24th International Conference
ENGINEERING MECHANICS 2018
Svratka, Czech Republic, May 14 –17, 2018
Paper **#107**, pp. 117–120, doi: 10.21495/91-8-117

CONDENSATION ON THE OUTER SURFACE OF POLYMER HOLLOW FIBER HEAT EXCHANGERS AND ITS INFLUENCE TO THE HEAT TRANSFER

T. Brožová[*], E. Bartuli[**], M. Raudenský[***]

Abstract: *Condensation influences significantly the heat transfer. Describing its mechanism is necessary for better understanding and leads to its beneficial use in applications. The contribution deals with the condensation on the outer surface of polymer hollow fibers that are made of polypropylene with outer diameter 0.8 mm. These fibers form the heat exchanger with total amount 2660 fibers that are divided into 20 equivalent layers. The wall thickness is approximately 10% of outer diameter. The testing air properties were set at 27 °C and 50% relative humidity that are the typical conditions for such tests in air-conditioning technology. The study focuses on the influence of the gravity and the air speed. Therefore, the polymer hollow fibers heat exchanger (PHFHE) was placed in three different positions (vertical, horizontal, and 45°) and the air velocity were chosen as 1 m s^{-1} and 3 m s^{-1}. The experiments shows that the PHFHE are able to stand up the conditions in air-conditioning applications. Moreover, they achieved the competitive results with common metal heat exchangers. The paper claims the perspective of PHFHE in air-conditioning technology.*

Keywords: hollow fiber, heat exchanger, heat transfer, condensation

1. Introduction

Polymer hollow fibers heat exchangers (PHFHE) are an alternative to the common metal heat exchangers (HEs) which are mainly made of copper, aluminum or steel. Polymer HEs provide many benefits as easy shaping and machining, low weight, low cost, and others. PHFHE are environmental friendly, the energy required to produce a unit of mass of plastic is about 2 times less than a unit of metal (Zarkadas, 2004).

PHFHE consists of hundreds or even thousands of polymer hollow fibers that have the outer diameter approximately 1 mm. Their key disadvantage seems to be the low thermal conductivity which is between 0.1–0.4 W m^{-1} K^{-1} (Astrouski, 2012). This disadvantage is negligible due to the wall thickness that is about 10% of outer diameter. On the other side PHFHE are highly compact. Considering their chemical resistance, they found the use in processes connected to extreme conditions – e.g., corrosive and chemically aggressive heat transfer media, and processes with sterile conditions. However, these PHFHEs were mainly developed as cheap alternative of metal heat exchangers for any use – e.g., HVAC (heating, ventilating, and air conditioning) technology, automotive industry (Krasny, 2016), and recuperation of waste thermal energy in wastewater. Their life expectancy was tested by pressure loading. The study proves that potted bundles are able to stand up more than 10^{6} pressure cycles at 3.5 bar with temperature of surrounding 80 °C (Brozova, 2016). More information can be found in literature – e.g., (Astrouski, 2016, 2015; Raudensky, 2017; Chen, 2016).

[*] Ing. Tereza Brožová: Heat Transfer and Fluid Flow Laboratory, Brno University of Technology, Technická 2896/2; 616 69, Brno; CZ, tereza.brozova@vut.cz

[**] Ing. Erik Bartuli: Heat Transfer and Fluid Flow Laboratory, Brno University of Technology; Technická 2896/2; 616 69, Brno; CZ, erik.bartuli1@vut.cz

[***] prof. Ing. Miroslav Raudenský, CSc.: Heat Transfer and Fluid Flow Laboratory, Brno University of Technology; Technická 2896/2; 616 69, Brno; CZ, miroslav.raudensky@vut.cz

There are two modes of condensation that can occur on the outer surface, the dropwise and film condensation (Incropera, 2011; Umur, 1965). The character of condensation is affected by the wettability of the surface. The hydrophobic material has the tendency to the dropwise condensation and the film condensation is observed on hydrophilic materials. The mechanism of the condensation inside and outside tubes of metal shell-and-tubes heat exchangers is described by Cavallini (2003).

Malik (2005) claims the great potential of PHFHEs in air-conditioning applications. The authors formulate the concern over the connecting hundreds of tubes to headers. The literature proves that this problem was already solved (Krasny, 2016; Raudensky, 2016, 2017).

2. Experimental section

The experiments were performed to observe and describe the mechanism of condensation on the outer surface. The air properties were set as the temperature 27 °C and 50% relative humidity. These are the typical air properties for such tests in air-conditioning technology. The air speed 1 m s^{-1} and 3 m s^{-1} were chosen. The cooling medium was inside the hollow fiber with the temperature 10 °C. Water was chosen as the cooling medium with flow rate 0.5 m^3 h^{-1}. The PHFHE was placed in testing tunnel and the fan was used to provide the air flow. The input and output air humidity, temperature, the air differential pressure were measured and the positions of the measuring probes are shown in the Figure 1. The experiments were performed in the calorimetric chamber with inner dimensions 4 m × 4 m × 3 m. This chamber served as storage room of the air with precisely given properties. The output air temperature was measured exactly behind the tested sample in six positions. Therefore, the temperature distribution was observed. At the end of the tested tunnel the bulk temperature was measured.

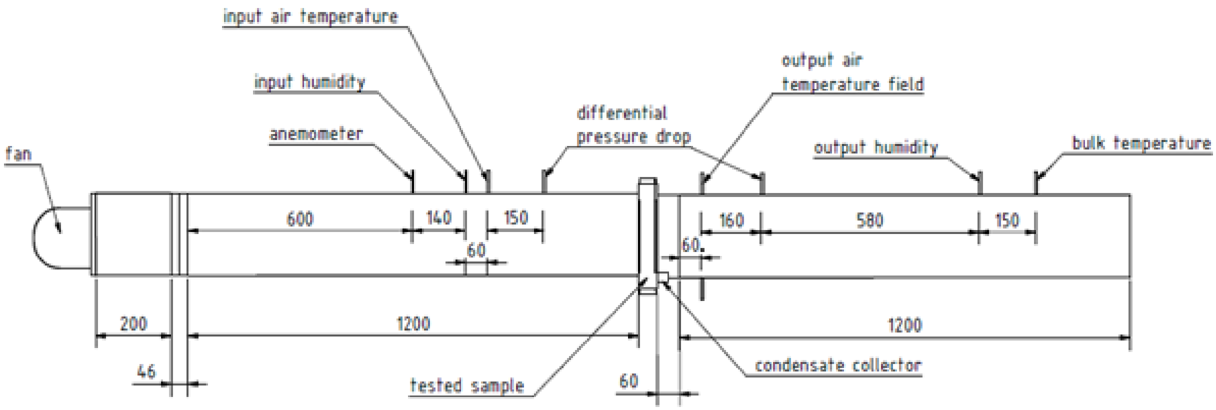

Fig. 1: Scheme of the positions of measurement probes and tested sample during experiments

The tested sample contains of 20 equivalent layers of the hollow fibers. Each layer consist of 133 fibers that gives total amount 2660 fibers. The PHFHE is displayed in the Figure 2. The dimensions of cross section are 190 mm × 225 mm where 190 mm is the effective length of the fibers.

Fig. 2: The polymer hollow fiber heat exchanger before testing

The condensation process is highly influenced by the wettability of the surface. Therefore, the wettability of these fibers was measured by Wilhelmy balance method and the advancing dynamic contact angle was defined as 107°. For comparison, the same angle measured for polyamide fibers is only 78.4°. The detailed description of the Wilhelmy balance method can be found in the literature (Tretinnikov, 1994; Yuan, 2013).

The influence of gravity was observed by placing the PHFHE in three different positions, horizontal, vertical and to the position when the fibers layers form the angle 45° with the gravity direction. The air flow was always perpendicular to the fibers.

3. Results and Discussion

The experiments showed that the gravity has significant influence on the remaining of the condensate on the fibers. The Figure 3 gives the comparison of the condensation in different positions. The test conditions are the same except the position. It can be observed that the condensate has the tendency to remain on the fibers when placed in horizontal position and also has the tendency to form larger droplets. It is possible to see that in vertical position of fibers the condensate is continuously removed from the fibers surface. The fog on the fibers is visible when HE placed in position 45°. Large droplets occur in horizontal position.

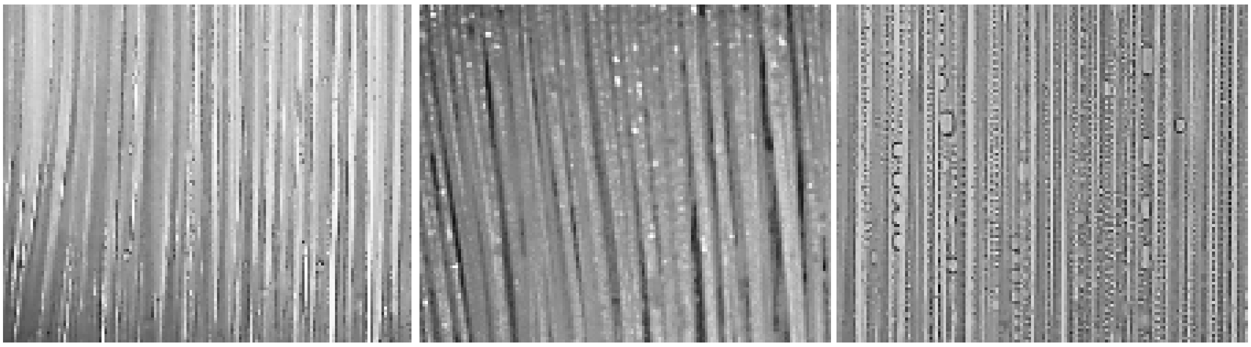

Fig. 3: The hollow fibers of PHFHE during the experiment placed in vertical (left), 45°(center), horizontal (right) position, air speed 3 m s^{-1}.

The Table 1 gives the overview of the measured results. The table shows significantly higher thermal power in horizontal position with air speed 3 m s^{-1}. That was caused by dropping of the condensate through the tunnel that caused cooling of the air along the tunnel before the bulk temperature was measured. The table also shows the comparison of dry and wet differential pressure. The dry differential pressure is measured when the air with testing properties is flowing through the HE without the condensate. The wet differential pressure is then measured when the HE is covered by the condensate. As one would expect the condensate contributes to the increase of the differential pressure. However, the dry differential pressure was still very large.

Tab. 1: The overview of measured results.

Fibers position	Air speed [m s^{-1}]	Output air relative humidity [%]	Bulk temperature [°C]	Thermal power [kW]	Dry differential pressure [Pa]	Wet differential pressure [Pa]
vertical	1	80.53	13.0	1.21	25.3	46.9
vertical	3	90.85	14.5	2.82	228	280
45°	1	74.6	13.21	1.23	25.3	68
45°	3	91.21	14.33	2.66	228	268
horizontal	1	79.45	12.1	1.28	25.3	67.1
horizontal	3	81.67	13.22	3.42	228	284

4. Conclusions

The study shows the significance of the gravity. The inclination of the fibers leads to the better removal of condensate thus smaller droplets size. That results in smaller differential pressure and thermal resistance.

The authors suggest to reduce the number of layers. The experiments expose that the HE was oversized. This resulted in large differential pressure which is the important parameter in industry. The study also proves that PHFHE are able to stand up the conditions that are typical in air-conditioning technology.

The authors also discourage from placing the HE in horizontal position. It results in remaining of the condensate on the fibers and also to the uncontrolled dripping of the condensate.

Acknowledgement

The research leading to these results has received funding from the MEYS under the National Sustainability Programme I (Project LO1202) and from the project EPSILON No.TH01020139, Heat exchangers with polymeric hollow fibres for energetic systems of buildings, granted by the Technology Agency of the Czech Republic.

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