New Low-Potential Heat Exchangers Design

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Abstract— *This article deals with the effects of different structural arrangements inside a heat exchanger made of polypropylene tubes on the overall heat transfer coefficient. The experiments indicated that overall heat transfer coefficient k with stretched tubes was lower than the value observed when the tubes were slightly loosened. Tubes should not be loosened by more than 5 % of their length. If this value is exceeded, tubes may accumulate near the wall and their contact with water is insufficient; this results in reduced heat transfer. Equally important is to prevent tubes from attaching to each other. This may be achieved with a variety of turbulators. A turbulator may be any small object, metal or plastic, which is inserted among the tubes. Laboratory investigation indicated that turbulators can increase overall heat transfer coefficient by as much as 54 %compared to heat exchangers without turbulators, in identical operating conditions.*

Keywords*— *Heat exchanger, atypical structure, polypropylene tube, turbulators.

I. INTRODUCTION

Heat exchangers which are primarily intended for the use with low-potential heat sources have been described in paper [1]. Heat-transfer surfaces in such heat exchangers are on polypropylene tubes and they may be either absolutely smooth and gas-proof or porous. Polypropylene tubes in these exchanges are hollow. A required amount of tube ends are sealed into a polyurethane tube approximately 35 mm long to form a potting. A fluid (water) which absorbs heat from the surrounding environment (a low-potential heat source) flows through these tubes sealed in the potting. An identical potting is on the outflow end of the heat exchanger. A length of tubes between the pottings ranges from approximately 400 mm to max. 1,000 mm. A heat-transfer surface area S is calculated using the amount and dimensions of the used tubes and it determines the heat output of a heat exchanger. An inner diameter of a capillary tube usually ranges between approximately 0.15 and0.30 mm. Heat exchangers of this type, with simple designs, have been subjected to experimental research aimed at obtaining information on the overall heat transfer coefficient k, as presented in the quoted literature.

The heat exchangers presented in this article consisted of the same tubes as described above, but with a special feature, i.e. the arrangement of tubes between the two pottings. The article describes an analysis of three different designs of a heat exchanger.

II. SHELL AND TUBE HEAT EXCHANGER

A heat exchanger of this type consisted of a cylindrical shell with a diameter of 60 mm. The shell was made of a PVC tube (Fig. 1). Both tube ends (2) contained a sealed-in potting of capillary tubes (1). The tubes inside the shell were arranged so that they crossed the baffles. The purpose of the ring-shaped baffles (3) was to direct the fluid stream into the tube bundle and across the whole heat exchanger. The baffles were designed so that all tubes in the bundle are evenly distributed along their outer circumference and that a baffle gently pushes the tubes against the inner wall of the heat exchanger shell. The fluid stream had to cross the freely placed tubes in order to return to the axis of the heat exchanger. The same principle was applied to the installation of the smaller ring-shaped baffles (4). Their purpose was again to ensure that the tubes are evenly distributed along their circumference. These smaller baffles were also intended to push the fluid stream away from the heat exchanger axis towards the walls; therefore, the stream had to cross the tubes in the bundle again. The effect of alternating positions of the small and large baffles was that the stream repeatedly crossed the tubes. The baffles were made of toughened polystyrene and the tubes were attached to them with silicone seal and water-proof sealing tape.

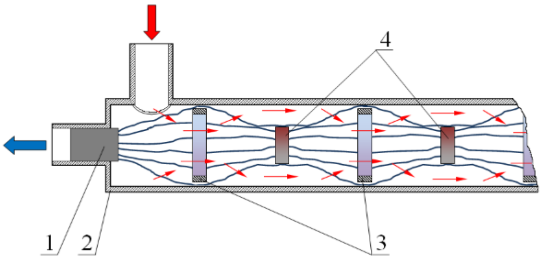

FIGURE 1: Shell and tube heat exchanger

The red arrows in Fig. 1 indicate the fluid stream flowing around the tubes and the blue arrow indicates the fluid stream flowing though the tubes. Fig. 2 shows a tube bundle with all baffles glued to it and Fig. 3 shows a detail of a small and a large baffle. The tube bundle with such an arrangement was inserted into a cylindrical body of a heat exchanger. To avoid damage to the baffles during insertion, the body was heated in a water bath to the temperature of 80 °C and the tube bundle was cooled to the temperature of 5 °C. This was carried out while using a relatively high expansibility of the used plastic materials. The parameters of the experimentally examined shell and tube heat exchanger are listed in Table. 1.

FIGURE 2: The adjusted bundle

FIGURE 3: A detail of the inner and outer baffles

TABLE 1
PARAMETERS OF THE SHELL AND TUBE HEAT EXCHANGER

Number of tubes	1,400 pieces	**Outer diameter of the tube**	0.275 mm
Tube length	550 mm	**Heat-transfer surface area**	0.665 m^2

During the experiment, the heat exchanger was in operation for approximately 10 minutes in a horizontal position. The obtained values of the parameters, which were necessary to calculate overall heat transfer coefficient k at a flow rate of fluid inside the tubes was V_{in} = 200 L·hr^{-1}, were used to plot a curve of a correlation between the overall heat transfer coefficient k and the time τ (Fig. 4).

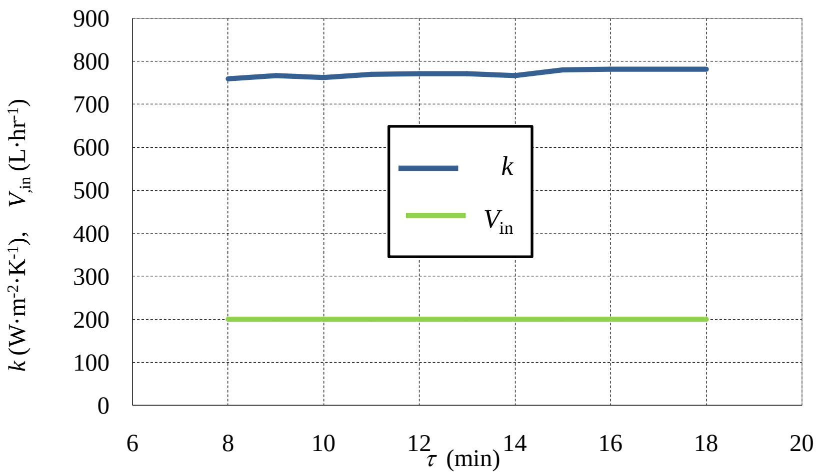

FIGURE 4: Overall heat transfer coefficient for a shell and tube heat exchanger

A maximum mean value of overall heat transfer coefficient k was 780 $W \cdot m^{-2} \cdot K^{-1}$. The method used for expressing this parameter is described in detail in paper [1]. Due to the fact that the obtained values of overall heat transfer coefficient were low, no further measurements were carried out on this type of heat exchanger.

III. HEAT EXCHANGER WITH TURBULATORS IN THE TUBE BUNDLE

In this type of heat exchanger, turbulators were inserted into the tube bundle. Turbulators were various small metal and plastic objects (nuts, bolts etc.). A detailed image of the bundle adjusted as described above is shown in Fig. 5. Parameters of the examined tube bundle are listed in Table2.

TABLE 2
PARAMETERS OF HEAT EXCHANGER WITH TURBULATORS

Number of tubes	1,400 pieces	**Outer diameter of the tube**	0.275 mm
Tube length	680 mm	**Heat-transfer surface area**	0.68 m^2

An inlet of the low-potential fluid into the heat exchanger was tangential (a yellow arrow in Fig. 6). During the experiment, the heat exchanger was positioned vertically.

FIGURE 5: A detailed image of turbulators

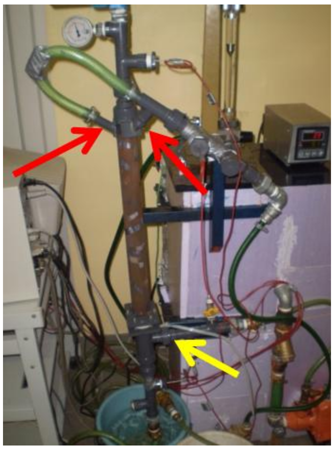

FIGURE 6: Heat exchanger arrangement during the experiment

Prior to the experiment, the tubes in the heat exchanger were loosened by3.7 %. This means that a tube with a length of 680 mm (Table 2) was placed inside a cylindrical shell of the heat exchanger with a length of only 655 mm. The overall heat transfer coefficient k was identified while applying the same method as before, as described in paper [1]. During the experiment, a flow rate of the fluid inside the tubes V_{in} was increased from 30 $L \cdot hr^{-1}$to 200 $L \cdot hr^{-1}$. The heat exchanger was in operation in a vertical position. The fluid exited the heat exchanger through two tangential outlets (red arrows in Fig. 6). The curve of a correlation between the overall heat transfer coefficient and the flow rate inside the tubes V_{in} is shown in Fig. 7.

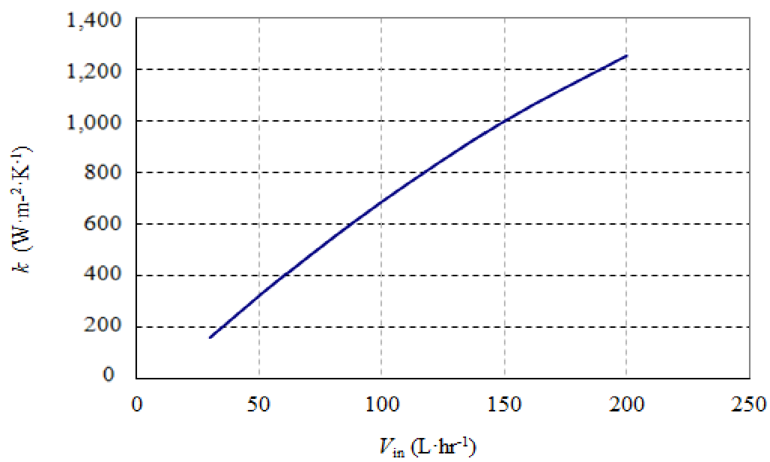

FIGURE 7: Overall heat transfer coefficient for heat exchanger with turbulators in the tube bundle

The curve indicates that optimal loosening of the tubes in the bundle and the use of turbulators may facilitate achieving a value of overall heat transfer coefficient as much as 1,200 $W \cdot m^{-2} \cdot K^{-1}$.

IV. HEAT EXCHANGER WITH TUBES WITH HINDERED TRANSVERSE MOTIONS

Laboratory tests were also performed with heat exchangers which were filled up with tubes so that their transverse motions were impossible. The body of such exchangers was made of a PVC tube. Parameters of the tested heat exchanger are listed in Table 3. The inner diameter of the PVC tube in this heat exchanger was 25 mm, and the number of tubes inside was 400. As the whole flow cross-section of the heat exchanger was filled up with tubes, the motions of the tubes were significantly hindered. The inlet and outlet for the fluid (low-potential water) were tangential (yellow arrows in Fig. 8). Therefore, in the heat exchanger with the parameters specified in Table 3, the fluid flew around the tubes in an oblique, lengthwise direction.

FIGURE 8: Heat exchanger with tubes with hindered transverse motions

TABLE 3
PARAMETERS OF HEAT EXCHANGER V001

Number of tubes	400 pieces	**Outer diameter of the tube**	0.6 mm
Tube length	260 mm	**Heat-transfer surface area**	0.196 m^2

The tubes in the bundle were loosened before they were sealed in a potting. Due to a diameter of the tubes, the loosening rate was only 0.5 %. This procedure was based on the knowledge obtained in experiments with a heat exchanger with turbulators. The temperature of fluid entering the heat exchanger was 50 °C. Flow rates inside the tubes were of three different values (150 $L \cdot hr^{-1}$, 300 $L \cdot hr^{-1}$ and 600 $L \cdot hr^{-1}$).A decisive factor was the flow rate of the fluid flowing outside the tubes, which amounted to950 $L \cdot hr^{-1}$ and 1,200 $L \cdot hr^{-1}$. Measurements were also made for a pressure drop in the heat exchanger; the measured values ranged from 30 to 150 kPa, depending on the flow rate (Fig. 9). Increased flow rates were reflected in increased values of overall heat transfer coefficient k, with a maximum value of 1,875 $W \cdot m^{-2} \cdot K^{-1}$. With regard to the fact that the fluid used in the experiment was pure water, such a value of overall heat transfer coefficient will not be feasible in real conditions. Water that will enter a heat exchanger will be polluted; therefore, there will have to be some free space among the tubes to avoid clogging of the heat exchanger with impurities, as this would reduce the k value.

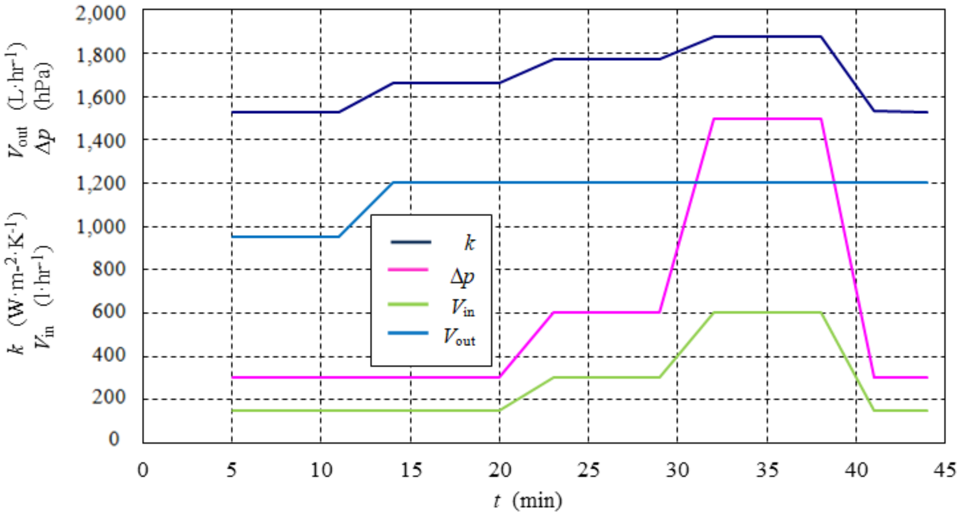

FIGURE 9: Values of overall heat transfer coefficient k and pressure drop Δp at different flow rates inside the tubes V_{in} and around the tubes V_{out}

V. CONCLUSION

The article describes three different designs of heat exchangers made of propylene capillary tubes. Results of this experimental laboratory investigation indicated that the most optimal design of a heat exchanger for achieving maximum values of overall heat transfer coefficient is the heat exchanger with tubes that are prevented from transverse motions and only slightly loosened (max 0.5 %). This type of heat exchanger meets the requirement of providing sufficient heat transfer from a heat-transfer fluid. However, it is necessary to bear in mind that these experiments were carried out with pure water. With polluted water, it is necessary to count with reduced amounts of transferred heat. In this investigation, with pure water, a maximum heat output of the heat exchanger was 4,450 W.

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