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An experimental study on the thermal and hydraulic characteristics of open-cell nickel and copper foams for compact heat exchangers

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ABSTRACT

High-porosity open-cell metal foams made of copper and nickel were inserted into a rectangular channel containing R245fa refrigerant with mass flux ranging from 76 to 391 kg/m^2 s. The single-phase heat transfer from the surrounding channels is driven by hot water in a closed cycle and ranges from 0.53 to 1.37 kW. The heat transfer and pressure drop across the embedded metal-foam samples were measured while maintaining constant conditions of the refrigerant inlet pressure and hot water supply. The heat transfer coefficient was calculated based on a modified Wilson-plot method. The results were compared with published correlations, and new correlations are proposed to take into account the characteristics of the foam geometry and material. In addition, three parameters are introduced to compare different types of metal foam samples. The results of the experiment show that the metal-foam-filled channel increases the Colburn *j*-factor by up to 6.3 times compared to an empty channel. As a result, the metal foams with higher pore density and higher thermal conductivity perform better than other samples in single-phase flow.

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1. Introduction

High-porosity open-cell metallic foams have extremely high heat-transfer area and many randomly connected paths inside the medium body. These foams can improve the thermal performance of compact heat exchangers. Many research groups have studied open-cell metal foams for heat exchanger applications due to their high surface-area-to-volume ratios (790–2740 m^2/m^3) and high porosity (>90%) [1–6]. Paek et al. [7] and Calmidi et al. [8,9] presented comprehensive analytical and empirical studies to determine the effective thermal conductivity, permeability, and inertial coefficient of aluminum foams with various pores per inch (PPI) and porosity using an air flow channel. Kim et al. [10] experimentally investigated the effects of porous fins on the pressure drop and heat transfer characteristics in plate-fin heat exchangers using aluminum foam. The results showed that the friction factor and heat transfer coefficient correlate with the permeability, porosity, and channel height.

Boomsma et al. [11–13] studied the effective thermal conductivity of a three-dimensionally structured metal foam saturated with liquid. They measured the hydraulic characteristics of compressed aluminum foams using water flows. Compact heat exchangers filled with several different types of compressed aluminum foam were tested. Water flows through the foam channel and cools the heat transfer area heated by an electric heater with heat flux of up to 688 kW/m^2. The aluminum-foam heat exchangers had lower thermal resistances than a commercially available heat exchanger and required the same pumping power.

Mahjoob [14] reviewed the available fluid and thermal transport models for metal-foam heat exchangers. Noh et al. [15] measured the pressure loss and forced convective heat transfer for water flowing in an annulus filled with aluminum foam. The aluminum foam enhanced the heat transfer from a surface compared with the laminar flow in a clear annulus. Dietrich et al. [16–18] published correlations for estimating the pressure drop and heat transfer of a single-phase flow in ceramic and metal sponges based on geometrical parameters obtained by magnetic resonance imaging (MRI). The sponges were made of alumina (Al_2O_3), mullite (Al_2O_3–SiO_2), and oxidic-bonded silicon carbide (OBSiC). The porosity ranged from 0.75 to 0.85, and the pore density ranged from 10 to 45 PPI.

Mancin et al. [19–22] presented experimental measurements of the heat transfer coefficient and pressure drop during forced-air convection through different copper and aluminum foam samples with various pore density and porosity. Lacroix et al. [23] studied the pressure drop behavior along the foam beds with a new geometrical model using an Ergun-type equation. Kamath et al. [24]

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