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Influences of nanoparticles on pool boiling heat transfer in porous metals

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HIGHLIGHTS

- Nanoparticles' influence on pool boiling heat transfer of copper foams is investigated experimentally.
- Nanoparticle materials are Al_2O_3 and SiC.
- Nanoparticles' effect depends on their concentrations, material, size and foam structures.
- Nanoparticle deposition considerably affects the foam boiling heat transfer.

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ABSTRACT

Influences of nanoparticles on pool boiling heat transfer in open-celled copper foams have been investigated experimentally at atmospheric pressure using deionized water as the base liquid. The foam pore densities are 5 PPI, 60 PPI and 100 PPI and the porosities are 0.9, 0.95 and 0.98, while the foam thickness remains a fixed value of 7 mm. Al_2O_3 and SiC nanoparticles are used in this study. Their average diameters are 20 nm and 50 nm, and volume concentrations are 0.01%, 0.1%, 0.5% and 1%. Deposited nanoparticle layers on foam fibers after boiling are captured by SEM. The results show that adding nanoparticles into deionized water significantly influence the pool boiling heat transfer performance of copper foams, and nanoparticle effects heavily depend on their concentrations, material, size and foam structures (pore density and cell size). Nanoparticle deposition on foam fibers changes pool boiling heat transfer performance of copper foams considerably.

1. Introduction

With regard to the energy crisis, the intensification of heat transfer processes and the reduction of energy losses are the important tasks to be investigated. Boiling heat transfer is used in various industrial processes and applications, such as power generation and electronics components. Enhancements in boiling heat transfer processes could make these previously industrial applications more efficient. Changing thermophysical properties of the boiling liquids and morphology of boiling surface are the two important methods to improve the boiling heat transfer performance.

Since the nanofluid was proposed by Choi and Eastman [1], it has been a hot research subject in the field of heat and mass transfer. Nanofluids are colloidal suspensions of nanoparticles that are smaller than 100 nm in a base fluid. Nanoparticles can be metal oxides, metallic, carbon et al. The base fluids can be water, light oils, refrigerant et al., which have low thermal conductivities. Adding nanoparticles can improve the effective thermal conductivities of base liquids.

Boiling heat transfer in nanofluids is influenced by many parameters, such as contents of nanofluids, morphology of nanoparticles, etc. Park and Jung [2] found that carbon nanotubes (CNTs) with the concentration of 1.0 vol% increase boiling heat transfer coefficients of R22 and water. Especially, large enhancement up to 28.7% was observed at low heat fluxes of less than 30,000 W m^{-2}. However, the enhancement was suppressed with increasing heat fluxes. Kedzierski [3] investigated the influence of CuO nanoparticle concentration on the boiling performance of R134a/polyolester mixtures on a roughened, horizontal flat surface. For a given superheat, mixtures with the 1% volume fraction nanolubricant had boiling heat fluxes average 140% larger than those for mixtures with the 0.5% volume fraction nanolubricant. Park et al. [4] found that critical heat flux (CHF) on a smooth square flat copper heater of the aqueous solution is enhanced greatly up to 200% for the CNT concentration of 0.001% compared to that of pure water. Ahn et al.

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Nomenclature

Cu	copper
d	thickness of nanoparticle layer on a foam fiber, m
h	boiling heat transfer coefficient, W m^{-2} K^{-1}
l	total length of foam fibers, m
PPI	pores per inch of the metal foam
q	heat flux on the boiling surface, W m^{-2}
r	average radius of foam fibers, m
R	thermal resistance, m K W^{-1}
S	surface area of metal foam, m^2
T	temperature, K or °C
Greek symbols	
δ	thickness of metal foam, mm
ε	porosity of metal foam
Subscripts	
f	foam's fiber
n	nanoparticle
s	saturation condition
w	wall surface condition

[5] found that the CHF enhancement ratio of nanofluids increases with the flow velocity under flow boiling conditions. The results of Pham et al. [6] showed that the three water-based nanofluids (0.05% Al_2O_3, 0.05% CNT + 10% H_3BO_3, 0.05% Al_2O_3 + 0.05% CNT) enhance CHF significantly. Al_2O_3 + CNT nanofluid showed the highest CHF enhancement and Al_2O_3 nanofluids showed the most modest. More recently, Wen [7] found that nucleate boiling heat transfer of alumina nanofluids is increased for the smooth surface but unchanged for the rough surface. The relative size ratio between nanoparticles and surface topography could lead to different boiling results.

However, other researchers found that adding nanoparticles into base liquids deteriorates boiling heat transfer. The results of Das et al. [8] indicated that Al_2O_3 nanoparticles have pronounced and significant influence on the boiling process, the degradation in boiling performance takes place which increases the heating surface temperature with increasing particle concentration. Bang and Chang [9] found that water–Al_2O_3 nanofluids have poor heat transfer performance compared to pure water in natural convection and nucleate boiling. Zhou [10] investigated heat transfer characteristics of copper nanofluids with and without acoustic cavitation. With regard to pool boiling of the nanofluids, boiling heat transfer was reduced. Trisaksri and Wongwises [11] investigated nucleate pool boiling heat transfer of a refrigerant-based-nanofluid at different nanoparticle concentrations and pressures using a cylindrical copper tube as a boiling surface. The results indicated that the nucleate pool boiling heat transfer deteriorates with increasing TiO_2 nanoparticle concentrations, especially at high heat fluxes.

Metal foam is a special man-made porous structure providing larger surface area and more nucleate sites, and can improve boiling heat transfer coefficient considerably [12–15]. Pool boiling heat transfer performance of metal foam is remarkably affected by the porosity, pore density and working fluid. Xu et al. [16]

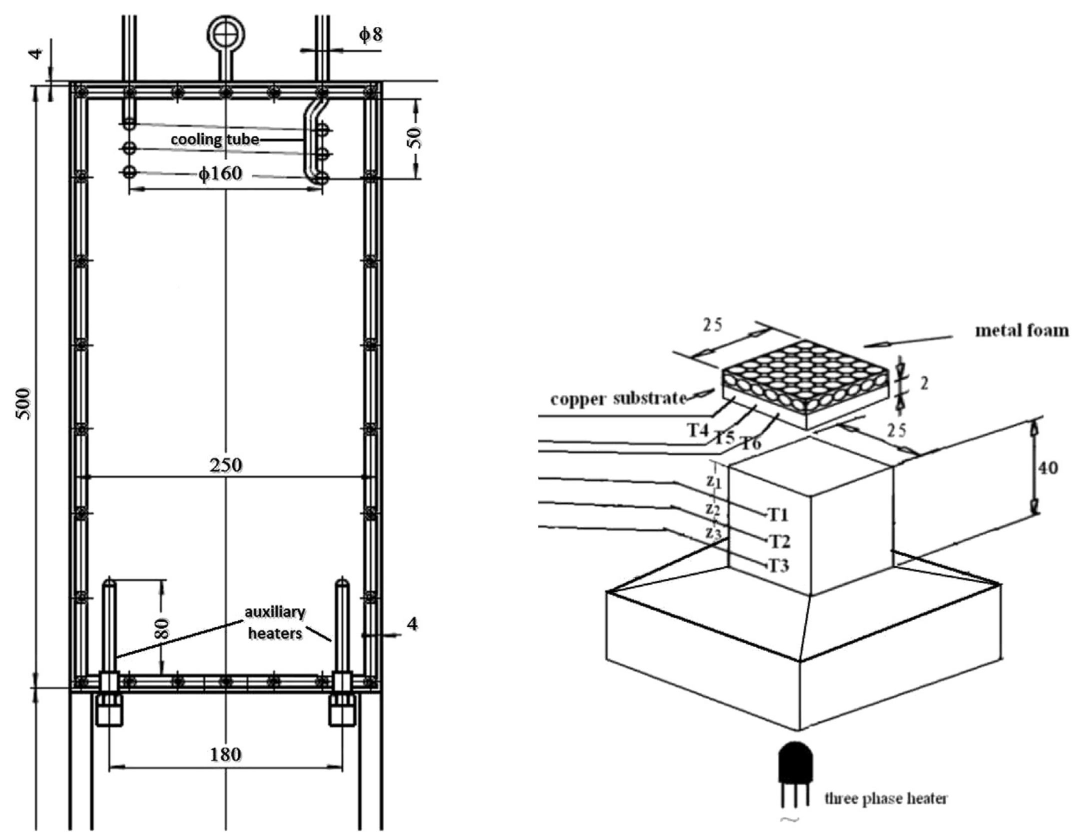

Fig. 1. Sketch of the experimental facility.