Non-typical designs of Polypropylene Capillary Heat Exchangers

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Received: 26 December 2020/ Revised: 6 January 2021/ Accepted: 12 January 2021/ Published: 31-01-2021

Abstract**—** *The present article describes a heat exchanger with transparent (smooth) fibres with an atypical body shape and an atypical arrangement of polypropylene capillaries inside. The exchanger cross-section was of a square shape. This type of exchanger was subjected to the investigation of the impact of the fibre arrangement on the overall heat transfer coefficient and behaviour of fibres during the experiment. The exchanger was examined in the counter flow arrangement. The exchanger with 1,400 transparent fibres with the outer diameter of 0.275 mm was examined at the secondary fluid flow rate of 150* $l \cdot h^{-1}$ *to identify the overall heat transfer coefficient k which amounted to 520* $W \cdot m^{-2} \cdot K^{-1}$*. When compared to an exchanger with identical parameters of fibres placed inside a cylindrical exchanger body, a decrease in the overall heat transfer coefficient represented 14%. At the flow rate of 200* $l \cdot h^{-1}$*, the value of the overall heat transfer coefficient identified experimentally was 632* $W \cdot m^{-2} \cdot K^{-1}$*. When compared to cylindrical exchanger with comparable fibre parameters, the value was 33% lower.*

Keywords**— *Heat exchangers, polypropylene fibres, typical designs Polypropylene Capillary.***

I. INTRODUCTION

The use of polypropylene fibres in heat exchangers, the benefits of the used material, the production of fibres (capillaries) and sealing them in a potting were described by several authors, for example in papers [1-3]. It is a novel approach to designing exchangers with the heat-transfer surface consisting of polypropylene fibres with either an absolutely smooth and gas-proof surface, or a porous surface. The number of capillaries in a bundle placed inside a polyurethane tube with a diameter of ca 30 mm may range from several hundreds to thousands of pieces. It depends on a fibre diameter and a potting size, but primarily on the desired exchanger performance.

II. DESIGN DESCRIPTION

The parameters of the experimentally examined exchanger with a square cross-section are listed in Table 1. These parameters fully correspond with the experimentally examined heat exchanger with a circular cross-section described in paper [4]. A partial cross-section of the design of the analysed exchanger is shown in Fig. 1. A standard potting (1) of the bundle was inbuilt in the exchanger body (2). The bundle of fibres was intertwined between the partition plates (3). The heat exchanger body was made of PVC boards and steel screws. A red arrow indicates the inflow of the working medium into the exchanger. The medium flowed around the fibres in the bundle and through the openings in the partition plates across the entire exchanger. The positions and sizes of the openings in the partition plates were chosen randomly to improve the flow of the medium around the fibres. A blue arrow indicates the outflow of the working medium flowing inside the fibres.

TABLE 1
TECHNICAL PARAMETERS OF THE EXAMINED BUNDLE OF CAPILLARIES

Parameter	Value	Size
Number of fibres	1,400	pc
Length of fibres	680	mm
Outer diameter of fibres	0.275	mm
Heat-transfer surface area	0.822	m^2
Material of capillaries	polypropylene	-
Material of potting	polyurethane	-

In the space between the body and the partition plates, the fibres were fixed using a silicon sealant with the aim to fix them along the entire width of the partition plate and avoid fibre clustering. A view inside the analysed exchanger is shown in Fig. 2.

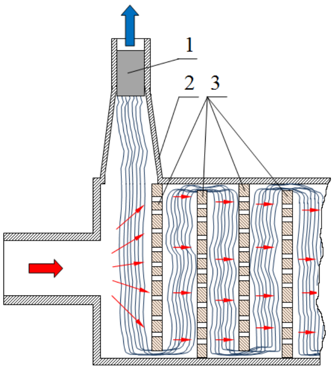

FIGURE 1: A cross-section of the square-shaped exchanger

FIGURE 2: A view inside the exchanger

III. RESULTS OF THE EXPERIMENTAL RESEARCH

The experiment preparation is documented in Fig. 3 which shows the procedure of installing individual fibres and partition plates into the exchanger body. The examined exchanger was attached to a measurement stand (Fig. 4) used in the experiment. The fibres in the bundle were filled with water from the distribution network and water flowing around the fibres was supplied from an accumulation tank.

The measurements were carried out by applying the standard procedure. Prior to the experiment, the fibres were subjected to a tightness test [5]. It was aimed at ensuring a faultless course of the measurements of temperatures and flow rates. Subsequently, the bundle was placed inside the exchanger body. After the exchanger was attached to the measurement stand, the tightness test was repeated [6] in order to exclude potential damage to the bundle caused by putting it inside the exchanger body. Following an inspection of the performance of the gauges (pressure meters, flow rate meters, thermometers), the flow rate of water flowing inside the fibres was set.

FIGURE 3: Procedure of installing fibres and partition plates

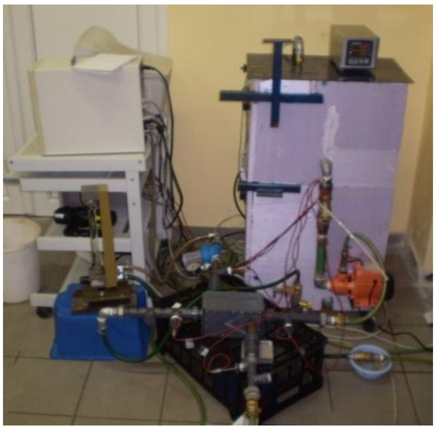

FIGURE 4: The exchanger during the measurements

A maximum flow rate value measured in the second tightness test was 200 l·h^{-1}. During the measurements, the flow rate range from 30 l·h^{-1}to 200 l·h^{-1}was divided into five intervals (30 l·h^{-1}; 60 l·h^{-1}; 100 l·h^{-1}; 150 l·h^{-1}; and 200 l·h^{-1}). Subsequently, the measurements were carried out from the lowest to the highest flow rate value. Water used in the experiment was supplied from the municipal distribution network. A temperature of water was constant during the entire experiment. The water pressure during the measurements was ca 400 kPa and it sufficiently covered the pressure loss of a single filter and flow rate meter which were installed in the inlet piping. After the parameters of water flowing through the bundle were stabilised, a water pump was used to force water around the fibres. The water was prepared in an external tank insulated on its external surface to avoid a heat loss. Water was heated by a 3 kW electric spiral. After the water circulation around the fibres was activated, temperatures were automatically measured by the computer software and displayed directly from a data logger on a computer screen. The whole process was visually monitored and as soon as the state was stabilised, i.e. when the measured parameters stopped exhibiting changes, a water flow regulation valve was used at the inlet into the bundle to set a new flow rate value for the water flowing inside the capillaries, i.e. in the secondary circuit of the exchanger. After the equilibrium state was reached, the flow rate was repeatedly adjusted to a higher value. The procedure was repeated until the flow rate of 200 $l \cdot h^{-1}$ was achieved. The time interval in which the equilibrium state was reached ranged from 3 to 5 minutes. In order to exclude potential technical failures of the used gauges, after reaching the steady state at the maximum flow rate of 200 $l \cdot h^{-1}$, the flow rate was gradually reduced in the same increments. After the measurements were completed, the recorded values of the measured parameters were further processed in a spreadsheet. The overall heat transfer coefficient was calculated using the formula (2). The number and length of fibres and their outer diameter were used to identify the heat transfer surface area. The size of this area is stated in Table 1.

Maximum thermal capacity of the exchanger was calculated using the following formula (1): [2]

$$P = k \cdot \overline{\Delta T} \cdot S = Q_{m2} \cdot c_p \cdot \left(T_2'' - T_2'\right) \text{ (W)} \tag{1}$$

Where in k is the overall heat transfer coefficient ($W \cdot m^{-2} \cdot K^{-1}$); $\overline{\Delta T}$ is the mean temperature gradient (K); Q_{m2} is the mass flow rate of water in the secondary circuit ($kg \cdot s^{-1}$); c_p is the specific heat capacity of water ($J \cdot kg^{-1} \cdot K^{-1}$); and S is the heat transfer surface area (m^2). T_2'' and T_2' are the temperatures of water in the secondary circuit at the inlet and outlet; T_1' and T_1'' are the temperatures of water in the primary circuit at the inlet and outlet.

The measured values of temperatures and flow rates may be used in the equation (1) to identify the overall heat transport coefficient, with the use of the equation (2). The following applies in general:

$$k = \frac{Q_{m2} \cdot c_p \cdot (T_2'' - T_2')}{\overline{\Delta T} \cdot S} \left(\mathrm{W} \cdot \mathrm{m}^{-2} \cdot \mathrm{K}^{-1}\right) \tag{2}$$

In the case of a counter flow exchanger, the mean temperature gradient was calculated using the following formula (3):

$$\overline{\Delta T} = \frac{(T_1' - T_2'') - (T_1'' - T_2')}{\ln \frac{T_1' - T_2''}{T_1'' - T_2'}} \tag{3}$$

A correlation between the overall heat transfer coefficient k and the flow rate in a partition plate heat exchanger with a square cross-section is shown in Fig. 5. Its maximum value was observed at the water flow rate inside the fibres of 200 $l \cdot h^{-1}$ and it amounted to as little as 630 $W \cdot m^{-2} \cdot K^{-1}$.

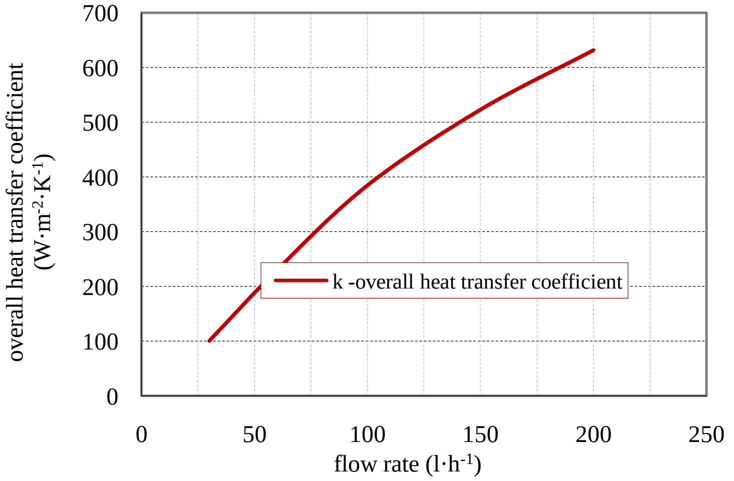

FIGURE 5: A correlation between the overall heat transfer coefficient and the flow rate

IV. CONCLUSION

An analysis of two different types of heat exchangers comprising polypropylene fibres with identical parameters showed that the heat transfer was more intensive in an exchanger with a circular body. This may be attributable to the fact that the fibres were forced against, and attached to, the wall (in a square-shaped exchanger body). At such places, the fibres were not sufficiently flown around by water (see Fig. 1), and such insufficient flow around the fibres was also observed in the entrance part of the exchanger - next to the potting. It is therefore possible to state that in this exchanger type a certain part of the fibres within their length practically did not contribute to the heat transfer. Removing this drawback in a square-shaped exchanger design might result in approximately a 20–25% increase in the value of the overall heat transfer coefficient. This analysis was based on a fictitious removal of the part of fibres which did not contribute to the heat transfer. As the fibres were forced against the wall, the heat-transfer surface area was in fact reduced.

A comparison of the results of the experimental identification of the value of the overall heat transfer coefficient in exchangers with circular or square external surface clearly indicated that higher intensity of the heat transfer may be achieved by using exchangers with cylindrical surfaces. As stated in the annotation of this article, at the maximum flow rate inside the fibres of 200 $l \cdot h^{-1}$, the square-shaped exchangers exhibited the value of the overall heat transfer coefficient which was lower in as much as 33%.

ACKNOWLEDGEMENTS

The paper has been produced as a part of a project KEGA 005TUKE-4/2019 and VEGA No. 1/0626/20.

REFERENCES

[1] D. M., Zarkadas, K. K. Sirkar, Polymeric Hollow Fiber Heat Exchangers: An Alternative for Lower. Temperature Applications. In Eng. Chem. Res., vol. 43, 2004, p. 8093-8106.

[2] M. Čarnogurská, R. Gallik, Special Types of Heat Exchangers, International Journal of Engineering Research & Science (IJOER) vol.6, 2020, p. 12-15.

[3] L., Jachuck, R. J. J. Zaheed, Review of polymer compact heat exchangers, with special emphasis on a polymer film unit. In Applied Thermal Engineering, vol. 24, 2004, no 16, p. 2323-2358.

[4] M. Čarnogurská, M.Příhoda, R. Gallik, Tthe impact of elementary structural parameters on the performance of heat exchanger made of polypropylene fibres, Materials and Technology, 54(6) 2020.

[5] R., Gallik, M. Dohnal, Potted sets of hollow fibers as low cost heat exchangers. (in Slovak). SROJÁRSTVO / SROJÍRENSTVÍ, (special edition). 2019, p. 61-62.

[6] K. Král, Technické merania. (in Slovak). Alfa, 2002, 155 s.