

EXPERIMENTAL VERIFICATION OF POLYMERIC DISTILLATION UNIT

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Abstract: *Desalination is common solution to a fresh water scarcity. The common desalination units are made of metal, which bring some disadvantage as corrosion or heavy weight. The presented paper describe principle of polymeric distillation and present results of experimental verification of prototype of fully polymeric distillation. This prototype is based on air gap membrane distillation and combines two type of polymeric hollow fibers. Porous hollow fibers were used as membrane and the non-porous hollow fibers were used for the condenser. The prototype was operated in long-term continuous operation. Six experiments with different flow rate and temperature were done. During testing the temperature, humidity and amount of condensate was measured.*

Keywords: Polymeric hollow fiber, Membrane hollow fiber, Distillation, Desalination.

1. Introduction

Desalination of sea or brackish water is nowadays common solution to fresh water scarcity. In some parts of the world it is the only way how to get drinking water. The desalination units used are usually made of metal, which brings some disadvantages. The long term exposure of the salt water leads to extensive corrosion, and in addition to this the desalination units are heavy and expensive. The attempts to make them from polymers, appeared, for example (Song, 2018) studied polymer hollow fiber heat exchanger in application to desalination.

In this paper the fully polymeric distillation unit is presented. This unit combines two types of polymer hollow fibers. First of them are membrane hollow fibers which allows transfer only gas phase. This is because of combination of hydrophobic surface of membrane and size of pores. Membrane hollow fibers can be also used for air filtration (Bulejko 2018) or for ammonia recovery (Darestani 2017). The second type are thermal hollow fibers which provides heat transfer, specifically condensation of vapour. The thermal conductivity of polymers is low, but this can be overcome by using the hollow fibers with wall thickness less than 100 μ m (Chen, 2016). In addition to corrosion resistance, polymer hollow fiber exchangers provides easy shaping and machining. They are low weight and their cost is lower than the metal unit. They are also environmental friendly, since the energy required to produce a unit of mass of plastic is about 2 times less than a unit of metal (Zarkadas, 2004).

The principle behind polymeric distillation is air gap membrane distillation. Membrane distillation is thermally driven separation process. Its driving force is the vapour pressure difference induced by the temperature differences between the two sides of the membrane pores. This temperature difference is in the order of 5-20 $^{\circ}$ C (Sørensen, 2014). There are several types of membrane distillation - direct contact, air gap, sweep gas, vacuum etc. As name of air gap membrane distillation suggest there is space filled with air (air gap) between the membrane and condensation surface (Drioli, 2015).

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2. Principle of polymeric distillation

As was mentioned, the main idea of polymeric distillation is to combine membrane and thermal hollow fibers. The hot brine flows inside the membrane hollow fiber and evaporates there. Since the membrane hollow fibers are made from hydrophobic polypropylene and are porous, they allow to pass through only the gas phase. The membrane module is placed inside distillation tunnel, where ambient temperature is significantly lower than inside the fiber, therefore the evaporated water passes through membrane into the tunnel. There is an electrical fan inside the tunnel, which forces the air to circulate inside the tunnel. Next to the membrane module in the direction of air flow stands cooler. The cooler is composed of polymer hollow fiber heat exchanger and the evaporated water condensate on it and the condensate is collected.

The membrane module of presented prototype consists of four bundles of polypropylene hollow fibers produced by ZENA s.r.o. Ostopovice, Czechia, see Fig. 1a. The membrane hollow fibers have outside diameter 0.5mm with the average pore size $0.1\mu\text{m}$ and the total inside surface area is 1.5m^2 . Around 50% of hollow fiber surface consists of pores. The thermal module is made of non-porous polymer hollow fibers. The heat exchanger with chaotic structure was used, see Fig. 1b. The fibers have 0.8mm outside diameter and their outside surface area is equal to 0.3m^2 . Both modules are placed inside the rectangular tunnel, see Fig. 2.

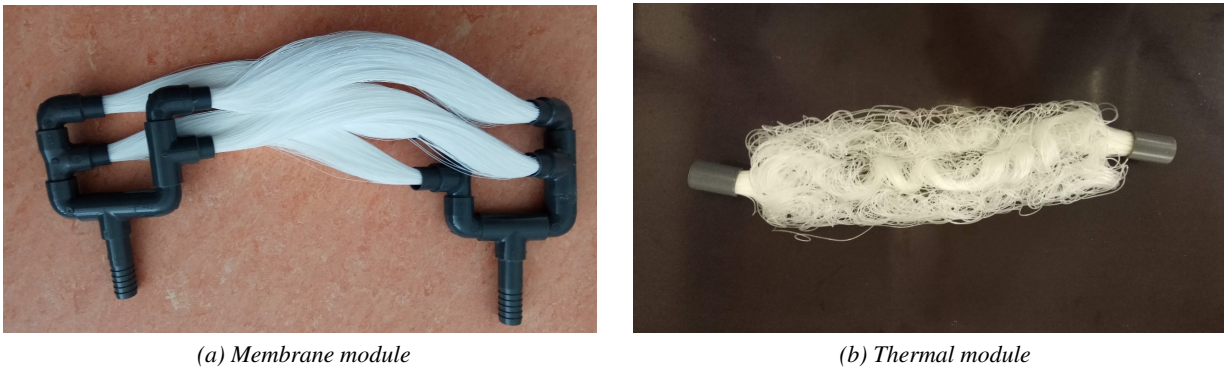


Fig. 1: Hollow fibre modules

3. Experimental verification

The functionality of the prototype was verified during continuous long-term operation. During this time six experiments were done. The brine was heated up in a tub. It was pumped inside the membrane module and back to the tub. Tapped water from water supply system served as coolant. All experiments (EXP01-EXP06) were done in steady-state according to plan presented in Table 1.

Tab. 1: Measurement plan

	$T_{m,in}$ [$^{\circ}\text{C}$]	Flow rate inside membrane	Flow rate inside thermal	Air speed [m/s]
		module [l/h]	module [l/min]	
EXP01	55	100	360	1.5
EXP02	55	60	360	1.5
EXP03	60	100	360	1.5
EXP04	60	60	360	1.5
EXP05	65	100	360	1.5
EXP06	65	60	360	1.5

The measurement was done at three different inlet temperatures of membrane module: 55°C, 60°C and 65°C. The flow of hot brine alternated in 60 and 100 l/h. The velocity of the air inside the tunnel remained the same for the whole operation time.

Temperature inside the tunnel ($T_1 - T_4$) was measured by four thermal sensors Pt100, which were placed in front of the membrane module (Pt100-A), between the membrane and thermal module (Pt100-B), behind the thermal module (Pt100-C) and in the other side of the rectangular tunnel (Pt100-D). Another four sensors (Pt100-E - Pt100-H) of the same type measured temperature of brine at inlet of membrane module ($T_{m,in}$), temperature of brine at outlet of membrane module ($T_{m,out}$), temperature of coolant at inlet and outlet of thermal module ($T_{t,in}$ and $T_{t,out}$) respectively. There are also four humidity sensors ($H_1 - H_4$) next to each temperature sensor inside the distillation tunnel, see Fig. 2. In addition the velocity of air was monitored.

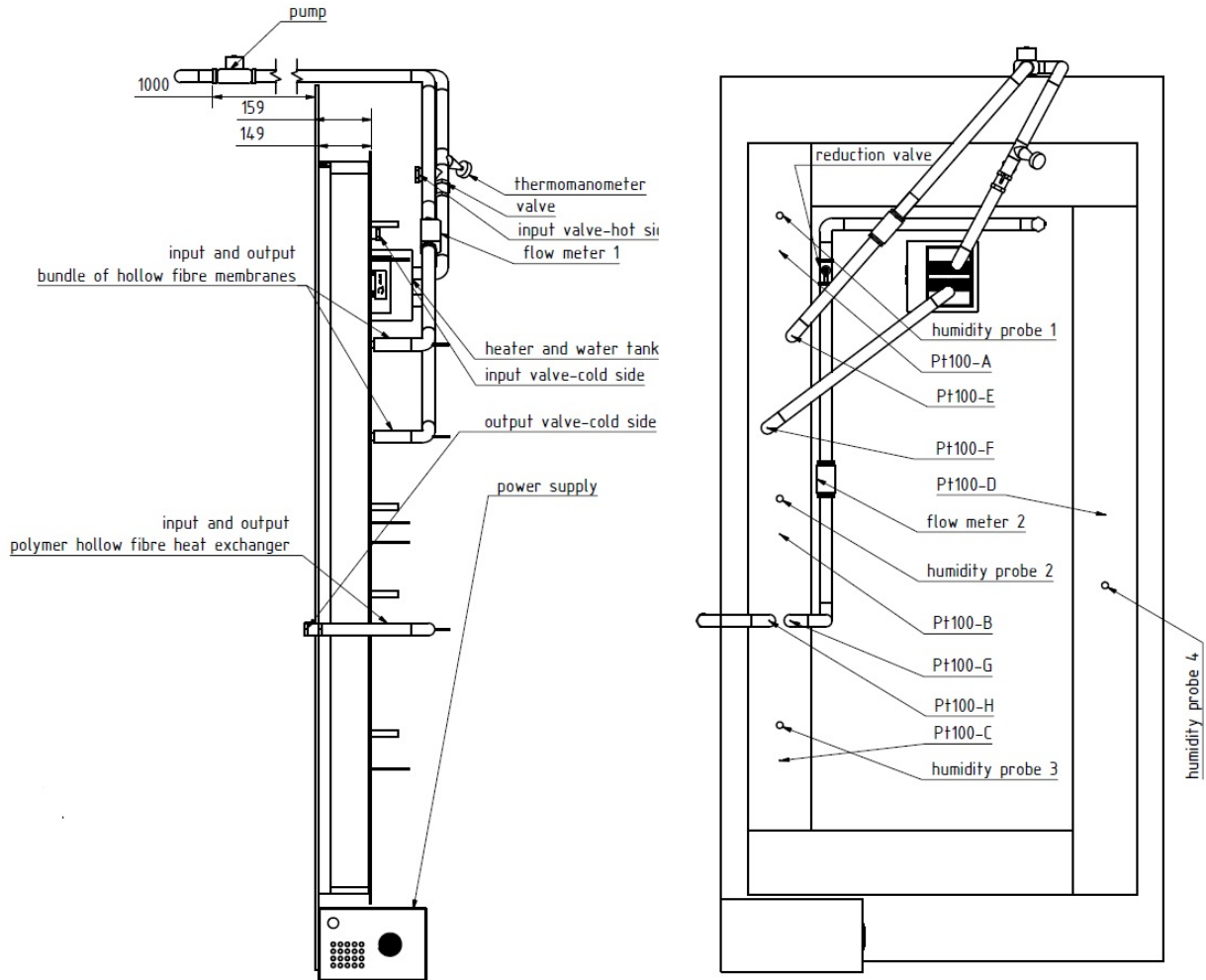


Fig. 2: Scheme of distillation tunnel, from side (left), from above (right)

The first drops of water appeared on the surface of thermal module when inlet temperature of membrane module was 30°C. The difference between the temperature inside membrane fibers and ambient temperature was around 10°C. This observation is in concordance with knowledge already mentioned in introduction. Table 2 presents values of measured quantities - temperature, relative humidity, amount of condensate (condensate).

The temperature and relative humidity inside tunnel changed according to the place. Naturally the highest temperature was between the membrane and thermal module (T_2), where the hot water steam was present. Then the water steam condensed on the thermal module and the air was cooled, therefore the lowest temperature occurred behind the thermal module (T_3), where flowed cold water. The temperature in the other side (T_4) and in front of membrane module (T_1) was similar and did not change rapidly. Similarly, the relative humidity reached the highest value between hollow fibers modules (H_2) and then dropped as the

Tab. 2: Measured data

	$T_{m,o}$	$T_{t,i}$	$T_{t,o}$	H_1	T_1	H_2	T_2	H_3	T_3	H_4	T_4	condensate
	[°C]	[°C]	[°C]	[%]	[°C]	[%]	[°C]	[%]	[°C]	[%]	[°C]	[ml/h]
EXP01	53.3	10.6	11.1	83.3	19.9	93.2	24.9	88	17.3	88.2	19	739
EXP02	52.3	10.6	11.1	82.7	19.8	93.4	24.6	89.7	17.4	85.9	19	778
EXP03	58.4	10.2	10.7	93.2	19.5	92.7	25.1	89.6	17.7	85	18.7	883
EXP04	57.1	10.5	11	81	19.6	93.3	24.8	85.5	17.3	84.1	18.8	817
EXP05	63.2	10.7	11.2	82.6	20.1	93.3	26.2	86.6	18.2	89	19.3	976
EXP06	61.9	10.7	11.2	83.8	20.1	93.7	26.1	86.4	18.2	86.7	19.3	950

water steam was condensed. The difference in H_1 and H_4 is given by the different temperature. The amount of condensate grew with increasing temperature and flow rate inside membrane module, because the water inside the module evaporated faster.

4. Conclusions

The polymeric distillation could be an alternative to metal desalination units since it does not suffer from exposure to salt water and it is low weight and more environment friendly. This paper presents a prototype based on membrane distillation, which important parts are made from polypropylene. The prototype was operated without any interruption or failure. The experimental verification of prototype showed that the thermal difference between the brine inside the membrane fibres and inside the tunnel is high enough to be a driving force for distillation. The unit began to distil when temperature of the brine was 30°C, but the volume of condensed water per hour grew with increasing temperature and flow inside the membrane module, therefore it is better to operate the unit at higher temperature.

Acknowledgments

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