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The flow in an oil/water plate heat exchanger for the automotive industry

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Abstract

This paper presents an experimental and numerical work to analyze the flow in an oil/water plate heat exchanger for the automotive industry. The plate heat exchanger is designed as 21 equal plates assembled in a stack. Each plate has a series of grooves in the surface, and is mounted upside down with respect to the preceding one, so that channels are formed that should direct the fluid motion and increase the heat transfer area. The flow has been experimentally studied by means of planar laser-induced fluorescence (PLIF) to visualize its structure, and particle image velocimetry (PIV) with fluorescent particle tracers to measure its velocity. It has also been numerically simulated. In both cases, it has been observed that, for the analyzed design and either for oil or water, the flow is not uniform, and preferentially moves along the lateral extremes of the plates that conform the heat exchanger.

Keywords: Plate heat exchangers; Herringbone heat exchangers; Flow visualization; Flow numerical simulation

1. Introduction

The increasingly restrictive laws regulating pollutant emissions from all kinds of automobiles, together with the continuous rising in the gasoline and diesel price justify the enormous research effort devoted to optimizing the efficiency of IC engines, and to reduce their maintenance costs. As an improving element, it has been suggested to include an oil/water heat exchanger to cool down the lubricating oil, preventing its degradation, extending its useful life, and enhancing the engine lubrication. As cooling fluid, the water from the car cooling circuit would be used. To be able to conveniently fit the exchanger near the car engine, it should be small and, preferably, light. Furthermore, to minimize costs, this unit should be simple and inexpensive. To fulfill all these requirements, serpentine, laminated, and parallel flow heat exchangers have been developed as an alternative to traditional fin-tube types.

An interesting possibility is to use a plate heat exchanger. This type of exchangers, introduced by Richard Seligman in 1923, consists of a series of thin corrugated metal plates that are piled up and clamped together, separated by sealing gaskets, so that the corrugations in adjacent plates form a series of channels, where the heat-exchanging fluids circulate [1]. Although these devices where first devised for the dairy industry, they are becoming increasingly popular and now they are common in many chemical and process industries. Among other advantages, they are compact, easily manufactured, simple to maintain and clean, and have very high heat exchange coefficients, enhanced by the often turbulent flow [2]. They can have 50% less volume than a fined tube heat exchanger, and 60% less than a serpentine one for the same thermal performance. The plate corrugations contribute to increase the total interchange surface and the flow path, consequently increasing the fluid residence time. In this way, a heat

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transfer coefficient 3–4 times higher than that for smooth channels can be achieved [3]. The effect on the heat transfer coefficient is similar to that produced by helical micro fin tubes when compared to smooth ones [4]. However, although several recent studies have discussed the thermal aspects of plate heat exchangers [5,6], details of the internal flow distribution are, in most cases, still unknown.

For this reason, this paper presents a study of the flow in a grooved plate heat exchanger with a herringbone configuration. The device here analyzed is a first prototype aimed for commercial purposes in the automotive industry, and the objective of the study is to evaluate its performance in order to improve it, and hence, the competitiveness of the system. Planar laser-induced fluorescence has been applied to visualize the streamlines, while particle image velocimetry has been employed to measure the velocity field inside the plates. Simultaneously, the flow has also been numerically simulated using the CFD FLUENT code. An excellent agreement between experimental and numerical results have been obtained revealing interesting details of the flowfield.

2. Description of the experiments

The plate heat exchanger here studied is designed as a series of 21 equal plates that are stacked forming a pile, so that each plate is mounted upside down with respect to the preceding one (*i.e.* after an in-plane 180° rotation). The plates, made of aluminum, are small trays 6 cm × 9.5 cm with a depth of 0.5 cm. In its surface, there is a series of V-shaped grooves 0.9 mm deep, with a semi-circular cross-section, in a herringbone pattern (see, for example [3,7]). When assembled, the corrugations of both plates form a series of channels that are expected to force the fluid to flow in a zigzag trajectory in order to increase the heat transfer area. The fluids, oil or water, circulate in the gaps between two contiguous plates, in alternate layers. Each plate has four orifices, two at each end. When a pair of plates is stacked together, two orifices serve as flow inlet and outlet, while the other two form a passing cylinder, so that the fluid is conducted to the adjacent plates. Fig. 1a shows one of the plates, while Fig. 1b is a sketch of the stacking arrangement.

The system is designed for water flow rates ranging from 13 to 20 l/min, and oil flow rates from 5 to 30 l/min.

It might be relevant to indicate that although stainless steel is generally preferred in most exchangers designed for process industries, mainly due to corrosion, cleanliness or mechanical requirements, aluminum is the material of choice for most of the automotive heat exchangers. Almost 100% of the oil coolers such as the one presented in this study are made of aluminum because of its good thermal properties and low weight. For serial manufacturing, the aluminum plates are brazed together in a controlled atmosphere furnace to produce a completely sealed heat exchanger in one shot, which is very convenient for the mass volume productions of the automotive industry.

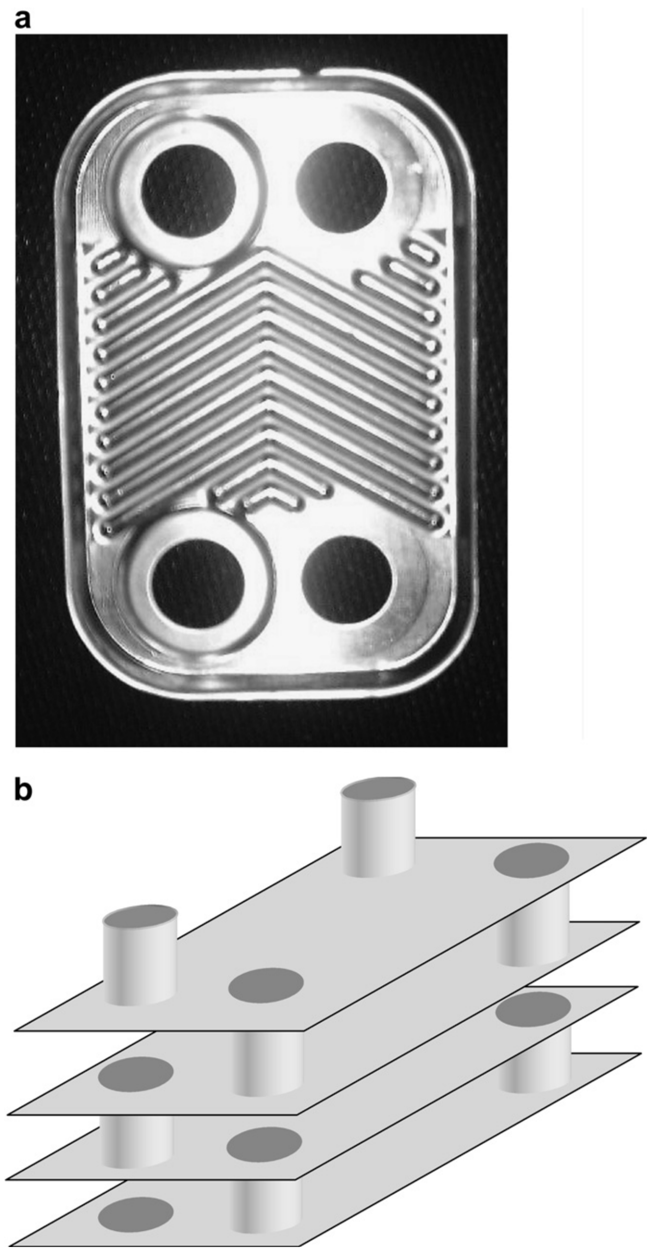

Fig. 1. Heat exchanger studied: (a) one of the aluminum plates that forms the stack in the final assembly and (b) sketch of the stacking procedure.

As representative of the whole heat exchanger, the flow between two plates has been analyzed, by planar laser-induced fluorescence visualization (PLIF) and particle image velocimetry (PIV). As both techniques require optical access, one of the plates has been an original unmodified one, supported by a 13.5 × 10.3 × 7.5 cm aluminum block. The other has been replaced by a transparent metacrylate piece, machined with the same embossed inner surface as the plates, but flat on the outer side, that was bolted to the aluminum block, sealing the joint with a rubber gasket. After machining, the piece had to be polished to achieve the transparency requirements needed to apply the experimental techniques. The assembly is shown in Fig. 2. The plate has been painted in black to minimize stray