THE USE OF MOBILE MEMBRANE UNIT WITH AUTOMATIC CONTROL FOR WATER TREATMENT

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Abstract
An objective of this work is to verify the mobile membrane unit equipped with spiral wound reverse osmosis modules for treatment of surface water to obtain drinking or supply water. Several days operational tests have shown long-term stability of separation processes and the reliability of the constructed processing equipment. A total of five operating tests took place with the length of a single test 3-5 days depending on the decrease in device performance caused by the fouling of the membrane modules. Separation experiments were terminated in case of decrease in permeate flux by 50 % compared to the value at the beginning. Site by the river Elbe Neratovice was chosen for operational test. The input surface water was pumped by means of pumps through a bag filter and sand filter on 8 spiral wound membrane modules. Producet permeate was conducted on a built-in UV lamp for sanitation. Samples of the input surface water and the permeate were subjected to chemical analysis. The results of this analysis showed the removal of almost all major components. Produced permeate is reaching its quality distilled water, and therefore does not meet the requirements for drinking water. For compliance with these requirements, pursuant to Decree No. 252/2004 Coll., automatic dosing of minerals is situated after the separation process.

Key words:
Pressure driven membrane separation processes, mobile membrane unit, spiral wound element, reverse osmosis, remineralization, drinking water.

Introduction

In recent decades, the pressure membrane processes have increasingly become economically equivalent replacement for other traditional separation processes (Mikulášek, 2013). They can be applied to manufacturing processes in many directions, while allowing technology to process waste, implement a low waste and non-waste technology, but also ensure the quality of water and food sources. Pressure membrane processes compared to traditional separation processes are characterized by high efficiency of separation of substances, typically at ambient temperature without additional chemicals, thereforewith forming of no secondary contamination of wastewater. They are space-saving and can be fully automated. They have considerably lower specific energy consumption during operation, since no phase change occures, as in conventional thermal processes. These processes, however, are not universal and therefore can not be always applicable. In some cases, pretreatment of the input stream is necessary to eliminate the influences acting on a membrane, such as the formation of deposit on the membrane surface (Mikulášek, 2013).

Space requirement and low energy consumption of pressure membrane processes allow their use as a mobile unit which can be transported from place to place as needed, without requiring its difficult disassembling and reassembling. They can therefore be used as an alternative source for water treatment (e.g. potable or process water, landfill leachate etc.).

Pressure membrane separation processes

Membrane separation processes include a wide group of processes which are associated by specific feature and it is the use of semi-permeable membrane as the main separation element. Processed raw material (feed) is fed so as to be in contact with the active membrane layer and the action of driving force is divided into a stream passing through the membrane (permeate) and the stream held by membrane (retentate or concentrate) (Mikulášek, 2013)

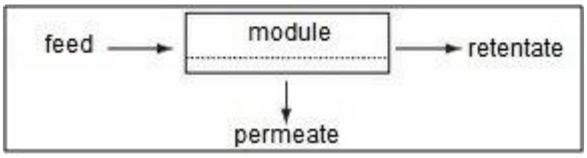

Fig. 1: Diagram of a membrane separation process (Mikulášek, 2013)

Thus formed two qualitatively different streams, as shown in (Fig. 1), the final product may be both permeate (clean stream) and retentate (concentrated stream). Among the pressure membrane processes belong microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). The driving force of these processes is the pressure gradient. Individual processes are different pore sizes in the membrane, and thus the required transmembrane pressure. Required operational pressure increases with decreasing diameter of pores in the membrane. In reverse osmosis and nanofiltration an overcoming of the osmotic pressure of the separated solutions plays an important role (Palatý, 2012; Melzoch, 2007).

Methodics

For the operating experiments with cell membrane unit a location by the river Elbe was chosen in Neratovice. For all experiments spiral wound membrane modules for reverse osmosis (Table 1) were used which are commercially available with size of 40 x 4 x 4 inches.

Table 1: Characteristics of membranes used.

Commercial name	Producer	MWCO [Da] (salt rejection %)	Material	Process
BW30	DOW-Filmtec	(99,50 %)	Polyamide Thin-Film Composite	RO

MWCO (molecular weight cut-off) - range division of the membranes which indicatsa molecular weight of molecules which do not pass through the membrane, expressed in Dalton (1D = $1{,}66053.10^{-27}$ kg).

<u>Description of the mobile membrane separation unit MEM-MOB 4040</u>

This mobile membrane unit was constructed at the Department of environmental Chemistry, University of Chemistry and Technology Prague. Entire facility, including all the equipment is placed in a container with chassis. (Fig. 2) and (Fig. 3) and is therefore fully mobile. The membrane unit contains several centrifugal pumps Grundfoss, which among other provides sufficient fluid flow through the whole technology and the pressure pump (booster) from the same company. Required flow of inlet water in the facility is set using a frequency converter of the working pump. The equipment includes four pressure vessels used for storing spiral wound membrane module of a standard commercial size "4040" (ie diameter 4', length 40'), in total 16 membrane modules can be stored in pressure vessels. The device is designed so that separation can take place through 4, 8, 12 or all 16 modules and permeation performance can therefore be controlled according to purified water needs. All valves in the fitting devices are controlled by servomotors. The membrane unit has an integrated pre-treatment of raw water and final subsequent treatment of permeate. For the mechanical pretreatment serves a sleeve and a sand filter. There is also the dosing system used for chemical pretreatment of inlet water and dosing system for remineralization of produced permeate. The dosing is realized by a pump Grundfos DDA 17-7. To permeate flow line is embedded UV lamp for additional sanitation of permeate.

The device is capable to operate at pressures up to 40 bar. The membrane unit is equipped with sensors to monitor pressure (BD Senzors) in several points of the technology (input branch, outputof the pressure pump, before the membrane module and after the module). This is a manual device to monitor any possible loss of pressure inside the device, which can be caused due to the membrane fouling and is able to flexibly respond to these changes. In order to monitor the quality of individual process streams machine is equipped with sensors for measuring pH and conductivity from Endress&Hauser. Feed permeate and concentrate section is mounted with flowmeters. Temperature monitoring ensures the sensor from Sensit. All these sensors are connected via cables with integrated programmable unit. The device is designed so that it can operate in automatic mode, the operator is running the required software for drinking water production. Separation is such that the sludge pump through the raw water is fed into the IBC tank, which serves as a buffer tank, then the water is pumped from IBC tank through bag filter and sand filter to the membrane unit. Before entering the membrane module the inlet water can be dosed with chemicals for pretreatment if necessery. Produced permeate is remineralized and then passed through a bulit tube UV lamp into the storage tank. The concentrate is continuously fed back into the watercourse. With increasing length of separation increases the possibility of creating a deposit on the membrane, which often has the effect of increasing pressure loss in the membrane device. Automatic machine increases the operation pressure by frequency converter of the pump, so that the required permeation performanceis achueved, up to the frequency maximum and then decline of permeation performance follows. Then follows the termination of the separation, shutdown, flushing and chemical cleaning. In addition to automatic pressure increase to maintain the desired permeate flow can be adjusted manually separating pressure, throttles on branch concentrate gradual closing of the valve.

Fig. 2: Mobile membrane unit **Fig. 3:** View of equipment mobile membrane unit

<u>Cleaning of the equipment</u>

The equipment includes a 1000 liter plastic tank for permeate, which is used for rinsing and cleaning of the modules. It also includes a 100 liter plastic container, which serves as the cleaning-in-place tank (CIP) in case of need of chemical cleaning of the technology. Removing of deposits from the membranes and devices is performed by combining both acidic and alkaline cleaning. To reservoir devices (CIP systém) permeate is filled which washes the membrane modules for 5 minutes. Then to the CIP reservoir hydrochloric acid is dosed in order to decrease the pH to a value of 2. Such acidic solution is circulated through the membrane modulesfor 45 minutes. Acidified solution is then drained and the apparatus is again washed with the permeate. Subsequently the permeate and an alkali surfactant P3-Ultrasil 11 are added into a storage CIP tank to increase the pH up to 11. This alkalic solution is circulated through the membrane modules for 45 minutes again. Finally the device is washed again with the permeate and thus ready for further operation.

<u>The course of operating tests</u>

In overall five long-term tests bearing the designation RUN1 to RUN5 were held. All experiments were carried out continuously under the same operating conditions, and each experiment was terminated after a decreased permeate flow rate of about 50 % in comparison with the flow at the beginning of the test.

Mobile membrane unit was transported to the locality by the river Elbe. Before the separation of the surface water it was sampled and subjected to chemical analysis. The separation of surface water was proceeded. Separation was carried out using 8 spiral wound reverse osmosis membrane module. Separation was set up automatically according to the selected program for drinking water treatment. Operational pressure was set to 15 bar manually so as to match the permeate flow of approx 1.2 $m^3 \cdot h^{-1}$. Input surface water was pumped by a pump through a bag filter with filter of a porosity of 50 μm, sand filter with grain size of 1,4 - 2 mm of sand, and further to the membrane unit. The treated permeate was led through the built-in UV lamp for sanitation to the storage tank and the concentrate was continuously returned to the water stream. Permeate was remineralized to values indicators required by Decree no. 252/2004 Coll., using a mixed solution of $NaHCO_3$, $MgSO_4 \cdot 7H_2O$, K_2CO_3 and $CaCl_2$, which was dosed continuously.

Membrane modules were restored to their original state after each test for equal conditions in all performed experiments. The original state has been achieved by combination of an acidic and alkaline cleaning of membrane modules. Acidic cleaning was used to dissolve carbonate deposits in the device formed during separation. The amount of deposits increases with increasing duration of the experiment, resulting in increasing pressure drop of the membrane device. Application of an alkaline surfactant assures removal of organic substances adhering to the surface during separation membrane.
Input samples of surface water and the produced permeate were taken during experiments.

The following analytical methods and equipment were used for the chemical analysis of samples:

- determination of metals by atomic absorption spectrometry / atomic emission spectrometry (AAS / AES) by the analyzer SensAA
- spectrophotometric determination of metals using photometry MultiDirect
- determination of anions by capillary zone electrophoresis CAPEL - 105M
- determination of the total organic and inorganic carbon by the analyzer liquiTOC II
- spectrophotometric determination of ammonium with indophenol method using an UV-VIS spectrophotometer GBC Cintra 101
- pH measurements using a digital pH meter: GMH 3530
- conductivity measurements using a digital conductometer: GMH 3430

Results and Discussion

In overal five separation experiments, designated RUN1 to RUN5were carried out. Each experiment lasted between 3-5 days, depending on the development of permeate flowvalues. Each experiment was terminated when a pressure dropped below a chosen threshold. For this paper two separation experiments RUN1 and RUN4 are selected.

Figures below show a plot of permeate flow in time during both selected experiments. At (Fig. 4) and Fig. 5) there is a decreasing flow of permeate during the separation in both runs. This decline can be described as a linear. The decline in permeate performance occurs due to membrane fouling during separation. A slight increase in permeate performance during the separation was due to an increase in the inlet temperature (Fig. 4). After a decrease of permeate flow under 50 % the experiments were terminated and followed by modules cleaning.

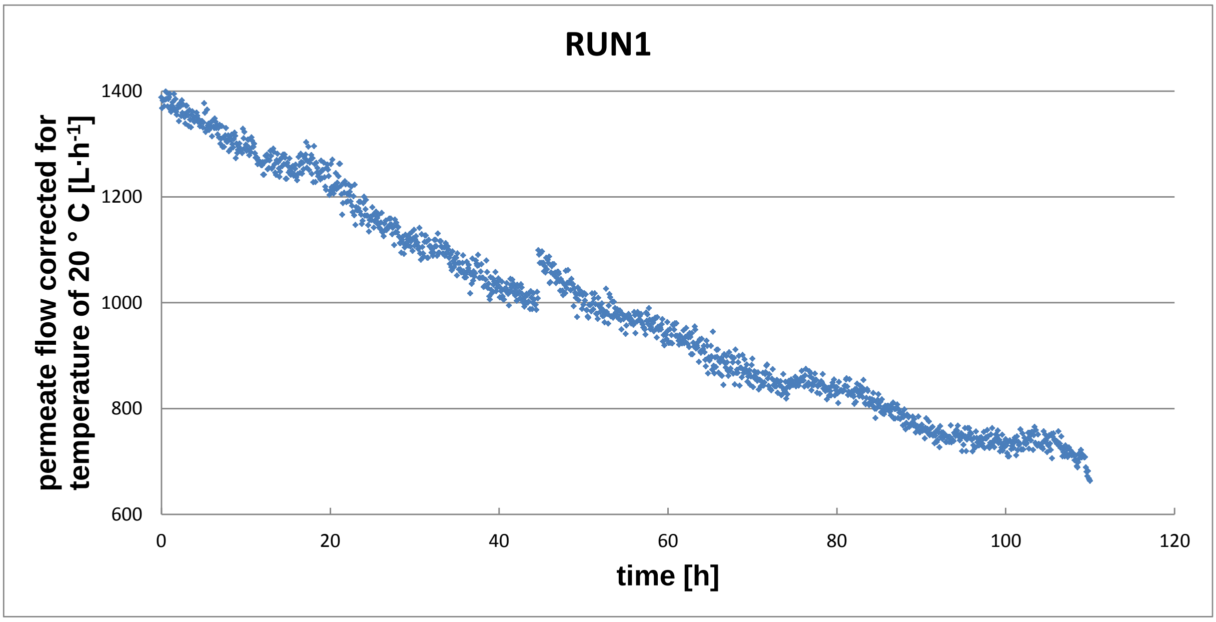

Fig. 4: Permeate flow dependence on the length of the experiment RUN1.

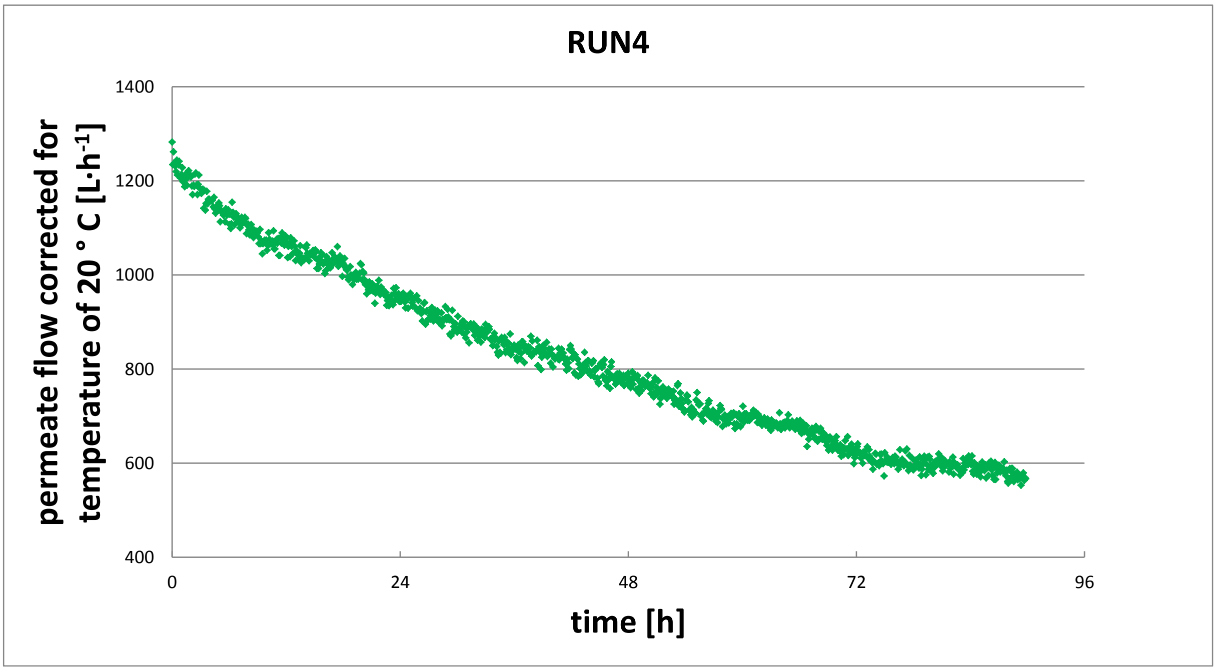

Fig. 5: Permeate flow dependence on the length of the experiment RUN4.

The result of the chemical analyses of samples taken during operational tests with a mobile membrane unit is shown in (Table 2) below. These chemical analyses show that there is very significant removal of major components from the input water. The water produced can not be considered as a drinking water, so it is necessary to put back after separation proces minerals intoarosing permeate to reach the values required by Decree no. 252/2004 Coll., for drinking water. However, if needed, it can be produced permeate used as supply water, for example, during natural disasters or accidents. After mineralization permeate water already meets the requirements for drinking water.

Table 2: The results of chemical analyses of input water and produced permeate.

		RUN1			RUN4		
		Feed	**Permeate**	**Remineralized permeate**	**Feed**	**Permeate**	**Remineralized permeate**
NO_3^-	mg·L^{-1}	20.1	< 0.5	< 0.5	22.3	< 0.5	< 0.5
NO_2^-	mg·L^{-1}	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
N_{amon}	mg·L^{-1}	<0.2	< 0.2	< 0.2	< 0.2	<0.2	< 0.2
SO_4^{2-}	mg·L^{-1}	134	3.1	98.5	130	2.4	101.3
Cl^-	mg·L^{-1}	75.4	4.1	86.8	79.5	1.8	89.5
TOC	mg·L^{-1}	3.7	< 2.0	< 2.0	4.2	< 2.0	< 2.0
TIC	mg·L^{-1}	28.7	< 2.0	15.6	29.6	< 2.0	18.3
conductivity	μS·cm^{-1}	493.3	19.6	338.9	501.1	8.5	352.3
pH		7.4	5.2	7.2	7.2	5.1	7.5
Ca	mg·L^{-1}	144	< 0,5	56.1	137	< 0.5	54.3
Mg	mg·L^{-1}	32.4	< 0,5	28.6	33.5	< 0.5	29.4
Na	mg·L^{-1}	22.8	3.7	35.7	22.3	< 1.0	34.4
K	mg·L^{-1}	9.6	1.1	12.8	9.2	0.4	12.3
Fe	mg·L^{-1}	0.15	< 0.05	< 0.05	0.12	< 0.05	< 0.05
Mn	mg·L^{-1}	0.08	< 0.01	< 0.01	0.07	< 0.01	< 0.01

Conclusion

This paper is focused on operational tests with a mobile membrane unit. In overall five separation experiments, designated RUN1to RUN5were carried out. Here two of these tests -RUN1 and RUN4 – are shown.

Operational tests confirmed the relatively long-term stability of the separation process and the reliability of the constructed process equipment. During the separation continuous decrease of permeate flow due to the fouling of the membrane modules occured in all operational tests. The precipitation of components present in the water did not take place, at least not at observable level. During separation the pressure drop was observed in part of the sand filtration as well as in the bag filter. From the data it can be concluded that using membrane separation, reverse osmosis membrane fitted with spirally wound modules, achiev high efficiency of removing solutes and in combination with UV lamps also microbiological contamination.
By applying a reverse osmosis membrane separation surface water permeate with quality of almost distilled wateris produced. The quality of the produced permeate can be modified by automatic dosing of minerals and can therefore obtain drinking water according to Decree no. 252/2004 Coll. The device performance can by regulated the flow of water in the device and concurrently closing or opening required number of branches, in which pressure vessel with membrane modules are placed. The device is capable to produce pure water in an amount of 1 m^3·h^{-1} to 5 m^3·h^{-1}as needed.

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