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Performance of microchannel condensers with metal foams on the air-side: Application in small-scale refrigeration systems

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ABSTRACT

The thermal-hydraulic performance of microchannel condensers with open-cell metal foams to enhance the air-side heat transfer is investigated in this paper. Three different copper metal foam structures with distinct pore densities (10 and 20 PPI) and porosities (0.893 and 0.947) were tested. A conventional condenser surface, with copper plain fins, was also tested for performance comparison purposes. The experimental apparatus consisted of a closed-loop wind tunnel calorimeter and a refrigerant loop, which allowed the specification of the mass flow rate and thermodynamic state of R-600a at the condenser inlet. The experiments were performed at a condensing temperature of 45 °C. The air-side flow rate ranged from 1.4×10^{-3} to 3.3×10^{-3} m^3/s (giving face velocities in the range of 2.1–4.9 m/s). The heat transfer rate, the overall thermal conductance, the Colburn *j*-factor, the friction factor and the pumping power were calculated as part of the analysis.

1. Introduction

The current generation of components used in computer processors are responsible for severe rates of heat dissipation per unit area which, if not appropriately controlled, can reduce the performance and decrease the reliability of electronic devices. Thus, the heat management of processors has become an essential part of computer technology, and a large number of studies have been devoted to engineering the removal of heat from these devices.

According to Ortega and Birle [1], natural and forced convection of air are no longer capable of maintaining the processor temperature below acceptable values. Recently, cooling technologies as diverse as heat pipes, liquid loops, jet and spray impingement and boiling in microchannels have been considered for high heat flux applications [2,3]. Agostini *et al.* [4] reviewed four different technologies for heat removal of computer chips and pointed out that boiling in microchannels yields the lowest pumping power and high heat dissipation rates, with the added flexibility of allowing an independent control of the refrigerant saturation temperature and flow rate. Currently, there is a call for combining such cooling technologies with vapor compression refrigeration in order to enable removal of high heat fluxes in a high-temperature environment [5,6].

Barbosa and co-workers [7–9] recently reviewed the literature on vapor compression cooling of computer chips. It is apparent that small parallel-plate (microchannel) evaporators are capable of providing the desired cooling capacity for such applications. Nevertheless, space restrictions (which impose a limit on the size of the refrigeration system) are among the most challenging aspects on this thermal solution. Therefore, the design of compact components of the cycle, such as compressors and condensers, is equally essential for advancing the technology.

This paper presents an experimental analysis of compact microchannel condensers for a miniature-scale refrigeration system. Copper metal foams were used as extended surfaces for enhancing the air-side heat transfer. Metal foams have several attributes often pursued in high performance heat exchangers, such as small weight, large surface area per unit volume, high effective thermal conductivity of the solid matrix [10,11] and large heat transfer coefficients.

A number of studies have emerged in recent years concerning the pressure drop and heat transfer characteristics of fluid saturated metal foams. Haack *et al.* [12] presented an overview of metal foam materials for high performance heat exchangers. They showed that, for a fixed coolant flow rate, both the heat exchanger effectiveness and the pressure drop increase with decreasing pore size. Calmidi and Mahajan [13] carried out a detailed experimental and numerical work to determine the thermal non-equilibrium and thermal dispersion effects in flows of air in highly porous metal foams. A correlation for the interstitial (solid-fluid) heat transfer coefficient

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