Experimental Investigation of Heat Transfer Study in Rectangle Type Straight and Oblique Finned Microchannel Heat Sink with Nanofluids

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Abstract - *In the present work, the effect of heat transfer performance of an oblique finned microchannel and straight finned microchannel heat sink was compared and investigated. Water, Al_2O_3/Water Nanofluid and SiO2/Water Nanofluid of volume concentration of 0.1% used as a coolant. The straight and oblique finned microchannels were designed with rectangle type cross-section channel. The microchannel heat sink considered in this study has evenly spaced 25 rectangular channels with a hydraulic diameter of 0.947 mm. The primary work of this project is to study the heat transfer and hydrodynamic characteristics in the straight microchannel and oblique finned microchannel. Heat transfer and flow characteristics are examined for rectangle type cross-section microchannel of varying flow rate and heat input. The results indicate that 0.1 % Concentration of Al_2O_3/Water Nano fluid exhibits better heat transfer enhancement rate of 24.15 % in the oblique finned microchannel than the water and 0.1 % Concentration of SiO_2/Water Nanofluid which gives 17.84 % and 22.37 % respectively in the oblique finned microchannel. The overall heat transfer enhancement rate in the oblique finned microchannel with respect to the conventional straight microchannel is found to be 21.45 %.*

Key Words: **Oblique finned microchannel and straight microchannel heat sink, Nanofluid, Heat transfer, Volume Concentration, Flow characteristics, Heat transfer enhancement rate.**

1. INTRODUCTION

For more than 40 years, the number of transistors that can be placed inexpensively on any integrated circuit irrespective of application have doubled approximately every 18 months globally, which paved the way for the improvements in the heat flux removal in the integrated circuit level. Nowadays, transistors are made even smaller, while integrated circuits (chips) have much higher on chip clock frequency than the previous generations in the previous eras. Unfortunately, the waste heat generated that is generated during the computation is also proportional to the clock frequency. Waste heat generated from electronics must be sufficiently removed to ensure that the operating temperature inside any device is kept within the optimum range of that electronics. Once the temperature exceeds this operating range, the performance of the device would either disintegrate or its working span would shorten drastically. To make the problem even worsen, the product miniaturization in any field eliminates the useful surface area for waste heat removal, leading to serious thermal management challenges. Thermal management, in the past, was considered as the secondary issue after product performance; however, this priority can no longer be assumed because performance of any device has its own relation with the thermal developed inside it. Hence, the quest for more effective cooling technology increased, thereby devices with the microchannel cooling systems are helpful for solving this problem. The present work does the same work with microchannel along with the Nanofluids.

Many works were undertaken concerning the microchannel along with many modifications with respect to the working fluids, geometry, pin configuration, type of flows generated, header configuration etc which will be dealt one by one. First one will be Tuckerman and Pease [1] model which was the first to work with the fluid flow through microchannels, who suggested that microchannel cooling is one of the very effective method to reduce the heat generated inside any electronic devices. Many researchers became motivated because of his research and started to work in microchannel fluid flow and heat transfer. Any Channels are said to be microchannels only if their hydraulic diameter is 1mm or less than 1 mm. While undertaking the heat transfer studies in microchannels, more works had been carried with water as working fluid generally both experimentally and numerically under uniform heating condition. The heat transfer characteristic in a single-phase microchannel heat sink was investigated by Qu and Mudawar [2] both in experimental and numerical wise. The heat transfer characteristics in microchannel heat sink were accurately predicted by conventional Navier Stokes equations and energy equation.

Park and Punch [3] conducted heat and fluid flow analysis both in experimental and numerical wise in a microchannel heat sink and the friction factor obtained as a result of the experiments showed that the theory of fully developed flow was valid. Xia et al.

[4] investigated numerical in fashion concerning the fluid flow and heat transfer in microchannel heat sinks and corelated the effects of inlet/outlet locations, header shapes and microchannel shapes.

Lelea [5] studied the microchannel heat sink using water as heat transfer fluid with the heat transfer occurring in partially heated fashion inside the microchannel test section which was the first among this type of investigation which consists of a numerical investigation and he concluded that thermal and hydrodynamic behaviour of micro heat sink depends mainly on viscosity of the fluid and heating position. Also, they added that the upstream heating exhibits lower thermal resistance when compared with central or downstream heating of the microchannel.

Choi et al. [6] investigated numerically and simulated the microchannel heat sink cooling performance with liquid refrigerant as working fluid. The simulation phase consists of various heating conditions. Among the various design parameters involved, the header shape has been selected as a major parameter among all. When the heat is applied locally or when the thermal load is large inside the microchannel, the flow distribution is poor.

Liu et al. [7] investigated experimentally the effect of non-uniform heating in a two-pass microchannel heat sink with water as the working fluid. It was reported that the heater location influences the maximum temperature and the average temperature in a microchannel heat sink to a considerable extent. When the heater is located near the inlet of the microchannel, maximum temperature is higher than when the heater was located at the rear of the microchannel under the same supplied input power.

An experimental investigation was conducted by Choi et al. [8] concerning microchannel heat sink cooling performance under varying heat flux conditions by taking into account the different geometries and header shapes with the aid of liquid refrigerant (R-123) as a coolant. Also, to provide a uniform and non-uniform heat flux environment, nine separate heaters were used to apply the varying heat input to the microchannel heat sink that is under consideration. It was concluded that, after considering the temperature distribution and pressure drop parameters, the diverging channel with trapezoidal header as the best header shape towards the construction of the microchannel heat sink which will be providing the better heat transfer characteristics.

Then, to enhance the heat transfer to a considerable extent in any microchannel, nanofluids are considered to validate the specific findings either via numerical model or experimental data. The term “Nanofluid” was employed by Choi et al. [9], who was the first among all to show that adding the nanoparticles increases the thermal conductivity of fluid than the water which is used conventionally. The cooling performance of a considered microchannel heat sink with Cu/water and diamond/water nanofluid as coolants of volume fraction of 1% was numerically investigated by Jang and Choi [10]. It was reported that the heat transfer performance was increased by 10% than water if diamond/water nanofluid is used as a coolant. There was reduction both in thermal resistance and the temperature difference between heated surfaces of microchannel heat sink and the coolant considered at that instant. It was also established that nanofluid cooled microchannel heat sink will be a potential cooling device for removing ultra-high heat flux. An experimentation was performed in a single microchannel heat sink by Jung et al. [11] with Al_2O_3 /water as the working fluid with a volume fraction of 1.8 %. In this experimental investigation, the Nusselt number measured increases with increasing the Reynolds number in laminar flow regime. A different type of convective heat transfer correlation was inferred from the experimental data of heat transfer coefficient for nanofluids in microchannels. Without any major friction loss, a considerable improvement was obtained in the convective heat transfer coefficient when nanofluid was used.

Then, Zhai et al. [12] performed an experimental investigation in microchannel heat sink with cavities using Al_2O_3 /water as nanofluid with volume fraction ranging from 0.1% to 1.0%. It was observed that the cavities made inside the micro heat sink and nanofluids together increased the heat transfer to some extent. Both the Nusselt number and friction factor were found to be directly proportional to both the volume fraction and Reynolds number respectively which increases with the increase in the proportional parameters as founded.

Then, the idea of changing the shape and size of the microchannel came into this battle of innovation towards the betterment to achieve the even better heat transfer rate higher than the conventional straight microchannel which is also validated through any of the numerical models available or adapting some experimental procedure to get the experimental data. An Experimental Investigation of flow boiling heat transfer and pressure drop in straight and expanding microchannels was performed by Balasubramanian et al. [13] with the aid of materials using copper with width 300μm. He concluded that the Expanding microchannel had a better heat transfer performance than straight microchannel heat sink.

Dayalpandey et al. [14] performed an Experimentation in a corrugated heat exchanger with nanofluid as a coolant. The test section taken for this experimentation consists of three same corrugated channels consisting an angle of 30° with the nanofluid flow in the middle channel and hot water flow in adjacent channels. They concluded that the better-quality of heat transfer characteristics is exhibited with the increase in Reynolds and Peclet number along with the decrease in nanofluid concentration flowing inside the channels.

It can be inferred from above works that the Heat transfer performance of microchannel heat sink can be increased by changing design, shape, size and coolant flowed. Now in recent times, the oblique microchannel comes into vogue which generates the secondary fluid flow for the heat transfer to take place in any cross-section in addition to the primary fluid flow by the straight microchannel which is conventionally existing by making the oblique fins with certain angle from 22° to 27°. An Experimental investigation of Channel cross section effect on heat transfer performance of oblique finned microchannel heat sink was performed by R. Vinoth et al. [15]. The effect of channel cross section on the heat transfer performance of an oblique finned microchannel heat sink was investigated. Water and Al_2O_3/water nanofluid of volume concentration 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 microchannel 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 the trapezoidal cross-section oblique finned microchannel is more suitable for heat transfer in the electronic cooling application.

Another type of flow boiling experiments were conducted and compared by Matthew Law and Poh-Seng Lee [16] taking the straight-finned and oblique-finned microchannels considering nearly same channel dimensions and operating conditions with the help of FC-72 dielectric fluid as the flowing fluid. The oblique fins are created to generate the secondary flow with respect to the straight-finned microchannel with an angle of 27 ° and width which is half of that of the parallel microchannel. Flow visualisations were performed on both microchannel geometries which showed that the increased bubbles generation in the nucleate boiling region and a continuously developing thin liquid-film in the convective boiling region for the oblique fins are the primary factor in heat transfer enhancement. The improved heat transfer performance of 1.2 and 6.2 times is exhibited by the oblique-finned microchannel with the higher pressure drop penalty (1.7 times) compared to its straight-finned microchannels.

A Numerical analysis was conducted by Poh-Seng Lee et al. [17] by considering the laminar flow and heat transfer with the modified microchannel heat sink which showed that the significant heat transfer enhancement can be achieved with minimal pressure drop between the inlet and outlet. The two hotspot scenarios which showed that the temperature hike and the temperature difference produced by the enhanced microchannel heat sink with variable pitch are reduced by as much as 17.1 °C and 15.4 °C respectively under normal operating conditions. The breaking up of continuous fin into oblique fins causes the thermal boundary layers to be re-initialized resulting in boundary layer thickness reduction. The presence of the oblique channels generated causes the flow fraction to branch into the adjacent main channels that is already existing. Improved heat transfer performance was exhibited with the combination of the entrance and secondary flow effect. Using the both above two mentioned phenomenal, the heat transfer enhancement (about 80 %) is attained with no or negligible pressure drop. Again, the similar numerical and respective experimental investigations was performed by Poh-Seng Lee et al. [18] taking the copper-based sectional oblique finned microchannel heat sinks which showed that better and uniform heat transfer enhancement is attainable with a passive technique itself when compared to the conventional microchannel. With the various dimensions and parameters like average Nusselt number, temperature rise, etc. considered, better heat transfer enhancement was obtained by utilising the water as the working fluid.

An Experimental investigation along with a parametric study was carried out by Yong Jiun Lee et al [19] with the enhanced microchannel heat sink with sectional oblique fins, differing the conventional straight microchannel with the silicon test vehicle by considering the hydraulic diameter 100 lm and 200 lm with the help of de-ionized water as the flowing fluid and hydraulic diameter of 100 lm is found effective though. The parametric study undertaken in this case focuses majorly on two critical design parameters such as Oblique angle and Oblique fin pitch, also suggesting the smaller oblique angle (27 °) and smaller fin pitch (400 lm) for better heat transfer enhancement. Better heat transfer enhancement is able to be achieved at 47 % when Re = 680 with comparable pressure drop to the conventional microchannel that is maintainable up to Re = 500.

Flow boiling experiments were conducted by Poh-Seng Lee et al. [20] to investigate the effects on two-phase heat transfer, pressure drop and instabilities with the oblique-finned microchannels consisting different oblique angles. The experiment was carried out using the different oblique angles of 10 °, 30 ° and 50 ° with FC-72 dielectric fluid as the flowing fluid. Varying mas flow rates and effective heat fluxes were considered for the purpose of exploring the physical boiling phenomenon in the microchannels. The results obtained showed that the heat transfer performance increases with the increasing oblique angles with the negligible pressure drop under same circumstances.

Zhong Lin Chiam at al. [21] conducted the investigations both in numerical and experimental fashion by taking the fluid flow and heat transfer behaviours in the novel sinusoidal micro-channels with secondary branches. The design of oblique fins was made in an alternative manner with ± 45 ° and the wavy channel configuration was created from the Reynolds number range of 50–200. With the addition of secondary branches, heat transfer performed is enhanced with pressure drop penalty and with the wavy channel configuration, better heat transfer was showed without pressure drop. The velocity and temperature profiles were obtained from the simulations. The numerical simulations were validated by the experiment conducted which shows that the scope of the introducing the secondary branches lies in the potential to enhance the heat transfer performance of the already established wavy channel configuration with minimal pressure drop penalty.

Bahram Rajabi Far at al. [22] modulated the 3D conjugated heat transfer model with the enhanced microchannel heat sink containing sectional oblique fins with the passage of Nano-Encapsulated Phase Change Material (NEPCM) particles as a coolant. For investigating the presence of NEPCM particles, three volume fractions from n = 0 to 0.3 were considered and the effects of introducing the tip-clearance to the heat sink was also studied by taking Four values of tip-clearance to channel width ratio (t/Wc) are investigated ranging from a no gap (t/Wc = 0) to t/Wc = 0.74. The cooling and hydrodynamic performance of the heat sink are analysed by using Nusselt and Euler numbers respectively. It was concluded that using of NEPCM slurry in contrast with pure water had produced the cooling performance enhancement in the heat sink but increasing the Euler number. The better heat transfer enhancement is exhibited by the NEPCM slurry when compared to the pure water.

Yan Fan at al. [23] simulated and investigated in the experimental fashion by taking the different type of cylindrical oblique fin minichannel heat sink rather than microchannel, that will be fit over cylindrical heat sources in the form of an enveloping jacket. The cooling effectiveness is compared with conventional straight fin minichannel heat sinks through experimental and numerical fashion by taking the Reynolds number ranging from 50 to 500. Heat transfer enhancement (E_{Nu}) and pressure drop penalty (E_f) exhibits improvement with the cylindrical oblique fin minichannel than the conventional straight fin minichannel.

Matthew Law et al. [24] conducted the flow boiling experiment in straight-finned and oblique-finned microchannels with similar channel dimensions by using the FC-72 dielectric fluid as the flowing fluid under operating conditions. Both the straight and oblique test pieces are made of a copper block with the dimensions of 25 mm × 25 mm and 40 parallel microchannels. Oblique cuts are made with an angle of 10 ° which is half of that of the parallel microchannels. Parameters like mass flow rates of 175 kg/m^2 s, 370 kg/m^2 s and heat fluxes from 14 W/cm2 to 42 W/cm2 are taken into account. The results indicate that the oblique-finned microchannels shows better heat transfer enhancement and remains stabilised for the two-phase cooling.

As seen above with many literatures, very limited research had been carried to compare the performance of straight and oblique finned microchannel heat sink with the aid of Nanofluids, and especially experimental data are scarce. To the best knowledge of the authors, no experimental work had been reported in the literature to address the effect of nanofluid on both the thermal performance of straight and oblique finned microchannel heat sink. This is the motivation for present work to carry out this experimentation with both the straight and oblique finned microchannel. The present study aims to experimentally analyze the heat transfer performance of both the straight and oblique finned microchannel heat sink with Al_2O_3/water nanofluid and SiO_2/water nanofluid with 0.1 % volume concentration and deionized water as working fluids to find the heat transfer enhancement rate of the oblique finned microchannel with respect to the conventional straight microchannel because the heat transfer is enhanced in the oblique finned microchannel with the generation of the secondary flow in the straight microchannel by the oblique fins for the fluid to flow.

Some of the nomenclature involved in the paper are Re- Reynolds number, n- number of channels, Nu- Nusselt number, etc.

2. EXPERIMENTAL SETUP

The experimental setup comprises of an integration of microchannel test section containing the straight and oblique finned microchannel, Rectangle type header having the inlet and outlet housing for the passage of any fluid inside the microchannel test section , peristaltic pump (RH-P120L, Ravel Hiteks Pvt. Ltd., with 20 to 196 rpm measuring capability) which is a device used to provide fluid like water and nanofluid on to the microchannel test section depending on the iteration done, by using this pump, the mass flow rate can be controlled in Kg/hr in this case and the Silicon tube was used to suck and deliver the water, calming section which cools the DAQ mainly, differential pressure transmitter (Make Honey well, model STD730, 25 mbar measuring capability) accurately measures different pressures and transmits a proportional signal by taking in and out any fluid which is passed through the connecting hoses connecting the test set-up, autotransformer (230 V) and data acquisition system (Make Keysight technologies, 34972A – LXI Compliant Data Acquisition device with 20 channels multi-plexer board installed) is that products and/or processes which is used to collect information to document or analyses some phenomenon like temperature, current, voltage that typically consist of sensors, signal conditioning, an analog input(A/D) board, computer and an output interface. The microchannel test section with headers were made up of copper. The straight microchannel consists of 25 number of rectangular microchannels of width 1 mm and depth 0.9 mm of hydraulic diameter 0.947 mm and length 80 mm. The oblique finned microchannel consists of 572 fins of 1 mm width and 0.9 mm depth. A transparent acrylic sheet is placed on the top of the microchannel to assist to view the flow of fluid. A mild steel plate was placed on the top of the heat sink to assure proper balancing forces. An asbestos sheet was placed below the heater for trapping the heat. The microchannel test section, heater, transparent acrylic sheet and mild steel plate were assembled together with the help of bolts. The heater of 80 W capacity will be placed in the pocket made on the bottom surface of the microchannel. Holes were drilled on either side of the microchannel test section to insert thermocouples of J type to measure the surface temperature of the microchannel and the wire of the heater used. Two thermocouples will be used to measure the inlet and outlet temperatures of the fluid.

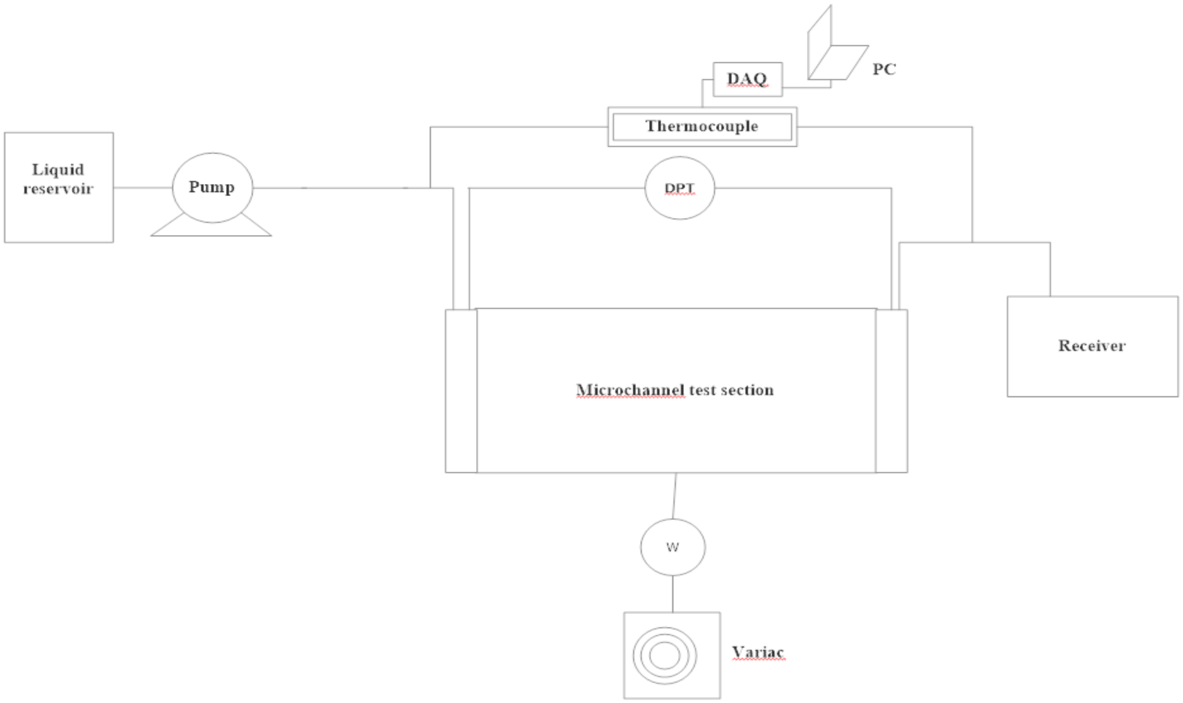

Fig -1: Schematic view of the experimental setup with test set-up section

2.1 Microchannel Test section geometry and various parts involved

The whole microchannel test section consists of following parts as follows:

- Microchannel (straight and oblique finned microchannel)
- Clamping plate (MS Plate)
- Cover plate (Acrylic sheet)
- Insulating plate (Asbestos sheet)
- 80 W Heater
- J-type thermocouple (Measures up to 400° C)
- Fasteners (M8 60 mm)

The straight microchannel heat sink containing an array of 25 straight channels and 775 oblique fins with rectangle channel cross section. The material was taken as copper with the dimensions of 48 × 80 mm and designed with AutoCAD. Table 1 shows the various dimensions with respect to straight and oblique finned microchannel which is under discussion.

Table -1: Channel dimensions (All dimensions are in mm)

Characteristics	Straight microchannel	Oblique finned microchannel
Number of straight microchannel	25	25
Number of oblique fins	-	572 (26×22)
Length of straight microchannel	80	80

Width of straight microchannel	1	1
Depth of both channels	0.9	0.9
Fin width	-	0.9
Fin pitch	-	3.75
Fin length	-	1.5
Oblique angle	-	26 °
Distance between each successive Straight microchannels	0.9	0.9
Oblique finned microchannel width	-	1

The clamping plate was designed with the provision for the viewing the fluid flow inside the microchannels which was placed above the cover plate and microchannel test section for clamping all together.

The cover plate and insulating plate are designed and placed above the microchannel test section to facilitate the viewing of the fluid flow inside the microchannels and below the microchannel test section to reduce the heat loss from the test section respectively.

2.2 Finished Microchannel test section

Both the machining of the straight and oblique finned microchannel was carried out in the CNC Milling machine (HASS make and VF2 model with 760 mm-1000 mm machining capability) with the copper alloy (brass) work piece for which the photos concerning the same is attached below as follows:

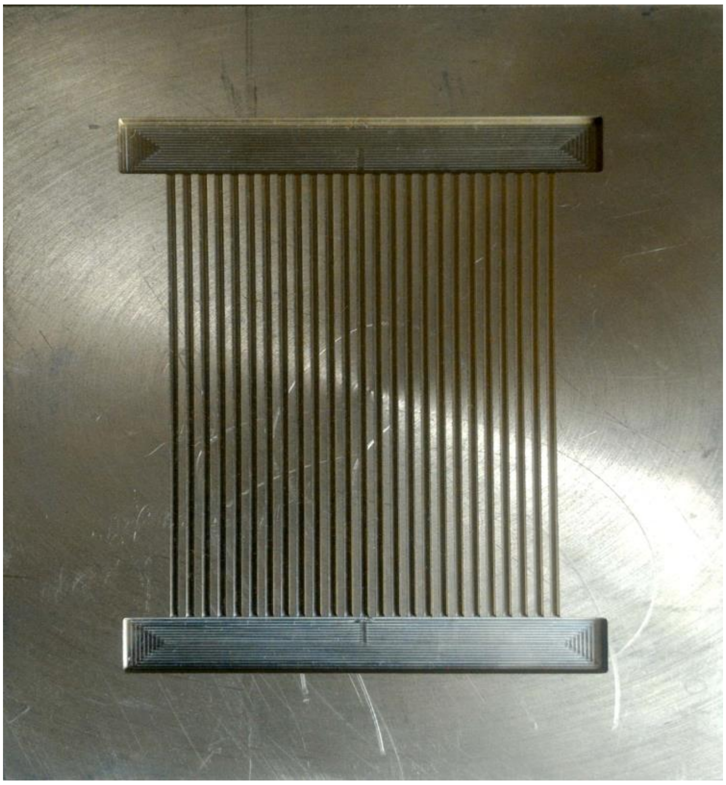

Fig -2: Finished Straight Microchannel Machined Brass Work Piece

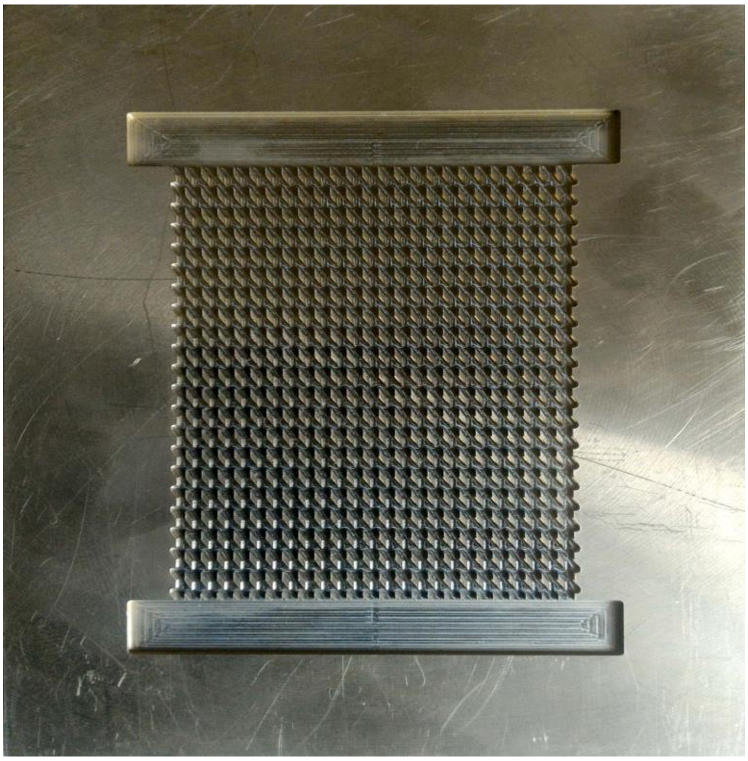

Fig -3: Finished Oblique Finned Microchannel Machined Brass Work Piece

2.3 Assembling of the test set-up

The various parts like clamping plate, cover plate, Microchannel test section, insulating plate, fasteners, 80w heater and 8 J type thermocouples, inlet and outlet housings in the test set-up were assembled and checked for the leak. The photos taken while assembling the overall test set-up is attached below:

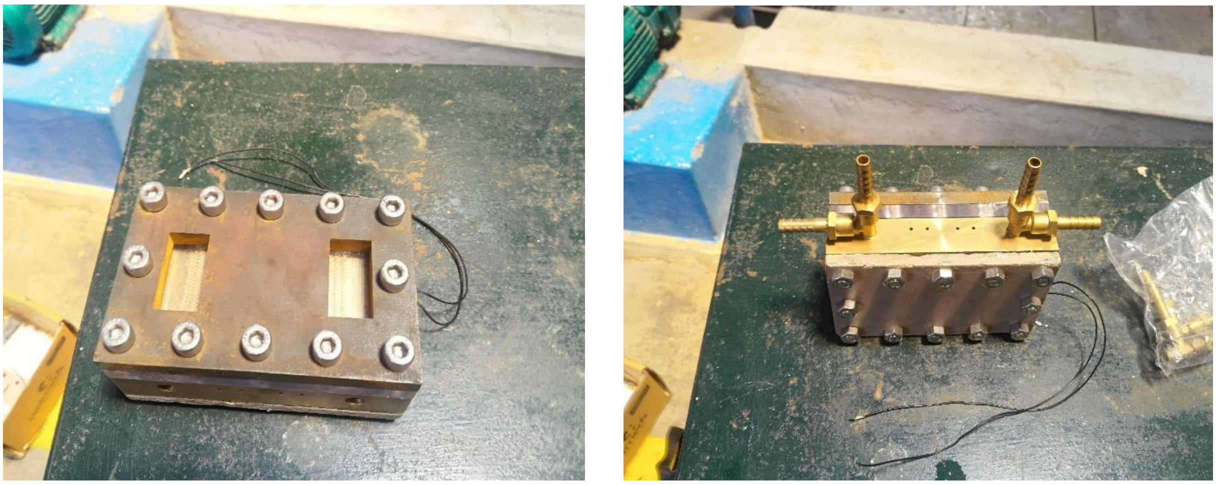

Fig -4: Assembling progress photos

3. EXPERIMENTATION WITH WATER AND NANOFLUID

The experimentation was carried out with fluids like water (distilled water with pH 7-12 ppm), 0.1 % concentration of SiO_2/water Nanofluid and 0.1 % concentration of Al_2O_3/water Nanofluid one by one in orderly manner by performing various iterations with the help of varying heat input and the mass flow rate.

3.1 Nanofluid Preparation

The Nanofluids used in this work are Al_2O_3 and SiO_2.The specification of SiO_2 Nano particle are as follows:

Appearance (Colour) : White

Appearance (Form) : Powder

Assay : min. 99.5%

APS : 15nm

SSA : 650 m^2/g

The specifications of Al_2O_3 Nano particle are as follows:

Appearance (Colour) : White

Appearance (Form) : Powder

Assay : min. 99.5%

APS : 15.0 nm

Both the Nano fluids SiO_2 and Al_2O_3 are prepared by using the both the devices namely, the magnetic stirrer and the ultrasonic vibrator. The Magnetic stirrer was used to stir the demineralized water with the Nano particles with 0.1% Volume concentration with the help of a pellet and the ultrasonic vibrator was then used to vibrate the Nano fluid to make it a stable one.

3.2 Experimentation

The experimentation was carried out with adoption of the experimental procedure by varying the Heat Input (W) with the help of an auto transformer (Variac), Plate type Heater from 60 W to 80 W and the mass flow rate with the help of the peristaltic pump from 18 Kg/hr to 27 Kg/hr. The iterations will be carried out in both the straight and oblique microchannels with water and nanofluid as a coolant to carry out the experiment to find all the experimental values. The fluid from the inlet container is suctioned by the action of the peristaltic pump on to the inlet of the test set-up with the help of silicon tube, then the fluid passes through the microchannels manufactured and finally gets discharged from the outlet of the test set-up to the discharge container. The experimental iterations are performed by first varying the mass flow rate from 18 to 27 Kg/hr with constant heat input of 60W and then alternatively the heat inputs are changed one by one by the auto transformer (Variac) from 65 W to 80 W with all mass flow rate values to get all the data. The picture taken while performing the experimentation is attached below:

Fig -5: Photo of Whole Experimental Set-up with Test Set-up

3.3 Uncertainty Analysis

The Uncertainty involved in this experimentation performed are analyzed and predicted. The major temperature measurement uncertainty in measuring the inlet temperature, outlet temperature and 8 surface temperatures per Microchannel test section considered measured by J type thermocouples were found to be in the range of 0.2 ° - 0.4 ° C due to the varying room temperature and overheated DAQ (after 4 hours of continuous usage) which was involved in the experimentation.

The uncertainties involved during the voltage and current measurement were found to be 0.2 % and 0.12 % respectively due to the varying alternating current reported at the time of experimentation. The Uncertainties indulged in the thermal resistance and heat transfer coefficients were found to be 0.2 % and 4-10% respectively. The Uncertainty reported while measuring the pressure difference was found to be 0.002-0.003 bar due to the bending of the silicon tube or connecting hoses if any were occurring. The uncertainty in some experimental data was caused by the sedimentation of nanofluid which was stirred again if it is necessary.

3.4 Data Reduction

The heat transfer coefficient was calculated by using the following relation.

$$Q = h\,A\,\Delta T \tag{1}$$

Where, Q – Heat input, W

h – Heat transfer coefficient, W/m^2K

A – Cross sectional area, m^2 and,

ΔT – Temperature difference between inlet and outlet, K

The Nusselt number was calculated by using the following relation.

$$Nu = h\,D_h/K \tag{2}$$

Where, Nu – Nusselt number,

h – Heat transfer coefficient, W/m^2K

D_h – Hydraulic diameter, mm and

K – Thermal conductivity, W/mK

4. RESULTS AND DISCUSSION

Various graphs were plotted by taking 2 parameters considered in the x-axis and y-axis respectively concerning the results of the experiment carried out and the discussion was made.

4.1 Mass Flow Rate V_S Temperature Difference (Δ T)

Graphs are plotted for three fluids namely, distilled water, SiO_2/water Nanofluid and Al_2O_3/water Nanofluid. All the fluids are flowing inside the straight microchannel and oblique finned microchannel.

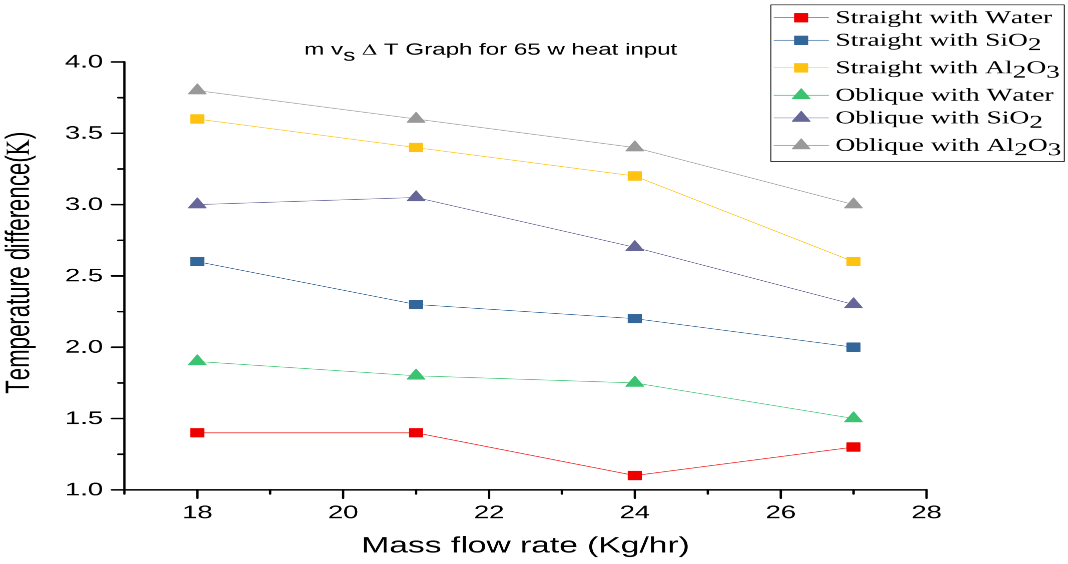

Fig -6: Mass Flow Rate VS Temperature Difference (Δ T) Graph for all flowing fluids

From the graphs for all the fluids employed which was found best among all plotted graphs in its same kind, it can be inferred that for varying mass flow rate, the temperature difference with respect to the inlet and outlet of the straight microchannel and oblique finned microchannel test set-up (Heat Sink) is higher for the oblique finned microchannel with the heat input of 80w and mass flow rate of 30 Kg/hr with some predicted uncertainties because of the secondary flow generated in the oblique finned microchannel with the help of the oblique fins created.

4.2 Mass Flow Rate V_S Pressure Difference (Δ P)

Graphs are plotted for three fluids namely, distilled water, SiO_2/water Nanofluid and Al_2O_3/water Nanofluid. All the fluids are flowing inside the straight microchannel and oblique finned microchannel.

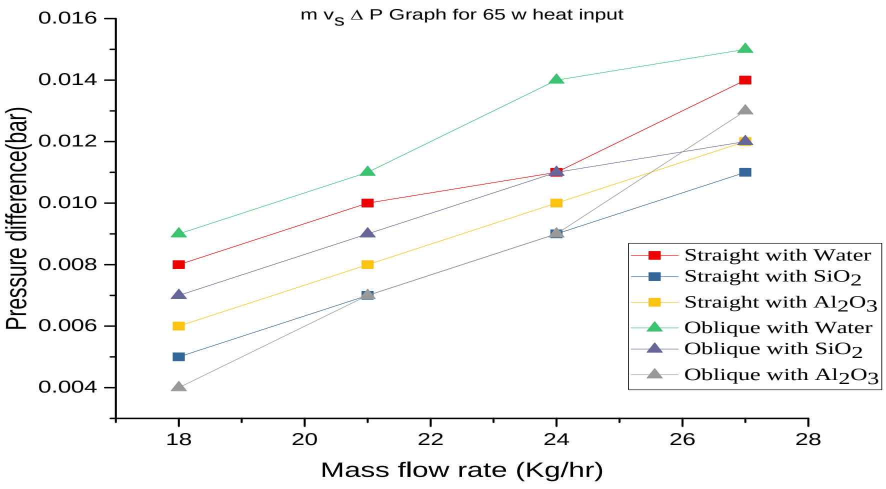

Fig -7: Mass Flow Rate VS Pressure Difference (Δ P) Graph for all flowing fluids

From the graphs for all the fluids employed which was found best among all plotted graphs in its same kind, it can be inferred that for varying mass flow rate, the pressure difference with respect to the inlet and outlet of the straight microchannel and oblique finned microchannel test set-up (Heat Sink) is higher for the straight microchannel with the mass flow rate of 45 Kg/hr and is lesser for the oblique finned microchannel because of the secondary flow generated in the oblique finned microchannel with the help of the oblique fins created which reduces the pressure difference considerably.

4.3 Mass Flow Rate V$_S$ Heat Transfer Coefficient (h)

Graphs are plotted for three fluids namely, distilled water, SiO_2/water Nanofluid and Al_2O_3/water Nanofluid. All the fluids are flowing inside the straight microchannel and oblique finned microchannel.

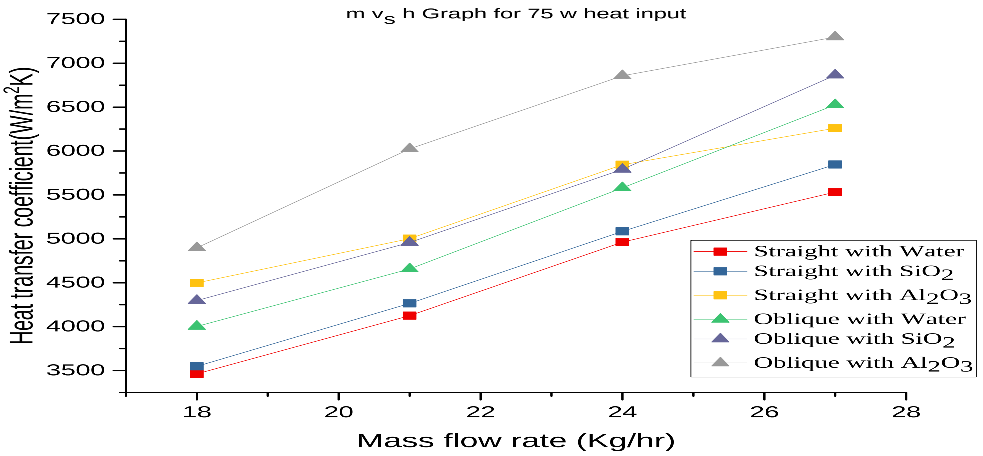

Fig -8: Mass Flow Rate VS Heat Transfer Coefficient (h) Graph for all flowing fluids

From the graphs for all the fluids employed which was found best among all plotted graphs in its same kind, it can be inferred that for varying mass flow rate, the heat transfer coefficient with respect to the straight microchannel and oblique finned microchannel test set-up (Heat Sink) is higher for the oblique finned microchannel with the heat input of 80 w and mass flow rate of 45 Kg/hr because of the secondary flow generated in the oblique finned microchannel with the help of the oblique fins created.

4.4 Mass flow rate V$_S$ Thermal Resistance (R)

Graphs are plotted for three fluids namely, distilled water, SiO_2/water Nanofluid and Al_2O_3/water Nanofluid. All the fluids are flowing inside the straight microchannel and oblique finned microchannel.

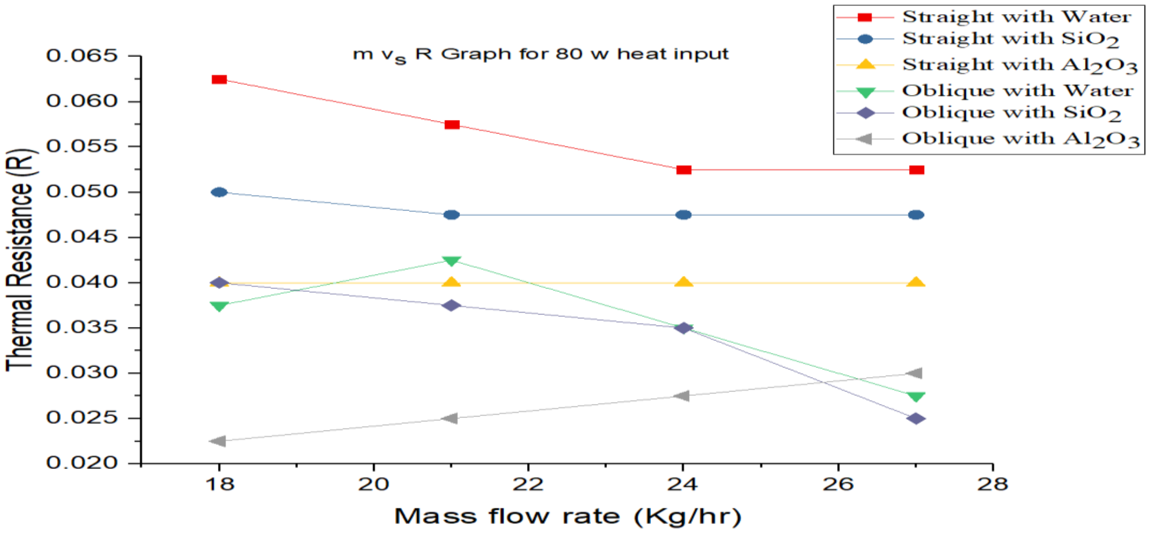

Fig -9: Mass Flow Rate Vs Thermal Resistance (R) Graph for all flowing fluids

From the graphs for all the fluids employed which was found best among all plotted graphs in its same kind, it can be inferred that for varying mass flow rate, the thermal resistance with respect to the straight microchannel and oblique finned microchannel test set-up (Heat Sink) is lower for the oblique finned microchannel with the heat input of 80 W because of the higher thermal conductivity of Al_2O_3.

4.5 Mass flow rate V_S Nusselt Number (Nu)

Graphs are plotted for three fluids namely, distilled water, SiO_2/water Nanofluid and Al_2O_3/water Nanofluid. All the fluids are flowing inside the straight microchannel and oblique finned microchannel.

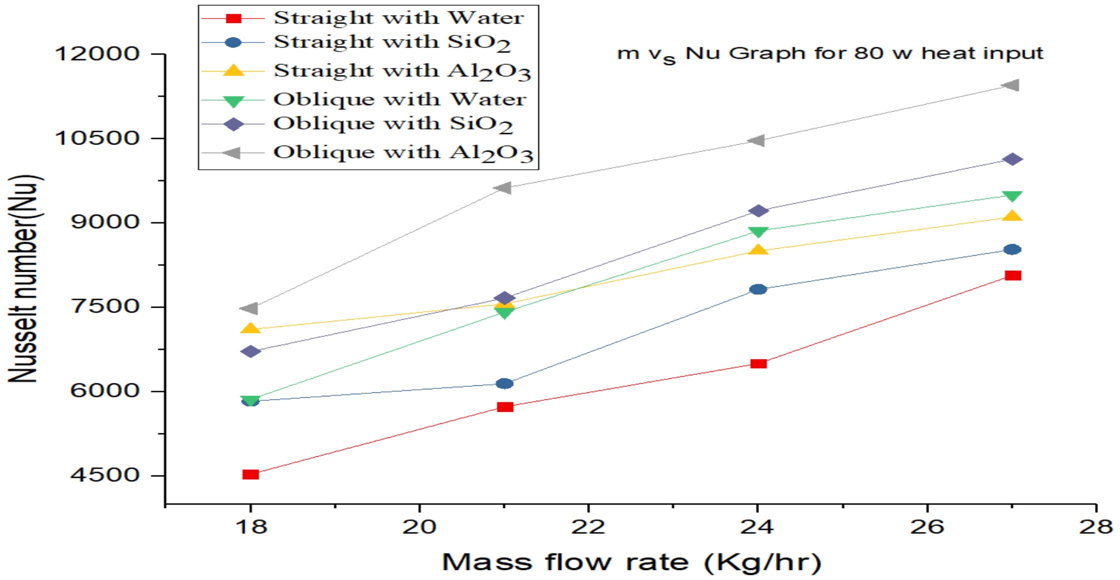

Fig -10: Mass Flow Rate VS Nusselt number (Nu) Graph for all flowing fluids

From the graphs for all the fluids employed which was found best among all plotted graphs in its same kind, it can be inferred that for varying mass flow rate, the Nusselt number with respect to the straight microchannel and oblique finned microchannel test set-up (Heat Sink) is higher for the oblique finned microchannel with the heat input of 80 w and mass flow rate of 45 Kg/hr because of the secondary flow that is generated in the oblique finned microchannel with the help of the oblique fins created.

4.6 Fluid Employed V_S Heat Transfer Enhancement rate

Graphs are plotted for three fluids namely, distilled water, SiO_2/water Nanofluid and Al_2O_3/water Nanofluid. All the fluids are flowing inside the straight microchannel and oblique finned microchannel.

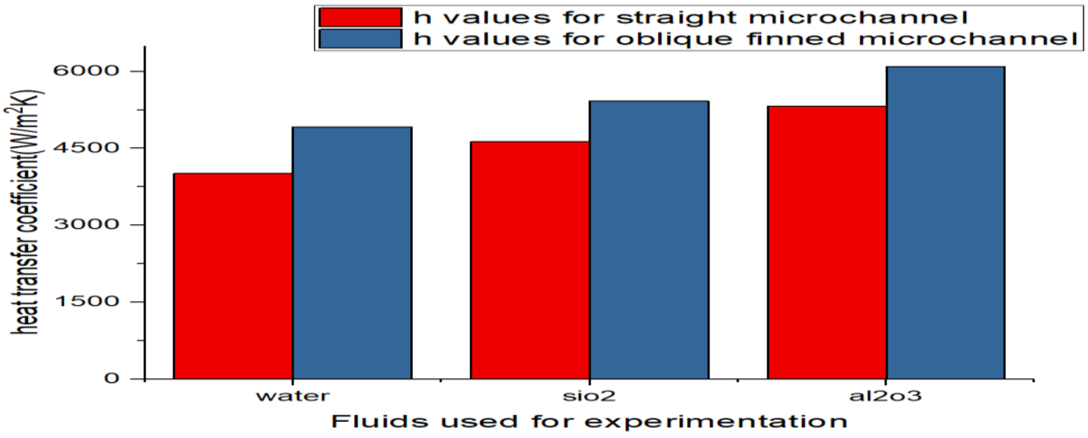

Fig -11: Fluids used for experimentation Vs heat transfer coefficient Graph

From the graph given above, it can be inferred that the average heat transfer enhancement rate of the oblique finned microchannel with respect to the conventional straight microchannel was 21.45 % considering all fluids all together, better heat transfer enhancement rate exhibited by Al_2O_3/Water Nanofluid was 24.15 %. Finally, the better characteristics shown by the 0.1 % concentration Nano fluids especially Al_2O_3/Water Nanofluid flowing in the oblique finned microchannel was showing better heat transfer enhancement rate when compared to the water because of the Brownian movement of the Nano particles and generation of the secondary flow in the oblique finned microchannel with the help of the oblique fins created.

5. Conclusions

The heat transfer experiments are carried out with the oblique finned microchannel and straight finned microchannel heat sink and comparison is made by using water, Al_2O_3/water Nanofluid and SiO_2/water Nanofluid of volume concentration 0.1 % as a coolant. The effect of heat transfer performance is studied thoroughly in both the straight and oblique microchannel heat sink and comparative study reveals the following findings as follows:

- The oblique finned microchannel produces the heat transfer enhancement rate of 21.45 % in average with respect to the conventional straight microchannel in comparison because of the secondary flow generated in the oblique finned microchannel with the help of the oblique fins (fins with angles from 22° to 27°) created.
- The better characteristics was shown by the 0.1 % concentration Nano fluids especially Al_2O_3/Water Nanofluid flowing in the oblique finned microchannel was showing better heat transfer enhancement rate of 24.15 % when compared to the water because of the Brownian movement of the Nano particles and higher thermal conductivity exhibited by Al_2O_3.
- As the heat input increases, the temperature difference increases and heat transfer coefficient also increases with certain exception cases because of the room temperature in operation.
- As the mass flow rate increases, the temperature difference decreases and pressure difference increases with certain exception cases because of the pipe bending.
- The Al_2O_3/Water Nanofluid exhibits better characteristics when compared to SiO_2/Water Nanofluid because of its thermal conductivity.
- Nusselt number was higher for the oblique finned microchannel with Al_2O_3/Water Nanofluid because of the higher thermal conductivity of Al_2O_3 and the secondary flow that is created due to the oblique fins.
- Thermal resistance was lower for the considered straight microchannel because the heat transfer rate in the oblique finned microchannel is higher due to the secondary flow that is created due to the oblique fins.

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