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Polymeric Hollow Fiber Heat Exchangers in Higher Temperatures

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Abstract **–** Fifteen years ago, polymeric hollow fibre heat exchangers were presented for the first time. Nowadays there are not only the shell-and-tube types as there were at the beginning. They are lightweight, easy to machine and forming. Due to the corrosion and chemical resistance, they have a potential in the chemical applications. The low thermal conductive of plastics is overcome by usage of thin wall which makes them an alternative in low temperature application. This study focusses on the special cases where the polymeric hollow fiber heat exchanger can be used in temperatures higher than recommended. Two experiments were done. The polyamide hollow fiber heat exchanger was placed inside the wind tunnel with flue gas flowed and the water at coolant side. In such a setup the heat exchanger can withstand the temperature higher than suitable for operating and even the temperature of melting point.

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

1. Introduction

Polymeric hollow fiber heat exchangers (PHFHE) are an alternative to common metal heat exchangers in low temperature applications. Their advantages are low cost, low weight and corrosion resistance. Their heat transfer surface consists of hundreds or even thousands of fibers with a small outside diameter, commonly 0.4 – 1.6 mm. Polymeric material provides such advantages as light weight, easy machining and forming, flexibility and corrosion resistance. The disadvantage of polymeric material is its low thermal conductivity (0.1–0.4 W m^{-1} K^{-1}), which is 100–300 times lower than metals. The high thermal resistance can be overcome by the hollow fibers having a small diameter and thin wall. According to [1] the wall thickness for PHFHE should be kept below 100 μm. PHFHE are mainly made of polypropylene (PP), but also other polymers are used, as polyamide (PA), polyetheretherketone (PEEK), polyphthalamide (PPA) or asymmetric polyethersulfone (PES). PHFHE were firstly presented by Zarkadas in [2] fifteen years ago as an alternative to conventional shell -and- tube heat exchangers. In his study the overall heat transfer coefficients were 647–1314 W m^{-2} K^{-1} for water–water system and 414–642 W m^{-2} $K^{-1}$for ethanol–water system. As PHFHE are corrosion resistant, they are mainly studied in the desalination process [3], [4]. But they were also studied for the cooling system of solar panel [5] or the HVAC (heating, ventilation, air-conditioning) applications [6].

The gas-liquid application was studied in [7], where two PHFHE prototypes were presented as a possible alternative to the aluminium automotive radiator. Two modules with a rectangular cross-section measuring 250 × 250 mm were prepared and tested. The 50/50% water glycol solution was used as a coolant. Both devices achieved similar heat transfer rate, up to 10.4 kW and high values of the overall heat transfer coefficient, up to 335 W m^{-2} K^{-1}. That study also mentions the significant influence of the diameter of the polymeric hollow fibre on heat transfer coefficients on both inner and outer surfaces of the fibre. The recent study [8] compare the commercially available aluminium automotive radiator with the PHFHE of the same measurements, so the direct change is possible. The tested PHFHE was 30% lighter than the metal one. The maximum heat transfer performance of the PHFHE was 30% higher than the metal one and reached a value of 70 kW. On the other hand, the PHFHE featured higher pressure losses on the air side.

Polymeric heat exchangers are generally considered a great alternative in the chemical industry, where corrosion and chemical resistance are needed, and the temperature is quite low. But they can be used even at higher temperatures than what is expected. This study focused on the usage of PHFHE in higher temperatures than the materials are designed.

2. Heat Transfer in Polymeric Hollow Fiber Heat Exchangers

Polymeric hollow fiber heat exchanger is in fact nothing other than a bank of thin tubes. To determine the heat transfer coefficient on the outer fiber side the regular empirical relation, which can be found in handbooks [9], [10], can be used with good agreement. The thermal resistance of the wall is not taken into computation in case of the metal heat exchangers. This is generally not true for the polymeric one, even with the thin wall the thermal resistance of the wall should be taken into account. Thermal resistance of the wall is up to 25 % of total thermal resistance of heat exchanger [11]. In the case of liquid-liquid application even higher. On the inner side of hollow fiber the Nusselt number is constant, since the flow is laminar, due to the small diameter of the hollow fiber.

For gas-liquid application, the heat transfer coefficient on the gas side is quite low, the thermal resistance on the outer side of hollow fiber is more than 60 %, sometimes up to 90 %. The temperature of the outer surface of the fiber will not be much higher than the temperature of a liquid inside, actually it will be almost the same. This can be beneficial in case when the cool liquid is in the fibers and hot gas outside fibers.

3. Experiment

The PHFHE was made from polyamide hollow fiber with the outer diameter of 1.3 mm, see Fig. 1. The fibers were arranged in 6 layers each with 67 fibers, i.e., 402 fibers in total. The frontal area of the heat exchangers is 200x200 mm and the heat transfer surface 0.33 m^2. The polyamide hollow fibers of this heat exchanger with water flow of 11°C and flow rate 18 l/min (from water supply system) inside should withstand temperature about 800°C. In practise the temperature would not be so high, since the other parts of the heat exchanger has to be taken into account, the flanges as well as the glue used to join the hollow fibers and the flanges.

Fig. 1: Caption for figure goes at the bottom.

During the experiment the PHFHE is placed in the wind tunnel, see Fig. 2, where the flue gas flows. The source of flue gas is coal boiler. The boiler is computer controlled on the side of intake air and coal supply. Inside the wind tunnel the temperature in front of and behind the HX is measured, as well as flue gas flow rate. On the water side, the flow rate and inlet and outlet temperatures are measured too.

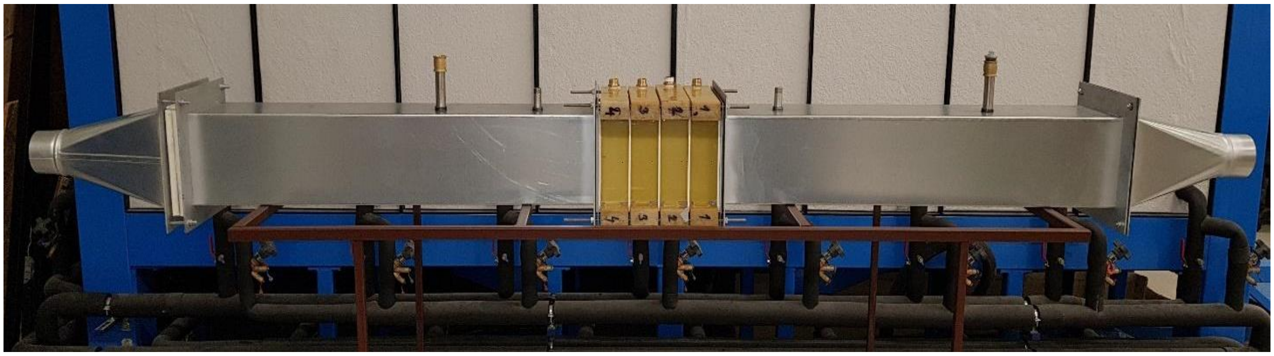
Fig. 2: The measuring wind tunnel with the heat exchangers

The first test was a five hours test with a flue gas temperature of 160°C. The output gas temperature was 101.5 °C. Water flowrate of 18 l/m was used for tests. Inlet water temperature was 11°C and outlet temperature was 15 °C. Boiler in the experiment did not work in optimal regime and a large number of solid particles was carried by the gas flow, which was done on purpose to find out the efficiency of the fouled HX. Heat exchanger in this boiler regime was seriously fouled by solid products of burning coal after five hours of test. Pressure loss on the gas side increased by 34% during the experiment but did not grow continuously for the whole experiment. There were observed some stem falls of pressure loss value. Explanation was found after test when removed the HX from the tunnel. Flexible fibers shake in gas flow. If the layer of ash on the surface is thicker, it becomes unstable, and segments of ash layer are taken away by gas. It should be noticed that the ash layer was easily removed from the fibers by shaking and by pressurized air.

In the second experiment the cleaned heat exchanger was operated with the same setting, only the flue gas temperature was elevated to 215 °C, which is the melting point of the PA. The heat exchanger was operated for approximately two hours. Then, it becomed leaking. After the disassembly of the measuring tunnel, the defect on the fiber was found, see Fig. 3. This is caused by the hot solid particle.


Fig. 3: Detail of defect on polyamide hollow fiber

4. Conclusion

The polymeric hollow fiber heat exchangers can withstand the elevated temperatures during their operation in gas-liquid application, when the coolant inside the fibers. The PHFHE withstand a 5-hour long test with flue gas of temperature 160°C, which is 30°C higher than recommended temperature for operating the polyamide hollow fibers. The test with the higher temperature 215 °C, which is the melting point of the polyamide, was successful only for two hours. Then due to the non-optimal regime of the boiler the hollow fiber was hit by the hot solid particle which caused defect and leakage of the heat exchanger.

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