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Experimental study of the thermal hydraulic performance of sub-cooled refrigerants flowing in smooth, micro-fin and herringbone tubes

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HIGHLIGHTS

- Thermo-hydraulic performance of different microfin tubes used for heat transfer enhancement.
- Evaluation of number of fins and working fluid effects.
- New results for herringbone tubes.

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ABSTRACT

The present paper reports an investigation of the thermo-hydraulic performance of two standard microfin tubes with different number of fins and a herringbone microfin tube. As a reference for comparison purposes a smooth tube of equal external diameter and wall thickness has been tested for similar operational conditions. Copper tubes of 9.52 mm external diameter, electrically heated, have been used in the investigation. Most of the reported data has been gathered with refrigerant R134a though refrigerant R22 was also used in some of the tests with both the smooth and one of the standard microfin tubes. The test tube entrance state of the working fluid was kept constant at a temperature of the order of −2.5 °C and a pressure of 500 kPa, whereas its mass velocity varied in the range between 100 kg/s m^2 and 1350 kg/s m^2. It has been found that the thermal performance of the herringbone tube is superior to that of the two standard microfin tubes though the pressure drop obtained with the former is clearly higher. All the microfin tubes present significant heat transfer enhancement with respect to the smooth tube. According to the present results, the enhancement ratio of the microfin tubes attains an asymptotic value for Reynolds numbers of the order of 20,000, the herringbone tube presenting the higher asymptotic value. A figure of merit parameter has been introduced to qualify each of the microfin tubes tested, with the both standard microfin tubes being the best qualified with respect to the herringbone one, especially for applications that operate at the intermediate Reynolds numbers range.

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1. Introduction

The interest in the thermal-hydraulic performance of micro and herringbone fins is due to the fact that the refrigeration industry has sought to develop new ways to enhance the heat transfer in internal flow with phase change, thus, achieving a reduction of both the manufacturing costs of heat exchangers, by reduction of their volume, and the inventory of refrigerant. The increment in the rate of heat transfer would also allow, with the same heat exchange area, increase the evaporation temperature and/or reduce the condensing temperature, thus improving the COP of the refrigeration plant with its consequent reduction in energy consumption.

Several ways of heat transfer enhancement have been devised such as those found in plate exchangers, and ventilated fins, tubes with insertion of tapes, and tubes with internal micro-fins to name few. Unfortunately, the heat transfer enhancement is generally associated to pressure drop increments, the extent being dependent on the particular enhancing geometry. Despite the intense

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scrutiny that heat transfer enhancement has received during the last twenty years, the heat transfer mechanisms involved in the process are still understood in a sketchy manner. Thus further investigation is still needed from both the theoretical and experimental points of view in order to acquire a reasonable knowledge that would allow an adequate design and optimization of enhancing heat exchangers.

The development of copper tubes with internal micro-fins, called "standard micro-fin", started in the late 70's by Hitachi Cable Ltd., aiming at improving the heat transfer characteristics in evaporators and condensers for refrigeration applications. Several views of one of these tubes are shown in Fig. 1, where a schematic representation and two micro-photographs of different scales are displayed. Currently, a relatively large number of alternative configurations have been developed by manufactures for specific applications. In general, the fin density of the inner microfins varies between 60 and 80 spiral fins, with helix angle ranging between 16° and 30°. The height of the fins is approximately equal to 0.2 mm. The tubes are characterized by reduced thickness, generally of the order of 0.5 mm (or less), a significant reduction with respect to conventional copper pipe thicknesses, an aspect that adds to the advantages of heat transfer enhancement promoted by the microfins. Thus these tubes are especially attractive for industrial applications given the economic potential they present.

Most of the published studies involving micro-fin tubes aim at determining the performance of refrigerants under phase change conditions. Those dedicated to the performance of single-phase fluid flow are rare. In part, this is due to the fact that their main applications are in evaporators and, especially, condensers. However, due to their heat transfer enhancement capabilities, microfin tubes could have a potential for single phase liquid flow applications.

Fig. 2 shows a microphotograph and a schematic representation of the so called "herringbone tube", a microfin configuration introduced in the late 90's. Few studies have dealt with this type of tube in the open literature, such as the ones by Ebisu, Miyara, Cavallini, Bandarra Filho et al. [1–4]. However, few studies have considered single-phase heat transfer. Khanpara et al. [5] evaluated the single phase heat transfer enhancement of liquid refrigerant R-113, a low pressure refrigerant, flowing in micro-fin tubes. The heating of the refrigerant was provided by water flowing in the annular space of concentric tubes. The test section was made up of a straight 9.52 mm diameter tube and it was design in such a way to allow both single and phase change experiments. Single-phase results were correlated in terms of the dimensionless parameter $Nu/Pr^{0.4}$ as a function of the Reynolds number. The results showed that the fin height of 0.15 mm performed better in the range of Reynolds greater than 6000, whereas, for Reynolds numbers from 4000 to 6000, the fin height of 0.18 mm was superior. Smooth tubes results were correlated by both the Dittus–Boelter and the Petukhov correlations within the range of ±10%, a figure that was considered adequate.

Panchal et al. [6] conducted heat transfer enhancement experiments in spiral aluminum pipes (spirally fluted tubes) 26.8 mm diameter and spiral angle of 30°. Ammonia and refrigerant R-114 were tested in condensation runs whereas refrigerant R-11 was used for evaporation tests. Single-phase flow tests were conducted in the investigation context, with results indicating an enhancement factor of the order of 1.63 with respect to smooth tubes. It must be emphasized that the area ratio was of the same order of magnitude. The pressure drop increment in the enhancing tubes was of the order of 1.25, a result rather interesting given the achieved heat transfer enhancement. As for the mechanism responsible for the observed enhancement, the authors suggest that it could be related to secondary flows promoted by the shape of the

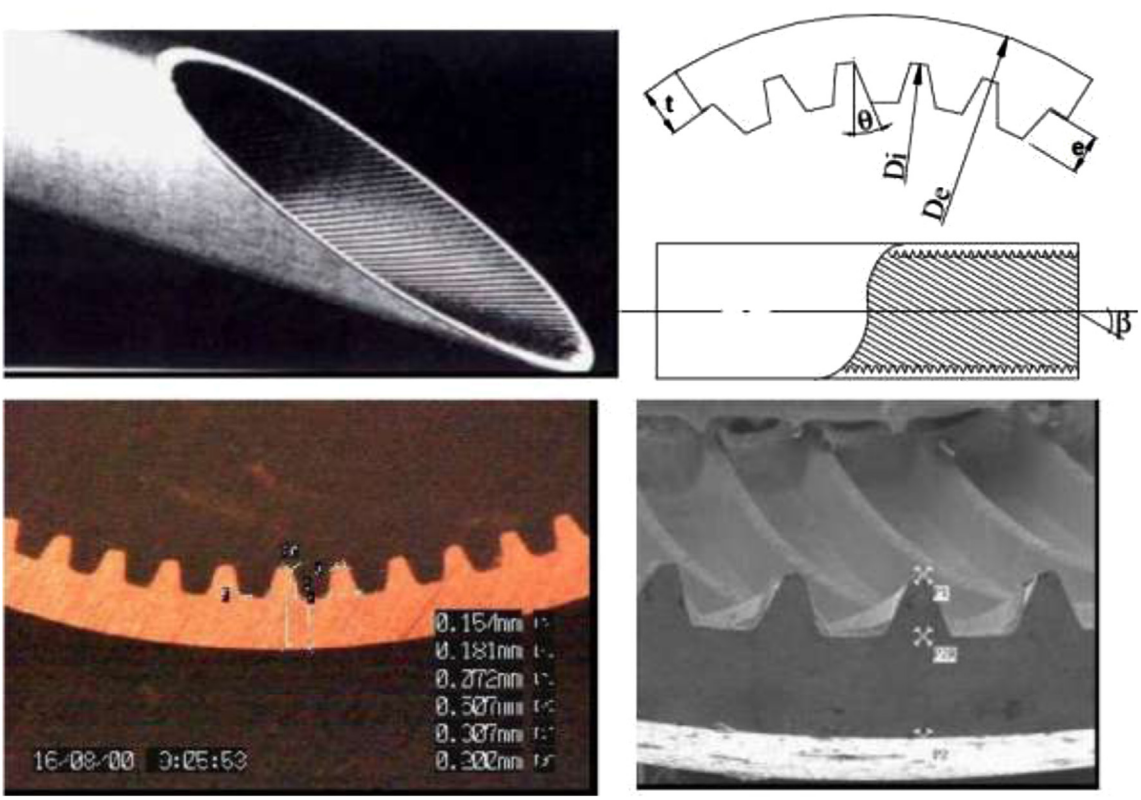

Fig. 1. Cross section, schematic and microphotographs of microfin tubes.

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