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Cooling performance investigation of electronics cooling system using Al_2O_3–H_2O nanofluid☆

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ABSTRACT

In this study, the cooling performance of Al_2O_3–H_2O nanofluid was experimentally investigated as a much better developed alternative for the conventional coolant. For this purpose the nanofluid was passed through the custom-made copper minichannel heat sink which is normally attached with the electronic heat source. The thermal performance of the Al_2O_3–H_2O nanofluid was evaluated at different volume fraction of the nanoparticle as well as at different volume flow rate of the nanofluid. The volume fraction of the nanoparticle varied from 0.05 vol.% to 0.2 vol.% whereas the volume flow rate was increased from 0.50 L/min to 1.25 L/min. The experimental results showed that the nanofluid successfully has minimized the heat sink temperature compared to the conventional coolant. It was noticed also that the thermal entropy generation rate was reduced via using nanofluid instead of the normal water. Among the other functions of the nanofluid are to increase the frictional entropy generation rate and to drop the pressure which are insignificant compared to the normal coolant. Given the improved performance of the nanofluid, especially for high heat transportation capacity and low thermal entropy generation rate, it could be used as a better alternative coolant for the electronic cooling system instead of conventional pure water.

1. Introduction

Nowadays, the nanofluids are being considered as the most advanced coolants used in the cooling devices. Nanofluids are consisted of ultra-fine particles mixing with the conventional fluid called base fluid like water, different types of oil, ethylene glycol, etc. But the mixture of these nanoparticles with the base fluid has its own specific process. Nanofluids have a great potentiality to improve the performance as a working fluid in the field of nuclear energy, renewable energy, electronic device cooling system, etc. After the invention of nanofluid in 1995 by Choi and Eastman [1], there has been done a lot of analytical and experimental research on it [2–5]. Within the recent three years (2011–2013) the number of publications on nanofluids exceeded the total number of publications published before 2011 since the establishment of the invention. This means that nanofluids are gaining in the process of time huge attention by different researchers.

The heat transfer performance of Al_2O_3–H_2O nanofluid was studied by Tullius & Bayazitoglu [6] through applying the minichannel heat sink. They have observed a significant enhancement in the heat transfer rate compared to the conventional coolant. Naphon & Nakharintr [7] also experimentally investigated the heat transfer capacity of the TiO_2–H_2O nanofluid in the application of the minichannel heat sink. They observed that the nanofluid increases the heat transfer rate considerably without increasing the additional pumping power. There have been done some of the numerical analysis to understand the thermal transportation properties of the nanofluid [8–10]. Moraveji et al. [8] numerically investigated the nanofluid cooling effects and the pressure drop across the minichannel heat sink. After getting satisfactory results compared to the other available analysis they proposed that there is a correlation between Nusselt number and friction factor. It is worth mentioning that, practically speaking, the nanofluid has not yet been used as a coolant for the electronic devices. For the purpose of practical application, the performance of Al_2O_3–H_2O nanofluid was studied here experimentally. That's why the application of nanofluid for practical purpose was investigated in this research article. The compact design of the heat sink and the performance improvement of the nanofluid would be a great replacement of the conventional cooling system for the electronic devices.

2. Experimental method

2.1. Experimental setup description

In the cooling system, the coolant passes through a close loop that consists of a minichannel heat sink, a radiator, a storage tank and a pump. The pump creates enough pressure to force the coolant to pass through the minichannel. During passing through the minichannel the

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Nomenclature

A	area, m^2
C_p	specific heat, J/kgK
D_h	hydraulic diameter, m
H_{ch}	height of the channel, m
$\bar{h}$	heat transfer coefficient, W/m^{2}K
k	thermal conductivity, W/mK
L_{ch}	length of the channel, m
$\dot{m}$	mass flow rate, kg/s
N	number of channel
$\overline{Nu}$	average Nusselt number
P	perimeter, m
$\dot{Q}$	volume flow rate, L/min
q_f	total absorbed heat by coolant, W
$S_{gen,f}$	frictional entropy generation rate, W/K
$S_{gen,t}$	thermal entropy generation rate, W/K
T	temperature, °C
u_m	mean velocity, m/s
vol.%	percentage of volume fraction
W	width, m
ΔT_{LMTD}	log mean temperature difference, °C
ΔP	pressure drop, psi

Greek symbols

η_{fin}	fin efficiency, %
ρ	density, kg/m^3

Subscripts

av	average
b	base of the heat sink
c	cross section
ch	channel
eff	effective
f	fluid
hs	heat sink
in	inlet
nf	nanofluid
out	outlet
tc	thermocouple

coolant absorbs heat produced just the bottom of the heat sink and rejects heat in the radiator section. In this way the heat sink becomes cool and maintains a certain temperature. After the cooling section the coolant comes to the storage and then recirculates through the system. The schematic of the flow technique is shown in Fig. 1. The dimension of the custom-made copper rectangular minichannel heat sink was 50 mm × 50 mm × 10 mm. The height and the width of each of the minichannel were about 0.8 mm and 0.5 mm respectively. Each channel was correspondingly spaced and the dimension of the fin was same as the channel. The heat was generated by using two cartridge heater of total capacity of 400 W and were placed just bottom of the heat sink. The temperatures at different points were measured using RTD type thermocouple (accuracy ±0.1°C). Total heat sink was placed inside an isolated box to make sure that there is no heat loss. A typical flow meter (accuracy ±0.3%–±1.0%) and a pressure transducer (accuracy ±0.3%) were mounted to measure the volume flow rate and the pressure drop respectively. All data were gathered using a digital data logger.

2.2. Experimental data calculation

All experimental data have been calculated using different types of equations. In this study, there was a requirement to identify the properties of the nanofluid to efficiently calculate its performance. The experimentally measured thermophysical properties of the nanofluid are given in Table 1.

The heat absorbed by the nanofluid can be evaluated using Eq. (1),

$$q_f = \rho \dot{Q} C_p (T_{out} - T_{in}). \tag{1}$$

The heat sink base temperature is calculated by Eq. (2a) where the base height is considered.

$$T_b = T_{av,tc} - \left(\frac{q_{in} H_b}{k_{hs} A_b}\right) \tag{2a}$$

where the base area of the heat sink is,

$$A_b = L_{ch} N \left(W_{ch} + W_{fin}\right). \tag{2b}$$

The log mean temperature difference (ΔT_{LMTD}) is calculated by Eq. (3),

$$\Delta T_{LMTD} = \frac{(T_b - T_{in}) - (T_b - T_{out})}{\ln\left(\frac{T_b - T_{in}}{T_b - T_{out}}\right)}. \tag{3}$$

The convective heat transfer coefficient is related with the log mean temperature difference and it is calculated by Eq. (4a),

$$\bar{h} = \frac{q_f}{A_{eff}(\Delta T_{LMTD})} \tag{4a}$$

where, the effective surface area of the minichannel,

$$A_{eff} = N L_{ch} \left(W_{ch} + 2\eta_{fin} H_{ch}\right) \tag{4b}$$

where, the fin efficiency is calculated by an iterative method using Eqs. (5) and (6) [11],

$$\eta_{fin} = \frac{\tanh(m H_{ch})}{m H_{ch}} \tag{5}$$

$$m = \sqrt{2\bar{h} / \left(k_{hs} W_{fin}\right)}. \tag{6}$$

The dimensionless Nusselt number can be evaluated using following Eq. (7),

$$\overline{Nu} = \frac{\bar{h} D_h}{k_{nf}}. \tag{7}$$

The friction factor can be calculated by Eq. (8),

$$f = \frac{2 D_h \Delta P}{\rho L u_m^2}. \tag{8}$$

The thermal entropy generation rate is calculated using following Eq. (9) [12],

$$S_{gen,t} = \frac{q^2 P D_h L}{\overline{Nu}\, k\, T_{ave}}. \tag{9}$$

The frictional entropy generation rate is evaluated by Eq. (10) [12],

$$S_{gen,f} = \frac{\dot{m}^3 f L}{\rho T_{ave} D_h A_c^2}. \tag{10}$$