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Research Paper

Intensification of heat transfer of polymeric hollow fiber heat exchangers by chaotisation

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HIGHLIGHTS

- Proper separation of polymeric hollow fibers must be used in case of single-phase flow.
- Chaotisation is simple method allowing to separate fibers and intensity heat transfer.
- Chaotized bundles of fibers can transfer up to 100 W/m^2 K for air flowing 2 m/s.

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ABSTRACT

Flexible polymeric hollow fibers are used as heat transfer elements. A potted bundle of several hundred such fibers can be used as a heat exchanger in different ways. The simplest application is a submerged bundle. The fibers studied in this paper have outside diameters below 0.8 mm. Such very small-diameter polymer fibers significantly facilitate heat transfer. However, these potted sets of fibers must be designed to guarantee that all fibers are in direct contact with the surrounding stream of fluid. It is possible to use textile technologies to keep fibers strictly parallel and separated. However, a parallel arrangement can be expensive and is not flexible. A low-cost variant utilizes bundle chaotisation, which means that each fiber has a unique shape. The consequence is that their mutual mechanical contacts are point-wise. Several methods of chaotisation are studied in this paper. The best variant is a permanent fiber deformation/chaotisation of fibers using integrated heating/cooling and stretching. The tested CFPFHEs (Chaotised Flexible Polymeric Fiber Heat Exchangers) had an overall heat transfer area of 1 m^2, and its length was approximately 700 mm. It achieved a water/air overall heat transfer coefficient of 100 W/m^2 K with an outside air flow of 2 m/s.

1. Introduction

In air-conditioning, refrigeration, and energy-recovery applications, heat exchangers are very important to the overall efficiency, cost, and size of the system. Currently, these applications rely heavily on fin-and-tube or plate-fin heat exchanger designs, often constructed using copper, aluminium, or stainless steel, see e.g. [1].

However, it has been recognized that some polymers offer many advantages over metals. For example, polymers exhibit superior resistances to corrosion. Their substantial weight, space and cost savings for both manufacturing and maintenance stimulated initial interest in the development of polymer-based heat exchangers. The parameters of these polymers determined the applications of polymer based heat exchangers in different industrial fields: air conditioning, seawater and brackish water desalination, material and heat recovery/heat pumps [2,3], etc.

The advantages and disadvantages of PHEs (Polymeric heat exchangers) are well-known, see [4,5]. The main disadvantage for application in heat transfer is the very low thermal conductivity of polymeric materials. Using polymeric fibers with small outside diameters between 0.4 and 0.8 mm and thin walls of about 10% of the outside diameter can eliminate this disadvantage very effectively. It should be noted that static pressure tests at room temperature (20 °C) showed that such fibers withstand internal pressures of over 50 bars without ruptures.

Plastic tubes used in existing heat exchangers have substantially larger diameters and wall thicknesses; see e.g. [6]. A special type of PHE is a heat exchanger with fibers of small diameters, namely FPHE (Fiber PHE). There is a relatively long tradition in manufacturing of making microfiltration bundles, see e.g. [7].

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These bundles can be flexible and if they are fully stretched then their fibers are parallel, i.e. non-chaotic. It is possible to replace porous microfiltration membranes with non-porous fibers and pot them, see Figs. 1 and 2. The transfer of microfiltration know-how into heat transfer know-how was used to minimise research and development costs. The same approach was used by Song et al. [8] to produce shell-and-tube heat exchangers made of hollow fibers (see Fig. 1 of [8]). An FPHE (see Fig. 1) is 750 mm long and has 400 fibers. The outside fiber diameter is 0.8 mm and the potting diameter is 25 mm, while the geometric heat transfer area is approximately one square meter.

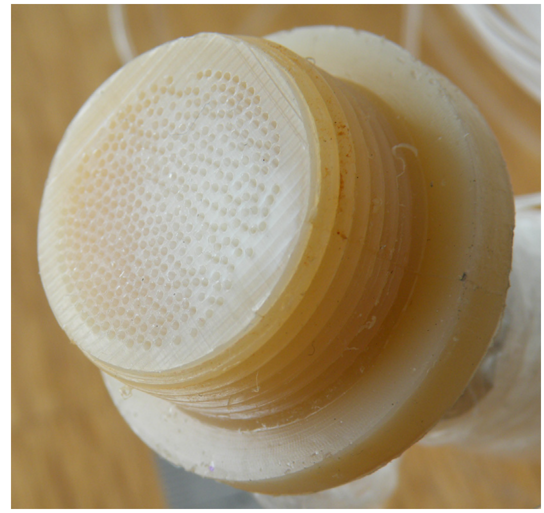

Fig. 2. Potting of flexible chaotised CPHE, diameter 25 mm.

2. Fiber polymer heat exchangers - FPHE

The small fiber diameters have essential advantages when used as heat transfer elements. Small wall thicknesses, e.g. 40 μm, eliminate the disadvantage of low polymer heat conductivity.

Liquid flow inside of a fiber is laminar. The Nusselt number is therefore mostly independent of inside flow conditions. This is why the heat transfer coefficient (HTC) grows rapidly with the decrease of diameters of the fibers. Stated differently, the HTC is high even for low velocities. Low velocities inside the fibers are typically used to reduce the hydraulic resistance of the heat exchanger.

The small fiber diameters also add a similar advantage of high HTCs on the outer surfaces. An example is shown in Fig. 3. The external air flow is perpendicular to the fibers. The curves graphically represent the mutual relationship of the heat transfer coefficient, air velocity and fiber outer diameter. The curves are evaluated using the Churchill & Bernstein equation for horizontal cylinder in cross-flow [9]. This graph covers the entire range of *Reynolds* numbers and is recommended for all $RePr \geqslant 0.2$. It is clear that heat transfer intensity on the outside surfaces grows rapidly with a decrease in the diameter of the tubes or fibers. Similar conclusions can be drawn when the surrounding fluid is not gaseous but liquid.

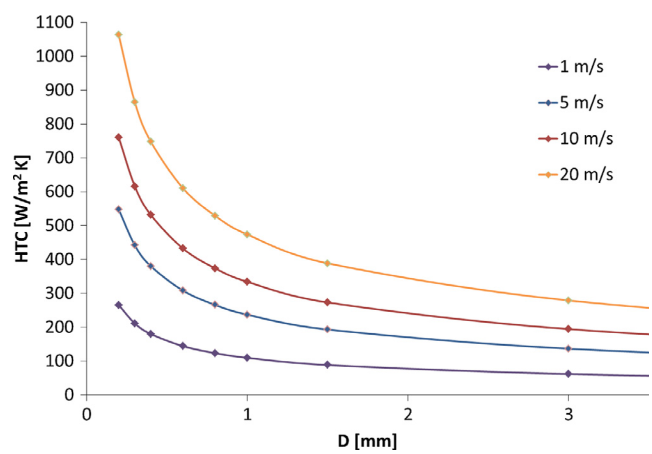

Fig. 3. Heat transfer coefficient at outer surface for external flow of air (20 °C) across separated fibers.

The difficulties related to the manufacturing of FPHEs are not studied in this paper, as they are problems of polymer engineering and the different resins used for potting. However, it must be emphasised that if the operating temperatures are below 60 °C then FPHEs can be low-cost heat exchangers. There is a chance to produce FPHEs for long-term higher operating temperatures as well. The manufacturing cost increases with increasing operating temperatures.

In fiber membrane processes, there are the forces (pressure and concentration gradients) which push the liquid or its components to move inside the compact bundle. In case of single-phase flow without mass-transfer, there are no such driving effects, thus proper fiber separation is needed. There are different FPHE manufacturing technologies which can keep fibers separated, including some developed for the textile industry, see e.g. Fig. 4.

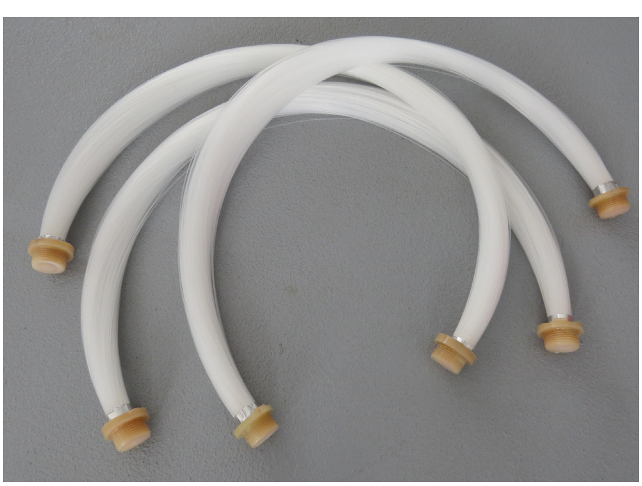

Fig. 1. Flexible non-chaotised CPHEs, length 750 mm.

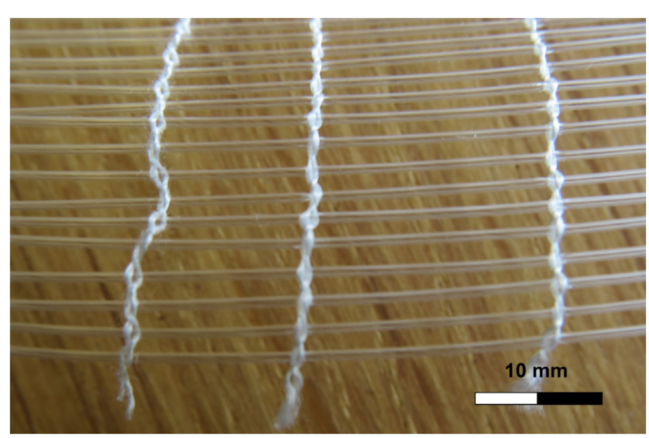

Fig. 4. Layer of fibers separated by weaving technology.