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Channel cross section effect on heat transfer performance of oblique finned microchannel heat sink

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ABSTRACT

In the present work, the effect of channel cross section on the heat transfer performance of an oblique finned micro-channel heat sink was investigated. Water and Al_2O_3/water nanofluid of volume fraction 0.25% were used as a coolant. The oblique finned microchannels are designed with three channel cross-sections namely square, semicircle and trapezoidal. The primary work of this paper is to study the heat transfer and hydrodynamic characteristics in the oblique finned microchannel. The experimental setup and procedure are validated using water as coolant in a micro-channel heat sink. Heat transfer and flow characteristics are examined for three cross-sections of varying mass flux. The trapezoidal channel cross-section increases the considerable heat transfer rate improvement for both water and nanofluid by 3.133% and 5.878% compared to square and semicircle cross section. Also, the pressure drop is higher in the trapezoidal cross-section over the square and semicircle cross section. This is due to increase in friction loss of trapezoidal cross section. The results indicate that trapezoidal cross-section oblique finned micro-channel is more suitable for heat transfer in the electronic cooling application.

1. Introduction

Advancement in the chip technologies emphasis the innovation on miniaturized cooling techniques. In recent days there are several attempts found to improve the micro channels by changing cross-sections and coolant. One of the methods used is the addition of nanoparticles with highly thermal conductive materials like carbon, aluminium and some of the metal oxides into heat transfer fluids to encourage the overall thermal conductivity. The thermal management of electronic components is essential because of electronic devices with high heat generation from small volume due to the technological advancements in microprocessor and microchips. Therefore, the search for more effective cooling technology becomes one of the stick-up problems for the secondary development of the industry. Devices such as the micro-channel cooling systems are helpful for solving this problem.

Water, engine oil and ethylene glycol are the common coolant used in the conventional heat exchangers. The design was most likely having coils through which the fluid flows, and due to the curvature, heat transfer was increased. One such was Conte et al. [1] investigated the heat transfer performance in a single round pipe rectangular coiled heat exchanger. The experiment was carried out on both inner and outer coils. The results showed that coiling a pipe helps to induce turbulence rather than increasing its velocity and therefore enhances the heat transfer in the pipe. The advancement in the Micro Electro Mechanical System (MEMS), the cooling system is required in micro size and also more efficiently. Thus this leads to the development and studies about micro-channel. Study on flow characteristics in the micro channel were carried out by Chiu et al. [2] and observed experimentally, the heat transfer performance and features of a liquid cooling microchannel heat sink. The effect of aspect ratio on pressure drop and heat transfer performance was observed.

In order to achieve higher effectiveness from the micro-channel heat sink the design of the micro-channel was modified and studied [3–6]. Garcia-Hernando et al. [3] performed an experimental analysis of the hydrodynamic and thermal performance of micro heat exchangers sized 100×100 and $200 \times 200\,\mu m$ square cross sections with deionised water as a working fluid is to be used. The obtained results were compared with the forecasts of the classical viscous flow and heat transfer theory. Tu-Chieh Hung et al. [4] designed a geometric parameter of the double layered micro-channel heat sink using conjugate gradient method in a 3-D fluid flow. The increase in pumping power results to decrease the thermal resistance with the decrease in the optimal value of β was found. Chao Liu et al. [5] performed an experimental investigation on heat transfer and fluid flow in rectangular

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micro-channels with long vortex generators (LVGs). From this study, the LVGs can enhance heat transfer compared with the smooth rectangular micro-channel. Sakanova et al. [6] performed a study with the new shape of the microchannel. The paper deals with the new shape of the microchannel by bringing out the wavy type of microchannel with 25 µm, 50 µm and 75 µm amplitude. The new structure is further investigated by varying the volume flow rate with three different concentrations of nanofluid. The change in performance was negligible.

Melanie Derby et al. [7] performed an experiment on condensation heat transfer. The comparison of square, triangular, and semi-circular channel geometries with the same hydraulic diameter of 1 mm was made. From the parametric study, the mass flux, saturation pressure and heat flux found to have significant effects on condensation whereas the channel shape had no significant effects on condensation. Quweilin et al. [8] conducted experiments to determine the flow characteristics in trapezoidal silicon micro-channels. The flow rate was up to 70 cm^3/min to be kept by means of the flow meter and Reynolds varied from 200 to 700.

Subsequently, the nano-technology came into the vogue. Thus making more studies related to the nanofluid [9–12]. The addition of nanoparticles to the fluid increases the thermal conductivity of the coolant. Since the thermal conductivity of the nanoparticles was greater than the base fluid. A heat transfer experiment on nanofluid over an annular duct was conducted by Nasiri et al. [9]. The experiment compares two nanofluid $Al_2O_3/H_2O$and TiO_2/H_2O on heat transfer performance at constant wall temperature boundary condition through an annular channel. There is no expressive difference on the heat transfer performance in comparing both the nanofluids. The heat transfer coefficient increased moderately with the increase in the concentration of both the nanoparticles. Jaafar et al. [10] consummate an experimental study on heat transfer over the horizontal shell and tube heat exchangers using Al_2O_3nanofluid at different concentrations. The size of the Al_2O_3 nanoparticles to be used is 30 nm. Dayalpandey et al. [11] performed an experimental analysis in a corrugated heat exchanger using nanofluid as a coolant. The test section consists of three same corrugated channels having an angle of 30° with the nanofluid flow in the middle channel and hot water flow in adjacent channels. They observed that the increase in Reynold's and Peclet number with the decrease in nanofluid concentration showed the better-quality of heat transfer characteristics. It was found from the literature survey, heat transfer performance of microchannel heat sink is increased by changing design and coolant. Xia et al. [12] performed a study in different types of nanofluids being used as a coolant when added with anon-ionic surfactant. The surfactant was added to avoid the particle aggregation and enhance stability. The study shows that the thermal performance of the microchannel was increased and intensified the heat transfer between fluids and channel walls due to the presence of the nanoparticles and the surfactant.

The present research work is carried out on heat transfer rate and flow analysis in the oblique finned microchannel. In this work, the effect of channel geometry has been studied. The channel geometry of heat sink is square, semicircle and trapezoidal. The Water and Al_2O_3 nanofluid with 0.25% concentration are tested for three cross-sections. Heat transfer and flow characteristics were performed for mass flux ranged from 90 to 480 kg/m^2 s. The analysis results of three cross-sections are compared with each other, and the desired performance is finally accomplished.

2. Materials and methods

2.1. Nanofluid preparation

Nanofluid is prepared by a two-step method. Initially, the powders are made either by physical or chemical methods, followed by suspending it in the base fluid. This is one of the most inexpensive ways of producing nanoparticle. The Al_2O_3 nanoparticles are disseminated into the water by using an ultrasonic vibrator for 6–10 h. The nanoparticles used in the experiment was 99.0% pure aluminium oxide, which was dispersed in water with desired concentration of 0.25% and its average particle size was 40–50 nm. The nanofluids with less than 4% nanoparticles were found to be stable, and stability lasted over 36 h, no intermediate mixing was considered necessary. It was observed that no sedimentation had occurred in the mixture as it will restrict the turbulent flow regime.

2.2. Thermo-physical properties of nanofluid

From theoretical studies on particle-fluid mixtures, the properties of nanofluids can be determined from the following formulae.

Pang et al. [13] measured the thermal conductivity of nanofluids, base fluid valued are used to determine the nanofluid value. The formula to find the thermal conductivity of nanofluid is given below.

$$k_{nf} = \frac{k_p + 2k_{bf} + 2(k_p - k_{bf})\varphi}{k_p + 2k_{bf} - (k_p - k_{bf})\varphi} \tag{1}$$

To solve the governing equation C_{pnf} Hung et al. [4] proposed the heat capacity equation, the equation is given below,

$$C_{\rho\, nf} = \frac{(1-\varphi)(\rho C_p)_{bf} + \varphi(\rho C_p)_p}{\rho_{nf}} \tag{2}$$

The density of the nanofluid is estimated from the work of Mohammed et al. [14].

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_p \tag{3}$$

Theoretical investigations on the viscosity of nanofluid are given by Mahbubul et al. [15] in the latest development of viscosity in a nanofluid. They concluded that particle size had adverse effect on nanofluid

$$\mu_{nf} = \mu_{bf}(1 + 2.5\varphi) \tag{4}$$

Where suffice 'bf' base fluids and 'nf' represents nanofluids.

3. Experimental setup

Fig. 1 shows the Photograph of the experimental setup and schematic diagram of experimental flow loop is shown in the Fig. 2. The test section consists of 7 temperature ports, each one at inlet and outlet and remaining five are utilised to determine the intermediate temperatures. The fluid is stored in the reservoir (2) made up of stainless steel which can hold a capacity of 5–6 l. Filter (3) made by Swagelok of 15 µm cross-section is mounted in mid-way between the reservoir and the pump. Gear pump (4) made by pedroRoquest capable up to 15 lpm is used with the flow rate of 0.1 lpm. The gate valve (5) is located after the pump to regulate the flow. Flow meter (6) with the measurement range from 0.1 to 2 lpm made by sunshine model S-FM was utilised as the flow measuring device. K-type temperature sensor made by AMBETRONIC k-type of range − 20 °C to 200 °C is used to measure the temperature. The end point of the probe is placed in the channel and fluid to measure the temperature. It gives reading in a digital manner to the temperature data logger make by AMBETRONICS model TC1600F of range − 50 °C to 500 °C.

The AMBETRONICS TC-1600F Data logger (7) consists of eight channels with six probes are used. There is also a pressure transducer make by SETRA model 3100 ranges from 0 to 2 bar that can sense the pressure of the fluid at both entry and exit of the micro-channel, which is kept in the test section. The pressure transducer is linked with a pressure data logger (9) make by AMBETRONICS model TC-800 ranging 0 to 5 bars which are used to visualise and record the pressure values. The hot fluid from the channel is passed on to the condenser (1) which cools the fluid for circulation. The test section (8) consists of oblique finned micro-channel made up of copper. The channel section is covered by fibreglass. Fig. 3 shows the test section of oblique finned