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Flow boiling performance in horizontal microfinned copper tubes with the same geometric characteristics

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ABSTRACT

This article reports an experimental investigation on flow boiling heat transfer and pressure drop of refrigerant R-134a in a smooth horizontal and two microfinned tubes from different manufacturers with the same geometric characteristics. Experiments have been carried out in an experimental facility developed for change of phase studies with a test section made with 9.52 mm external diameter, 1.5 m long copper tubes, electrically heated by tape resistors wrapped on the external surface. Tests have been performed under the following conditions: inlet saturation temperature of 5 °C, vapor qualities from 5% to 90%, mass velocity from 100 to 500 kg/s m^2, and a heat flux of 5 kW/m^2. Experimental results indicated that the heat transfer performance was basically the same for both microfin tubes. The pressure drop is higher in the microfinned tubes in comparison to the smooth tube over the whole range of mass velocities and vapor qualities. The enhancement factor, used to evaluate the combination of heat transfer and pressure drop, is higher than one for both tubes for mass velocities lower than 300 kg/s m^2. Values lower than one have been obtained for both tubes in the mass velocity upper range as a result of a significant pressure drop increment not followed by a correspondent increment in the heat transfer coefficient. Some images, illustrating the flow patterns, were obtained from the visualization section, located in the exit of the test section with the same internal diameter of the tested tube.

1. Introduction

The development of heat transfer enhancement surfaces has been strongly studied during the last three decades. As should be expected, most of the effort has been focused in the air side due to its higher thermal resistance. Manufacturers have tried to upgrade the internal heat transfer coefficient, especially in dry expansion evaporator coils, by inserting devices to promote better contact of the liquid with the tube wall. These devices are in fact efficient in upgrading the heat transfer coefficient but at the cost of significant pressure drop. This enhancement surfaces allows getting very compact heat exchangers, reducing area and, consequently, costs. The tendency relatively new in the refrigeration and air conditioning industries is the use of copper tubes with thin wall having the inner surface covered by fins of reduced size, forming the so called microfinned tubes. Several of these fins have been developed, and are presently used in the refrigeration field, mostly in air cooled condensers, but also in evaporators. These fins promote significant increments in heat transfer though not affecting in the same proportion the pressure drop. These characteristics have promoted their widespread application in the refrigeration industry. The manufacturers claim that the performance of halogenated refrigerants is significantly increased when the phase is changed inside the tube. Researches carried out in countries like Japan and United States have confirmed this tendency.

Microfin tubes were introduced into the market in the late seventies by Hitachi Cable Ltd. An image of a microfinned tube is shown in Fig. 1. As a general rule, the fins run helically along the tube. The helix angle, β, generally, varies in the range between 16° and 30°, depending on the manufacturer, and the number of fins typically founded varies from 60 to 70. The height of the fins varies from 0.15 mm to 0.25 mm, and the actual thickness of the copper tubes is rather small, varying in the range between 0.3 mm and 0.5 mm. The reduced thickness makes the manufacturing process rather simple and economically sound to the coil manufacturer.

Though the investigation of flow boiling in tubes with internal heat transfer enhancement devices is not new, dating back to the 1950s and 1960s, Lavin [1] and Lavin and Young [2], studies involving microfinned tubes are more recent. According to Webb [3], one of the first known papers dealing with microfins is the one by Fujie et al. [4], reporting a research performed for Hitachi Cable Ltd. As a general rule, all the published papers report that the microfinned

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Nomenclature

D	diameter (m)
E	enhancement factor
G	mass velocity (kg/s m^2)
h	heat transfer coefficient (W/m^2 K)
i	enthalpy (J/kg)
L	length (m)
$\dot{m}_r$	mass flow rate (kg/s)
Q	electrical power (W)
T	temperature (K)
x	quality

Greek symbols

ΔP	pressure drop (kPa)
ϕ	heat flux (W/m)

Subscripts

e	external
f	fluid
fg	liquid/vapor
in	inlet
o	outlet
PH	pre-heater
r	refrigerant
sat	saturation
TS	test section

tubes under flow boiling conditions present a better heat transfer performance though the pressure drop is significantly increased with respect to their smooth counterpart. Reported increments in the heat transfer coefficient with respect to the smooth tubes range between 1 and 3 times whereas the pressure drop increases between 20% and 80%, depending on the mass flow rate. Important studies on flow boiling in microfinned tubes have been presented in the literature, Cavallini et al. [5], Bandarra Filho et al. [6] among others and also important books, Webb [3] and Thome [7,8].

In the present work, experimental results of an experimental investigation on flow boiling of refrigerant R-134a in a smooth horizontal and two microfinned copper tubes, from different German manufacturers, of same geometric characteristics are presented and discussed. Microphotographies of these tubes are shown in Fig. 2. Comparison of the obtained results for these microfinned geometries were performed in terms of the enhancement factor, which takes into account the combined effects of heat transfer and pressure drop.

2. Experimental facility and procedures

A schematic diagram of the experimental facility used in the present investigation is shown in Fig. 3. The refrigerant is pumped from the condenser through a filter dryer and a sight glass (SG) to the coriolis mass flow meter and pre-heater before reaching the entrance of the test section (TS). Upon leaving the pre-heater, the refrigerant flows through a straight section of 1.2 m length made out of the same internal diameter as the test section in order to allow for flow development. The results reported herein have been obtained in copper tubes of 1.5 m length and 9.52 mm nominal external diameter. Both the microfinned tubes investigated in the present study had the same geometric characteristics, as follow:

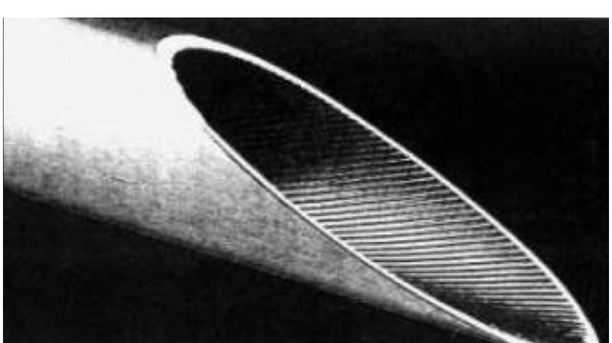
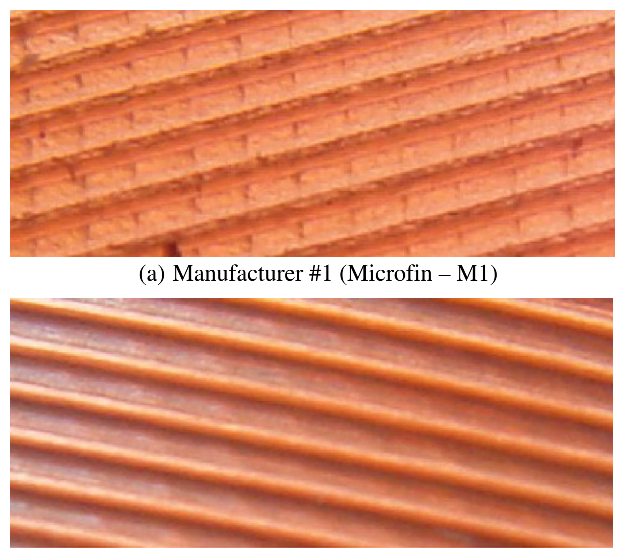


Fig. 1. Image illustrating the internal microfinned tube.

– External diameter: 9.52 mm.
– Internal diameter: 8.92 mm.
– Number of fins: 60.
– Height of fins: 0.20 mm.
– Helix angle: 18°.



(a) Manufacturer #1 (Microfin – M1)

(b) Manufacturer #2 (Microfin – M2)

Fig. 2. Microphotography of the microfinned tubes used in the present work.

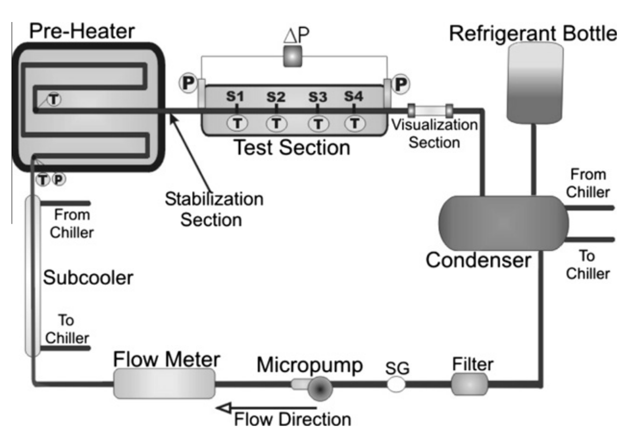


Fig. 3. Schematic diagram of the experimental facility used in the present investigation.