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Thermal performance of water-based suspensions of phase change nanocapsules in a natural circulation loop with a mini-channel heat sink and heat source

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HIGHLIGHTS

- Phase-change nanocapsule suspensions can enhance the heat-transfer performance of the loop.
- The 0.5% suspension was most prominent in the hot wall temperature reduction.
- High viscosity of the suspension at low temperature affects the heat transfer.
- Nusselt numbers at the inlets increased with increases in the Rayleigh number.

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ABSTRACT

In this study, the heat transfer characteristics of water-based suspensions of phase-change nanocapsules were investigated in a natural circulation loop with a mini-channel heat sink and heat source. A total of 23 and 34 rectangular mini-channels, each with a width of 0.8 mm, a depth of 1.2 mm, a length of 50 mm, and a hydraulic diameter of 0.96 mm, were evenly placed on the copper blocks as the heat source and heat sink, respectively. Adiabatic sections of the circulation loop were constructed using polymethylmethacrylate tubes with an outer diameter of 6 mm and an inner diameter of 4 mm, which were fabricated and assembled to construct a rectangular loop with a height of 630 mm and a width of 220 mm. Using a core material of eicosane and a shell of urea-formaldehyde resin, phase-change nanocapsules with a mean particle size of 150 nm were successfully fabricated and then dispersed in pure water as the working fluid to form water-based suspensions with nanocapsule mass fractions in the range of 0.1–1 wt.%. The results clearly indicate that water-based suspensions of phase-change nanocapsules can markedly enhance the heat-transfer performance of the natural circulation loop considered.
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1. Introduction

Natural circulation (thermosyphon) loops of various configurations and under various operating conditions have been the subject of numerous investigations due to their wide range of technological applications. These applications include nuclear reactor emergency cooling systems, solar heating and cooling systems, geothermal energy generation, waste heat recovery systems, turbine blade cooling, and electronic cooling. In a natural circulation loop, fluid flow driven by thermally induced density gradients removes heat from a heated section and transports the heat to a cooled section at a higher elevation. Such a loop can serve as a low-cost and highly reliable passive heat-transfer device.

Extensive analytical and experimental investigations have been conducted to study the dynamic response of natural circulation loops to variations in the loop configuration, loop materials, geometric parameters, and instabilities, as exemplified in Refs. [1–8]. In most cases, the heating conditions considered were restricted to those of a time-independent heat input at the heated section of the loop. In practice, however, the circulation loop could be subjected to a time-dependent heat load, which, for example, could be provided by temporal variations in solar irradiation or nuclear reactions. Moreover, the influence of the time-dependent boundary condition is of interest with respect to the feasibility and means of controlling the thermal behavior of circulation loops through boundary perturbations. Tan and Ho [9] experimentally investigated the thermal

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characteristics of a rectangular, annular, single-phase natural circulation loop in which the inner tube was filled with a solid–liquid phase-change material (PCM) under a cyclic pulsating heat load.

The thermal performance of natural circulation loop systems can be improved not only by modifying the loop itself but also by either enhancing the heat-exchange performance of the heated end or the cooled end or by changing the working fluid. Many studies have focused on micro-level heat dissipation because of the increasing demand for a high heat-dissipation density in the heat-exchange region [10–12]. The heat transfer enhancement obtained by using PCM suspensions as the working fluid has been demonstrated extensively for forced convection [13–17]. In contrast, limited studies have been reported on heat transfer enhancements obtained by using PCM suspensions in a natural circulation loop. Ho et al. [18] used a 2D analysis to explore the feasibility of incorporating PCM suspensions as the heat transfer enhancement medium in such a loop. This study experimentally investigates the thermal performance of a rectangular circulation loop with a mini-channel heat sink and source, as illustrated in Fig. 1, filled with a water-based suspension of phase-change nanocapsules.

2. Experiments

2.1. The natural circulation loop

The rectangular natural circulation loop constructed is schematically illustrated in Fig. 1 and has a height of 630 mm and a width of 220 mm. The 120-mm-long heater section and 155-mm-

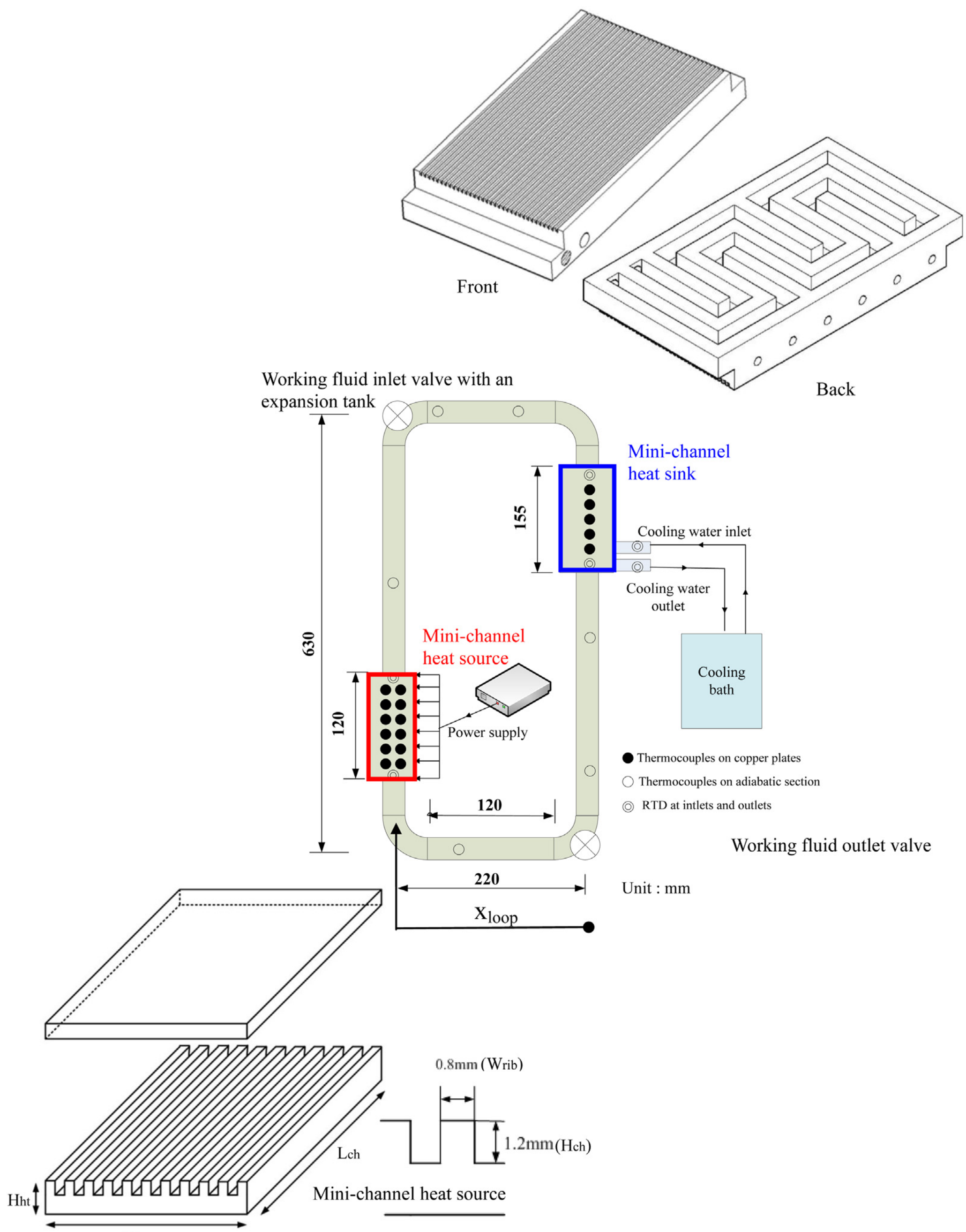

Fig. 1. Schematic of the experimental setup.

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