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Simple, Cheap and Low Waste System for Drinking Water Treatment Using Fabricated Polymeric Spiral Wound Ultrafiltration Modules

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Abstract

Simple, cheap and low waste system for drinking water treatment was designed and installed as a pilot system. Ultrafiltration polymeric membranes were prepared using polyvinylchloride and polyvinylidene di fluoride. The membranes were prepared by phase inversion process and were characterized by scan electron microscope, mechanical testing and membrane performance test. Spiral wound polymeric membranes modules were fabricated and used in fabricated pilot system. Continuous tap water stream was used in this experiment for six months. The results indicated that PVC spiral wound membrane module provides high productivity 9.36 m3/d, with organic removal (COD) 100%, blue green algae removal 100%, 95.7% for total algae removal and clear bacteria from water efficiently. The results of this study affirm that none of the water quality parameters (chemical or biological) that were monitored in this study exceeded the Standard Specification for Egyptian Drinking Water.

Keywords: Drinking water; Polyvinylchloride; polyvinylidene di fluoride; Spiral wound module

1. Introduction

Water is the building block of the life for all living organisms. It is very unique substance due to the different physical and chemical characteristics [1-3]. It emerges as a critical aspect for the quality of life and sustainable development [4]. Potable water is necessary for life and thus plentiful and safe water stock must be available to the public [5].

Surface water holds appreciable amount of suspended solids particles, algae, bacteria, organic substances, causing bad smell and taste, so it should be treated before using as a drinking water[6].There are two ways for treating surface water, firstly conventional method includes many processes like clarification (coagulation/flocculation process, sedimentation or dissolved air flotation), sand filters, activated carbon adsorption and disinfection. Second way is the advanced way by using ultrafiltration (UF) membranes [7].

Ultrafiltration membranes able to remove the dissolved macromolecules and small suspended particles from a feed fluid with pore size ranges from 1 to 100 nm. In addition, these membranes can concentrate the bulky components of the feed fluid on one part of the membrane, as the micro solutes and the solvent are drained as they can transfer through the membrane, bacteria and viruses are successfully removed.

The UF membrane serves as a selective barrier retaining particles with molecular weights higher than a few thousand of Dalton (macro solute), while particles with the small sizes (solvent and micro solutes) transfer easily through the membrane pores [8-11] .The range of 1–10 bars is the common operating pressure for UF for the removal of dissolved particles of different sizes and properties [8, 9,11]. Relying on their pore size, UF technology

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is applied for crucial separation processes like treatment of product streams in the food and beverage industry, filtration of colloidal suspensions, recovery of beneficial matters from coating or dyeing baths in the automobile and textile industries and treatment of industrial wastewaters, also in medical, biotechnological industries, paper and dairy industries [12-15].

Most polymeric materials which were used in UF preparation are cellulose acetate due to it has high hydrophilicity and low price, polysulfone and polyethersulfone because they have good pH stability, good oxidation resistance and good intensity. Polyvinylidene fluoride also, has good resistance to oxidation and high mechanical properties. Polyvinylchloride has high flexibility, long lifetime, and highly resistant to chemicals [16]. To improve performance of membrane, there are additives should be added like pore formers, polyethylene glycol and polyvinyl pyrrolidone. The most problems during UF membrane operation is decline in the flux due to fouling of the surface. Many researches were studied, the improvement in the membrane structure during formation to provide chemical and thermal stability, good hydrophilicity, membrane-forming property, microbial corrosion, acid, alkali and oxidation resistance, and good mechanical strength for the produced membrane. However, many modifications can be carried on the membrane surface by different coating ways or using blending between two polymers or nanomaterials to enhance the membrane performance. Also, adjusting backwash system in the installed UF plant to be controlled system depends on the decline of the permeate flux to certain limit that can reduce fouling of membrane and increase lifetime of membrane and reduce chemical using during membrane cleaning [17-19].

In this work simple, cheap and low waste system for drinking water treatment was designed and installed as a pilot system. Ultrafiltration membranes were prepared from main polymers polyvinylidenefluoride (PVDF) and polyvinylchloride (PVC), then rolling them in the form of spiral wound modules. Low cost simple installed ultrafiltration pilot unit composed of carbon filter and ultrafiltration module was used in pilot testing and longtime experiments. The novelty of this work improves the quality of the surface water by using low cost system with high productivity and low waste after backwash step. Also, this system can be used in treatment of surface water that was contaminated by sewage wastewater, which is considered one of the major problems occurs in the villages in third world countries.

2. Experimental

2.1. Preparation of ultrafiltration PVDF and PVC flat sheet membranes

PVDF and PVC membranes were prepared using phase inversion process. The polymer dope solutions of 18% PVDF were dissolved in NMP with 2% of polyethylene glycol (PEG), the mixing process was carried out for 8hrs. The other ultrafiltration membrane was prepared by 16% PVC with 2% PEG which were dissolved in NMP at mixing time 24hrs. The polymeric solutions were cast on nonwoven supports fixed on a glass plate and the casting process was carried out using fabricated large scale casting machine was fabricated in Egyptian workshop, this machine can produce large scale flat sheet membrane with length 110 cm and width 65cm. Table 1 indicates the polymeric solutions compositions and time of mixing.

Table 1: Polymeric solutions composition for prepared membranes.

Membrane Symbol	Composition (Weight percentage)			
	PVDF %	PEG 400 %	NMP %	PVC %
U1	18	2	80	0
U2	0	2	82	16

2.2. Membrane characterization

A. Scanning electron microscopy (SEM)

Scanning electron microscopy (SEM; a JMS-5600 Electron Microscope, Germany) in the central lab, National Research Centre, was used to indicate the images of morphology of produced membranes. The cross-sectional images of membrane were taken using a JEOL 5410 scanning electron microscope (SEM) at 20 kV electron beam intensity.

B. Mechanical properties

Tensile strength and elongation were tested as mechanical properties of prepared flat sheet membranes by mechanical testing system (INSTRON-5500R) using sample area of 25 cm^2.

2.3. Spiral wound membrane fabrication

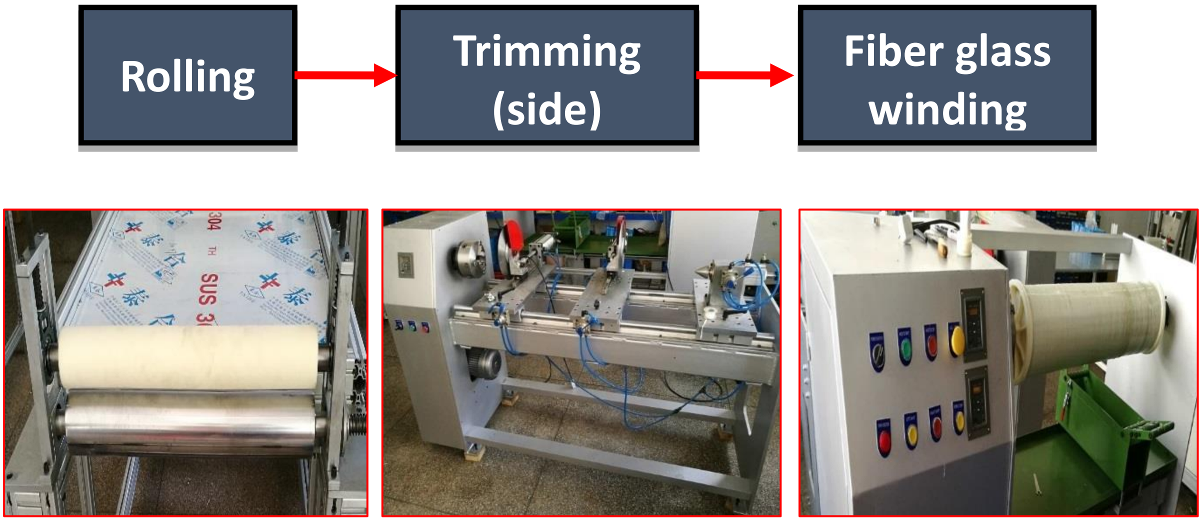

Fig. 1. spiral wound module machines

The prepared membranes were rolled and formed as spiral wound modules for pilot test. National Research Centre, Egypt has spiral wound module fabrication machines, as shown in figure (1). The prepared membranes were cut and adjusted to be 50 cm width and 90 cm long. Six folded membranes were used to prepare spiral wound module 4021. Feed space was used between folded membrane and permeate carrier was used to collect the permeate water to the perforated tube. finally, fiberglass winding machine was used to enhance the module by fiber glass to protect and make the module able to carry pressure.

2.4. Ultrafiltration system design and module evaluation

The system was designed to compose of activated carbon filter as a pretreatment step before ultrafiltration membrane. The activated carbon filter was used to remove dissolved impurities and disinfection byproducts that can make water taste bad. It fabricated from carbonaceous source materials, such as coal, coconuts, nutshells, peat, wood, and lignite, which have networks of submicroscopic pores that provide large surface area per unit volume. Activated carbon filter contains three regions: Micropore region - less than 100 Angstroms, Mesopore region - between 100 and 1,000 Angstroms and Macropore region - greater than 1,000 Angstroms. Ultrafiltration spiral wound module was the next step after pretreatment. The system has flow meter to read the flow during operation as shown in fig.2. The system was connected directly to the tap water. The produced purified water was collected and analyzed.

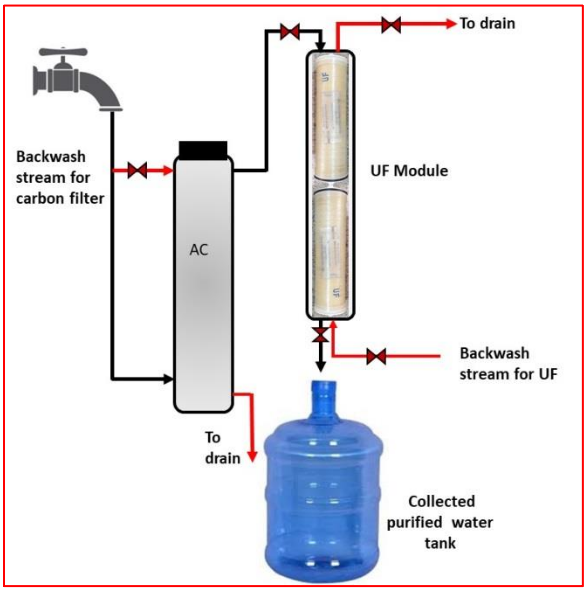

Fig. 2. schematic drawing for UF pilot system

Spiral wound module housing in the pilot system can carry two modules of code 4021 connected by connector. flowmeter was fitted with the permeate line to estimate the flow rates together with the feed pressure through a pressure guage. A pressure plunger pump was attached with the pilot plant to circulate the feed in UF membrane module.PVDF UF membrane modules and PVC UF membrane modules have an effective area of 8.1m2. feeding tap water was continuously fed to the spiralwound module and the backwash was carried out weekly. The collected samples of permeate and backwash were analyzed and the average reading was recorded. The experiments were carried out on two modules PVDF and PVC for 6 months. Fig. 3. indicates the Ultra filtration(UF) pilot unit.

Fig. 3. Installed UF pilot testing machine

2.5. Water analysis

The performance of the system was evaluated by monitoring the quality of the tap water and effluents of treatment units. All physico-chemical and bacteriological examinations (using pour plate method) were carried out according to the American Public Health Association for the Examination of Water and Wastewater [20].

2.6. Identification of algal community structure

Samples for algal identification and count were collected from the inlet and outlet of the unit. Lugol'-iodine solution was used to preserve the algal sample. Subsamples were dispensed into glass Sedgwick-Rafter cells and examined using OLYMPUS CX41 microscope. Algal identification and count has been done according to the main references used in phytoplankton identification [17].

2.7. Toxicity Assay

Toxicity of untreated and treated drinking water was measured in Environmental Microbiology Lab, Water Pollution Department, National Research Centre, using Microtox Model 500 Analyzer I llumino-meter (Modern Water Inc., USA). The Microtox model 500 is in vitro computerized system with self-calibrated photometer and capable for measuring the acute toxicity of water and wastewater within 15 min. The toxicity results were determined either as an effective concentration value (EC_{50}) or as a toxicity unit (TU).

3. Results and discussion

3.1. Membrane characterization

A. SEM

Fig. 4a. illustrates the SEM cross section photos of prepared PVDF membranes (U1), which indicates finger like on the sub-layer and the bottom layer was the compacted structure of nonwoven support. Fig.4b. indicates PVC membrane which has spongy structure with large finger like structure. Addition of PEG leads to formation of fingerlike structure and improve the porosity of the membranes depending on pore size of membranes.

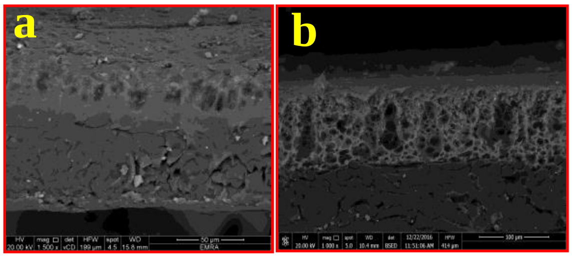

Fig. 4. SEM for prepared membranes (a) U1 (PVDF) and (b) U2 (PVC)

B. Mechanical properties

The mechanical properties of the prepared membranes were investigated. The results indicate that the tensile strength of PVDF membrane was 39.6 kg/m^2 with elongation of 19.2 mm. While, the tensile strength of PVC membrane was 107 kg/m^2 with elongation 16.4 mm.

3.2. Spiral wound module performance

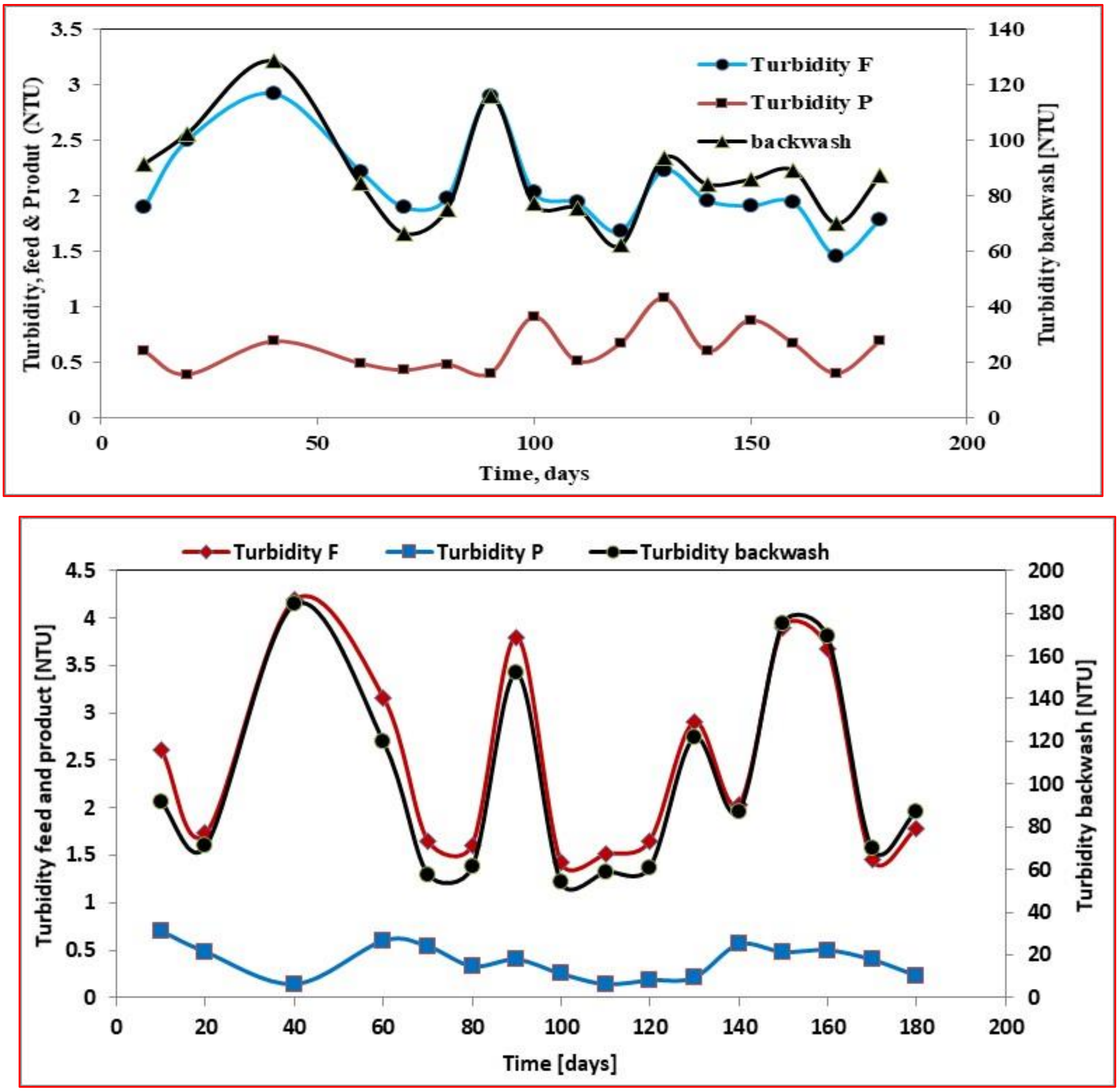

Fig. 5. Turbidity indications of feed, product and backwash for fabricated modules, (a) PVDF, (b) PVC

The performance of PVC membranes spiral wound modules and PVDF membranes spiral wound modules were tested using UF pilot testing unit. Continuous feeding flow rate for two modules during two experiments was fixed at 15L/min. Results of physicochemical characteristics illustrated in Table (2). The results showed that the physicochemical parameters including pH, turbidity, T.D.S., Total Hardness, have been examined. The pH is a critical factor which is important in estimate the acid-base balance of water. In addition, it acts as an indicator for the acidic or alkaline status of water. WHO has recommended maximum acceptable range of pH from 6.5 to 8.5. The recent investigations are 7.2, 7.5, and 7.4 which are in the range of WHO standards. The overall result reveals that the tab water (Feed) and treated water (Product) are within the desirable and suitable range as shown in Table 2. In addition, PVDF and PVC membranes efficiently removed turbidity with removal efficiencies of 91.57% and 84.21 %, respectively. In another study, The PVC-UF membrane effectively reduced turbidity, suspended solid particles and color, with removal efficiencies of 96.41%, 88.33%, and 50%, respectively [21].

EC is measurement of salts dissolved in water to conduct electricity not water salinity. Also, water conductivity is a measure of ability of a solution to conduct electrical current through it and relies on the

Table2: Physico-chemical characteristics' of feeding water, product and backwash

Parameters	Unit	Result of PVDF membranes			Result of PVC membranes			Egyptian Standard 2007
		Feed	P	B.W	Feed	P	B.W	
pH		7.5	7.4	7.4	7.2	7.4	7.7	6.5-8.5
Turbidity	NTU	1.9	0.16	91.5	3.8	0.6	41.6	1
Electric Conductivity	µmohs/ Cm	546	532	562	434	431	444	
Total Dissolved Solids	mg/L	298	293	308	241	240	246	1000
Total Hardness (as $CaCO_3$)	mg/L	186	180	220	152	144	156	500
Calcium Hardness (as $CaCO_3$)	mg/L	110	108	128	90	86	90	350
Magnesium Hardness (as $CaCO_3$)	mg/L	76	72	92	62	58	66	150
Chloride	$mgCl_2/L$	56	56	56	36	36	38	250
Sulfate	$mgSO_4/L$	47.2	47	47.8	46.8	45.3	45.6	250
Nitrate	mg NO_3/L	0.5	0.3	0.6	0.2	0.2	0.3	45
Iron	mg/L	0.16	0.13	2.2	0.2	0.2	7.2	0.3
Chemical oxygen demand (COD)	mgO_2/L	1	0.0	47	4.3	0.0	18	
Biochemical oxygen demand (BOD)	mgO_2/L	0.0	0.0	20	0.0	0.0	8	

concentration of ions and load of nutrients. Electrical conductivity is used to show the total ionized components of water. It is the sum of the cations and anions. The results of EC were 546 and 431which indicates moderate electrical conductivity, implying the existence of balanced level of ionic species. Total Dissolved Solids (TDS) is the critical factor for the potable water. The high TDS content indicates that water is highly mineralized. Acceptable range for drinking water TDS is from 500 mg/l and to 1000 mg/l. The TDS content in the present study is observed in the range of 298 and 240 mg/l. Hardness is a very crucial parameter in reducing the toxic effect of poisonous element. The hardness was found to be in the range of 186 and 144 mg/L in $CaCO_3$. This range is within the acceptable level. None of the samples exceed the maximum permissible limits of 500 of WHO and standards [22]. Other parameters including Chloride, Sulfate, Nitrate, were within range before and after treatment so the membrane has no effect in salts present in water sample. Referring to COD, the membrane removed COD with the percentage of 100%. These results indicated that water produced after the membrane has not been affected permanently and remained under the standard specifications of Egyptian drinking water.

On the other hand, microalgae ultra-filtration by spiral wound membrane: influence of two membrane materials results (Table 3) showed that blue green microalgae were completely retained (100%) and retention in turbidity is appreciably equivalent for each membrane. To reduce membrane fouling periodic backwashing were investigated. Cell concentration was determined by microscopic counting. Table 3 indicates the removal of algae which was 100% for blue green algae for both two membranes PVC and PVDF. While, it was 95.7% of PVC membrane and 87% of PVDF membrane for total algae removal.

Table 3: Algae microscopic counting

Algae group	Result of PVC membranes			Result of PVDF membranes		
	Feed	Product	Backwash	Feed	Product	Backwash
Blue- green algae (Organism/ml)	16	0.0	114	32	0.0	196
Total algal count (Organism/ml)	376	16	2304	440	57	3607

Table 4: Bacteriological and toxicity Assay

Samples	Total bacterial count (CFU/ml)		Total Coliform (CFU/ml)	*Faecal coliform* (CFU/ml)	*Faecal streptococci* (CFU/ml)	Toxicity
	37°C	22°C				
Feed	3	4	ND	ND	ND	
Product	2	3	ND	ND	ND	Nontoxic
Backwash	322	332	ND	ND	ND	

Fig. 5. illustrates the turbidity of feed, product and backwash during operation in 6 months, where Fig. 5a. indicates turbidity for PVDF modules and Fig. 5b. for PVC module. The results indicated that the removal of turbidity of the produced water from both PVDF and PVC reached to 91.5% for PVDF and 87.5% for PVC. Fig. 6. indicates the comparison between the productivity of two modules, where the productivity of PVC was higher than the PVDF, which reached to 9.36 m^3/d compared with PVDF which was 4.75 m^3/d. the zigzag curve is indication for backwash which was carried out every 10 days.

3.3. Bacteriological and toxicity Assay:

Referring to bacteriological examination for water after using membrane, results in table (4) showed that water follows the Egyptian standard specifications (2007). In addition, Toxicity bioassay test showed no toxicity effect for both membranes. This indicates that PVDF and PVC membranes can be used for drinking water safely. Unfortunately, the backwash water of membrane filters contains much more

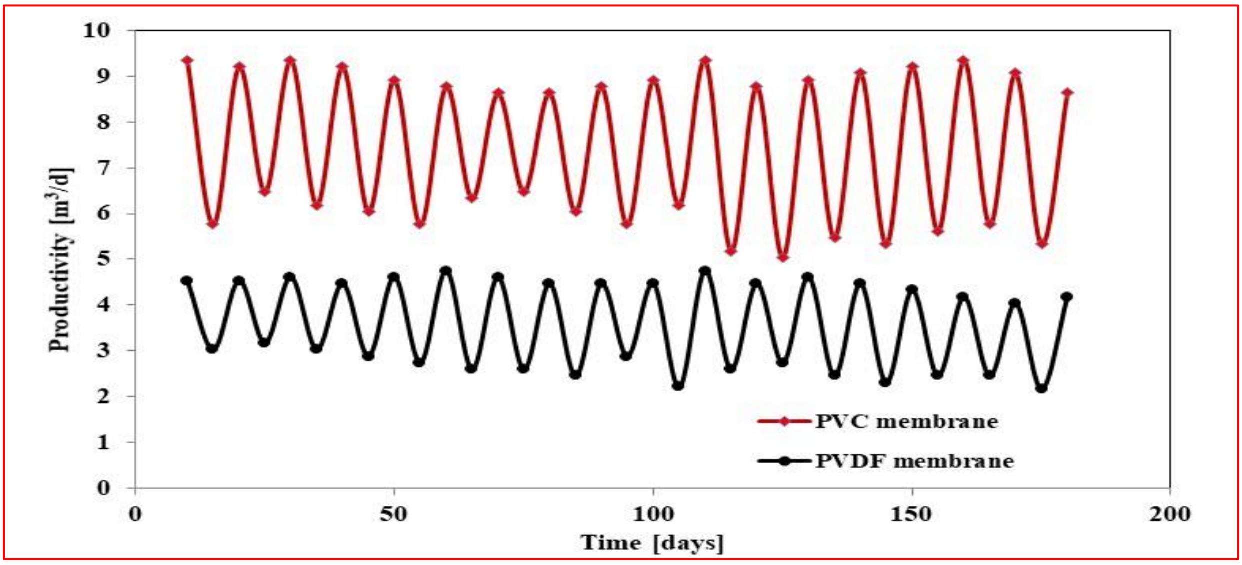

Fig. 6. Modules productivity

bacterial count than that of the feed; therefore it has higher microbiological risk [23-34]. Thus, a period of enough feed and backwash is very important before using once installed the membrane filters. It is not preferred to drink the effluent directly at the first seconds. The filters should be washed and replaced in time during the operation process.

4. Conclusion

Pilot scale system was designed and installed to test the treatment drinking water. PVDF and PVC membranes were prepared for comparison in productivity and separation percentage of turbidity, organic compounds in the form of COD and algae. The removal of algae which was 100% for blue green algae for both two membranes PVC and PVDF. While, it was 95.7% of PVC membrane and 87% of PVDF membrane for total algae removal. PVC spiral wound module provides high productivity than PVDF. PVDF and PVC membranes efficiently removed turbidity with removal efficiencies of 91.57% and 84.21 %, respectively. Toxicity bioassay test indicates no toxicity effect for both membranes. This indicates that PVDF and PVC membranes can be used for drinking water safely.

5. Conflicts of interest

“There are no conflicts to declare”.

6. Acknowledgment

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