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Treatment of Natural Waters Using Capillary Membranes

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Abstract

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 water with a constant and well adjusted quality. Moreover, membranes remove a wide range of substances, ranging from particles to ions, including bacteria and viruses, and they can operate without any chemical addition to raw water.

This paper presents the results of investigations concerning the application of capillary microfiltration (polypropylene) and ultrafiltration (polysulfone) membranes for the purpose of treatment of natural water. The effectiveness of ultra- and microfiltration was assessed by volumetric measurements of the permeate flux as well as by microbiological and physico-chemical analyses.

Keywords: Natural waters; membrane water treatment; ultrafiltration; microfiltration; capillary membranes

Introduction

Due to an extensive pollution of natural waters, the supply of water for public use is becoming a serious social issue. Potable water as well as water used for industrial purposes should meet respective bacteriological standards and should have respective physicochemical properties [1]. To meet these requirements, it is necessary to operate the process of water treatment, and the disinfection process being a part thereof. The main objective to apply disinfection is to remove bacteria and viruses left in water after the main technological process of water treatment had been completed, to meet respective standards, and to ensure conditions which would prevent the development of such bacteria or viruses in the water supply system.

Chlorination is the most common method of water disinfection. Apart from gaseous chlorine, chlorine compounds are also applied, mainly sodium or calcium chlorate (I) as well as chlorine dioxide [2]. The role of chlorine in the disinfection process consists of oxidizing organic compounds present in water and destroying microorganisms. The negative effect of the application of chlorine is the formation of chloroorganic compounds. The basic ones formed during the process are trichloromethane, tribromomethane, dichlorobromomethane, and others. The said compounds are strongly toxic and therefore it is recommended to avoid their presence in potable water. The chlorination of waters containing lignins or humic substances may result in the formation of an exceptionally mutagenic compound known under the symbol MX (3-chloro-4-(dichloromethylo)-5-hydroxy-2(5H)-furane) [3,4]. Ozonation is an alternative chemical method of water disinfection [2]. In this process, air saturated with ozone is introduced to water, and after its decomposition into molecular and atomic oxygen it shows bactericidal properties. The ozone also effects partial decomposition of humic compounds, phenols and other chemical compounds.

The disinfection process is also complemented with physicochemical methods, such as treatment with ultraviolet radiation, with ultrasound [2], and recently, membrane methods, principally micro- and ultrafiltration [5-8]. Semipermeable membranes constitute a physical barrier for microorganisms, so the water passing through such membranes is totally pure with respect to bacteria. There are also other advantages arising from membrane filtration of water, such as: invariable quality of produced water, considerably smaller quantity of chemicals added to the water, easy process development (module system), a possibility to run the process in a continuous mode in mild environmental conditions, and lower consumption of energy as compared with other treatment techniques [9-10].

This paper presents investigative results involving the membrane filtration of well waters and surface waters with the application of two modules with capillary membrane made of polypropylene (type: Aceurel 1800) and made of polysulfone (type: Euro-Sep). The investigation cycle comprised conditioning and testing of the membrane, actual treatment with invariable operation parameters, final characterization of the membrane, and microbiological and physicochemical assessment of the feed and permeate.

Experimental

Apparatus and Membranes

The investigations were carried out using a large-scale laboratory membrane installation provided by the firm "EURO-SEP" (Poland), whose schematic diagram is presented in Fig.l.

Characteristics of the installation:

- capacity: 5-200 dm^3/h,
- number of modules: 1
- working temperature in the circulation system: 5-40°C
- max. pressure: 0.2 MPa,
- dimensions: length - 1200 mm, width - 600 mm, height - 1600 mm,
- compressed air parameters during backflushing: pres sure 0.6 MPa, demand ca. 50 dm^3/h,
- method of control - manual

The installation can work in the feed-and-bleed mode and continuous mode.

In the feed-and-bleed mode, raw water fed to the container is equal in volume to the volume of obtained permeate. The feed pump supplies raw water through a candle filter, which protects the membrane against coarse impurities, to the ultrafiltration module. Permeate is taken from the module and passed to the backflush container, and after the latter has been filled up, it is passed to the permeate container. Retentate is returned to the raw water container. In the open-flow system, raw water is supplied in the continuous mode to the container feeding the system, and its volume is equal to the volume of obtained retentate which is not returned to the raw water container but is taken out from the system.

Backflushing is effected by a compressed air container and a system of electromagnetic valves. The time and frequency of backflushing can be set on a digital time relay. During backflushing, the relay gives a signal effecting the

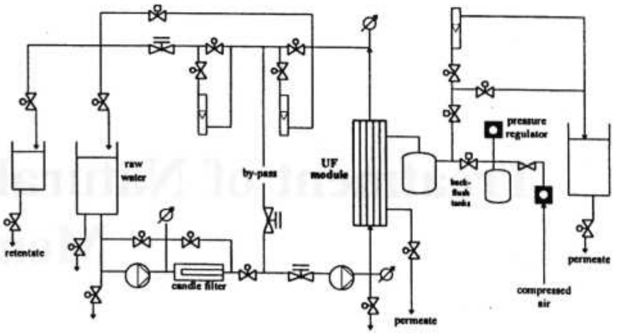

Fig. 1. Diagram of the system used in the investigations involving the filtration process with the application of capillary membranes.

opening of the electromagnetic valve whereafter the compressed air present in the backflushing container dislocates the filtrate out of the container and pumps it through the membrane walls in the direction opposite to the direction of the actual membrane filtration under way. At the same time the cut-off valve for the filtrate flow-out to the permeate container shuts off, and the valve for retentate flow-out opens up. The backflushing having been completed, the valves return to their initial position, and the container is again filled up with compressed air [11].

The testing was carried out using a microfiltration module with capillary membranes from polypropylene (PP) and an ultrafiltration module with capillary membranes from polysulfone (PSf)- The characteristics of the modules are presented in Table 1.

Methodology of Testing

For the purposes of testing, underground natural water containing coli-type and mesophilic bacteria was selected from an individual well in Gliwice-Zernica (Poland). The testing was carried out in February 1997. The testing cycle of surface water involved the water intake in Kozlowa G6-ra (Poland) on the through-flow water reservoir "Swierklaniec". The water in question also contains bacteriological impurities, and from time to time algae blooming can be observed; therefore, prechlormation and pretreatment on active carbon was applied at the treatment station. The flow chart of the water treatment station at Kozlowa Gora is presented in Fig. 2, where the place of water collection for

Table 1. Characterization of modules used in the investigations (data from manufacturer)

Properties	Polypropylene module	Polysulfone module
module type	PRIMA HD type DN50/0.5/1.8	ULTRA-5 type DN50/0.5/6008
module dimensions	DN 50 x 500 mm	DN 50 x 500 mm
surface area of the membrane	0.48 m^2	1.17 m^2
membrane type	capillary ACCUREL® K1800	capillary SPS6008
membrane material	polypropylene	polysulfone
capillary number	190	1056
inner capillary diameter	1.8 mm	0.8 mm
wall thickness	0.4 mm	80 µm
average pore size	200 nm	-
max. pore size	600 nm	-
max. transmembrane pressure	1.6 MPa	5 MPa

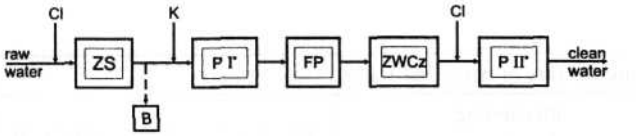

Fig. 2. Flow chart of the water treatment station at Kozlowa Gora (Poland) (ZS - raw water container, PI° - pumping station 1°, FP - rapid graveller-carbon filters, K- coagulant, CI - prechlormation and final disinfection, ZWCz - clean water container, PII° - pumping station II°, B - place of water collection for testing).

testing was marked as B. The testing of surface waters was carried out in April 1997.

The membrane filtration of well water was carried out using the feed-and-bleed method, i.e. the tested water was being fed to the container over 5 hours, and the volume of fed water was equal to the volume of obtained permeate. The permeate was collected from the system by taking samples for analysis every hour. The testing was carried out with invariable process parameters: pressure 0.1 MPa, linear velocity 1.73 m/s or 1.97 m/s, temperature 300-312 K.

The testing with respect to surface waters lasted 40 hours, with the application of the open-flow system, where the permeate was collected for testing every 10 hours. The testing was carried out at the pressure 0.1 MPa, linear velocity 1.31 m/s or 0.83 m/s, at constant temperature 280 K.

Before the actual filtration of natural waters, the capillary membranes were subjected to conditioning and testing, which consisted of passing deionized water through the module under different pressures over 5 hours. In this way the measurement of volumetric water flux was carried out for new membranes, after the filtration of natural waters and after the disinfection of the system with dialine M.

The effectiveness of the membrane filtration process was determined by measuring the volumetric permeate flux in time. Bacteria content in raw water as well as in permeate was defined. Also, the raw water as well as filtrate were analysed with respect to chemical structure. The content of the following was determined:

- iron, manganese, chlorides and sulphates with the ap plication of tests of the firm Merck, using an SQ 200 Merck photometer,
- magnesium and calcium, using the titrimetric method with EDTA,
- total organic carbon (TOC), using a Beckman type 915-B analyzer,
- turbidity, using a model 800-P turbidimeter from En gineered System & Designs,
- pH, using a CP-315 pH-meter from firm Elmetron (Poland),
- conductivity, using a CC-311 conductometer from El metron (Poland),
- absorbance with the wave length 254 nm, using a CE CIL 1000 spectrometer,
- total solids, using the gravimetric method.

The disinfection process of natural waters were controlled with respect to microbiology standards in accordance with regulations [1]. Permeate samples were subjected to analysis after 1, 2, 3, 4 and 5 hours for ground water and after 5, 10, 20, 30, 40 hours for surface water. Microbiological testing involved the determination of the following:

- number of mesophilic bacteria using the cast plate method with agar bouillon. 1 cm^3 of water being tested was placed on Petri dish using a sterile pipette, whereafter ca. 10 cm^3 of culture medium was poured in. After the culture solidified, the plate was incubated for 24 h at temp.37°C.
- determination of coli factor (an index specifying the number of coli bacteria in 100 cm^3 of tested water) using the method of membrane filters. The sample of 50 cm^3 (or smaller volume respectively dissolved) was filtered under pressure through a cellulose membrane filter in a Sartorius apparatus; then the filtrate was placed on the plate with selective culture Endo and incubated at temp. 37°C. After 24 h the characteristic E-coli colonies grown after that pe riod were counted.

Table 2. Volumetric flux of deionized and well water as dependent on time

Time [h]	deionized water flux for new membrane		well water flux		deionized water flux after testing		deionized water flux after disinfecting	
	$J_w \cdot 10^5$ [m^3/m^2s]	temp. [K]	$J_v \cdot 10^5$ [m^3/m^2s]	temp. [K]	$J_w \cdot 10^5$ [m^3/m^2s]	temp. [K]	$J_w \cdot 10^5$ [m^3/m^2s]	temp. [K]
Polypropylene capillary (process parameters: ΔP = 0.1 MPa u = 1.73 m/s)								
1	6.58	296	6.35	282	6.67	298	9.84	298
2	6.58	299	6.15	286	6.25	306	7.93	303
3	6.35	303	5.56	287	6.25	308	8.33	307
4	6.35	306	5.48	288	6.15	310	7.92	309
5	6.08	306	4.63	288	6.14	312	4.92	310
Polysulfone capillary (process parameters: ΔP = 0.1 MPa u = 1.97 m/s)								
1	1.22	293	1.15	289	1.34	295	1.60	299
2	1.22	301	1.12	289	1.41	301	1.94	303
3	1.39	305	1.10	294	1.41	305	1.96	303
4	1.43	307	1.10	294	1.43	307	2.13	305
5	1.46	308	1.05	294	1.46	309	2.20	310

ΔP - pressure, u - linear velocity over membrane surface

Table 3. Volumetric flux of deionized water as dependent on pressure

Pressure [MPa]	Volumetric flux of deionized water					
	new membrane		after testing with well water		after disinfecting with dialine M	
	$J_w \cdot 10^5$ [m^3/m^2s]	temp. [K]	$J_w \cdot 10^5$ [m^3/m^2s]	temp. [K]	$J_w \cdot 10^5$ [m^3/m^2s]	temp. [K]
Polypropylene capillary (u = 1.73 m/s)						
0.075	4.94	301	5.31	300	5.14	299
0.1	5.03	303	5.73	307	5.33	308
0.125	6.25	305	5.21	310	6.60	311
0.15	5.31	306	5.10	312	8.33	314
0.175	5.31	306	5.46	313	8.09	314
Polysulfone capillary (u = 1.97 m/s)						
0.075	1.05	293	1.39	299	1.60	295
0.1	1.29	299	1.48	304	1.96	301
0.125	1.48	302	1.63	305	2.27	303
0.15	1.77	302	1.72	306	2.68	304
0.175	1.82	303	1.82	308	2.77	305

u - linear velocity over membrane surface

- determination of NPL (most probable number of E-coli bacteria in 100 cm^3 of water) and coli titre (the smallest volume of tested water where the presence of coli bacteria was discovered), using the fermentation method with lactose culture. In this method, the tested water was inoculated in relevant concentrations on liquid Ejkman culture, the samples were placed in a thermostat having at 37°C over 24-48 h. Based on the positive results obtained (change of colour and the presence of gas in Durham pipes), NPL and coli titre were taken from the tables. This methodology was introduced due to the fact that very often the determination involving the number of E-coli bacteria defined by means of the membrane filters method was not very precise and sometimes even impossible due to a great number of other saprophytic bacteria covering the filter. The fermentation method is used with respect to more polluted waters.

All described procedures involving the sanitary analysis of water were carried out in sterile conditions. Sterilization methods concerning the laboratory glass, culture background and glass used in the applied backgrounds have been described in the standard [12].

Results and Discussion

Capacity of Capillary Membranes for Ground Water

The capacity of the membrane filtration method of well water was defined by determining the dependence of the volumetric permeate flux (of water) on time and pressure. The obtained results have been presented in Tables 2 and 3.

When analyzing the capacities of tested modules for ground water, we can say that the short-term operation of membranes in polluted well water did not significantly affect their capacity, and the disinfection with dialine M improves it considerably. The fact that the capillary membrane retains its transport properties after the operation in well waters may mean that membrane pores are not blocked with substances present in water. Over the 5-hour testing cycle the decreasing tendency can be observed, and with the increase of pressure, the volumetric permeate flux increases.

Capacity of Capillary Membranes for Surface Water

The obtained results involving the carried out characteristics of the deionized water volumetric flux for a new membrane, after actual testing and after carried out disinfection as a function of time and pressure, are presented in Fig.3 and Table 4.

A considerable decrease of deionized water flux can be observed after the testing with surface water. Disinfection improves the operating properties of the membrane to a satisfactory level, although the obtained results are lower as compared with initial testing. Similar results were obtained when testing the dependency of deionized water volumetric flux on pressure. It was probably effected by much higher pollution of surface water as compared to well water.

Actual testing results involving the volumetric flux of permeate as dependent on time, carried out in the open flow system in the surface water treatment station at Kozlowa G6ra are presented in Fig. 4.

The capacity of the polypropylene module decreased over the first ten hours, after which it assumed stability and became constant at the level ca. $2 \cdot 10^{-5}$ m^3/m^2s. Changes of the capacity taking place in the course of the testing are effected by the application of backflushing. The capacity of polysulfone membranes was stabilized as early as after 4-hour operation at the level ca. $0.54 \cdot 10^{-5}$ m^3/m^2s. The dependence of the volumetric flux of tested water on time can be expressed by the following logarithmic equation:

$$J_v = a \cdot \ln(t) + b$$

where J_v stands for volumetric permeate flux, and t for operation time of the membrane in tested water. The equa-

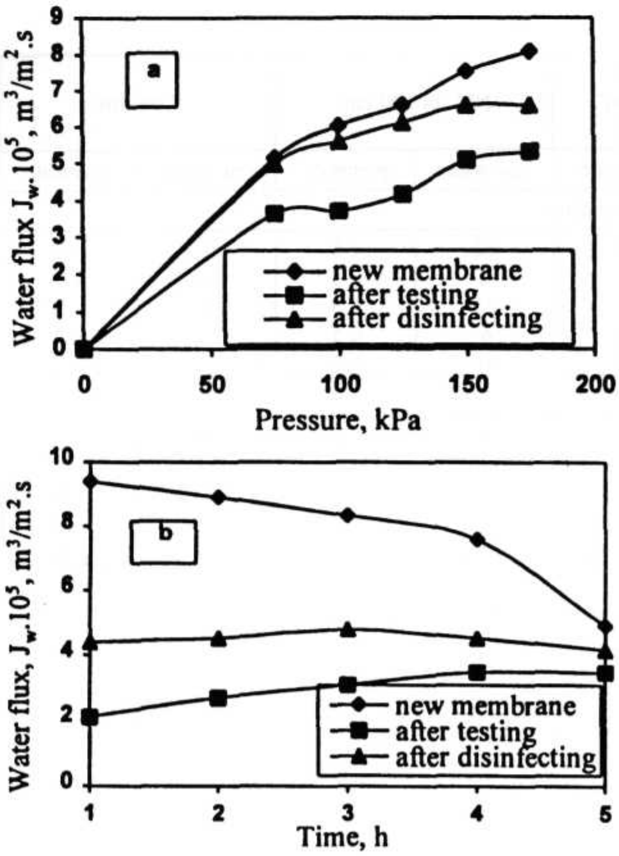

Fig. 3. Volumetric flux of deionized water as dependent on pressure (a) and time (b) for a polypropylene module in the testing cycle for surface waters (J_w - volumetric water flux, AP.= 100 kPa - Fig. 3b)

tions for both membranes together with determination coefficients r^2 are as follows:

- polypropylene $J_v = (-4.32 \cdot 10^{-6}) \cdot \ln(t) + 3.44 \cdot 10^{-5}$
  $r^2 = 0.9022$
- polysulfone $J_v = (-8.61 \cdot 10^{-7}) \ln(t) + 8.03 \cdot 10^{-6}$
  $r^2 = 0.8549$

Table 4. Volumetric flux of deionized water as dependent on: a) time and b) pressure for surface water and capillary module from polysulfone (linear velocity over the membrane surface u= 1.97 m/s).

Time [h]	Volumetric flux of deionized water			
	new membrane		after 40-hour of membrane working time with surface water	
	$J_w \cdot 10^5$ [m^3/m^2s]	temp. [K]	$J_w \cdot 10^5$ [m^3/m^2s]	temp. [K]
1	2.36	297	0.59	297
2	2.80	301	0.62	305
3	2.61	303	0.69	307
4	2.56	307	0.82	311
5	2.69	310	0.85	312
Pressure [MPa]	**Volumetric flux of deionized water**			
	new membrane		after 40-hour of membrane working time with surface water	
	$J_w \cdot 10^5$ [m^3/m^2s]	temp. [K]	$J_w \cdot 10^5$ [m^3/m^2s]	temp. [K]
0.075	1.86	296	0.87	312
0.100	1.79	303	1.15	312
0.125	2.35	308	1.58	312
0.150	1.97	308	1.27	313
0.175	2.54	309	1.41	313

Bacteriological Testing

Table 5 presents the results of microbiological tests of raw waters and permeates obtained as a result of membrane filtration of ground waters using polypropylene and polysulfone capillary membranes.

The tested ground water was heavily polluted, and the obtained permeate after each hour of operation contained neither coli bacteria or mesophilic bacteria. The obtained permeate satisfied sanitary conditions for potable waters specified in the Regulation of Ministry of Health and Social Care [1], it did not contain any bacteria and the retention coefficient was 100% in each case.

Table 5. Results of microbiological analyses for ground water.

Time [h]	Number of mesophilic bacteria after 24 h in 1 cm^3		Number of coli bacteria in 100 cm^3 (dilution 10:100)		NPL in 100 cm^3		Coli titre	
	raw water	permeate	raw water	permeate	raw water	permeate	raw water	permeate
Polypropylene capillary								
1	1960	0	1530	0	> 2400	< 5	< 0.04	> 20
2	1925	0	1800	0	> 2400	< 5	< 0.04	> 20
3	1810	0	countless	0	> 2400	< 5	< 0.04	> 20
4	885	0	countless	0	> 2400	< 5	< 0.04	> 20
5	940	0	countless	0	> 2400	< 5	< 0.04	> 20
Polysulfone capillary								
1	1170	0	1150	0	> 2400	< 5	< 0.04	> 20
2	1130	0	1125	0	> 2400	< 5	< 0.04	> 20
3	1120	0	1130	0	> 2400	< 5	< 0.04	> 20
4	1115	0	1120	0	> 2400	< 5	< 0.04	> 20
5	1110	0	1170	0	> 2400	< 5	< 0.04	> 20

Table 6. Results of microbiological analyses for surface water

Time [h]	Number of mesophilic bacteria after 24 h in 1 cm^3		Number of coli bacteria in 100 cm^3 (dilution 10:100)		NPL in 100 cm^3		Coli titre	
	raw water	permeate	raw water	permeate	raw water	permeate	raw water	permeate
Polypropylene capillary								
1	24	0	86	0	62	< 5	2	> 20
10	19	2	21	0	6	< 5	17	> 20
20	24	0	9	0	23	< 5	4	> 20
30	22	0	13	0	6	< 5	17	> 20
40	19	0	4	0	6	< 5	17	> 20
Polysulfone capillary								
1	23	4	13	1	5	< 5	20	> 20
10	28	12	28	13	130	23	0.8	4
20	29	9	23	10	23	< 5	4	> 20
30	29	15	5	1	6	< 5	17	> 20
40	22	15	21	1	23	< 5	4	> 20

Table 7. Results of physicochemical analyses obtained during the membrane filtration of ground water with the application of capillary membranes

Water loading factor*	1-st hour			3-rd hour			5-th hour		
	water	permeate	R, %	water	permeate	R, %	water	permeate	R, %
Polypropylene capillary									
Mg^{2+}, mg/dm^3	84.6	78.8	6.8	84.6	82.7	2.2	82.7	80.7	2.4
Ca^{2+}, mg/dm^3	99.4	96.2	3.2	94.6	93.0	1.7	97.8	96.2	1.6
TOC, mg/dm^3	17.5	16.1	8.0	10.7	10.1	5.6	15.2	9.54	37.2
Conductivity, mS/cm	0.77	0.78	-	0.79	0.77	-	0.77	0.75	-
Turbidity, NTU	7.0	0.28	96.0	4.42	0.10	97.7	7.0	0.08	98.8
Fe, mg/dm^3	0.57	0.04	93.0	0.48	0.04	91.7	0.57	0.03	94.7
Mn, mg/dm^3	1.06	0.95	10.4	1.05	0.84	20.0	1.04	0.84	19.2
pH	6.28	6.35	-	6.42	6.35	-	6.46	6.49	-
Cl^-, mg/dm^3	81	80	1.2	83.0	81.0	2.5	89.0	84.0	5.6
SO_4^{2-}, mg/dm^3	205.0	182.0	11.2	210.0	168.0	20.0	205.0	183.0	10.7
Absorbance, λ = 254 nm	0.090	0.033	63.3	0.088	0.041	53.4	0.090	0.040	55.5
TS, mg/dm^3	606	603	0.5	636	620	2.5	657	643	2.1
Polysulfone capillary									
Mg^{2+}, mg/dm^3	77.8	72.9	6.3	77.8	73.97	5.00	77.8	74.9	3.70
Ca^{2+}, mg/dm^3	92.9	91.4	1.60	91.4	91.4	0	94.6	92.9	1.80
TOC, mg/dm^3	32.0	15.1	53.0	30.9	6.6	78.7	29	7	75.7
Conductivity, mS/cm	0.95	0.94	-	0.94	0.94	-	1.00	1.00	-
Turbidity, NTU	1.87	0.27	85.5	1.95	0.36	81.5	1.80	0.28	84.4
Fe, mg/dm^3	0.25	0.18	28.0	0.21	0.18	14.3	0.27	0.15	44.4
Mn, mg/dm^3	0.94	0.84	10.6	0.76	0.54	30.0	0.80	0.59	30.0
pH	6.11	6.11	-	6.15	6.03	-	6.17	6.20	-
Cl^-, mg/dm^3	63.0	63.0	-	67.0	67.0	-	64.0	64.0	-
SO_4^{2-}, mg/dm^3	> 214	208	3.00	213.0	207.0	-	214	207	3.3
Absorbance, λ = 254 nm	0.073	0.059	19.0	0.065	0.039	40.0	0.071	0.046	35.2
TS, mg/dm^3	827	608	26.4	992	701	29.3	1049	690	34.2

TS - total solids, R - retention coefficient, TOC - total organic carbon, * - the average error of determination: 0.5-3%

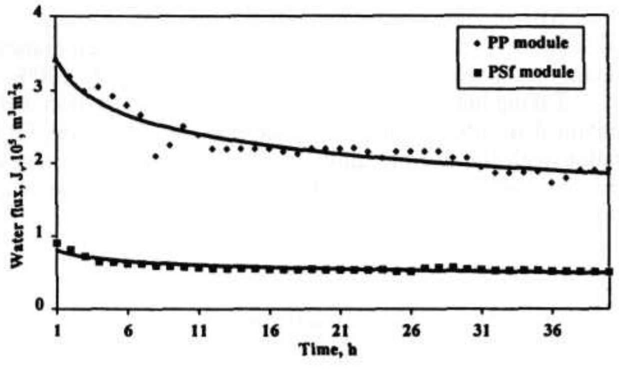

Fig. 4. Dependence of volumetric permeate flux on time for capillary modules from PP and PSf in the surface water testing cycle. The line presents matching of the logarithmic curve with the obtained measurement results.

Table 6 presents the results of microbiological analyses for the testing cycle involving surface water at Kozlowa G6ra during a 40-hour measurement cycle.

During the membrane filtration of surface waters, the total amount of coli-type bacteria and mesophilic bacteria was retained. The water which had been subjected to the filtration on the polypropylene module met the sanitary standards required for potable water or water for industrial use [1]. But the water which had been subjected to ultrafiltration on the polysulfone module contained coli-type bacteria and other bacteria, which was caused by the mechanical failure of capillaries (which was found out after the testing).

The obtained results have proved the thesis that polypropylene capillary membranes can constitute an effective barrier against bacteria, and they may successfully replace chemical disinfection methods, which involves the introduction of other, additional substances to water, which, when entering into reaction with water pollutants, can affect the formation of compounds hazardous to human

Table 8. Results of physicochemical analyses obtained during the membrane filtration of surface water with the application of capillary membranes

Water loading factor*	1-st hour			10-th hour			40-th hour		
	water	permeate	R, %	water	permeate	R, %	water	permeate	R, %
Polypropylene capillary									
Mg^{2+}, mg/dm³	46.6	45.7	1.9	48.6	45.7	6.0	46.6	44.7	4.1
Ca^{2+}, mg/dm³	59.3	56.1	5.4	56.1	52.9	5.7	56.1	52.9	5.7
TOC, mg/dm³	21.1	20.6	2.4	25.1	22.6	10.0	22.8	20.0	12.3
Conductivity, mS/cm	0.34	0.35	-	0.37	0.25	-	0.36	0.36	-
Turbidity, NTU	5.84	1.46	75	5.62	0.12	97.9	3.8	0.21	94.5
Fe, mg/dm³	0.20	0	100	0.1	0	100	0.07	0	100
Mn, mg/dm³	< 0.05	0	100	< 0.05	0	100	< 0.05	0	100
pH	8.58	8.6	-	8.6	8.56	-	8.86	8.72	-
Cl^-, mg/dm³	18	18	0	18	17	5.5	15	15	0
SO_4^{2-}, mg/dm³	81	64	21.0	121	91	24.8	146	79	45.9
Absorbance, λ = 254 nm	0.210	0.191	9.0	0.244	0.160	34.4	0.278	0.195	29.8
TS, mg/dm³	295	292	1.0	317	294	7.2	291	278	4.5
Polysulfone capillary									
Mg^{2+}, mg/dm³	47.6	45.7	2.40	47.6	46.7	1.9	46.7	44.7	4.3
Ca^{2+}, mg/dm³	59.3	57.7	2.7	59.3	57.7	2.7	59.3	57.6	2.9
TOC, mg/dm³	23.7	22.8	3.80	23.6	22.0	6.80	23.3	21.9	6.0
Conductivity, mS/cm	0.30	0.25	-	0.29	0.33	-	0.28	0.35	-
Turbidity, NTU	4.52	1.64	63.7	4.33	1.90	56.0	4.70	2.78	40.8
Fe, mg/dm³	0.19	0.0	100.0	0.10	0.00	100	0.08	0.0	100
Mn, mg/dm³	~ 0.05	0.0	100.0	0.06	0.0	100	~ 0.80	0.0	100
pH	8.65	8.7		8.30	8.39		8.62	8.41	-
Cl^-, mg/dm³	18.0	18.0	0.0	18.0	18.0	0.0	15.0	14.0	6.7
SO_4^{2-}, mg/dm³	101	92.0	8.9	115	86.0	25.3	149.0	92.0	38.2
Absorbance, λ = 254 nm	0.191	0.149	22.0	0.192	0.165	14.0	0.225	0.167	25.8
TS, mg/dm³	294	287	2.40	281	276	1.80	287	264	8.00

* - the average error of determination: 0.5-3%.

health. Furthermore, by the introduction of membrane techniques to the treatment of water, the amount of post-coagulation sludge generated in effect of the conventional treatment methods will not be increasing.

Physicochemical Testing

The effectiveness of the removal of chemical compounds during the membrane treatment of ground waters is presented in Table 7.

The removal level of iron and turbidity is high, and total carbon is removed within 40-76%, depending on the type of membrane. The number of organic humus compounds (THM precursors) was substantially reduced, which is confirmed by lower absorbance - the value of retention coefficient is 40-60%. The content of salt decreased only slightly in effect of the filtration process, which is confirmed by the constant value of conductivity and slightly lowered value of dry residue.

Table 8 presents the results of physicochemical analyses obtained as a result of a 40-hour microfiltration of surface water at Kozlowa Gora.

Capillary membranes removed iron and manganese in 100%, whereas turbidity in 64-95%. Total carbon and absorbance were removed to a slightly lower degree. And the removal of ions by the membranes is nearly non-existent. The conductivity were maintained at the constant level.

Conclusions

- Volumetric permeate flux with respect to natural waters is lower than the volumetric flux for deionized water. This results from the fact that natural water is a mixture of various components such as microorganisms, dissolved and colloidal substances as well as suspended matter, which are retained by the membranes.
- It has been observed that the disinfecting process of the system with dialine M, after the testing cycle with natural water, contributes to regeneration of the membranes. With respect to well water, the volumetric flux of deionized water increased as compared to the initial flux of deionized water. With respect to surface water, a partial regeneration of the membrane is taking place, i.e. an increase of the volumetric flux of deionized water is observed as compared to the values obtained directly after the characterization of the membrane taking place after the testing cycle. Yet the membrane did not regain a water flux characteristic for a new membrane, which means that a permanent fouling of the membrane surface had taken place.
- A higher retention coefficient of iron and manganese was obtained during the membrane filtration of surface water (100%), whereas for underground water these values were lower (92-98%).
- Capillary membranes remove turbidity very well, on average 90%. But the removal of organic compounds is much lower, on average 40%.
- The content of calcium and magnesium after the filtration process did not change considerably.
- Microbiological testing has shown that in both test filtration cycles with natural water, capillary membranes retain mesophillic bacteria and coli-type bacteria in 100%.
- Taking into consideration the technological aspect and obtained results, we may conclude that the membrane filtration with the use of capillary polypropylene membranes may be applied as a disinfection stage in the technological process for the treatment of natural water.

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