Special Types of Heat Exchangers

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***Abstract*— *The article describes the results of experimental research of a new type of heat exchangers in which the heat transfer surface consists of smooth polypropylene fibres with the outer fibre diameter of 0.5 mm and the total heat transfer surface area of 0.14 m^2. The research output is the information on the value of the heat transfer coefficient, exchanger heat capacity and pressure loss. This type of heat exchangers is contemplated for applications in areas where high chemical resistance of the equipment is required, as well as a relatively low weight and price and excellent resistance to the formation of wall deposits.*

***Keywords*— heat exchangers, polypropylene fibres, structure.**

I. INTRODUCTION

Within the new approach to the heat exchanger structure, the heat transfer surface consists of polypropylene fibres with an absolutely smooth and gas-proof surface or a surface with porous walls. The polypropylene fibres, which form plastic capillaries of exchangers, currently seem to be a very simple and cost-efficient component to be used in the structure of heat exchangers. Table 1 contains the technical parameters of a bundle of plastic capillaries which has been subjected to the experimental investigation. The purpose of the investigation was to identify the cooling capacity of the exchanger, but primarily the heat transfer coefficient of the transfer of heat from water in a polypropylene capillary to water in the surrounding environment.

TABLE 1
TECHNICAL PARAMETERS OF THE INVESTIGATED BUNDLE OD CAPILLARIES

Capillary material	Polypropylene
Potting material	Polyurethane
Number of capillaries	300 pieces
Length of capillaries	300 mm
Inner diameter of capillaries	0.42 mm
Outer diameter of capillaries	0.5 mm
Heat transfer surface area in the exchanger	0.14 m^2

Heat exchangers consisting of polypropylene fibres must meet certain requirements in terms of the pressure of the medium inside the capillaries p_{in} and on their outer wall p_{out}. The "*burst*" pressure is the maximum over pressure inside the capillaries relative to the external pressure at which the capillary wall bursts [1]. Its maximum value was identified experimentally as $4{\cdot}10^5$ Pa. The *"collapse*" pressure is the overpressure from the outer wall of the capillary against the inner wall, at which the fibre wall collapses with the subsequent reduction of its flow cross-section. The maximum value of such pressure was $2{\cdot}10^5$ Pa. The maximum operating temperature of the exchangers made of polypropylene fibres was 70 °C.

II. STRUCTURE DESCRIPTION

The new generation of heat exchangers, which are made of polypropylene fibres, uses hollow fibres while their ends are potted into a polyurethane tube. The fibres may be regarded as capillaries, and by potting them into the tube it is possible to create a whole bundle of capillaries (Fig. 1). The Figure shows one of the ends of such bundle. The part of the tube where the plastic capillaries are potted into the PVC tube is referred to as the *potting* [2]. Fig. 2 shows that the capillary diameters vary and they also vary along the capillary length. This is caused by the capillary manufacturing technology.

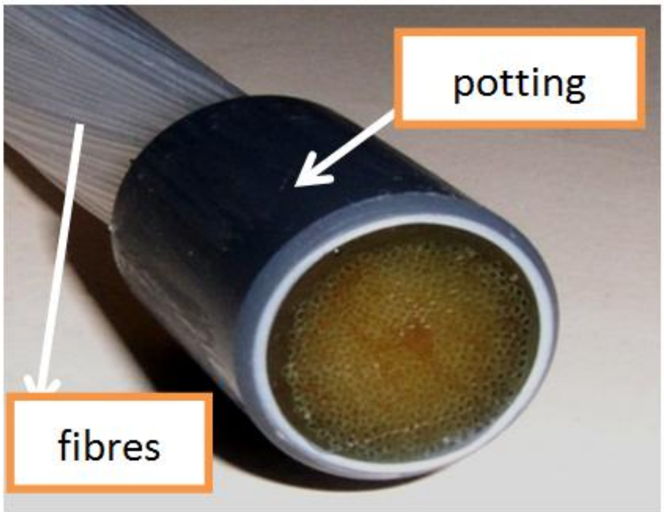

FIGURE 1: Fibres sealed in the potting

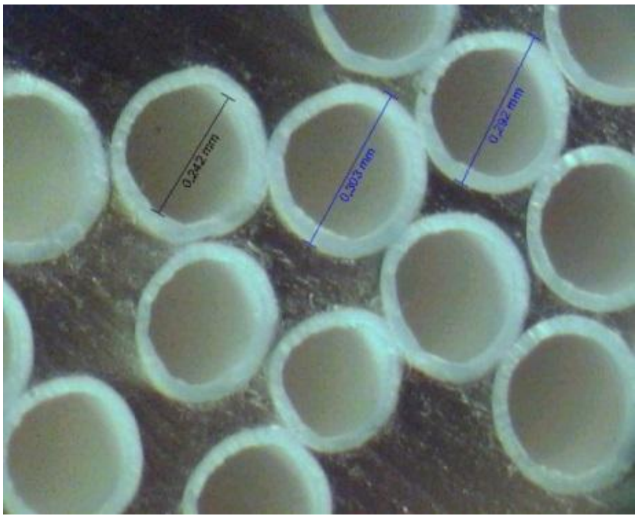

FIGURE 2: A detailed image of the fibres

The number of capillaries in a single working bundle may vary. In the version shown in Fig. 3, the PVC tube with the diameter of 50 mm may contain 300 to 1,500 pieces. The number of fibres potted into a PVC tube depends primarily on their outer diameters. A bundle with the outer fibre diameter of approximately 0.5 mm contains about 300 capillaries in the bundle, and with the diameter of 0.18 mm as much as 1,500 pieces. Generally, fibres may be more than 1 m long. However, their length is limited by the pressure loss of the bundle determined by its structure and strength. The length, outer fibre diameter and the number of fibres also determine the area of the heat transfer surface which in real operations ranges from 0.1 m^2 to 1.5 m^2. Fig. 3 shows the bundle of capillaries made by potting the fibres into the end of a transparent PVC tube. Such bundles are installed into heat exchangers used in counter flow Tube and Shell exchangers (Fig. 4). The red arrow indicates the flow of heated water in fibres which is supplied into the exchanger, and the blue arrows indicate the flow of the cooled medium.

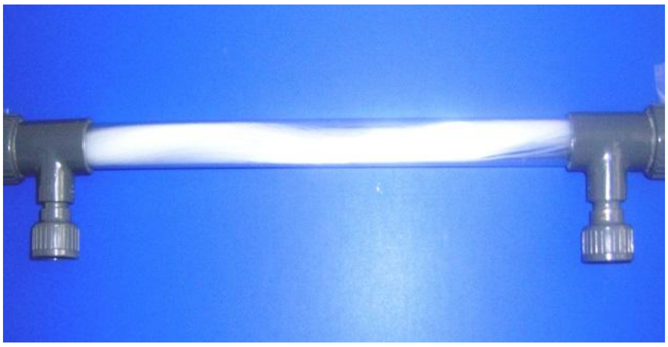

FIGURE 3: The bundle of fibres in a transparent tube

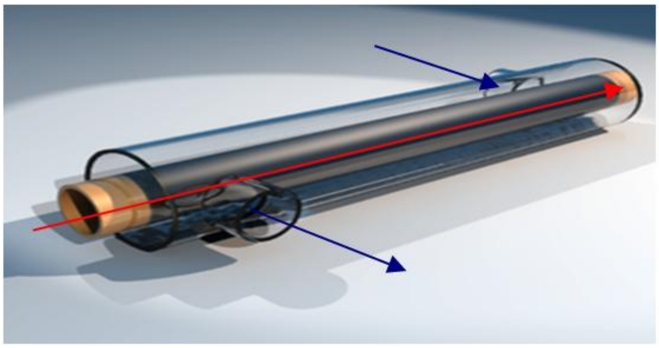

FIGURE 4: The Tube and Shell exchanger

The analysis of the heat exchanger made of polypropylene fibres comprised the assessment of the *fibre stretching degree*; it may also be referred to as the *fibre loosening degree*. In the “active” mode of the exchanger, at 0 % fibres loosening the fibres were assumed to be stretched slightly and in the same degree. For example, at the bundle length of 700 mm and the 6 % fibre loosening, which corresponded to 42 mm of the length of a fibre itself, the fibres were absolutely free and moved by water flowing around them in the entire dedicated space. The fibres were irregularly oscillating and this contributed to an increase in turbulence and subsequently to an increase in the heat transfer coefficient and specific thermal capacity of the heat exchanger.

Another parameter subjected to examination in exchangers made of polypropylene fibres was the *surface of fibres* as such. The test specimen of the heat exchanger described above was subjected to measurements using the fibres with absolutely smooth surfaces. Porous fibres are hydrophobic, but not gas-proof. Fig. 5 shows the surface of a porous fibre, and Fig. 6 shows the surface of a smooth fibre used in the test heat exchanger.

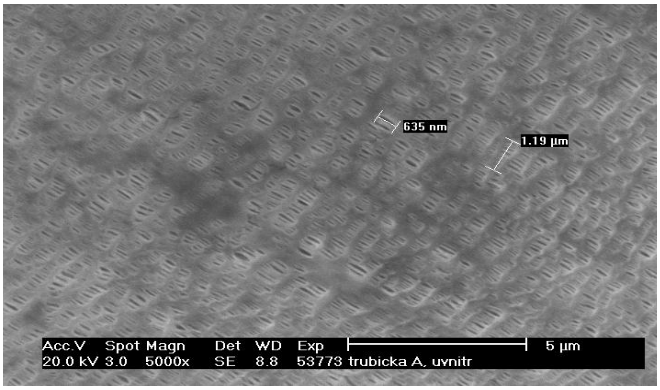

FIGURE 5: Porous fibre surface

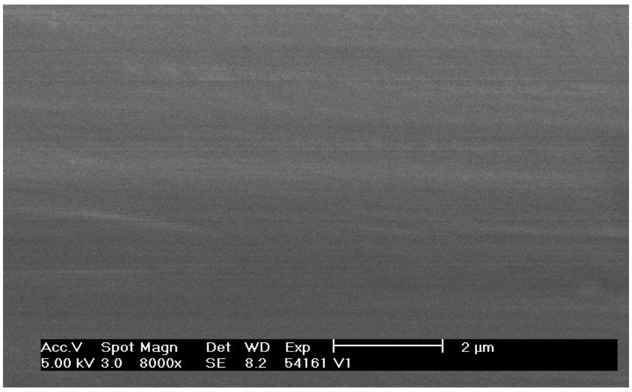

FIGURE 6: Smooth fibre surface

III. EXPERIMENTAL RESEARCH RESULTS

The experimental research was carried out with a compact exchanger with polypropylene fibres of the inner diameter of 0.5 mm. The number of potted fibres in one bundle was 300 fibres. The tube into which the fibre ends were potted was made of PVC and its diameter was 20 mm. Fig. 7 shows the inlet and outlet positions of the medium (water) supplied to the exchanger (positions 1–2: inlet and outlet of the heated medium; positions 2–3: inlet and outlet of the cooled medium). The distance between the point where water enters the exchanger and the point where it leaves the exchanger was 300 mm. The heat transfer surface area of the bundle of fibres was approximately 0.14 m^2.

At constant volumetric flow rate of water $Q_{V,\text{out}}$ = 270 $l \cdot h^{-1}$on the outer side of polypropylene fibres (0.075 $kg \cdot s^{-1}$), the thermal capacity of the exchanger was monitored for three different mass flow rates of water flowing through polypropylene fibres. The flow rate values were 0.042 $kg \cdot s^{-1}$; 0.083 $kg \cdot s^{-1}$; and 0.125 $kg \cdot s^{-1}$ (alternatively expressed as volumetric flow rates, the values were 150 $l \cdot h^{-1}$; 300 $l \cdot h^{-1}$; and 450 $l \cdot h^{-1}$). The obtained data on the heat transfer coefficient, one of the key indicators of heat transfer intensity, as well as on the pressure loss in the bundle of polypropylene fibres and individual mass flow rates are represented in Fig. 8. Maximum thermal capacity achieved during the experiment was approximately 4,400 W and it was identified using the following formula (1).

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

Where k is the heat transfer coefficient ($W \cdot m^{-2} \cdot K^{-1}$); $\overline{\Delta T}$is the mean temperature difference (K); Q_{m2} is the mass flow rate of water in the secondary circuit ($kg \cdot s^{-1}$); c_p is the specific thermal capacity of water ($J \cdot kg^{-1} \cdot K^{-1}$); and S is the heat transfer surface area (m^2).

Using the measured values, formula (1) was used to identify the heat transfer coefficient. In general, the following applies:

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

For the counter flow heat exchanger, the mean temperature difference was calculated using the following formula (3):

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

The maximum value of heat transfer coefficient, calculated using the thermal capacity at 450 $l \cdot h^{-1}$, represented approximately 1,700 $W \cdot m^{-2} K^{-1}$. The pressure loss in polypropylene tubes (Δp_{in}), identified experimentally at the above specified flow rate, amounted to approximately $1.5 \cdot 10^5$ Pa, and the pressure loss measured at the outer side of tubes (Δp_{out}) was approximately $0.21 \cdot 10^5$ Pa.

Fig. 8 presents the graph containing all examined parameters in three different steady states. At the volumetric flow rate of 300 $l \cdot h^{-1}$, the mean value of heat transfer coefficient was 1,620 $W \cdot m^{-2} \cdot K^{-1}$, and the total pressure loss was $0.95 \cdot 10^5$ Pa. At the flow rate of 150 $l \cdot h^{-1}$, the pressure loss was $0.4 \cdot 10^5$ Pa, and the heat transfer coefficient was approximately 1,450 $W \cdot m^{-2} K^{-1}$.

Reduction of pressure loss in this type of exchangers requires either increasing the number of fibres in the bundle, or increase the inner diameter of fibres. A larger inner diameter of fibres would result in a decrease in the total heat transfer surface area and an increase in the dimensions of the exchanger, provided that the cooling capacity remains the same. It is at the designer's discretion to choose the optimal method of exchanger adaptation to a particular type of real operation or facility as well as the reasons of such choice.

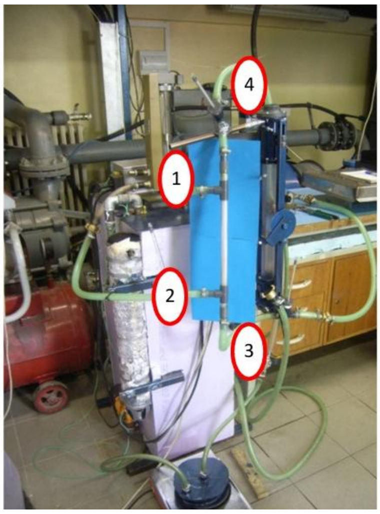

FIGURE 7: An image of the test equipment

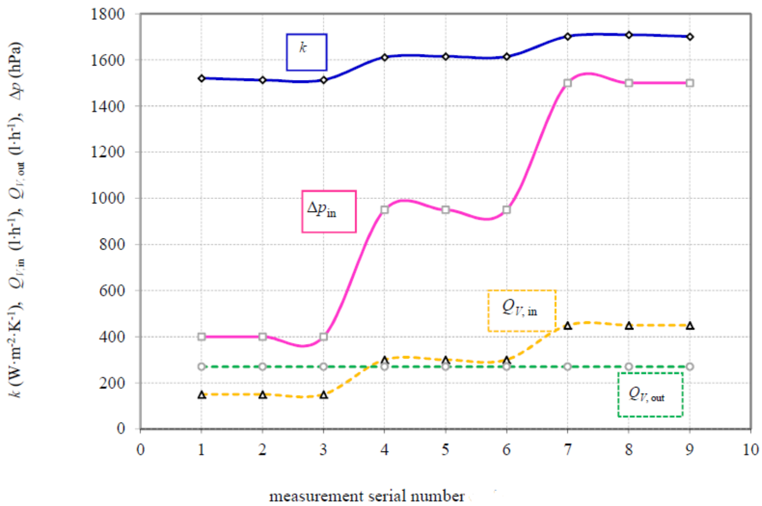

FIGURE 8: Measurement results

IV. CONCLUSION

At present, real technical operations lack a heat exchanger made of polypropylene which would offer strength and heat-transfer properties similar to those of metal exchangers while exhibiting excellent chemical resistance, relatively low weight and price, and resistance to the formation of wall deposits [3, 4].

The current increased interest in the use of propylene fibres for heat-transfer surfaces may be explained mainly by chemical stability of such heat-transfer surfaces, their resistance to corrosion and self-cleaning capacity. This facilitates the use of fibre bundles in operations where the use of conventional exchangers is impossible. Therefore, it provides a possibility to recover the residual thermal energy for example from waste waters. Such considerations are in favour of the use of exchangers made of polypropylene fibres, which will only be possible under certain conditions. It is also obvious that the use of such exchangers will be limited by their resistance to heat and pressure, or by their strength. Very thin fibres require proper balance between mechanical and operating parameters. Designing such exchangers require the application of the correct correlation between the fibre wall thickness, maximum pressure loss and heat transfer coefficient.

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