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Research Paper

Flow and heat transfer characteristics of nanofluids in a liquid-cooled CPU heat radiator

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HIGHLIGHTS

- Nanofluids as liquid-cooled CPU cooler heat exchanger working fluid.
- To explore comprehensive performance of the nanofluid in the heat absorbing box.
- Nanofluids make the CPU surface temperature decreased 4–18 °C to deionized water.

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ABSTRACT

The convective heat transfer coefficient and flow resistance coefficient of Cu-water and $A1_2O_3$-water nanofluids with a mass fraction of 0.1–0.5% was measured experimentally in a liquid-cooled central processing unit (CPU) heat radiator in the Reynolds number range of 400–2000. The results show that the cooling performance of a CPU heat radiator was enhanced significantly by applying the Cu-water and $A1_2O_3$-water nanofluids, and the surface temperature of the CPU chip decreased 4–18 °C compared with the deionized water. The convective heat transfer coefficient of nanofluids with a mass fraction of 0.1–0.4% was significantly higher than deionized water, and the convective heat transfer coefficient of Cu-water nanofluids was about 1.1–2 times the heat transfer coefficient of the DI water. The convective heat transfer coefficient of nanofluids with a mass fraction of 0.5% and 0.4% are close. Compared with deionized water, the flow resistance coefficient of the Cu-water and $A1_2O_3$-water nanofluids both increased to a certain degree; however, the increasing rate slowly lowered as the Reynolds number increased. Finally, a correlation which concerns the convective heat transfer coefficient and flow resistance coefficient was proposed for low concentration nanofluids in the CPU heat radiator. The proposed correlation and its calculated value agrees well with the experimental results.

1. Introduction

This project's central processor, also referred to as a central processing unit (CPU) is a VLSI, and it is the computing core and control center (control unit) of a computer. To further enhance the CPU capabilities, a microcomputer CPU chip was integrated leading to higher and higher performance. For example, in the latest Core series, the number of internal transistor has reached 580 million [1]. A high level of integration can produce high heat flux density, and the reliability of microelectronic devices is very sensitive to its running temperature; thus, the reliability can drop 5% as the temperature of the device increases for each additional degree at a level of 70–80° [2]. Therefore, it is particularly important to study the heat transfer and flow problems under microscale conditions and improving thermal conductivity of the working fluids becomes the key factor to solving this problem.

In 1995, Choi and Eastman [3] first proposed the concept of nanofluids while working on a DOE-funded grant at the US Argonne National Laboratory. Nanofluids are a colloidal dispersion system, which is composed of the dispersed phase (nanoparticles) and the dispersion medium (base fluid). Since the thermal conductivity of the dispersed nanoparticles is several orders of magnitude higher than that of the base liquid, the prepared nanofluids have a high thermal conductivity [4–6]. Moreover, the effective thermal conductivity of nanofluids is strengthened due to the interaction and collision between nanoparticles as well as nanoparticles and substrate solution [7–10]. The nanoparticle activity can create wear problems generated by the millimeter- and micrometer-sized particles; thus, the nanoparticles can have a lubricating effect under certain circumstances [11,12]. Therefore, applying nanofluids as

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Nomenclature

A	the effective heat transfer area, m^2
c	specific heat, J kg^{-1} K^{-1}
D	the average particle diameter of nanoparticles, nm
De	equivalent diameter, m
d	pipe diameter, m
f	flow resistance coefficient
k	thermal conductivity
h	convection heat transfer coefficient, W m^{-2} K^{-1}
L	wetted perimeter, m
l	tube length, m
Nu	Nusselt number
P	pressure, Pa
Pr	Prandtl number
Q	average heat flow, W
$\overline{Q}$	the average heat flux, W m^{-2}
q	mass flow, kg s^{-1}
Re	Reynolds number
S	flow area, m^2
s	the specific surface area, m^2 g^{-1}
T	temperature, K
u	velocity of flow, m s^{-1}
v	kinematic viscosity, m^2 s
w	nanoparticle mass fraction, %
ε	heat balance deviation
δ	nanoparticles purity
λ	thermal conductivity, W m^{-1} K^{-1}
μ	dynamic viscosity, Pa s
ρ	density, kg m^{-3}
φ	nano-particle volume fraction, %
η	thermal coefficient of performance

Subscripts

bf	base fluid
cpu	CPU heat box
in	import
nf	nanofluids
out	export
p	nanoparticles
ptc	PTC heating film
Reg	the regression equation
w	pipe wall
water	water

new refrigerants for heat transfer enhancement has drawn much attention from scholars and has led to several new developments in the field of heat transfer.

With the development of microelectronics, computer CPU cooling has been studied by more and more domestic and foreign scholars [13–16]. Chein and Huang [16] analyzed the cooling performance of nanofluids in silicon microchannels experimentally, and found that the heat dissipation performance of nanofluid was greatly increased. In the presence of nano-particles, the coolant pressure drop was not significant. Wu et al. [17] analyzed the laminar flow and heat transfer characteristics of nanofluids experimentally in silicon chip trapezoidal microchannels, each with an equivalent diameter of 194.5 μm. The results showed no significant increase in pressure drop after using nanofluids; The convective heat transfer Nusselt number has significantly increased compared with deionized water. With the increase of volume fraction, heat transfer resistance decreases significantly. In 2002, Liu and Zhou patented a method using liquid metal (room temperature gallium and its alloys) for CPU chip cooling [18]. The liquid metal has a very high thermal conductivity, which is the heat working fluid for fourth-generation nuclear power plants [19]. Most research for liquid metal is based on the gallium alloy, but its high price is the biggest obstacle keeping it from being used in the cooling of CPU chips. Therefore, finding a highly efficient and economical cooling refrigerant for a CPU radiator is a top priority.

The preceding literature review indicates that the study on flow and heat transfer of Cu-water nanofluid in a CPU heat box has not been as thorough as it needs to be. Thus, the flow properties and heat transfer performance of Cu and Al_2O_3-water nanofluids are compared in this study to show the better thermal performance of Cu nanofluid as well as the comprehensive performance of two kinds of nanofluids in a CPU heat box.

2. Experimental systems and process description

2.1. Test system

An assembled computer CPU liquid cooling system shown in Fig. 1 was the experimental device. Using PTC heating film as an analog computer, the CPU chip lever sets the regulator for its heating power. The determination section is the CPU heat box; non-measurement segments are radiators, tanks, pumps and connecting pipes. The CPU absorbing cartridge structure is shown in Fig. 2. At the bottom is a high-purity copper plate with micro-grooves, which have a height of 0.3 mm, a length of 40 mm, a width of 40 mm, and a thickness of 2 mm. The upper part is acrylic material with a stainless steel supportafter plating. The fluid flow cross section is 40 mm × 1 mm. In this experiment, the radiator coil water cooling system ensures a constant inlet temperature of the test section. The tank diameter is 50 mm and height is 190 mm. The connecting pipe inner diameter is 10 mm. The outer diameter for the transparent acrylic tube is 14 mm. With an endothermic heat source outside the box, asbestos insulation is inserted and wrapped in aluminum foil tape for insulation.

Four K-type thermocouples were installed on the surface of a PTC heater, and the average temperature was used to characterize the surface temperature of the microcomputer CPU. Four more K-type thermocouples were installed on the side surface of the copper plate of the microcomputer CPU heat cartridge and were used to determine the wall temperature of the copper upper surface; Two K-type thermocouples and two Rosemount 3051S pressure transmitters were installed – one each on the import connector and one each on the export connector – of the computer's CPU heat box. These thermocouples and pressure transmitters were used to determine the import and export temperature and pressure difference of the working fluid, respectively. A turbine flowmeter was used to determine the outlet flow of the pump. Agilent 34972 data acquisition was used to acquire and record the experimental data. The related equipment parameters of the experimental device system are shown in Table 1.

2.2. Preparation of nanofluids

In this experiment, Cu and Al_2O_3 nanoparticles were used as the dispersed phase, and deionized water was used as the dispersion medium, the sodium dodecyl benzene sulfonate (SDBS) was used as the dispersant. The properties of Cu and Al_2O_3 nanoparticles are shown in Table 2. Preparation method: First, add the same mass of nanoparticles and dispersant SDBS into the base fluid with