Environment Protection Engineering

Vol. 24 1998 No. 1–2

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TREATMENT OF SURFACE WATERS WITH POLYMERIC ULTRAFILTRATION MEMBRANES

Among all the technologies of water treatment, membrane technology appears to be the most promising. The major advantage of this technology is its ability to produce the water of a constant and well adjusted quality. Moreover, membranes remove a broad spectrum of substances, ranging from particles to ions, including bacteria and viruses, and they can operate without any addition of chemicals to raw water.

The paper discusses the results of investigations concerning the application of polymeric ultrafiltration membranes in the treatment of surface waters. The effectiveness of the process was assessed by measurements of the volumetric permeate flux as well as by microbiological and physicochemical analyses.

1. INTRODUCTION

Membrane techniques have not so far been applied in the treatment of potable water, except for reverse osmosis, which has widely been used for water desalination [1], [2]. Due to a different approach to the concept of water treatment for consumer use, and first of all due to more stringent standards concerning the quality of potable water, the techniques in question are currently regarded as alternative processes for water treatment [3]–[9]. Principally, it involves ultrafiltration, but also microfiltration and nanofiltration are taken into consideration. Membrane systems can be used for the removal of impurities from water as separate operations, or in combination with other physical, chemical or biological processes [9].

The necessity to improve the existing water treatment techniques and to introduce new ones resulted from three basic factors [9]:

- gradual deterioration of the quality of water resources caused by the increasing volume of impurities introduced to the environment, which damages natural mechanisms of self-purification,

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- increasing demand for high quality water,
- more stringent legal regulations concerning the quality of potable water and used waters discharged to the natural environment.

Surface waters, as compared to underground waters, are often characterised by the presence of a large amount of bacteria, viruses and another micro-organisms, high turbidity, high concentration of organic substances and the presence of microimpurities such as pesticides, odorants and food additives. Membrane processes applied as single processes are not suitable for efficient treatment due to hydraulic reasons (limited capacity caused by membrane fouling) and inappropriate quality of produced water [3], [4]. Therefore in such cases the ultrafiltration process is combined with oxidation and/or adsorption on powdered active carbon, or nanofiltration is applied [4], [5], [7]. Such systems are applied either directly in the treatment of raw water or after the clarification stage using the classical method.

Comparative studies involving nanofiltration and other treatment systems based on ultrafiltration have been carried out in France [4]. The results show that the combinations of oxidation, adsorption on active carbon and ultrafiltration as well as nanofiltration are the most effective solutions with respect to hydraulic capacity and quality of treated water [4]. The membranes used in the tests had different module configurations, different membrane material, internal fibre diameter and cut-off (table 1) [5].

Table 1

Quality of permeates for various surface water treatment systems using ultrafiltration

Feed	Treatment	Turbidity (NTU)	Coli bacteria removal	20 nm particle removal	DOC removal	UV absorbing substances removal	Pesticides (antrazyne, simazyne)
Raw water	UF	< 0.1	100%	100%	10–20%	10–20%	0
	PAC+UF	< 0.1	100%	100%	40–70%	40–70%	<DL
	O_3+PAC+UF	< 0.1	100%	100%	60–80%	–	<DL
	ZENON UF	< 0.1	100%	100%	50–60%	60–80%	–
Water after clarification	UF	< 0.1	100%	100%	10–15%	10–15%	0
	PAC+UF	< 0.1	100%	100%	20–30%	30–35%	<DL
	O_3+PAC+UF	< 0.1	100%	100%	20–30%	30–50%	<DL
	NF Filmtec	< 0.1	100%	100%	90%	90%	<DL

UF – ultrafiltration through membranes of pore size of 0.01 μm, O_3 – ozonization, PAC – powdered active carbon, ZENON UF – ultrafiltration through membranes of the cut-off range of 4000–500 daltons, NF Filmtec – nanofiltration through membranes from Filmtec, DOC – dissolved organic carbon, DL – detection limit.

The work was aimed to define treatment effectiveness and disinfection of surface water due to the application of polymeric ultrafiltration membranes. The testing involved the surface waters from the treatment station taking water from reservoir and membranes from polyacrylonitrile (PAN) and polysulfone (PSF) of various compactness.

2. EXPERIMENTAL

2.1. APPARATUS AND MEMBRANES

Figures 1 and 2 present the apparatus used for membrane filtration of surface water and for testing the membranes.

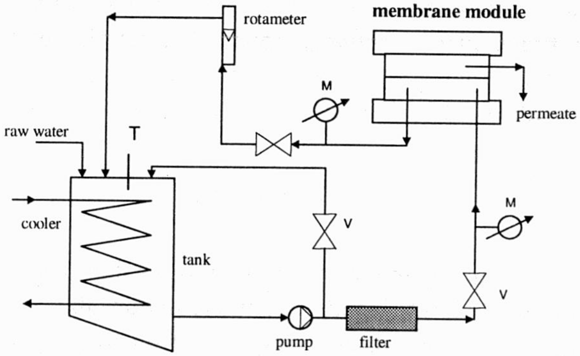

Fig. 1. Diagram of the apparatus for the characterisation of polymeric sheet membranes (M – manometers, V – valves, T – thermometer)

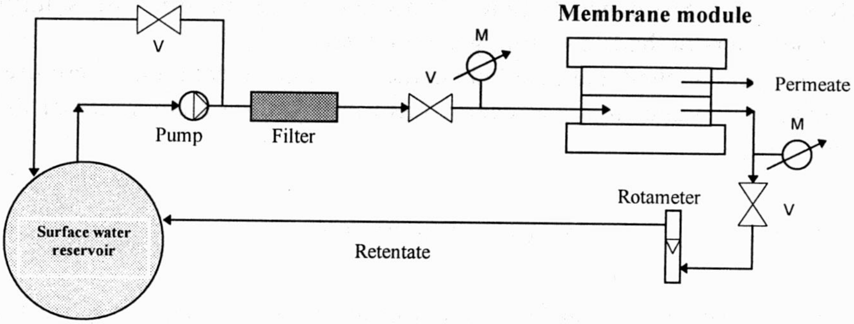

Fig. 2. Diagram of the apparatus for membrane filtration of surface waters (M – manometers, V – valves)

The testing sets consisted of the following elements:

- membrane module,
- coarse filter of the pore size from 50 to 100 μm,

- valves for pressure control,
- set of manometers to measure working pressure,
- rotameter to measure flow intensity,
- tank without an outlet (in the case of testing in a closed cycle), or a system of mains for the supply and draining of water (in the case of testing in an open cycle),
- pumps of the type CN2 of the firm Grundfos,
- cooler (in the case of closed cycle),
- thermometer.

For the testing of water treatment with the application of membrane method, we used the membrane module, type SEPA CF-NP, with the membrane area of 0.0155 m^2 manufactured by the American firm Osmonics. It consists of two plates from plastic material and a membrane placed between them. The whole set is placed in a steel casing which allows us to change the value of pressure acting on the membrane [10]. The system worked with constant linear velocity of 1.5 m/s.

2.2. MEMBRANES

The membranes used in testing were from polyacrylonitrile (PAN), polysulfone (PSF) and the mixture of PAN/PSF, and were made in our laboratory:

- PAN-13 (13% concentration of polymer in the film-forming solution),
- PAN-15 (15% concentration of polymer in the film-forming solution),
- PSF-13 (13% concentration of polymer in the film-forming solution),
- PSF-15 (15% concentration of polymer in the film-forming solution),
- PAN/PSF-15 (15% concentration of polymer in the film-forming solution and the ratio of polymers in the film-forming solution was 10:1).

The preparation method and detailed characteristics of membranes were presented in [11]. These membranes may be regarded as ultrafiltration membranes of different compactness [11].

2.3. OBJECT OF TESTING

For the tests, we selected surface waters from the water intake at Kozłowa Góra (province of Katowice, Poland) situated on the through-flow water reservoir "Świerklaniec". The water is polluted with bacteria, and periodically water blooming can be observed, hence prechlorination and filtration on active carbon were applied at the treatment station at Kozłowa Góra. A flow diagram of the treatment station at Kozłowa Góra is presented in figure 3, where the place of water collection for testing is marked as B. The actual testing was carried out in the closed cycle within a seven month period (X 96–IV 97) (table 2).

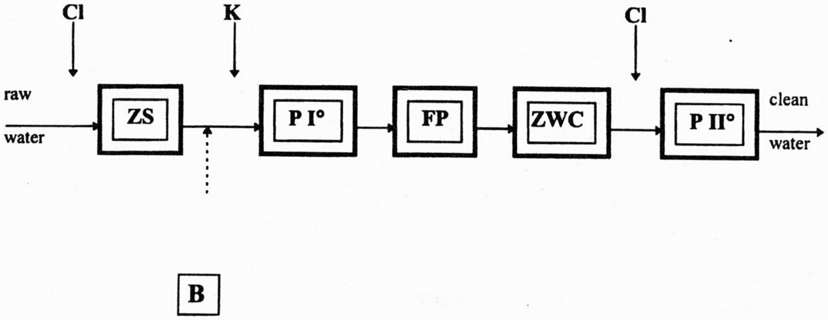

Fig. 3. Flow diagram of the water treatment station at Kozłowa Góra (ZS – raw water tank, K – coagulant, P I° – pumping station I°, Cl – prechlorination and final disinfection, FP – graveller–carbon rapid filters, ZWC – clean water tank, B – place of water collection for testing, P II° – pumping station II°)

Table 2

Dates of the tests carried out involving the surface water at Kozłowa Góra

Membrane type	Date	Temperature of water [K]
PAN-15	21 X 1996	285 (12°C)
PSF-15	25 XI 1996	283 (10°C)
PAN-13	17 XII 1996	279 (6°C)
PAN+PSF-15	8 III 1997	279 (6°C)
PSF-13	20 IV 1997	283 (10°C)

2.4. METHODS OF THE INVESTIGATION

Investigations comprised the following operations:

- conditioning of the membrane, testing with deionized water,
- disinfection of the testing system,
- actual testing involving the ultrafiltration of surface water,
- final testing of the membrane with deionized water.

The membranes were being conditioned by passing deionized water through the system over 16 hours in order to obtain stable operating parameters. The conditioning of membranes was carried out in the closed cycle, i.e. the permeate was being returned to the feed tank. The conditioning parameters were as follows: pressure, 0.1 MPa; temperature, 297 K; and cross-flow velocity, 1.5 m/s.

Testing of membranes with deionized water allowed determination of the following parameters:

- The dependence of the volumetric water flux on the pressure within the range of 0.075–0.25 MPa, in the sections of every 0.05 MPa. The cross-flow velocity of the liquid over the membrane surface was 1.5 m/s.
- Changes of the volumetric water flux over 5 hours under the pressure of 0.2 MPa and cross-flow velocity of 1.5 m/s.

In both cases, the temperature was maintained at the level of 292–295 K. The testing was carried out using the batch method, i.e. after passing over the membrane surface, the water was being returned to the feed tank (figure 1).

Following the testing of the membranes, the systems were subjected to disinfection with 1% solution of dialine (a mixture of acetic acid and peracetic acid with the addition of stabilizers). The disinfection lasted 15 minutes whereafter the systems were washed a few times with deionized water.

The investigations with natural waters were carried out using open system (figure 2). The feed was collected directly from the raw water reservoir, and the permeate was returned to the water reservoir. The testing cycle lasted 10 hours. The filtration was carried out under invariable operating conditions: pressure of 0.2 MPa and cross-flow velocity 1.5 m/s. The temperature of raw water was dependent on the year season in which the testing was carried out and oscillated within 279–285 K. The volumetric permeate flux was measured every 60 minutes. Simultaneously, the samples of the feed and permeate were collected for physicochemical and bacteriological analyses. The samples for analysis were collected after 1, 5 and 10 hours of the operation of the system.

The final testing of the membrane with deionized water was carried out in the same way as the preliminary one. Their main objective was to the determine tear and wear of the membranes (changes in capacity) and the necessity to carry out a regeneration process of the membranes.

2.5. ANALYTICAL METHODS

The efficiency of the membrane filtration process was defined by measuring the volumetric permeate flux in time; also the content of bacteria in raw water and in permeate was being defined. Chemical composition of raw water as well as of the water after filtration was also determined.

The physicochemical tests involved:

- determination of magnesium and calcium concentrations using the titrimetric method with EDTA,
- determination of the concentrations of iron, manganese, chlorides and sulphates with the use of tests of the firm Merck, with the application of a photometer SQ 200 Merck,
- determination of total organic carbon (TOC) using a carbon analyzer of the firm Beckman, type 915-B,

- measurement of turbidity, conductivity, pH by means of respective meters (turbimeter model 800, pH-meter CP-311, conductometer CC-311 of the firm Elmetron),
- determination of dry residue content using the gravimetric method.

The disinfection efficiency of the water tested with various membranes applied was determined by means of the sanitary analysis of water [12]. It consisted in determining the following parameters of the feeds and permeates:

- coli index, i.e. number of *Escherichia coli* present in 100 cm^3 of water,
- coli titre, i.e. the smallest volume of water tested in which the presence of coli group bacteria has been found,
- number of mesophilic bacteria in 1 cm^3 of water,
- NPL , the most probable number of *E. coli* bacteria.

The *Escherichia coli* bacteria were being determined in particular tests making use of the membrane filters' method. 50 cm^3 of water (or smaller volume diluted with the physiological salt, depending on the expected level of pollution, but the total volume of the sample should be 100 cm^3) was being filtered under pressure in the Sartorius apparatus through a cellulose membrane filter of the 0.45 μm porosity. Then the filter was transferred onto the surface of a solidified selective nutrient Endo and placed in a thermostat of the temperature of 37 °C. After 24 h the characteristic shiny colonies of *E. coli* bacteria were counted.

The number of mesophilic bacteria was determined using the method of cast plates with nutrient agar. The 1 cm^3 sample was moved with a sterile pipette onto the sterile Petri dish, then 10 cm^3 of the nutrient was added, and afterwards, after closing the dish, the material inoculated with nutrient was mixed with slow, round movements applied for this purpose. After the nutrient solidified, the dish was turned upside down and put into a thermostat of the temperature of 37 °C for 24 h, whereafter the grown colonies were collected.

NPL, i.e. the most probable number of bacteria in 100 cm^3 of the water tested, is calculated on the basis of the probability calculus and allows us to read out the coli titre from the tables [12]. The analysis with the use of the said method consisted in inoculating the water tested with lactose nutrient (Eijkman's), the inoculation materials were incubated at the temperature of 37 °C for 24–48 h; the result of the inoculation was considered positive when the fermentation of lactose effecting the acidification of the nutrient was determined in the inoculated material (change of colour from green to yellow) as well as the presence of gas in the Durham tubes was stated.

According to Polish Ministry Regulation [13] the disinfected water delivered to water supply systems should meet the following conditions:

- the number of coli group bacteria of the faecal type in 100 cm^3 of the water tested should not be higher than 0,
- the number of coli type bacteria in 100 cm^3 of water should not be higher than 0,

- the number of colonies on the nutrient agar after 24 hours at a temperature of 37 °C should not exceed 10.

3. RESULTS AND DISCUSSION

3.1. TRANSPORT OF DEIONIZED WATER

Membranes can be characterized using various methods as, for example, by determining the transport of deionized water as a function of time or pressure.

For the membranes tested, the influence of pressure on the volumetric flux of deionized water was determined, with constant cross-flow velocity – 1.5 m/s (figure 4), as well as the changes of the volumetric flux of deionized water in time, with constant cross-flow velocities (1.5 m/s) and constant pressure (0.2 MPa) (figure 5).

With the increase of pressure, all membranes had the increased volumetric permeate flux. The highest capacity was exhibited by the membrane PAN/PSF 15, whose flux passing through the membrane was more than twice as high as in the case of membranes from polysulfone. The dependence of the volumetric flux of deionized water on pressure can be expressed by the following equation:

$$J_v = a(\Delta P)^2 + b \cdot \Delta P + c.$$

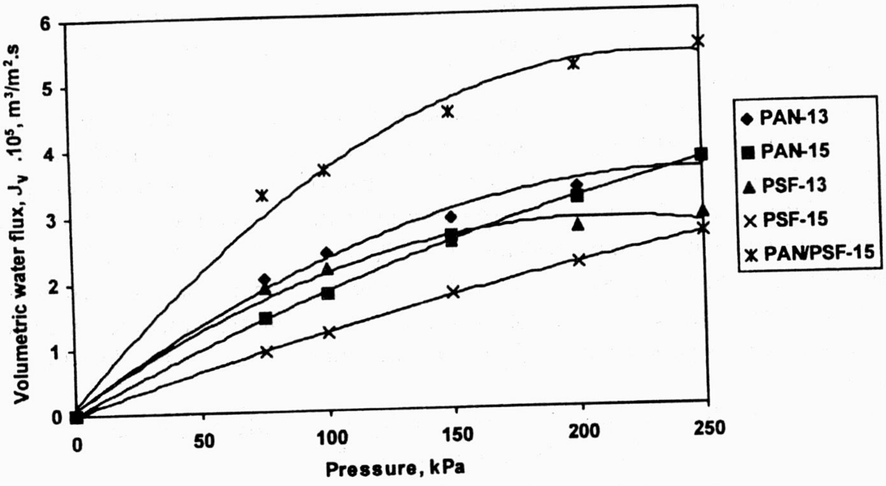

Fig. 4. Experimental dependence of the rate of deionized water transport on pressure and membrane type (cross-flow velocity, 1.5 m/s; temperature, 293–295 K)

Table 3 presents the calculated values of the equation constants and of the determination coefficient (R^2). High values of the coefficient R^2 indicate that there is a good agreement between the measurement results and the above equation.

Table 3

Coefficients of the equation which describes the dependence of the volumetric flux of deionized water on pressure for the membranes tested

Membrane	a	b	c	R^2
PAN-13	– 55.8	28.0	0.082	0.9902
PAN-15	– 22.6	20.5	0.0023	0.9992
PSF-13	– 62.9	26.5	0.083	0.9844
PSF-15	– 11.2	13.3	– 0.0018	0.9998
PAN/PSF-15	– 97.0	45.1	0.125	0.9895

During the operation the capacity of the deionized water flux decreased in time with respect to polymeric membranes, with the extent of this decrease being dependent on the compactness of the membrane. The highest drop of the volumetric permeate flux was reported for the membrane PAN/PSF-15.

The investigations carried out have confirmed that there is a mutual dependence between a type of membrane and the volumetric permeate flux (figures 4 and 5).

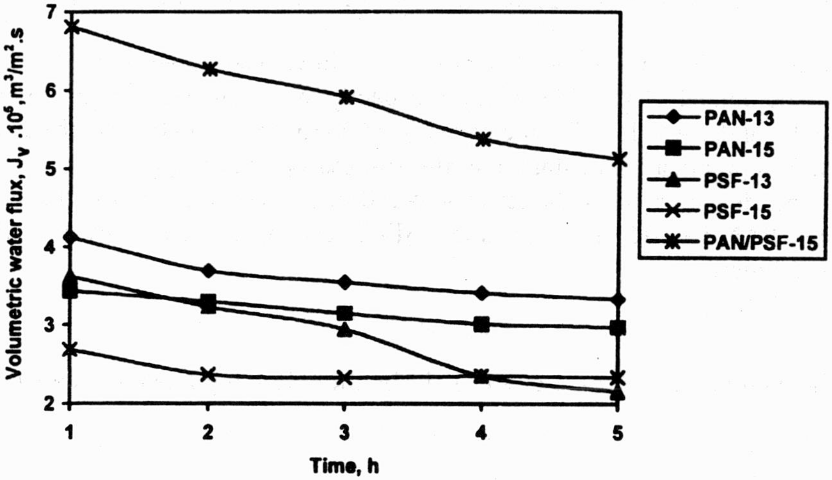

Fig. 5. Dependence of the volumetric flux of deionized water on time (pressure, 0.2 MPa; cross-flow velocity, 1.5 m/s; temperature, 293–295 K)

3.2. TRANSPORT OF SURFACE WATER

The tests on natural surface water were carried out in a 10-hour cycle, under the pressure of 0.2 MPa and with cross-flow velocity over the membrane surface equal to 1.5 m/s. Figure 6 presents the results obtained.

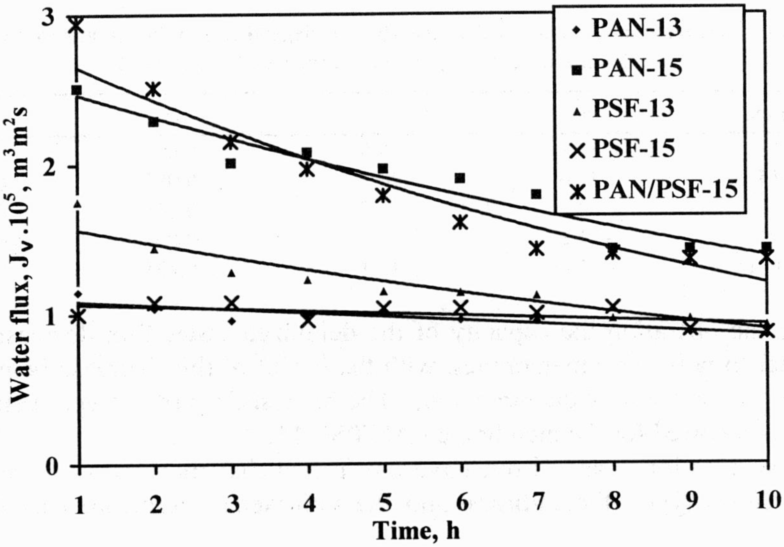

Fig. 6. Dependence of the volumetric flux of water passing through the membrane on time during ultrafiltration of surface water (pressure, 0.2 MPa; cross-flow velocity, 1.5 m/s)

The values of the volumetric flux of surface water were lower than the respective values for deionized water. The highest capacity was exhibited by the membranes PAN/PSF-15 and PAN-15. The membranes PAN-13 and PSF-15 had the lowest capacity – it was practically constant over the 10-hour operation cycle.

The dependence of the volumetric water flux (J_v) on time (t) for the polymeric membranes PAN/PSF-15, PAN-15 and PSF-13 can be described by the following exponential function:

$$J_v = A \cdot e^{-B \cdot t},$$

and for the membranes PAN-13 and PSF-15 by the following linear dependence:

$$J_v = A + B \cdot t.$$

Table 4 presents the character of these equations for particular membranes as well as the values of the determination coefficient (R^2).

The polymeric membranes applied in the ultrafiltration process of surface water were characterized by unstable capacity. The volumetric permeate flux of the membranes PAN-15 and PAN/PSF-15 generally showed a decreasing tendency during the whole test, i.e. over 10 hours, although with respect to the whole operating time, the said capacity was higher as compared to the remaining membranes. And the membranes PAN-13, PSF-13 and PSF-15 were characterized by more stable capacity, but with considerably lower values of J_v.

Table 4

Equations which describe the dependence of the volumetric flux of surface water on the time of ultrafiltration process

Membrane	Equation	R^2
PAN-13	$J_v \cdot 10^5 = -0.0156 \cdot t + 1.112$	0.8254
PAN-15	$J_v \cdot 10^5 = 2.63 \cdot e^{-0.0639 \cdot t}$	0.9266
PSF-13	$J_v \cdot 10^5 = 1.66 \cdot e^{-0.0622 \cdot t}$	0.9156
PSF-15	$J_v \cdot 10^5 = -0.0256 \cdot t + 1.086$	0.4185
PAN/PSF-15	$J_v \cdot 10^5 = 2.89 \cdot e^{-0.0875 \cdot t}$	0.9344

R^2 – determination coefficient.

Relatively great differences of the volumetric flux of natural water with respect to the capacity of deionized water were probably effected by lower operating temperatures of surface waters (table 2). For example, the filtration of surface water through the membrane PAN-15 was carried out at the temperature of 12 °C, and with respect to the membrane PAN-13 – at the temperature 6 °C, which is twice as lower. Therefore the surface water flux of the membrane PAN-15 was higher than that of PAN-13, whereas for the deionized water it was the other way round (figure 5).

As it has already been mentioned, the permeate flux during the ultrafiltration of surface water had lower values than in the case of deionized water. It was caused by the presence of micropollutants and bacteria in raw water, which effect clogging of membrane pores (fouling).

A typical change in the capacity of ultrafiltration membranes as the function of time is presented schematically by figure 6 (membrane PAN/PSF-15). Initially the drop is rapid, and then the flux assumes a semi-constant value. It is effected by the deposition of particles on the membrane surface. The resistance of the polarization layer (gel layer) is increasing until the moment when equilibrium is achieved between the transport of the particle towards the membrane and the backward transport. A respective limiting permeate flux is independent of the membrane type and is approximately proportional to the coagulation rate along its surface, but it depends at the same time on the type (character) of pollutants present in water. However, this model cannot be applied in the prediction of the slow long-term drop of permeate flux, since fouling is difficult to define in terms of quantity [4].

From the economic viewpoint, the practical permeate flux observed in the equilibrium state is relatively low. It necessitates the application of methods enhancing the capacity of membranes. Backflushing restores the initial value of the permeate flux of hydrophilic ultrafiltration membranes, but for the hydrophobic or microfiltration membranes the restoration of the initial capacity is lower or does not take place at all. The investigations carried out on the long-term basis and involving various types of water have proved that the constant permeate flux can be maintained at the level which can be regarded as economic, without the necessity to apply chemical cleaning of the membranes. Hydrophilic membranes are less sensitive to fouling than hydrophobic ones due to the penetration of particles to the inside of membrane pores [3]–[5], [7].

3.3. FOULING AND REGENERATION OF MEMBRANES

Final testing of membranes with deionized water was aimed to compare the transport properties of membranes working with natural waters and new membranes. This helped to establish if the fouling of membranes had taken place and if their regeneration was required.

Figures 7–9 present the dependence of the volumetric flux of deionized water on time for new membranes as well as for the membranes after 40 hours of operation and on the permeate flux of surface water. The results obtained from the tests were presented for 5-hour measurement cycles.

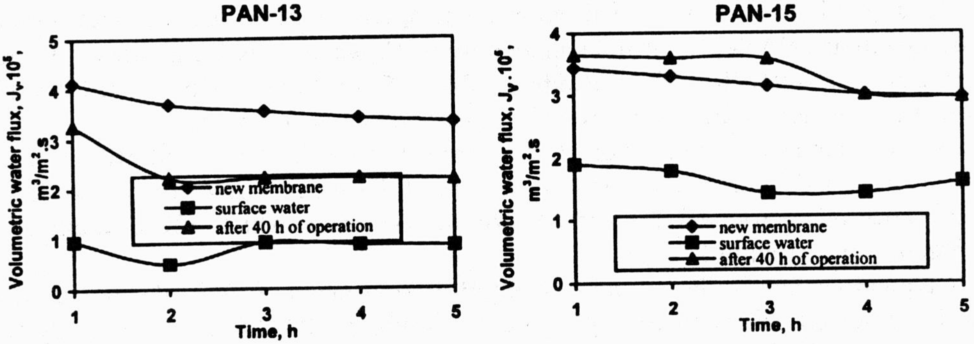

Fig. 7. Dependence of the volumetric flux of deionized water on time for new membranes and after 40 hours of operation and on the permeate flux of surface water (PAN membranes; cross-flow velocity of water, 1.5 m/s; pressure, 0.2 MPa; testing time, 5 h)

Having assessed the volumetric permeate flux for deionized water before and after testing a raw water, the following conclusions can be drawn:

- the highest drop of the volumetric permeate flux during the tests with surface water, as compared to preliminary testing with deionized water, was exhibited by the membrane PAN/PSF-15,

- the smallest differences in the values of volumetric permeate flux of deionized water before and after tests with natural surface water were recorded for the membranes PSF-15, PAN-15 and PSF-13.

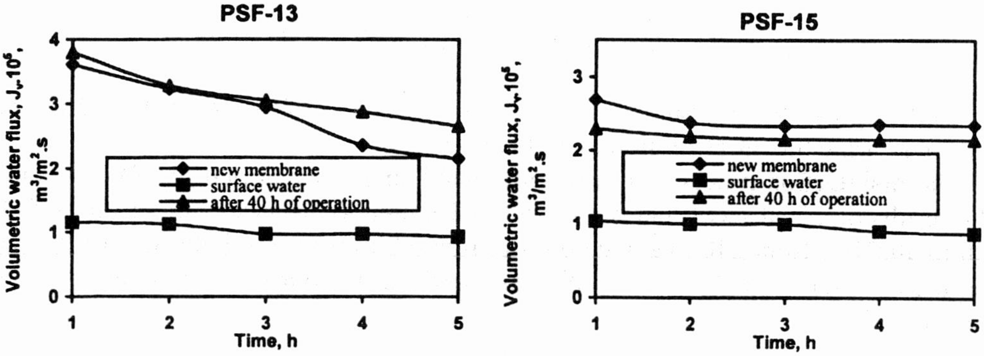

Fig. 8. Dependence of the volumetric flux of deionized water on time for new membranes and after 40 hours of operation and on the permeate flux of surface water (PSF membranes; cross-flow velocity of water, 1.5 m/s; pressure, 0.2 MPa; testing time, 5 h)

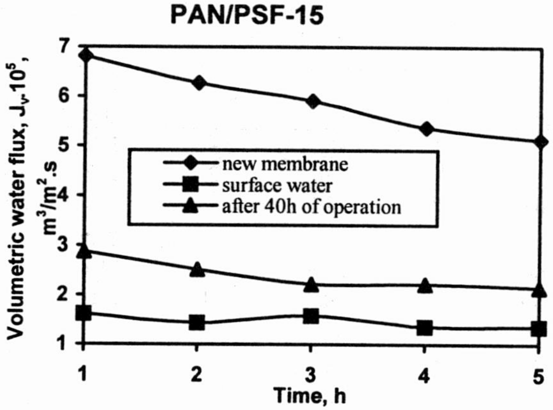

Fig. 9. Dependence of the volumetric flux of deionized water on time for new membranes and after 40 hours of operation and on the permeate flux of surface water (PAN/PSF membranes; cross-flow velocity of water, 1.5 m/s; pressure, 0.2 MPa; testing time, 5 h)

We can therefore voice the opinion that the recovery of the capacity similar to the initial one is more effective for hydrophobic membranes (PSF) and more compact ones (PAN-15). The regeneration of membrane surface with dialine is for the said membranes more effective.

The obtained results involving faster filtration rates (volumetric permeate flux) were effected by the opening of membrane pores due to carried out disinfection with dialine and due to washing out of impurities by means of a turbulent flow of the solution over the membrane surface.

3.4. ASSESSMENT OF THE DISINFECTION EFFECTS

Table 5 presents the results of bacteriological testing of raw waters and permeates obtained during the ultrafiltration of surface water.

The disinfection process on polymeric membranes was carried out for 10 hours. The results obtained – coli index from 60 to 10, number of mesophilic bacteria from 320 to 30, NPL from 240 to 2 and coli titre from 62 to 0.1 – are indicative of the fact that the raw water was heavily polluted and unfit for the purposes involving the food industry [13].

Table 5

Disinfection results of surface water

Membrane type	Time [h]	Coli index in 100 cm^3		Number of mesophilic bacteria in 1 cm^3 after 24 h		NPL in 100 cm^3		Coli titre calculated as 100/NPL	
		Raw water	Permeate	Raw water	Permeate	Raw water	Permeate	Raw water	Permeate
PAN-13	1	40	–	80	–	240	–	0.4	–
	5	62	0	36	3	240	<5	0.4	>20
	10	63	0	36	3	240	<5	0.4	>20
PAN-15	1	60	–	200	–	240	–	0.4	–
	5	60	0	260	1	240	<5	0.4	>20
	10	60	0	205	1	240	<5	0.4	>20
PSF-13	1	50	–	200	–	4	–	25	–
	5	50	0	210	0	2	<5	25	>20
	10	45	0	250	0	4	<5	23	>20
PSF-15	1	60	–	320	–	240	–	0.4	–
	5	50	4	220	4	130	8	0.8	12.5
	10	10	0	200	4	100	<5	0.1	>20
PAN/ PSF-15	1	30	–	60	–	23	–	4	–
	5	30	6	30	15	23	6	4	17
	10	30	8	30	20	20	6	4	17

The disinfection efficiency of particular membranes was high with respect to both *E. coli* bacteria and mesophilic bacteria. The former were removed to a very high degree since the retention coefficients reached the value of 100% practically for all membranes except for the membrane PAN/PSF-15 which did not remove *E. coli* bacteria to the level required [13]. Also the removal of mesophilic bacteria was high and reached 84–100% (except for PAN/PSF-15 where the mesophilic bacteria were removed in 34%).

The tests carried out have proved the thesis that membranes are an effective barrier against bacteria and can successfully be applied instead of chemical methods being criticised recently. Coli type bacteria and mesophilic bacteria were removed practically in 100%. The water, which passed through the membranes, satisfied the conditions required for consumption or economic purposes in view of infection hazards (coli indexes obtained in permeates were lower than those required by respective regulations [13]). Water subjected to the process was characterized by variable bacteriological load (different year seasons). Basing on the results obtained, it seems that the membranes of polymeric type are slightly inferior to ceramic membranes in view of the capability to retain bacteria of various types [14].

3.5. PHYSICOCHEMICAL TESTS

The results obtained involving the ultrafiltration treatment of water with the application of all five membranes tested are presented in tables 6 and 7.

Table 6

Results of physicochemical tests of raw water and permeates obtained during the ultrafiltration through membranes from polyacrylonitrile

Water loading factor	Membrane PAN-13			Membrane PAN-15			Membrane PAN/PSF-15		
	Raw water	Permeate	R^* [%]	Raw water	Permeate	R^* [%]	Raw water	Permeate	R^* [%]
pH	7.7	7.8	–	7.8	7.9	–	7.7	7.9	–
Mg, mg/dm^3	76.85	65.25	13.9	46.6	38.9	16.5	59.3	58.3	1.69
Ca, mg/dm^3	86.6	78.55	9.30	51.3	44.8	12.7	67.3	62.5	7.13
Fe, mg/dm^3	0.05	0	100	0.19	0	100	0.03	0	100
Mn, mg/dm^3	0.15	0	100	0.11	0	100	0.19	0.08	57.9
Chloride, mg/dm^3	15.0	15.0	0	25.0	25.0	0	18.0	18.0	0
Sulphate, mg/dm^3	59.0	45.0	23.7	80.0	60.0	25.0	113	86.0	23.9
Conductivity, mS/cm	0.233	0.178	23.6	0.228	0.213	6.58	0.273	0.273	0
Dry residue, mg/dm^3	300	257	14.3	280	214	23.6	333	315	5.41
Total carbon, mg/dm^3	38.8	28. 9	25.8	45.0	25.5	43.3	30.4	26.9	11.5
Turbidity, NTU	4	0.1	97.5	6.5	0.05	99.2	2.3	0.16	93.0

[*] *R* – retention coefficient.

With respect to all the membranes investigated the following observations were gathered:

- iron and manganese were removed completely, except for the membrane PAN/PSF-15, which is vital with respect to such applications as water treatment and disinfection,
- turbidity was removed to a very high degree (91–97%),
- calcium and magnesium were removed only slightly (2–20%), depending on the type of membrane,
- the removal of chlorides from the water tested was not observed, but the sulphates were removed in 16–32%,
- conductivity and dry residue of the surface water were reduced to the level dependent on the compactness of the membrane (6–28%),
- the reduction of total organic carbon was satisfactory (within 26–40%), except for the membrane PAN/PSF-15.

Table 7

Results of physicochemical tests of raw water and permeates obtained during the ultrafiltration through membranes from polysulfone

Water loading factor	Membrane PSF-13			Membrane PSF-15		
	Raw water	Permeate	Retention coefficient	Raw water	Permeate	Retention coefficient
pH	8.1	8.1	–	7.75	7.85	–
Mg, mg/dm^3	43.8	39.8	9.13	80.7	73.9	8.43
Ca, mg/dm^3	59.3	46.5	21.6	93.0	77.0	17.2
Fe, mg/dm^3	0.18	0	100	0.28	0	100
Mn, mg/dm^3	0.02	0	100	0.30	0	100
Chloride, mg/dm^3	17.0	17.0	0	15.0	15.0	0
Sulphate, mg/dm^3	72.0	49.0	32.0	89.0	75.0	15.7
Conductivity, mS/cm	0.190	0.178	6.31	0.228	0.202	11.4
Dry residue, mg/dm^3	295	240	18.6	307	219	28.7
Total carbon, mg/dm^3	29.5	21.2	28.1	38.5	23.4	39.2
Turbidity, NTU	3.5	0.3	91.4	6.0	0.06	99.0

The obtained results of physicochemical determinations allow for the application of membranes in the treatment and disinfection of potable water since all indexes comply with the conditions to be observed for potable water and water for economic purposes [13].

4. CONCLUSIONS

- The tests showed that the highest volumetric flux of deionized water was characteristic of the membranes obtained from the mixture of polymers PAN and PSF (PAN/PSF-15).

- The volumetric permeate flux was increasing together with the increase of transmembrane pressure.
- The volumetric permeate flux for the (raw) water tested is lower than the flux of deionized water. It is caused by the fact that raw water contains more substances which are retained by the membranes and its operation temperature is lower.
- The decrease of the volumetric permeate flux as the function of time, both for deionized water and raw one, is caused by the pressure-effected compression of membrane pores and clogging of the micropores of the membrane.
- Higher operating stability with raw surface water was exhibited by the membranes PAN-13 and PSF-15. It results both from the compactness of membranes and operation temperature.
- For all the membranes investigated the retention coefficients of iron, manganese and turbidity were very high.
- The removal of total organic carbon was within the range from 26 to 40%, except for the membrane PAN/PSF-15.
- Other indexes of water loading were removed to a small degree.
- Microbiological tests have shown that membranes are an effective barrier against coli type bacteria and mesophilic bacteria.
- The values of coli titre obtained in permeates were always lower than those specified in the standards, except for the membrane PAN/PSF-15.
- The value of each of the indexes investigated in permeate is in agreement with standards for potable water.
- The results obtained confirm our earlier studies carried out for underground waters that membrane techniques may successfully be applied instead of chemical treatment methods [15].

The work has been sponsored within the Research Project No. 7TO7G 015 financed by the State Committee for Scientific Research in Warsaw in the years 1996–1998.

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UZDATNIANIE WÓD POWIERZCHNIOWYCH ZA POMOCĄ ULTRAFILTRACYJNYCH MEMBRAN POLIMEROWYCH

Ze wszystkich technologii uzdatniania wody najbardziej obiecujące są technologie membranowe. Główną zaletą tych technologii jest możliwość produkcji wody o stałych parametrach i wysokiej jakości. Ponadto podczas procesów membranowych usuwa się zanieczyszczenia o wielkości od jonów do cząsteczek, w tym bakterie, wirusy, i mogą one być prowadzone bez dodatku substancji chemicznych do surowej wody.

Przedstawiono wyniki badań związanych z zastosowaniem ultrafiltracyjnych membran polimerowych do uzdatniania wód powierzchniowych. Efektywność procesu oceniano, mierząc objętościowy strumień permeatu i dokonując analizy mikrobiologicznej i fizykochemicznej.