Experimental Analysis of Micro Channel Heat Sink with Spiral Configuration

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Abstract
This paper aims at the experimental analysis of micro channel heat sink with spiral configuration for measuring heat transfer characteristics. Base plate of aluminium has been used for the designing of spiral micro-channels. The cross section of channel is rectangular with sides 1mm x 0.5mm. Water has been used as the working fluid for testing purpose and final results are obtained on nano-fluids as the medium of heat transfer in the heat sink. Tests are performed by nano-fluids entering from one end and exiting from the other end. The experimental setup has been analysed for variations of thermal resistance, pressure drop and flow rate with respect to Reynolds's number. Data acquisition system for the micro-channel heat sink is designed for monitoring and processing the data obtained from the sensors at the initial and final ends of the micro-channel heat sink, including temperature sensors, pressure gauges and flow sensors. The data acquired from the sensors has been taken from self-designed data acquisition system and processed on National Instruments software Lab VIEW. The monitoring and graphical display is performed on hardware based Liquid crystal display and virtual instrument designed on NI Lab view.

Keywords: Spiral micro-channel; heat sink; data acquisition system; nano-fluids; Reynolds's number

1. INTRODUCTION

With the development in design of the modern electronic systems, microelectronic devices and very large scale integrated circuit (VLSI) technology has come up in the market as a boon to the electronics market. Heat sinks are known for their efficient removal of heat for these devices. Design of heat sinks with high heat flux removal from unit surface area is an important criterion in the efficient working of these compact modern electronic systems. Moreover, the operational reliability of the micro-electronics systems depends on the efficient removal of internally generated heat. Over the past decade, internal heat dissipation requirements have exponentially increased due to high-powered and high-density microelectronic circuitry in modern devices. The traditional cooling techniques including the fan-cooled heat sinks have become grossly inadequate and impose limits on product design in the case of micro-electronic systems. A significant amount of research has been made to develop innovative cooling techniques that have the potential to deliver high-heat flux rates for micro-electronics applications. Micro-channel heat sinks find various applications in modern electronics including portable electronic equipment, miniature fuel cells, and very large scale integrated (VLSI) electronics etc. Comparing with other cooling techniques, micro-channels can be directly embedded closely to heat sources for compact and efficient designs. Zhizhao Chea et al. [1] have developed various techniques for high efficiency cooling including heat pipes, spraying, jet impingement, and micro-channels. The concept of micro-channels is identified as a highly viable practical alternative for meeting the future cooling needs of advanced electronic applications. Convective heat transfer in droplet-based micro-channel heat sinks can be enhanced by the re-circulating vortices due to the presence of interfaces. In rectangular micro-channels, the three dimensional structures of the vortices and the 'gutters' (i.e., the space between the curved droplet interface and the corner of the micro-channel) can significantly affect the heat transfer process. Numerical simulations of the heat transfer process are performed to study the three dimensional features in droplet-based micro-channel heat sinks. Weilin Qu et al. [2] explored several issues important to the thermal design of single-phase and two-phase micro-channel heat sinks. The first part of the paper concerns single-phase heat transfer in rectangular micro-channels. Experimental results are compared with predictions based on both numerical as well as fin analysis models.

Andrew J.L. Foong et al. [3] presents a numerical study to investigate the fluid flow and heat transfer characteristics of a square micro-channel with four longitudinal internal fins. Three-dimensional numerical simulations were performed on the micro-channel with variable fin height ratio in the presence of a hydro dynamically developed, thermally developing laminar flow. Results of the average local Nusselt number distribution along the channel length were obtained as a function of the fin height ratio. M. Ghobadi et al.[4] examined the heat transfer in a spiral heat sink experimentally and analytically. Heat transfer behaviour over a wide range of flow rates from laminar to turbulent has been examined. The dimensionless mean wall flux and the dimensionless thermal flow length were used to analyse the experimental data instead of Nusselt number and channel length. The spiral channel has been discretized, so that a single Dean number can be assumed in each cell, and two current models were applied to obtain the average Nusselt number.

Alok Narayan Bahera et al. [5] performed a three-dimensional numerical analysis to understand the effect of axial wall conduction on conjugate heat transfer during single phase pulsatile flow in a square micro-channel with wavy walls. Mark E. Steinke et al.[6] evaluated the applicability of these techniques for single-phase flows in micro-channels and mini-channels. The single-phase heat transfer enhancement techniques are well established for conventional channels and compact heat exchangers. The major techniques include flow transition, breakup of boundary layer, entrance region, vibration, electric fields, swirl flow, secondary flow and mixers. The micro-channel and mini-channel single-phase heat transfer enhancement devices will extend the applicability of single-phase cooling for critical applications, such as chip cooling, before more aggressive cooling techniques, such as flow boiling, are considered.

Satish G. Kandlikar et al. [7] provides a roadmap of development in the thermal and fabrication aspects of micro-channels as applied in the microelectronics and other high heat-flux cooling applications. Z.Che et al. [8] examined that the re-circulating flow in multiphase micro-fluidics can effectively enhance heat transfer by bringing fresh fluid from the centre of the channel to the wall, and transporting heated fluid from the wall to the centre of the channel. T. Bandara et al. [9] have performed many experiments to measure the heat transfer enhancement in micro-channels with droplets, slugs, or plugs. Some experiments used cylindrical micro-tubes [10, 11, 12, 13], while others used rectangular micro-channels [14, 15, 16, 17]. To address the effect of interfaces on heat transfer process, some simulations employed assumed interface shapes for the sake of simplicity [8, 18], while others used interface capturing methods to accurately predict interface shapes. Various interface tracking/capturing techniques have been employed to simulate the heat transfer in droplets, slugs, and plugs, such as the volume of fluid method [19], the level set method[20, 21], and the phase field method [22].

2. EXPERIMENTAL SETUP

The experimental setup for the analysis of micro-channel heat sink with spiral configuration is depicted in figure 2. The experimental setup includes an inlet pump for water or nano-fluid. T-junctions as mechanical joints between the paths is made of plastic connectors. A pipe is connected to the output of the T-junction. The diameter of pipe used is cm and it's made of plastic material. A flow sensor (F1) is placed onto the input path. The output of the flow sensor is given to the data acquisition (DAQ) device for monitoring purpose. Then a pressure gauge (P1) is connected at the input path and a temperature sensor (LM35) or (T1) placed for measuring the temperature of inlet flow stream. After this, a suitable O ring is placed to reduce the dimension of pipe connected and a small diameter plastic pipe matching the inlet heat sink pipe is joined to the output of O-ring. This is then joined to the input of the micro channel heat sink. Another temperature sensor (T2) is placed onto the top of heat sink using thermal paste. Output of T2 is given to DAQ device.

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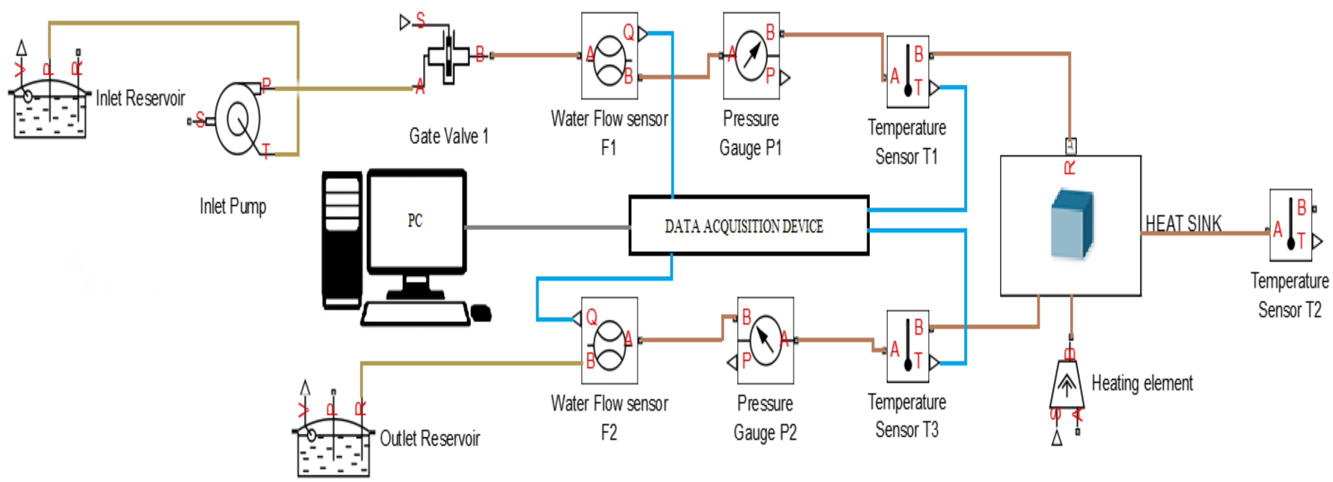

Fig. 1: Complete Experimental Setup.

A flow sensor (F1) is placed at inlet. The output of the flow sensor (F2) is given to the data acquisition device (DAQ) for monitoring purpose. Following the flow sensor (F1) and pressure gauge (P1) is connected at the input path and a temperature sensor (T1) placed for measuring the temperature of inlet flow stream. After this, different O-rings are used to reduce the dimension of pipe connected and a small diameter plastic pipe matching the inlet heat sink pipe is joined to the output of O-ring. This is then joined to the input of the micro channel heat sink. Another temperature sensor (T2) is placed onto the top of heat sink using thermal paste. Output of T2 is given to DAQ device. The output of the micro channel heat sink is joined with an output pipe of smaller diameter that is further connected to an O-ring to increase the pipe diameter. A larger diameter output pipe is connected to the O-ring connector output. This pipe is similar to the inlet pipe. Temperature sensor (T3) is placed in the outlet flow stream to measure the output water stream temperature. A pressure gauge (P2) is connected to the output of the pipe to measure the pressure of the output flow stream. Finally, the flow sensor (F2) is placed in the output flow stream to measure its flow rate. The output of T3 and F2 is also connected to the DAQ device.

The output of the micro channel heat sink is connected with an output pipe of smaller diameter further connected to O-ring to increase the pipe diameter. A larger diameter output pipe is connected to the O-ring connector output. This pipe is again similar to the inlet pipe. Temperature sensor LM35 (T3) is placed in the outlet flow stream to measure the output water stream temperature. A pressure gauge (P2) is connected to the output of the pipe to measure the pressure of the output flow stream. Finally, the flow sensor (F2) is placed in the output flow stream to measure its flow rate. The output of T3 and F2 is also connected to the DAQ device. The main parts of the experimental setup includes three different types of sensors to be used including temperature sensor (LM35), pressure gauge and flow sensor, and the data acquisition device for monitoring purpose on LCD and computer. A 2x16 LCD is used for monitoring the quantitative values of T1, F1, T3 and F2. LabVIEW software is used for monitoring and plotting the different graphical values such as thermal resistance and flow rate. Temperature sensor T2 is a digital thermometer and depicts the temperature of the heat sink on a small LCD display mounted on itself. Pressure gauges P1 and P2 analog type gas/fluid pressure monitoring device and depicts the pressure in Psi. The pump for inlet temperature of the water is powered by an AC source. However, the electronic system is powered by a 5 volts DC power supply.

3. PERFORMANCE EQUATION

$$R_{th} = \frac{T3-T1}{qA} \qquad (1)$$

$$Q = h\,(T3-T1) \qquad (2)$$

$$Re = \frac{\rho u D}{\mu} \qquad (3)$$

$$Nu = \frac{hL}{k} \qquad (4)$$

4. RESULTS AND DISCUSSIONS

The experimental setup for micro channel heat sink (MCHS) with spiral configuration was tested with different fluids including water, nano-fluid with 1% concentration, nano-fluid with 2% concentration and nano-fluid with 3% concentration and various results were obtained. These results were obtained at different volumetric flow rates and also different volumetric concentrations with the help of a knob at the inlet of the pipe coming from the pump submerged in a chamber of water. These results are illustrated below.

Figure 2 illustrates the inlet temperature (T1), Heat sink temperature (T2) and outlet temperature (T3) at different instants of time monitored with the help of LM35 temperature sensors and Arduino Uno microcontroller board.

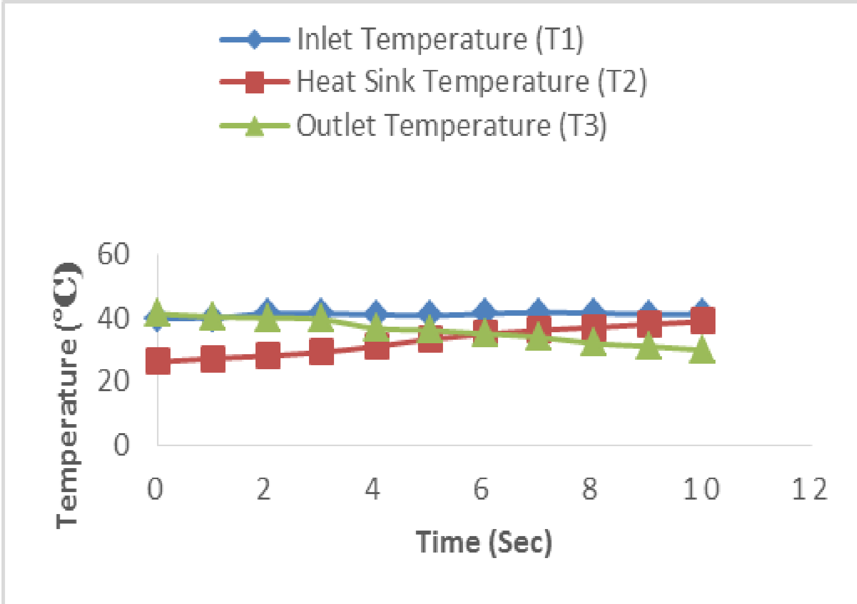

Fig. 2: Temperature of Inlet, Heat Sink and Outlet vs time

It could be depicted from figure 2 that inlet temperature is almost constant around 40 °C, however after passing through the MCHS, the outlet temperature reduces significantly and heat sink temperature increases proportionally.

Figure 3 depict the average temperature rise in heat sink temperature after passing the heated water through the micro channel heat sink.

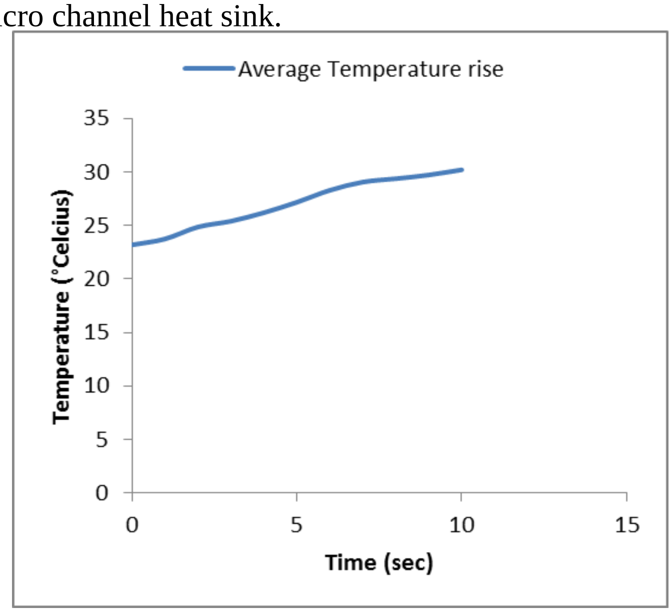

Fig. 3: Average temperature rise of Heat Sink for water

Figure 4 represents the values of flow rates obtained by the flow meters placed at the inlet and the outlet of micro-channel heat sink.

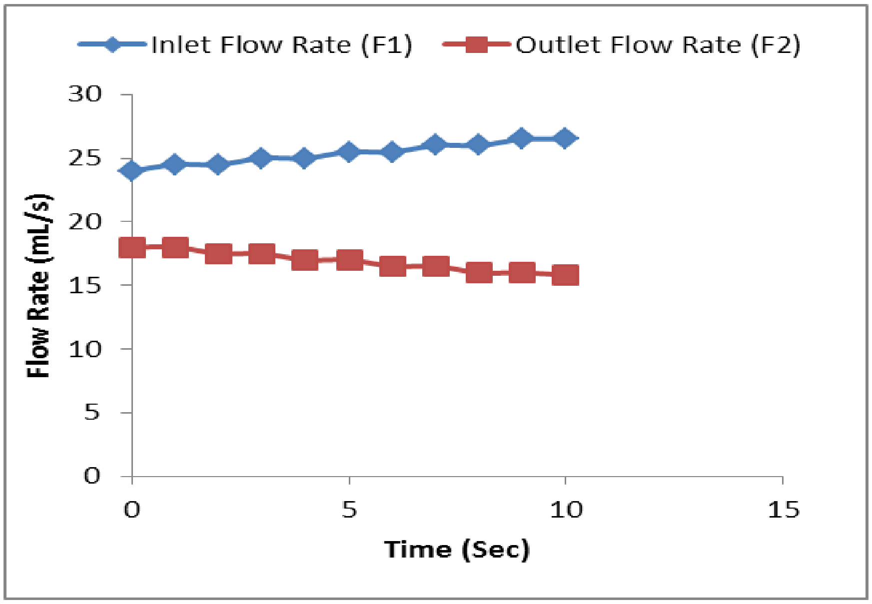

Fig. 4: Inlet and outlet volumetric flow rate vs time

It could be illustrated from the above figure that volumetric flow rate reduces significantly after passing through the micro channel heat sink.

Figure 5 represents the thermal resistance offered to water as the working fluid through the micro-channel heat sink with respect to the volumetric flow rate. Fig.- 6 represents the values of pressure drop vs volumetric flow rate for water.

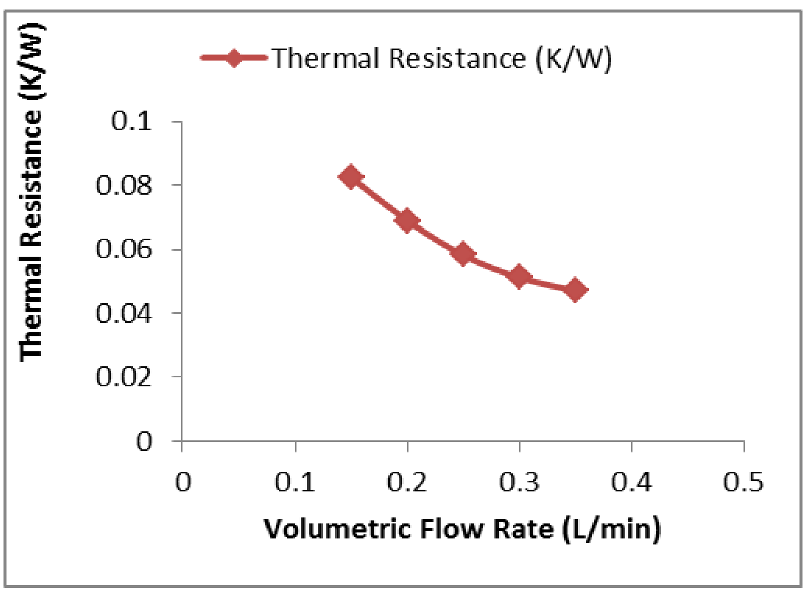

Fig. 5: Thermal resistance vs volumetric flow rate for wate

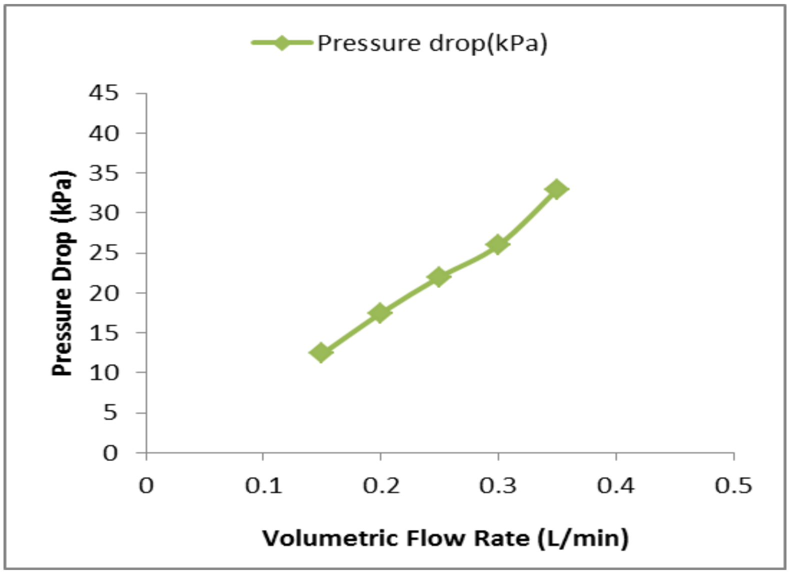

Fig. 6: Pressure drop vs volumetric flow rate for water

After generating results for water as the working fluid, next step was to determine the same results for various concentrations of nano-fluid by mixing Aluminium oxide (Al_2O_3) particles in water at different concentration. Different concentrations of nano-fluid employed in this analysis are 1% Al_2O_3 in water, 2% Al_2O_3 in water and 3% Al_2O_3 in water. Figure 7 depicts the values of thermal resistance vs volumetric flow rate for various concentrations of nano-fluid and water.

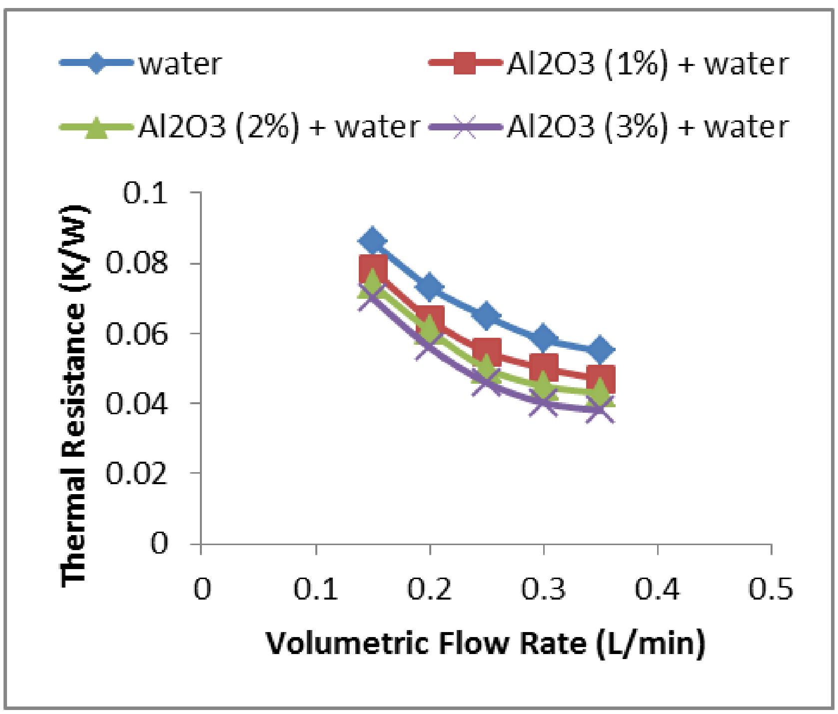

Fig. 7: Thermal resistance vs volumetric flow rate for water, Al_2O_3 (1%) - water nano-fluid, Al_2O_3 (2%) - water nano-fluid and Al_2O_3(3%) - water nano-fluid

Figure 8 represents the values of heat transfer coefficient (h_{nf}) vs Reynolds number (Re) for various concentrations of nano-fluid.

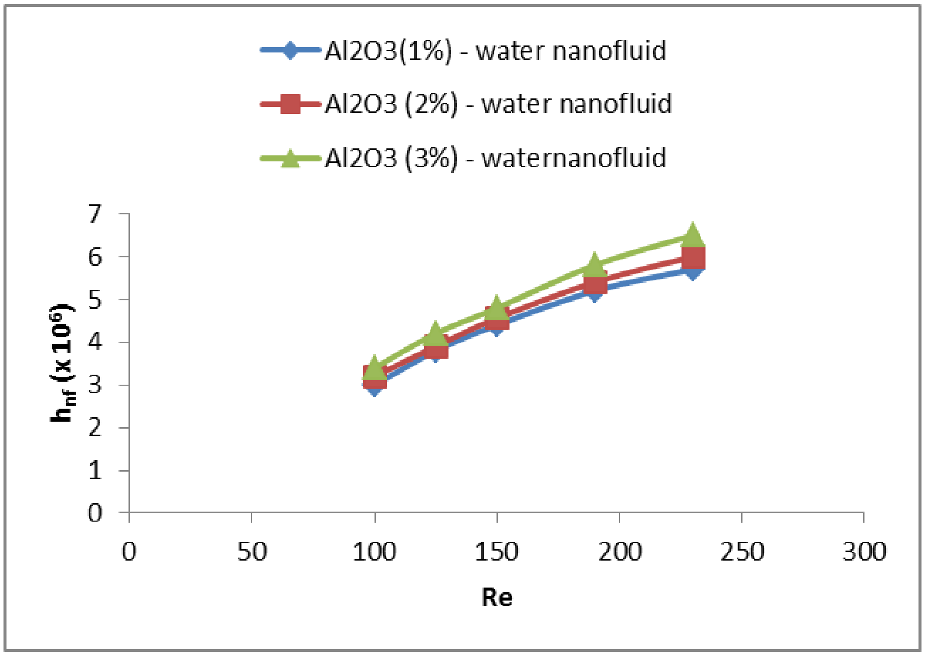

Fig. 8: Heat transfer coefficient vs Reynolds number for Al_2O_3 (1%) - water nano-fluid, Al_2O_3 (2%) - water nano-fluid and Al_2O_3(3%) - water nano-fluid

Figure 9 represents the pressure drop v Reynolds number (Re) for various concentrations of nano-fluid and water.

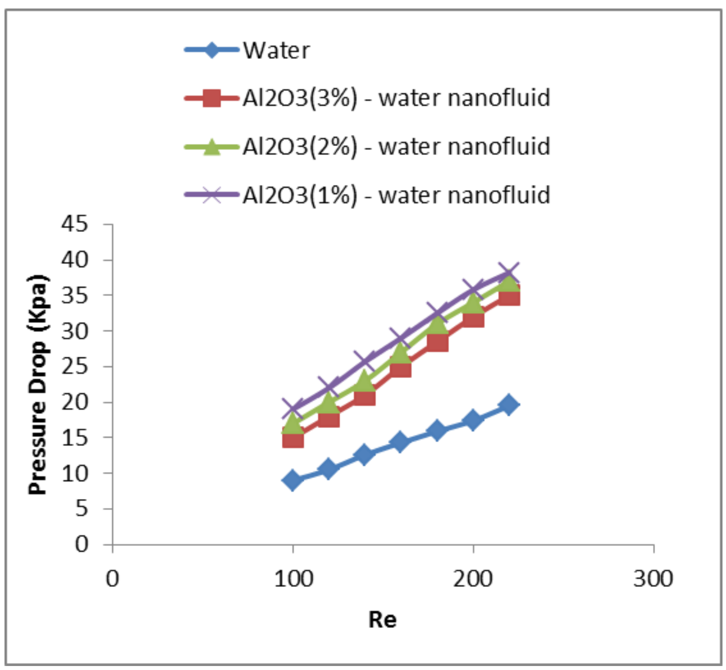

Fig. 9: Pressure drop vs Reynolds number for Al_2O_3 (1%) - water nano-fluid, Al_2O_3 (2%) - water nano-fluid and Al_2O_3 (3%) - water nano-fluid and water

Figure 10 depicts the different values of thermal resistance for various volume concentrations of nano-fluid at Re = 99. **Figure 11** depicts the different values of thermal resistance for various volume concentrations of nano-fluid at Re = 230.

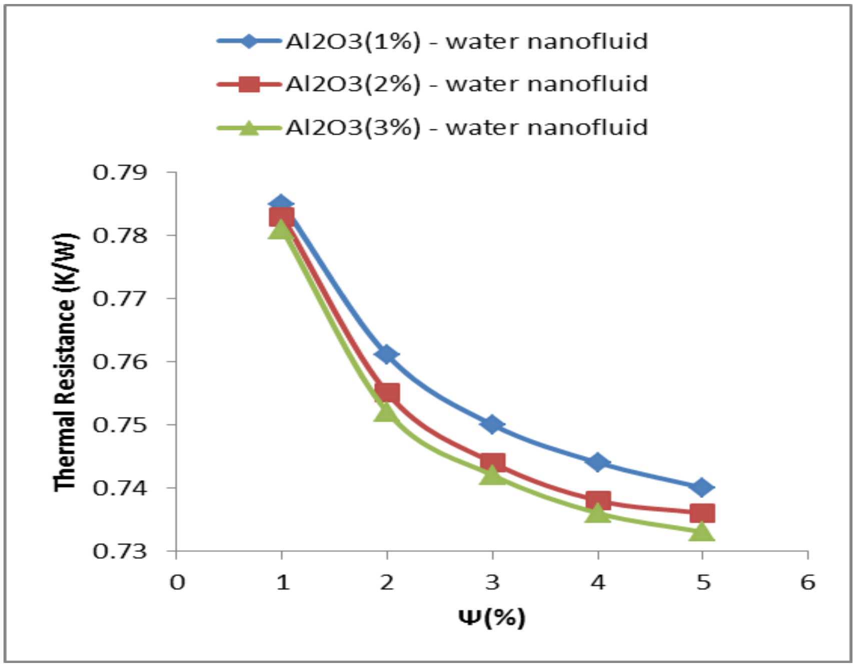

Fig. 10: Thermal resistance vs Volume concentration for Al_2O_3(1%) - water nano-fluid, Al_2O_3(2%) - water nano-fluid and Al_2O_3(3%) - water nano-fluid at Re = 99

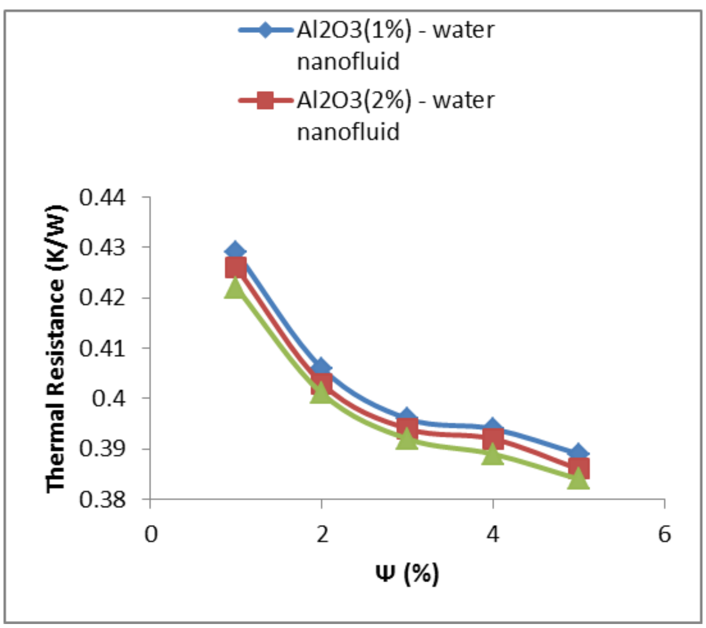

Fig. 11: Thermal resistance vs Volume concentration for Al_2O_3 (1%) - water nano-fluid, Al_2O_3 (2%) - water nano-fluid and Al_2O_3 (3%) - water nano-fluid at Re = 230

Figure 12 shows the variation of thermal resistance with different Reynolds number for various volume concentrations of nano-fluid.

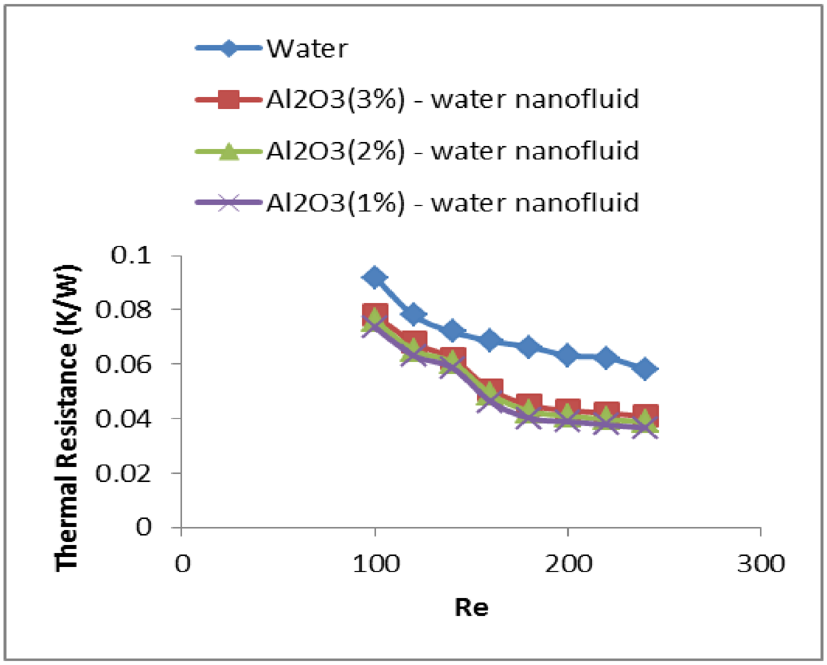

Fig. 12: Thermal resistance vs Reynolds number for Al_2O_3(1%) - water nano-fluid, Al_2O_3(2%) - water nano-fluid and Al_2O_3(3%) - water nano-fluid and water

Next, data computation was performed in order to plot the overall heat transfer coefficients of the designed spiral micro channel heat sink and associated flow of water through it represented in terms of Reynolds number vs Nusselt number. This graph is depicted in the figure 13.

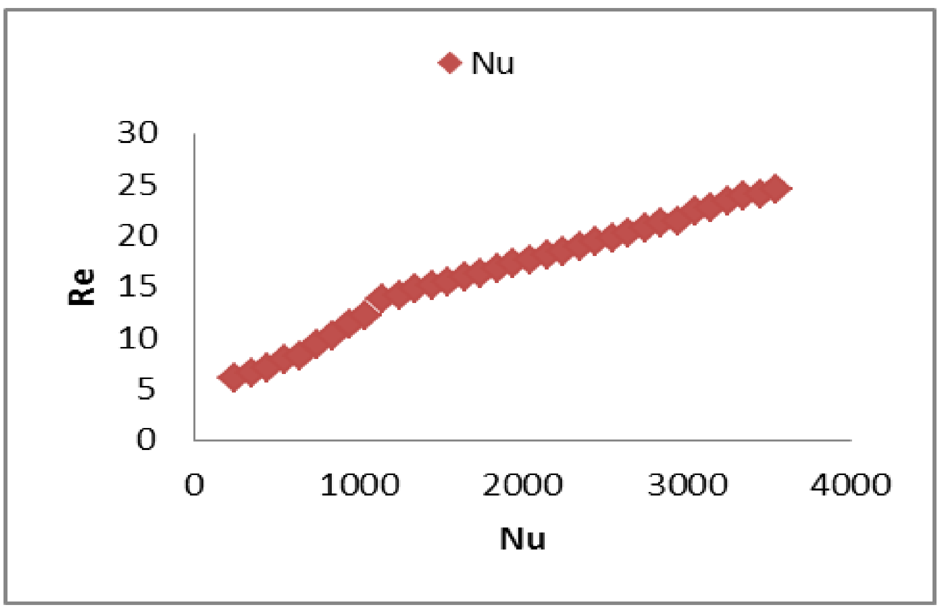

Fig. 13: Reynolds number vs Nusselt number for spiral micro channel heat sink

Figure 14 shows the values of temperature of outlet sensor T3 for various nano-fluid concentrations at different inlet velocities. This is achieved by changing the inlet flow rate using the control knob of the inlet flow control valve.

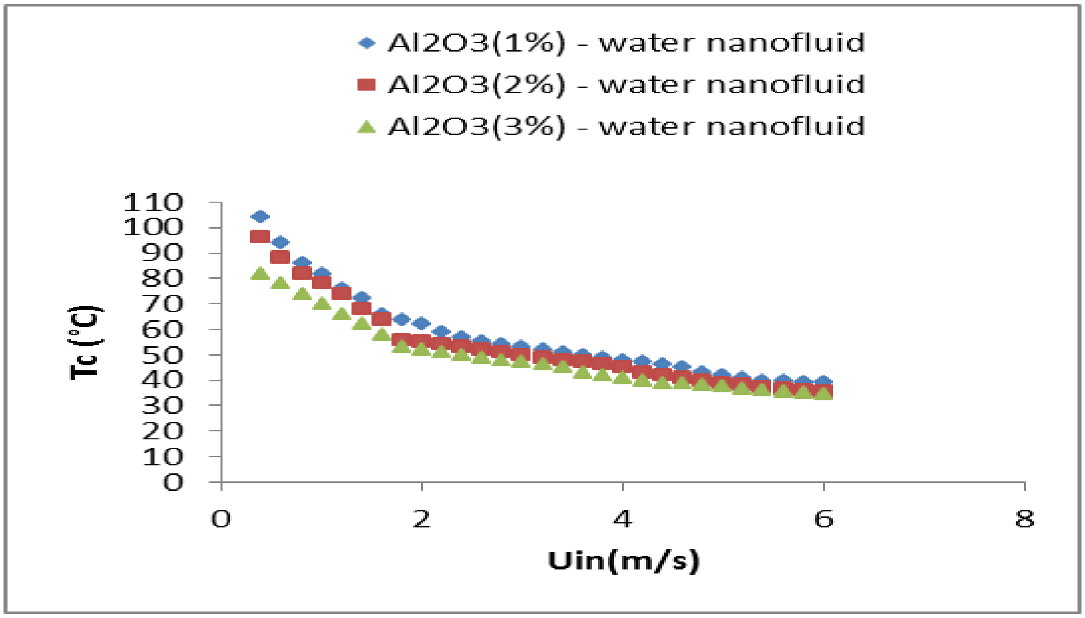

Fig. 14: Temperature vs inlet fluid velocity for Al_2O_3(1%) - water nano-fluid, Al_2O_3(2%) - water nano-fluid and Al_2O_3(3%) - water nano-fluid

6. CONCLUSIONS

From various results obtained in this experimental study, it has been inferred that the incipient boiling heat flux increases with increasing inlet velocity and decreasing inlet temperature. Also, by studying the heat transfer characteristics for different fluids in the micro channel heat sink with spiral configuration, it has been concluded that thermal resistance decreases with increasing the volumetric flow rate, however, the pressure drop across the heat sink decreases with increasing volumetric flow rate. Also, after studying the heat transfer characteristics for various fluids including water and water nano-fluid mixture at different concentrations, higher concentration nano-fluid shows best results as compared to lower concentration in terms of thermal resistance, convective heat transfer coefficient as well as pressure drop. Also, the designed micro channel heat sink with spiral configuration was able to remove the heat flux through small surface area after passing different concentration nano-fluids in water.

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NOMENCLATURE

A_{tot} Area of the specimen (m^2)

L Characteristic length of the rectangle (m)
h Overall heat transfer coefficient of convection (W/m^2K)
D_h Hydrodynamic diameter (m)
C_p Specific heat (kJ/kgK)
K Thermal conductivity (W/mK)
R_{th} Thermal resistance (W/mK)
q_{gain} Power gain of the water flowing through the heat sink (W)
T_o Temperature fluid at the outlet (K)
Q_{bulk} Total heat removed by the fluid (W/m^2)
T_i Temperature of fluid at the inlet (K)
$\dot{Q}$ Flow rate (mL/s)
u Velocity of fluid (m/s)
T_j Temperature of the heat sink (K)
$\dot{m}$ Mass flow rate (kg/s)
T_m Mean temperature (K)

Greek Symbols
ρ Density of fluid (Kg/m^3)
α Thermal diffusivity (m^2/s)
μ Viscosity of the fluid (Ns/m^2)
ψ Volume concentration (%)

Dimensionless Numbers
Re Reynolds's number ($\rho u D_h/\mu$)
Nu Nusselt number (hL/K)

Units
m meter
s seconds
W Watts
K Kelvin
kJ kilo Joules
N Newton

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