM fouling mechanisms [24]. This type of fouling is difficult to be removed by the hydraulic backwashing.

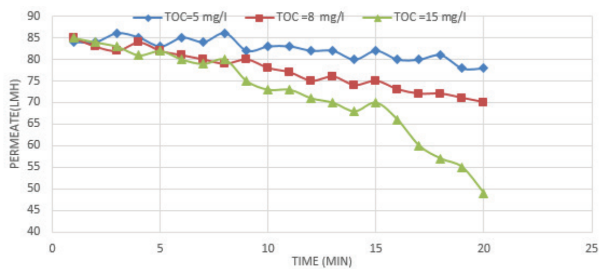

Fig. 3. Effect of initial TOC concentration on the permeate flux of MF membrane.

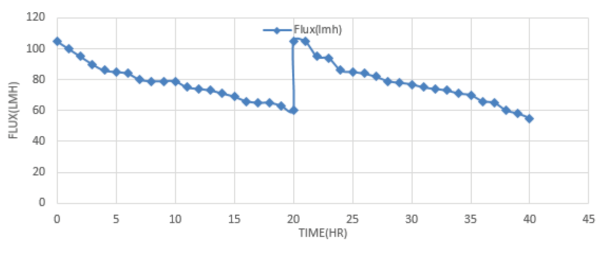

Fig. 4. Permeate flux after hydraulic backwashing and chemical cleaning.

3.3. Effect of coagulation on MF performance

Coagulation of the raw water before MF has been reported as an excellent pre-treatment method for particles and NOM removals, and hence results in significant improvement of the membrane flux [1,22,26].

To study the effect of chemical conditioning of raw water with coagulant (alum) on the MF performance, the system was operated at different alum dose of 0, 6, 8 and 10 mg/L. Initial TOC concentration was 4.2 mg/L. As shown in Fig. 5, TOC removal increased with the increase of alum dose. It is increased from 25% at zero alum dose to 50% at 10 mg/L alum dose. The increase of TOC removal with the increase of alum dose could be ascribed to the charge neutralization and adsorption to metal–NOM complex [27].

To study the effect of coagulant addition on the MF fouling control, permeate flux as a function of operation time was monitored as presented in Fig. 6. As is shown in the figure, the addition of coagulant has a significant impact on the MF performance in terms of membrane flux. The permeate flux increased with the increase of alum dose. It increased from 77 lmh at zero alum dose to 95 lmh at 10 mg/L alum dose. The decrease of permeate flux at zero alum zone could be ascribed to the membrane fouling by NOM. NOM is reported as a primary component of fouling in low-pressure membrane filtration, either solely, or in combination with colloidal particles [27]. As reported in the literature, narrowing of the permeate channel due to the attachment of NOM to the membrane pores could be the fouling mechanism [27,28]. However, increase of permeate flux at 10 mg/L; alum dose could be ascribed to the formation of large size flocs that prevent the fouling of the membrane pores [17]. Increasing of flocs concentration on the membrane surface may increase the adsorption of the NOM and small colloids [26]. This agrees well with the previous studies which reported that coagulation process is an effective method in removing NOM [26,29,30].

3.4. Effect of powdered activated carbon addition on MF performance

PAC is one of the most widely known adsorbent that is used for the NOM removal in combination with MF or UF [31]. To study the effect of PAC addition on the MF performance in terms of TOC removal and permeate flux, PAC dose of 0, 25, 50 and 75 mg/L was added to the raw water before the MF. Initial TOC concentration was 4.2 mg/L. The MF performance in terms of TOC removal is presented in Fig. 7. The TOC removal increased with the increase of PAC dose. TOC removal increased from 24% at zero PAC dose to 51% at PAC dose of 75 mg/L. The increase of TOC removal with the increase of PAC dose could be ascribed to the charge adsorption of organics on the powdered activated carbon [25,24].

The MF performance in terms of permeate flux is presented in Fig. 8. As is shown in the figure, the addition of PAC has a slight improvement on the MF performance in terms of permeate flux. The permeate flux increased with the increase of PAC dose. After 20 min of the MF operation, permeate flux increased from 75 lmh at zero PAC dose to 80 lmh at 100 mg/L PAC dose. Fig. 7 shows also recovery of membrane permeates after the hydraulic backwashing. This could be ascribed to the easy removal of the deposited PAC particles on the membrane surface [32]. The PAC particles are big

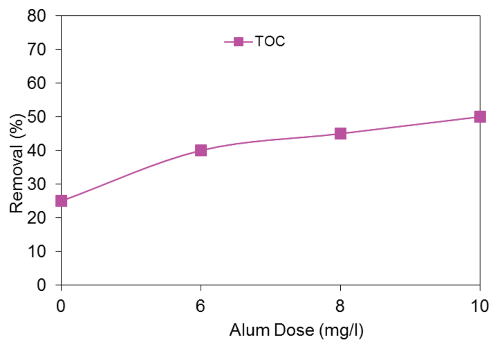

Fig. 5. Effect of coagulant dose on MF performance in terms of TOC removal.

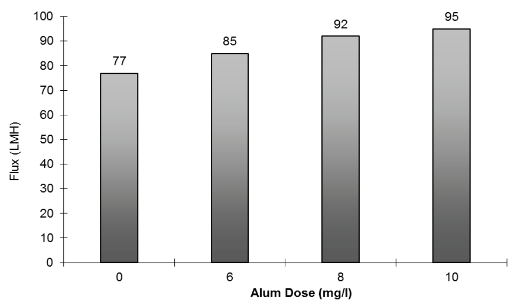

Fig. 6. Effect of coagulant dose on the MF permeate flux.

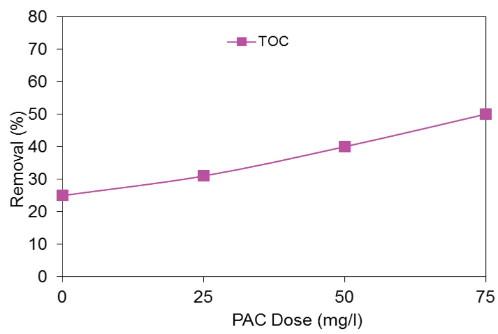

Fig. 7. Effect of PAC dose on MF performance in terms of TOC removal.

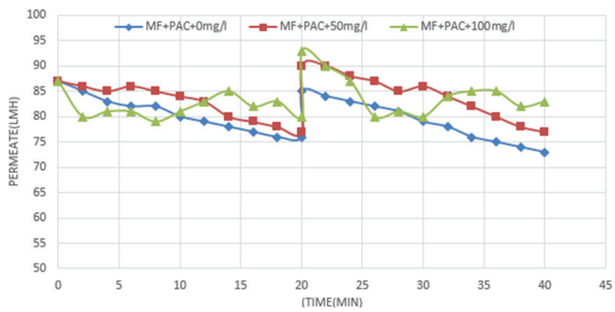

Fig. 8. Effect of PAC dose on the MF membrane performance.

to block the membrane pores and they are deposited on the membrane surface. So, PAC cake structure should not affect the process performance [6].

4. Conclusions

- Use of MF membrane for surface water treatment achieved high effluent quality. The permeate turbidity was 0.1 NTU which is complying with the local and international regulations.
- MF permeate flux decreased with the increase of NOM concentration in raw water; it decreased after 20 min of operation from 85 lmh to 77, 70 and 48 lmh at TOC concentration of 5, 8 and 15 mg/L respectively.
- Addition of coagulant (alum) to raw water significantly improved the MF performance in terms of TOC removal and permeates flux. TOC removal increased from 25% at zero alum dose to 50% at alum dose of 10 mg/L. The permeate flux increased from 77 lmh at zero alum dose to 95 lmh at alum dose of 10 mg/L.
- Use of PAC with MF significantly improved the MF performance in terms of TOC removal and permeate flux.
- Use of MF coupled with PAC/alum achieved high effluent quality and significantly improved the TOC removal.

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