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Pool boiling heat transfer of R134a on single horizontal tube surfaces sintered with open-celled copper foam

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ABSTRACT

The pool boiling heat transfer performance of refrigerant R134a on single horizontal tube surfaces sintered with open-celled copper foam was studied at $T_s = 6\,^{\circ}C$ and $P_s = 3.62$ bar. Three pore density values: 40, 80, and 130 PPI; two porosity values: 90% and 97%; and two thickness values: 1.6 and 2.5 mm, characterize the 12 studied tubes. The nucleate boiling data and heat transfer coefficients were obtained. The influences of pore density, porosity, and foam thickness on heat transfer performance were investigated as well. The foam provides activated nucleation sites; however, it also causes transport resistance for the bubbles within the foam to move from the active nucleation sites to the surface. Performance is dependent on whichever of these two prevails in the heat transfer process. The foam-coated tubes show significant performance enhancement compared with plain tubes at heat fluxes below 30 kW/m^2. However, a sharp reduction in heat transfer coefficient is encountered for 130 PPI at larger heat fluxes. Tubes coated with thin foam and high porosity, e.g., pore density: 80 PPI, porosity: 97%, and thickness: 1.6 mm, exhibit a comparatively superior heat transfer performance. The current experimental data provide useful information for the design of highly effective boiling surfaces.

1. Introduction

Metallic foam is characterized by randomly connected inner cells and three-dimensional intensive structures generally subdivided into open and closed cells. Owing to unique comprehensive advantages such as low density, impact energy absorption capacity, a highly strong structure, gas and liquid permeability, as well as a large surface area in finite volume, the material has numerous potential applications in heat exchangers [1,2].

With structures containing dispersed linking ligaments, open-celled metal foam consists of dodecahedron-like cells having 12–14 pentagonal or hexagonal faces. The edges of these cells are composed of solid fibers which are frequently intersected with lumping at the joining points [3,4]. The porosity ε of foam is estimated as the ratio of the mass of a given sample volume to the density of the basic metal without pores. Pore density π_d is defined as the number of pores per unit length of the foam sample specified as pores per inch (PPI). The porosity and pore density are nominal values supplied by the foam manufacturer. The average pore diameter, which can be estimated from pore density, typically varies from 0.2 to 4 mm [1,2,5].

As indicated in several reviews, the porous matrix of foam may conform to the heat transfer characteristics of pool boiling [6,7]. The techniques developed for creating enhanced heat transfer surfaces are categorized into three principal groups: (1) Attached promoters, these include nucleation activators such as pierced three-dimensional covers, steel wires, or screens attached to or bonded to the base heating surface. (2) Coatings including metal or non-metal varieties attached to the base surface, such as non-wetting and porous coatings as well as electroplating structures. (3) Integral fins and various methods in which nucleation sites are formed by mechanically fabricating porous surfaces or by chemical etching of the base surface.

All these techniques improve nucleation heat transfer through mechanically introduced nucleation sites. Open-celled metal foam initially possesses traits advantageous to pool boiling. Saeed et al. [8] studied the heat transfer of water and FC-72 on a 3 mm thick metal foam and a mesophase graphite foam surface. Significant heat transfer enhancement of water was observed with copper foam at 30 PPI (95% porosity) compared with the plain surface, whereas no enhancement was achieved at 80 PPI (90% porosity). However, substantial enhancement was obtained by these two samples when FC-72 was used as the boiling medium. Xu et al. [9] studied the pool boiling heat transfer of a horizontal open-celled copper foam surface with acetone. The foam was welded onto the top of a copper block and the pore densities obtained were 30, 60,

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