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# A Study of Heat Transfer in Microchannels using Aluminium oxide Nanofluids

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***Abstract*— High performance heat exchanger devices with higher thermal conductivity of coolants are the need for micro industry, domestic and automobile industry. Thermal conductivity of coolants plays an important role in designing, selection, fabrication of high surface to volume ratio devices to extract higher heats from small spaces.Lower thermal conductivity of conventional fluids like water, ethylene glycol and oils has put a question on their credibility in small spaces high heat extraction devices.Nanofluids, suspensions have nano sized particles (upto 100nm) is seems to be promising solution of this problem. Furthermore, higher surface to volume ratio devices extract more heat than convention heat exchanging devices, microchannels stands by these constraints and proved a valuable asset for heat exchanger category.**

***Keywords*— Flow Rate; Heat Transfer; Nanofluid; Microchannel.**

## I.INTRODUCTION

A lot of advancement has been made by microelectronics industry,resulting in development of high heat generating microelectronic devices.The heat generated by these devices which is an important issue for consideration of their use in industry or everyday activities.High heat buildup in microelectronic devices can not only hamper its performance but can also damage the device.Hence finding solution to this heat buildup is an important but challenging task.Now this heat disscipation task can either be achieved by increasing surface to volume ratio of heat exchangers or by employing better coolants or by both the methods.The problem here with conventional coolants like water,oils,ethylene glycols is that that they have been proved futile due to their low thermal conductivity that leads to poor heat disscipation and slows down the device.

In 1873,it was put forward by J.C Maxwell [1] that to increase the thermal conductivity of base fluid,very small solid particles must be added to the base fluid which can lead to higher heat disscipation.This happens due to higher heat capacity of very small solid particles as compared to base fluid and gives a boost to the heat capacity as well as thermal conductivity of base fluids.However experiments have also shown that addition of micro particles and millimeter sized particles to base fluids also leads to problems like abrasive wearing of pipeline,channel clogging,sedimentation and pressure drop.The above problems has put a restriction on their use in industry.To bypass these problems the use of nanoparticles was introduced.

Microsized flow passasges having hydraulic diameter range between [3]10 micrometer to 200 micrometers and that have other dimensions also in micro are called microchannels.Microchannels consists of high surface area to volume ratio enabling higher heat transfer rates.Microchannels can fit in very small spaces owing to their small size.It can fit into small spaces where heat generation is more and where conventional methods fail to disscipate the heat.Many researchers have done experimentation for studying the heat transfer through microchannels using nanofluidsThe experiments carried out by these researchers have shown increased thermal conductivity upto 790W/cm2 and the maximum temperature can rise upto 71$^0$C [2] higher than that of water.In the microchannels small channels which can be seen have hydraulic diameters ranging from 10mm – 200mm.Microchannels are generally manufacteured on silicon wafers because of simple process of stereo lithography and ease of manufacturing.Although this method is easier but it has a drawback related to manucaturing accuracy and thus it leads to discrepancy between theoretical and experimental results.Hence due to this drawback a new method of cnc wire cutting on aluminium is generally utilized.The revolutionary work of tuckerman and Pease[2] in 1981 gave a boost to the microchannels research.After this the research focus shifted to design implementation from 1986-1988.This was further followed by understanding the design fundamentals of flow of fluid through microchannels during the period of 1992-2002 and then the interest shifted towards practical application in 2002.

During the period after the focus shifted towards validating the research work which had already bee done.From the findings of Satish. G. Kandlikar [3] it has been found that for practical use more research needs to be done in microchannel area.

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## II. MICROCHANNELS

*A. Introduction*

*B.* Microlelectronics devices are very small in shape but they generate a lot of heat in a small area.To disscipate heat generated from microlectronic devices very small heat exchanging devices are required that can not only fit into small spaces but also are light weight.Microchannels are hand in glove with these requirements.Microchannels are small heat exchanging devices which comsists of very small passages through which coolants or heat exchanging fluid flows.These small microchannel passages have very high surface to volume ratio which allows very high heat transfer rates from small spaces.Microchannels can lent themselves useful in applications where there are restrictions of weight and space.These small passages have hydraulic diameters ranging from 10µm - 200µm [4] .[5] [6].

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*C. History and literature*

Tuckerman and Pease [7] in 1981 gave a boost to the research in the area of microchannels and gave the direction in which the research is to be done.[8-15]Till 1988 the focus of the researchers was on design as well as implementation of microchannels technology.After thorough analysis of design and implementation the the focus of the researchers shifted towards studying the flow behavior through small microchannel passages. [15- 20]From 1990 – 2000 a lot of work was done by researchers using experiments but they could not find a solution or answer the problem of applying the continuum t

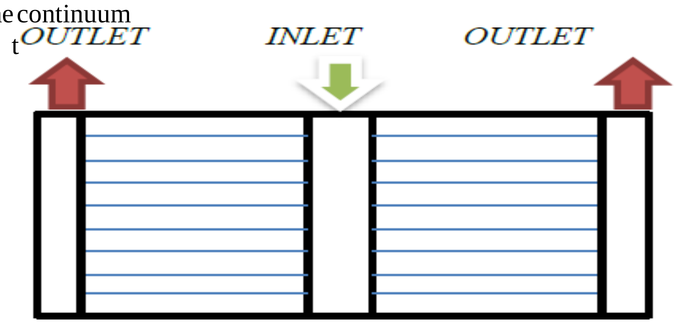


Fig.1 Microchannels

Heat dissipation and work on design and implementation gets started, continues till 1988. After design and implementation the researchers researched upon the fundamental understanding of flow characteristics in microchannels. The experimental research work of many researchers in 1990s still cannot solve the question of credibility of continuum theory to the liquid flow. Later Xu et al [21] neglecting the entrance and exit effects, validated the applicability of conventional theory in microchannel. However later the study by Palm [22] concluded that the research of that time is still inconclusive regarding the applicability of continuum theory in microchannels. The researchers Qu and Mudawar [23] , Steinke and Kandlikar [24] presented the experimental data that confirms the validity of continuum theory in microchannels. Later Lee *et al* [25] validated the applicability of continuum theory in microchannels with careful consideration on boundary conditions during experiment. Hence the validation of continuum theory has been accepted in single phase flow in microchannels. Two phase flow is still in under active research and conclusion has to be made yet. Single phase flow is considered in this experimental work. However the research work by many researchers is taken as reference for designing of the microchannels. Gunnasegaran et al [19], in 2009, carried out the experiments to study pressure drop and flow friction measured in different shapes of microchannels, and found out that Poiseuille number decreases in series –

triangular, trapezoidal , rectangular channels. Zhang et al [26], in 2014, did computational work on Design optimization of microchannels and found that The geometry of the channels strongly influences the pressure needed for the flow. Manay et al [27], in 2012, numerically Investigated heat transfer characteristics and compared with experimental data and concluded that Mixture model theory can be applied to nanofluids flow and heat transfer enhancement was 2.87 and 3.21 times for $Al_2O_3$ and CuO respectively. Farsad et al [28], in 2011, did the numerical simulation of microchannels and concluded that Heat transfer increases with increases with increase in concentration and metals have higher thermal conductivity than corresponding oxides. Mohammed et al [29], in 2011, did experiments on diamond , $Al_2O_3$, Ag, CuO, $TiO_2$, $SiO_2$ in triangular microchannels and found out that Diamond has highest heat transfer coefficient and alumina with lowest , $SiO_2$-$H_2O$ has highest pressure drop, Ag-$H_2O$ shows no wall shear stress. Hamid et al, in 2011, investigated the performance index and efficiency of counterflow microchannel heat exchanger(CMHE) numerically and found out that performance index and effectiveness of CMHE decreases with increase in Reynolds number and pumping power and performance index are insensitive to volume fraction at all Reynolds number. Tannaz et al, in 2009, performed the experiments to check effect of channel geometry on performance of microchannels and concluded that Heat transfer coefficient is independent of channel width above 400µm and cross sectional geometry of channels effects the heat transfer coefficients in microchannels. Manay et al, in 2016, investigated the effect of microchannel height on performance of nanofluids and found out that Increase in height of microchannels decreases the heat transfer coefficient and increases pressure drop.

## III. EXPERIMENTAL SETUP

The directions for making the experimental setup was obtained from the literature review which described the effect of aluminium oxide – water nanofluids on the heat disscipation capacity of microchannels.Experimental apparatus was designed at T.I.E.T Patiala and manufactured at the Global instrument company ambala Haryana.

Rate of flow through the microchannels was controlled by computer operated syringe pumps.Flow meters were needed in this study since syringe pumps already provide highly precise flow rates.Thus highly accurate rate of flow was achievable by syringe pumps.The heat flux for heating of the microchannels was provided by the heater installed in the setup.This heat flux was controlled by carrying the current and voltage.Further the current and voltage were controlled by a dimmersta provided in the setup.The nanofluids after pasing through the microchannels go into the reservoir.In this

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study single pass flow is considered.However the study could also be conducted using continuous flow.The main issue of leakage in microchannels is solved by using grease paper.

*A. Fabrication of test section and setup.*

Syringe pump: They form the main part of the experimental apparatus.Syringe pumps are devices that cause the nanofluids to flow through the microchannels.They provide the required pressure to flow the nanofluids through the microchannels.Syringe pumps can provide constant flow rates through the microchannels ofr set duration of time with very high degree of accuracy.Since syringe pumps are highly accurate,there is no requirement of flow meter in the passage.The syringe pumps used in this study have been procured from E-spin nanotech,Kanpur,UP.

Heaters: The heater used in the study is a low watt heater with a adjustable variate.These low watt heater have a wattage rating of only 35 W.These heater are highly effective in adjusting the heat fluc to the microchannels.The heat flux can be controlled with help of a adjustable variate.Using these heaters the temperature can be kept at a constant $40^0$C .The temperature can be increased further by adjusting the variate.These heater allows us to maintain the temperature in required range successfully.

a) Temperature sensors: The temperature sensors employed in this study are PT – 100.These temperature sensors are highly accurate temperature sensors for the measurements of temperature.These temperature sensors encapsulate the concept of resistance thermometers.The concept is that the resistivity of sensor changes with change in temperature.These temperature sensors are also more preferred as compared to thermo – couple sensors due to high precision.

b) The calibration was done at NIIRT – Lab situated at Industrial area,Panchkula,Haryana.The calibration is valid for one year from the date on which calibration was done.The calibration was done and the report was provided.

CNC wire cutting technique was found to be the most cost effective technique for manufacturing of microchannelsand was also available at location from where transportation was also viable.

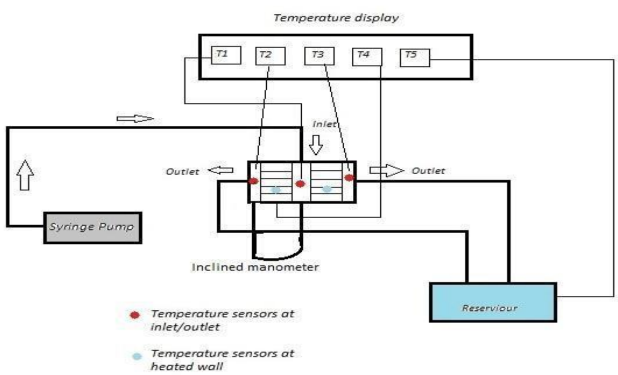


Fig. 2. A) Experimental setup layout

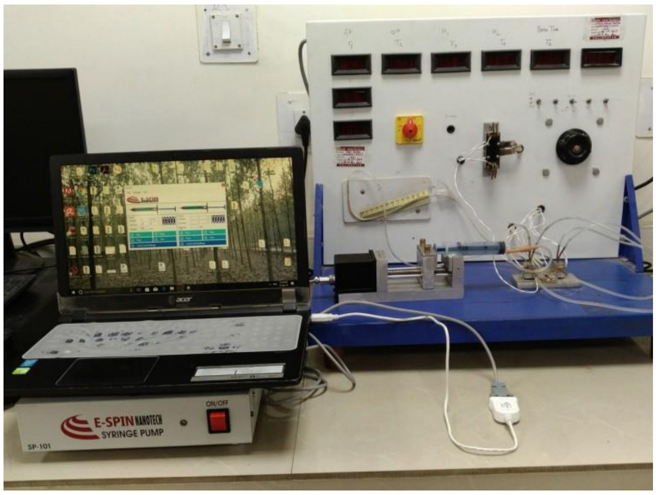


Fig.2. B) Pictorial view of setup

The calibration was done at NIIRT – Lab situated at Industrial area,Panchkula,Haryana.The calibration is valid for one year from the date on which calibration was done.The calibration was done and the report was provided CNC wire cutting technique was found to be the most cost effective

Table 1.

| Cross section | Material | Type of flow | Type of channe ls | Process of manufa ct uring |
|---|---|---|---|---|
| Rectangul ar | Aluminum | Single pass | Split flow type | CNC wire cutting |

The cross sectional view with dimensions of channels is shown as

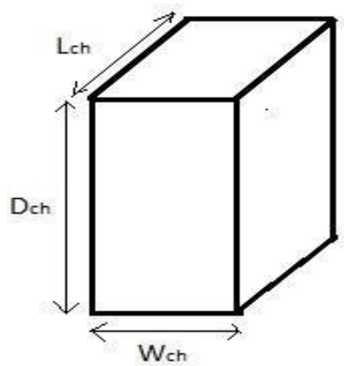


Fig. 3.Cross sectional view of microchannel

The dimensions of the microchannels are given in the Table 2.

Table-2: Dimensions of micochannels

| Dch | Wch | Lch (each side) |
|---|---|---|
| 2mm | 0.25mm | 20mm |

- The width of the microchannel was chosen as .25 mm since it is the limiting width which can be produced from CNC wire cutting.
- Only rectangular geometry of microchannel can be manufactured by CNC wire cutting this fixes the geometry of microchannel.
- The dia for inlet and outlet manifold pipes is fixed to 2.5 millimetre due to availability constraint.

This is the little glimpse of designing procedure has been given here.

*B. Flow loop and working*

The syringe pumps are computer controlled and are operated through software interface which is installed on the computer from CD provided with the syringe pumps.The name of the software installed on the computer for operating the syringe pumps is SP – 102.Various inputs are feeded into the software and the syringe pumps work according to these inputs.The various input parameters required to be feeded into the software before operation are :- a) Dia of syringe b) rate of volume flow c) Volume of the syringe d) Time duration for which the experiment is to run.According to the feeded inputs the computer computes the revolutions per minute of the motor.This information is then fed to the syringe pump controller.The controller then provides input to the syringe pump.

*C. Preparation and properties of nanofluids of nanofluids*

Nanofluids can be prepared by the following two methods :-

- One – step method
- Two step method

In this study two – step method has been employed for preparation of nanofluids.The two – step process of preparation of nanofluids has the following steps :-

- Preparation if nanofluids
- Dispersion of nanofluids in the base fluid

The Aluminium oxide nanoparticles are purchased from Nanoshell Technologies, specification of particles is given in Table 3.

In this study for preparing the nanofluids,nanoparticles were dispersed in the DI water which acts as the base fluid.Four different samples were prepared with volume concentrations of 0 %,.2 %,.3 %,.6 %.Four distinct volume flow rates are chosen for each of the volume concentrations.The four distinct volume flow rates are .5 ml/min,1 ml/min,1.5 ml/min and 2 ml/min.In this study surfactants and additives were not added to nanofluids as these can alster the properties of the nanolfuids.Aluminium oxide – water nanofluids have higher stability and thus experimentation with them was much more comfortable.Ultra – sonication is done for 90 min to increase the stability nanofluids.

Table 3. Specification of nanoparticles

| | |
|---|---|
| Particles used | Aluminium oxide |
| Appearance | White |
| Morphology | Spherical |
| Purity | 99.9+% |
| Average particle size | Less than 80 nm |
| Thermal conductivity | 36 W/mk |

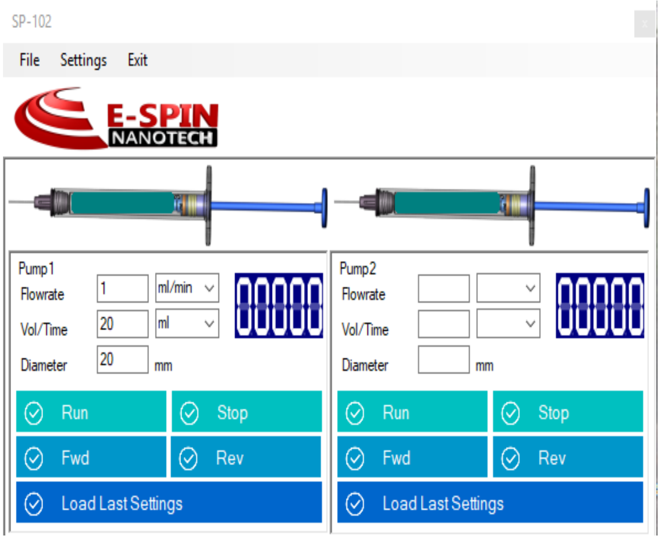


Fig. 4. Software interface

In present work double distilled water was used as base fluid in which nanoparticles were dispersed slowly. Four concentrations are chosen for experimental work: 0%, 0.1%, 0.25%, 0.5% at four different flow rates: 0.5 ml/min, 1.0 ml/min, 1.5 ml/min, and 2.0 ml/min. No surfactants were used in nanofluids as they affect the thermophysical properties of nanofluids. Also the $Al_2O_3$-H $_2$O is stable for longer time and experiments can be done very easily with them. To make nanofluids more stable they are dipped in sonicator bath for 90 minutes.

*D. Equations used*

Experimental calculations were done for finding heat transfer coefficient for microchannels and then comparison is carried out with different fluids in similar conditions. Thermo physical properties like density, specific heat capacity, thermal conductivity, dynamic viscosity were taken at bulk mean temperature. The following equations have been used for the calculations:

In the first step hydraulic diameter is to be calcucated for which equation used is given by

$$D_h = \frac{4A_c}{P} \quad (1)$$

Where Ac is area of cross section, P is perimeter of microchannels

Reynolds number gives the ratio of inertial force to the viscous force and is given by equation

$$Re = \frac{v * D_h}{\vartheta} \quad (2)$$

Here v is average velocity of flow inside microchannel, $\vartheta$ is kinematic viscosity, v the average velocity of working fluid is obtained from following equation

$$v = \frac{\dot{m}}{N \rho A_c}$$

Here N is total number of microchannels; ρ is density of working fluid.

Q is the total heat removed by the fluid and is given as

$$Q = \dot{m} C_p (T_o - T_i) \quad (3)$$

Where $C_p$ is the specific heat capacity of fluid, $T_O$ is outlet temperature and $T_i$ is the inlet temperature of fluid.

In order to calculate heat transfer coefficient for microchannels; mean temperature difference between walls and fluid flowing is to be known, which is obtained as

$$\Delta T_m = \frac{1}{5}(T_1 + T_2 + T_3 + T_4 + T_5) - \frac{1}{2}(T_i + T_o) \quad (4)$$

Where $T_1$, $T_2$, $T_3$, $T_4$, $T_5$ are the temperatures measured by temperature sensors at different locations in microchannels. $T_1$ is the temperature measured by sensor at inlet plenum wall. $T_2$, $T_3$ are temperature at left and right plenum walls. $T_4$, $T_5$ are the temperatures at bottom wall of microchannels. Heat transfer coefficient in this study has been calculated by using the equation

$$h = \frac{Q}{N * A_w * \Delta T_m} \quad (5)$$

Where h is convective heat transfer coefficient, $A_w$ is the area of heat transfer which is total area from where heat transfer is going on.

Since we are having two side flow in microchannels hence the overall heat transfer coefficient (U) is given as.

$$\frac{1}{UA} = \frac{1}{h_1 A_1} + \frac{1}{h_2 A_2} \quad (6)$$

Where A is the total heat transfer area, $h_1$ is the heat transfer coefficient of one side, $h_2$ is the heat transfer coefficient of another side, $A_1$ $A_2$ is heat transfer areas of sides respectively. Thermo physical properties of nanofluids; density, thermal conductivity, specific heat, dynamic viscosity are measured by using following formulas:

1. Density [33]

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi \rho_p \quad (7)$$

2. Specific heat

$$(\rho C_p)_{nf} = (1-\varphi)(\rho C_p)_f + \varphi(\rho C_p)_p \quad (8)$$

3. Dynamic viscosity

$$\mu_{nf} = \mu_f \frac{1}{(1-\varphi)^{2.5}} \quad (9)$$

4. Thermal conductivity

$$k_{nf} = \frac{k_p + 2k_f + 2(k_p - k_f)\varphi}{k_p + 2k_f - (k_p - k_f)\varphi} k_f \quad (10)$$

Where ρ is the density, $\varphi$ is particle volume fraction, μ is dynamic viscosity, k is thermal conductivity. Subscripts p, nf, f stands for particle, nanofluids and base fluid respectively, all other symbols carry their usual meaning.

Prandtl number ratio of momentum diffusivity to thermal diffusivity, is given as

$$Pr = (\mu Cp)/k$$

## IV. RESULTS AND DISCUSSIONS

### *A. HEAT TRANSFER COEFFICIENT*

This study was conducted with a view to enhance the heat transfer coefficient in the microchannels by utilization of nanofluids as heat transfer fluid in the microchannels.For this purpose alimunium oxide – water based nanofluids are prepared in four different samples with different volume concentrations.

There are two ways to increase the heat transfer coefficient in the microchannels by :-

- By increasing the particle volume concentration of nanofluids.
- By increasing the volume flow rate of the nanofluids through the microchannels.

The heat transfer capability of the heat transfer fluid can be increased by using nanofluids.The volume flow rate can be increased with help of high precision computer controlled syringe pumps.

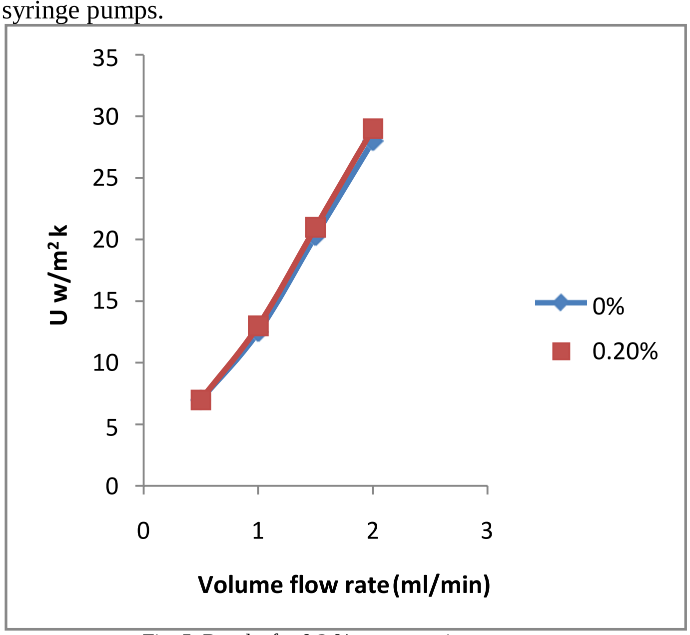


Fig. 5. Results for 0.2 % concentration

- The above graph represents the variation of heat transfer coefficient with volume flow rate. The results are compared with that obtained by using water as the cooling fluid. From the above graph it can be seen that the trend of heat transfer coefficient with the volume flow rate is consistent for both water as well as aluminiumoxide – water based nanofluid.

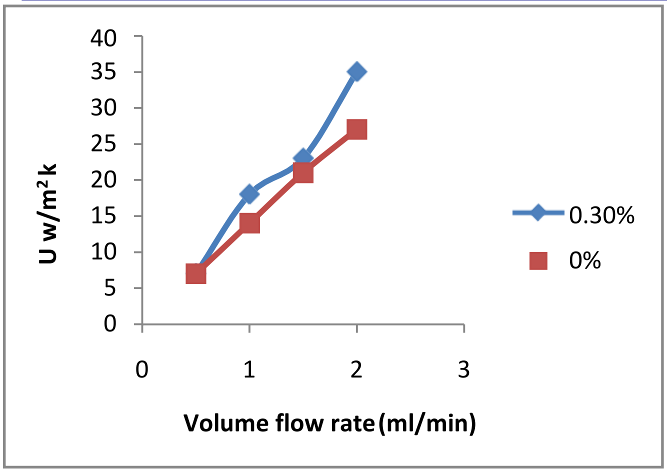


Fig. 6. Results for 0.3 % concentration

- The above graph represents the variation of heat transfer coefficient with volume flow rate.\
- The results are compared with that obtained by using water as the cooling fluid.
- From the above graph it can be seen that the trend of heat transfer coefficient with the volume flow rate is consistent for both water as well as aluminiumoxide – water based nanofluid.

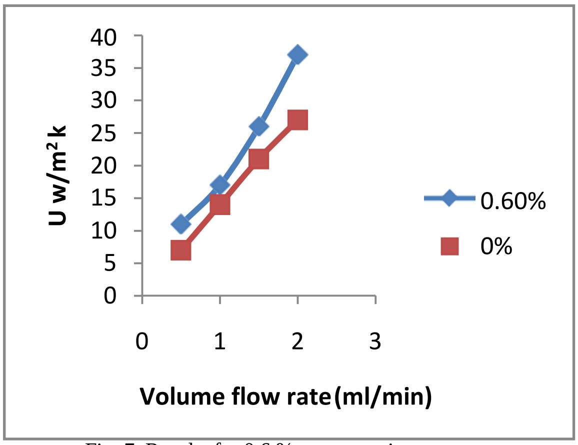


Fig. 7. Results for 0.6 % concentration

- The difference between heat transfer coefficient in case aluminium oxide – water based nanodluid in comparison to water is not very high

The above graph shows the results of experiments that were conducted for finding the heat transfer coefficient at four different flow rates by using aluminium oxide – water nanolfuids with volume concentration of 0.6 % byvolume. The results obtained are compared with that obtained with water as cooling fluid. The trend for heat transfer coefficient as shown in the above graph is similar to that obtained in case of .2 % volume concentration and .3 % volume concentration as well as the results that are obtained in case of water

Two major observations were made which are as follows.
*1)* As flow rate of fluids increases there is an obvious increase in heat transfer coefficient in similar manner as volume flow rate is increasing.
*2)* At the same volume flow rate the heat transfer coefficient increase with increase in particle volume fraction as compared to pure water. This was due to presence of more number of higher thermal conductivity particles in fluid. As volume flow rate increased from 0.5ml/min to 2ml/min and particle volume concentration is varied from 0% to 0.5%.vol. the heat transfer coefficient is increased by 6.2 - 27%. This clearly shows that convective heat transfer can be enhanced in aluminium microchannels by using $Al_2O_3$-H $_2O$ nanofluids instead of pure water.

### *B. PRANDTL NUMBER*

Prandtl no is a property of a very high significance of the nanofluids.It has a significant effect on the heat transfer characteristics of the nanofluids.Thus it is imperitive to find how the Prandtl no is afftected by the volume concentration of the nanofluid. It is the ratio of momentum diffusivity to thermal diffusivity.

The prandtl no is the property of the fluid and its value relies on dynamic viscousity,thermal conductivity as well as specific heat of the nanofluids.The value of these three variables is reliant on volume concentration as well as temperature.fig 8. shows the represents the variation of Prandtl no with volume concentration of the nanofluid.From the this trend it is interpreted that the Prandtl no varies directly with particle volume concentration of the aluminium oxide – water based nanofluids.

It provides a strong case for the usage of nanofluids.Based on calculations done in this study it is shown that prandtl no can be boosted by 24 % by using higher particle volume concentration.Thus by using aluminium oxide – water based nanofluids of high concentrations a better value of Prandtl no can be obtained.Now viscosity as well as thermal conductivity varies directly with particle volume concentration of the aluminium oxide – water based nanofluids but the specific heat of nanofluids varies inversely with the particle volume concentration.

The viscousity has a much more profound effect on the value of Prandtl no as compared to other variables,Thus it is imperitive that the value of the Prandtl no becomes higher with higher values viscousity.Thus the viscosity overshadows the role of thermal conductivity in determining the value of Prandtl

The above graph shows the results of experiments that were conducted for finding the heat transfer coefficient at four different flow rates by using aluminium oxide – water nanolfuids with volume concentration of 0.6 % by volume. The results obtained are compared with that obtained with water as cooling fluid. The trend for heat transfer coefficient as shown in the above graph is similar to that obtained in case of .2 % volume concentration and .3 % volume concentration as well as the results that are obtained in case of water.

The heat transfer coefficient is continuously increasing with increase in volume flow rates. Hence it also points to the fact that thermal diffusivity varies directly with particle volume concentrations of the aluminuim oxide – water based nanofluids.[51] has given the variation of Prandtl no of the nanofluids with the temperature.In the study they have used copper oxide,silicon dioxide as well as alumiunium oxide nanoparticles based nanofluids.Particle volume concentration of .6 % was chosen for this study..They have shown that prandtl no varies directly with temperature.

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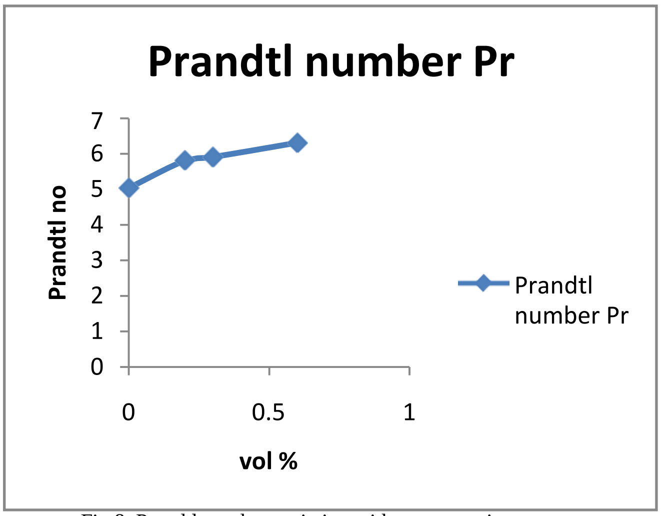


Fig 8. Prandtl number variation with concentration

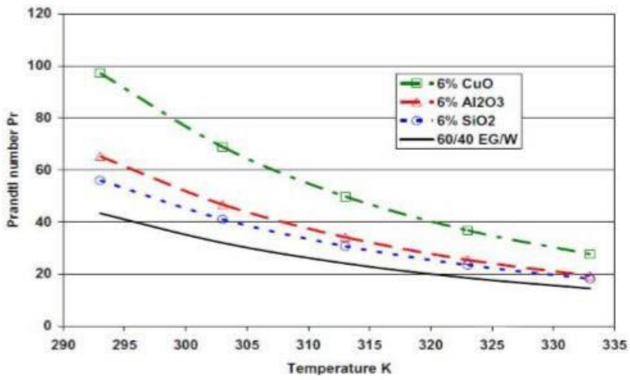


Fig 9. Temperature dependency of prandtl number

### C. REYNOLDS NUMBER

It is the ratio of inertia force to viscous force.It is a very important thermo – physical property of the nanofluid property of nanofuid flow.It is therefore imperitive to find how the Reynolds no varies with volume concentration of the nanofluids.For keeping the experimental conditions similar for experimentation with different samples of nanofluids the variables such as velocity as well as diameter are fixed.In the graph it is observed that the Reynolds no varies inversely with particle volume concentration for each value of volume flow rate.The viscousity of nanofluids vary directly with particle volume concentration of nanofluid.However there is a significant increment in the value of the viscousity as compared to the increment in the density and this leads to the viscous force overshadowing the inertia force.This further leads to decrement in the value of Reynolds no. In the preceding two passages discussing about the Prandtl no and Reynolds no,it has been presented that increasing particle volume concentrations of the nanofluids leads to higher value of Prandtl no but lower values for Reynolds no.Thus at greater particle volume concentrations the value of Prandtl is greater but at lesser particle volume concentrations,the value of Reynolds no is greater.Hence it becomes imperitive to consider both Reynolds no and Prandtl no to find the best balance as both have a positive effect on heat transfer.

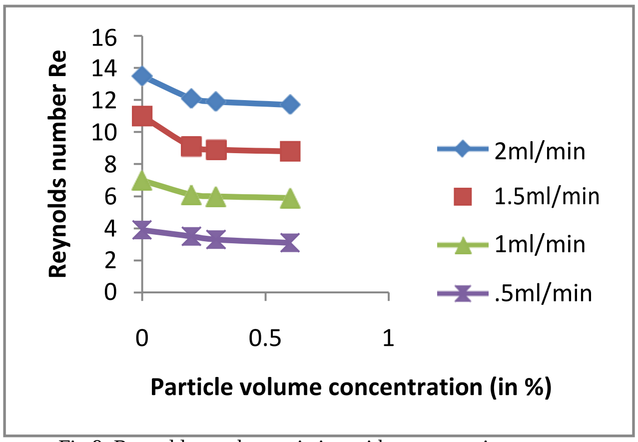


Fig 9. Reynolds number variation with concentration

### D. CONCLUSION

As compared to water the aluminium oxide – water based nanofluids showed better thermo – physical properties.The nanofluids showed a higher and better thermal conductivity which has been a major area of interest for many researchers.A significant increment of 5.75 % is observed as compared to water at the particle volume concentration of .6 % for alumiunium oxide – water based nanofluid. Viscousity of the nanofluids vary directly with parricle volume concentration of the nanofluids.A higher viscousity tends to elevate the required pumping power for fluid flow through the microchannels. The heat transfer through microchannels has been observed at different combinations of particle volume concentrations of nanofluids and volume flow rates.The variation of various variables such as Reynolds no,heat transfer coefficient,Prandtl no with volume flow rate as well particle volume concentration is established. In this study it has been observed that Reynolds no varies inversely varies with particle volume concentration.A decrement of 19 % is observed for nanofluids as compared to water in case of particle volume concentration of .6 % by volume. Heat transfer coefficient has seen an increment of 30 % for nanofluids of .6 % particle volume concentration at the volume flow rate of 2 ml/min.The temperature readings are taken for each combination of particle volume concentration and volume flow rate.

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