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Investigation of flow and heat transfer characteristics in micro pin fin heat sink with nanofluid

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HIGHLIGHTS

- I studied the effect of using nanofluid in micro pin fin heat sink.
- Two nanofluids have been studied (diamond-water and Al_2O_3-water).
- Three fins shapes (square, triangular and circular) and unfinned heat sink.
- Results show that nanofluid increase the thermal performance and pressure drop.
- The circular fins give higher heat transfer rate compared with other fins.

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ABSTRACT

In this paper a micro pin fin heat sink is numerically investigated with three fins geometries (square, triangular and circular) in addition to the unfinned microchannel heat sink. Nanofluid is used as a cooling fluid, since the flow and heat transfer have been studied with two types of nanofluids (Diamond-water and Al_2O3-water) in addition to the pure water. The volumetric concentration of selected nanofluids has been chosen in range (1–4)%. The comparison of hydrodynamic and thermal characteristics of different fin geometries and cooling fluids has been made under the same value of Reynolds number and constant wall temperature thermal boundary condition, the range of *Re* used is (100–900) to ensure that, the flow remains in the laminar regime. The results obtained indicated that, using of nanofluid instead of pure fluid as a coolant leads to enhanced heat transfer performance by increasing the amount of heat dissipated but it also leads to increased pressure drop for all fins shapes and nanofluids studied.

1. Introduction

The development of modern electronic devices production has necessitated to find an effective solutions which are capable of dissipating high heat flux from the microelectronic systems to ensure stable and optimum operation. Many novel cooling techniques have been studied and designed to fulfill this demand, such as microchannel heat sink with different designs in addition to different types of cooling fluids.

To overcome the ever-increasing heat removal rate, new and efficient approaches have to be explored. Microchannel heat sinks due to their small mass and volume as well as larger area to volume ratio are very attractive for cooling of high heat flux chips. To improve the cooling performance and temperature uniformity of these devices, many new innovative ideas have been proposed such as using pin fins with different shapes and different arrangements. Fins as an extended surfaces play an important role in enhancing heat transfer process by increasing the area of heat transfer.

In order to further enhance micro heat sink performance, the nanofluids is used. Nanofluid is a kind of fluid containing small quantity of nano-sized particles (usually less than 100 nm) that are uniformly and stably suspended in a liquid. The dispersion of a small amount of solid nanoparticles in conventional fluids changes their thermal conductivity remarkably.

There are many researches in literature made to study the micro pin fin heat sink with different fins profiles and configurations and to study the flow and heat transfer in nanofluids.

Soodphakdee et al. (2001) [1] studied the heat transfer performance of heat sink with commonly used fin geometries (round, elliptical and square) also the plate fins in staggered and inline arrangement. They found that, in all cases, staggered geometries perform better than inline, also at lower values of pressure drop and pumping power, elliptical fins work best. At higher values, round pin fin offer highest performance. Ricci and Montelpare

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Nomenclature

c	volumetric concentration of nanofluid
Cp	specific heat (J/kg K)
D_h	hydraulic diameter (m)
k	thermal conductivity (W/m K)
$\dot{m}$	mass flow rate (kg/s)
P	total pressure (Pa)
q	heat transfer rate (W)
SH	solid particle shape factor
Re	Reynolds number
T	temperature (K)
u	fluid x-component velocity (m/s)
v	fluid y-component velocity (m/s)
V	velocity vector
w	fluid z-component velocity (m/s)
W	width (m)
x	axial coordinate (m)
y	vertical coordinate (m)
Z	horizontal coordinate (m)
ΔP	pressure drop across heat sink (Pa)

Greek symbols

ρ	density (kg/m^3)
μ	dynamic viscosity (m^2/s)
ψ	sphericity

Subscripts

f	fin
HS	heat sink
i	inlet
o	outlet
pf	pure fluid
nf	nanofluid
p	particle

(2005) [2] Experimentally investigated the pin fin heat sink with fins in different shapes (circular, square, triangular and rhomboidal) arranged inline with constant heat flux boundary condition. They found that, the triangular geometry is on an average the best with respect to the others. Shaeri and Yaghoubi (2009) [3] numerically investigated the fluid flow and heat transfer from an array of solid and perforated fins that are mounted on a flat plate with incompressible air as working fluid. Results show that, fins with longitudinal pore, have remarkable heat transfer enhancement in addition to the considerable reduction in weight by comparison with solid fins. Liu et al. (2011) [4] experimentally studied the flow and heat transfer in micro square pin fin heat sink with staggered arrangement, using water as coolant, the Reynolds number selected ranging from 60 to 800. They found that, both the Nusselt number and pressure drop increased with *Re* and the heat resistance decreased with the pressure drop. Mohammed et al. (2011) [5] discussed the impact of using various types of nanofluids on heat transfer and fluid flow characteristics in triangular shaped microchannel heat sink. The nanofluids used are Al_2O_3, Ag, CuO, Diamond, SiO_2 and TiO_2 all with water as base fluid. It is inferred that Diamond-H_2O nanofluid has the lowest temperature and the highest heat transfer coefficient. While Ag-H_2O has the lowest pressure drop and wall shear stress. Therefore Diamond-H_2O and Ag-H_2O nanofluids are recommended to achieve overall heat transfer enhancement and low pressure drop respectively compared with pure water. Hung et al. (2012) [6] investigated numerically the heat transfer in microchannel heat sink using many types of nanofluids. The results show that the best heat transfer enhancement can be obtained by using Al_2O_3-water nanofluid. The heat transfer performance of Al_2O_3-water and Diamond-water nanofluids was 21.6% better than that of pure water. Ho and Chen (2013) [7] experimentally investigated the forced convective heat transfer performance of using Al_2O_3-water nanofluid to replace the pure water as the coolant in a copper minichannel heat sink. With the Reynolds number ranging from 133 to 1515. Compared with the results for the pure water, it was found that the nanofluid cooled heat sink has significantly higher average heat transfer coefficients and hence outperforms the water cooled heat sink. Naphon and Nakharintr (2013) [8] studied the heat transfer characteristics of nanofluids cooling in the mini-rectangular heat sink. The nanofluid used is Tio_2-water. They found that average heat transfer rates for nanofluids as a coolant are higher than those for water.

Most of the studies in literature made to investigate heat transfer and flow characteristics in pin fin heat sink with pure fluids and as the author knowledge there are no researches available in which the nanofluid used as a coolant in mini and micro pin fin heat sink. In this paper two types of nanofluids were used as a coolant in micro pin fin heat sink and the effect of using these nanofluids instead of pure water on the thermal and hydrodynamic performance of pin fin heat sink is numerically investigated.

2. Problem description

The model studied in this paper is 3D micro pin fin heat sink consists of 50 fins with three shapes (square, circular and triangular) fins. The length of heat sink is 16 mm and its width and height are 6 mm and 1 mm respectively. All fins have same height 0.5 mm and base dimensions $W_f = D_f = 0.5$ mm. Fig. 1 show the physical model represent the studied micro pin fin heat sink with three geometries of fins in addition to the unfinned heat sink. Fig. 2 show the description of fins geometries. The fins are arranged in staggered configuration which is better than inline configuration from the heat transfer point of view as it used by many references such as [1,9], the values of fins spacing are $s_x = 0.5$ mm and $s_z = 0.5$ mm. Fig. 3 shows the staggered arrangement used in this paper.

3. Mathematical formulation

For modeling, nanofluid is treated as a single − phase fluid. This assumption can be applicable since the particles are ultra fine and they are easily fluidized [10,11]. Moreover, the particle volume fraction in nanofluid is usually low. Under such assumptions the governing equations for the nanofluid flow and heat transfer are greatly simplified and local fluid and particles are in thermal equilibrium.

For steady state, 3-D, incompressible and laminar flow the following equations are solved to calculate the distributions of velocity and temperature [12]:

Continuity equation:

$$\nabla V = 0 \tag{1}$$

Momentum equation:

$$\rho(V\nabla V) = -\nabla P + \nabla(\mu\nabla V) \tag{2}$$

Energy equation: