Study of Heat Transfer of Aluminium Oxide Nanofluids using Aluminium Split Flow Microchannels

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***Abstract*—Experimental investigations were performed on Al_2O_3-H_2O nanofluids using split flow type microchannels with particle volume fractions of 0, 0.1%, 0.25%, 0.5% (vol.) with the flow rate ranging from 0.5ml/min to 2.0ml/min. The effect of Prandtl number and Reynolds number is also studied. Experimental results show that thermal conductivity increases and viscosity decreases with increase in temperature. Thermal conductivity and viscosity increases with increase in concentration of nanofluids. Heat transfer coefficient, Prandtl number. It is seen that heat transfer coefficient and Prandtl number increases with increase in concentration of particles whereas Reynolds number decreases with increase in concentration. The heat transfer coefficient increased by maximum of 27% for 0.5% (vol.) concentration and Prandtl number increased by 22% maximum. However Reynolds number had decreased by maximum of 28% for 0.5ml/min flow rate and least decrease by 18% for 2ml/min flow rate.**

Keywords—Nanofluids; Thermophysical Properties; Split Flow Microchannels

I. INTRODUCTION

With the time electronics industry has grown into new transcending dimensions. The salient features of today's modern industry are: (1) Reduction in size of components, (2) Lighter weight foe ease in carrying, (3) Faster in response. These features has taken the electronic industry to new heights but there come some problems with this achievements which are mainly: (1) the thermal management of high performance electronic devices, (2) compactness of heat exchanging devices. They electronic devices produces heat which has to carried out from small spaces in minimal time. Conventional fluids like water, ethylene glycol and oils proved futile in this areas due to their lower thermal conductivity as a result the heat accumulated causes the response of electronic devices slower or even due to accumulation of heat electronic chips may even damage. This problem can be rectified mainly by three methods viz. increasing the surface to volume ratio of compact heat exchangers, Increasing the overall convective heat transfer coefficient and Using higher thermal conductivity coolant. Therefore in 1873, J.C Maxwell proposed to add very small solid particles in the fluids (base fluids) to increase their thermal conductivity which further can increase the heat dissipation capacity. Small solid particles have higher thermal conductivity than base fluid hence an overall increase in heat dissipation capacity and thermal conductivity of base fluid [1]. Micro and milli-sized particles were having associated problems with them: (1) very low stability time, they settle down quickly, (2) clogging in the pipes, (3) erosion of the pipe materials, (4) high pressure drop [2]. Then nanosized particles were introduced and they gained the attraction of researchers. Nanofluids are the class of fluids which are formed by dispersing nano sized high conductivity materials (nanofibers, nanotubes, nanorods, nanowires, nanoparticles or nanosheets) into the base fluid, generally water, oils, ethylene glycol [3]. Nanofluids are dispersions with particle size lesser then 100nm. These particles may be metallic and non-metallic: Al_2O_3, CuO, SiO_2, TiO_2, Cu, Ni, Al, ZnO [4]. Due to the better thermophysical properties of nanofluids they are preferred over the base fluids. Thermal conductivity is the most studied property of nanofluids as can be seen from the available literature [5-12]. From the literature available it can be concluded that thermal conductivity of nanofluids increases with increase in concentration of nanoparticles in base fluids, also the thermal conductivity increases with increase in temperature. A foretaste of nanofluidic thermal conductivity can be seen in reviews by Murshed et al. [13], Das and Choi [14]. Another thermophysical property viscosity has also attracted the researchers [7,15-17].It is seen from these investigations and reviews that the viscosity increases with increase in concentration of nanofluids and decreases with decrease with increase in temperature as concluded by Saini et al. [3] in his review. So this was the one of the method enlisted above to increase the heat dissipation from the small spaces.

Now turning the light to the other methods i.e. increasing the surface to volume ratio of compact heat exchangers, increasing the overall convective heat transfer. To tackle this challenge small scale heat exchangers are to be needed with high heat flux coolants. In achieving these objectives the idea small micro size heat exchanger: microchannels have been introduced. Hence the use of nanofluids in microchannels meets the demand of time.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

II. MICROCHANNELS

A. Introduction

Microchannels are the micro sized flow passages with hydraulic diameter ranging from 10 to 400 micrometers. Such small passages have high surface to volume ratio which enables higher heat transfer rates [18]. Microchannels are the small heat exchanging devices which fit in very small and compact spaces where heat dissipation is more and conventional methods fails to dissipate the accumulated heat. Many experiments have been carried out by many researchers to study the heat transfer behavior in microchannels using nanofluids [8, 15, 17]. These experiments show an increase in thermal conductivity of fluid using nanofluids and high heat dissipation capacity upto 790 W/cm^2 with maximum temperature rise of 71 ^{0}C above the water temperature [19]. Fig. 1 shows the split flow type microchannels.

B. History and literature

The impulse for microchannels research has started after the revolutionary work of Tuckerman and Pease [20] in 1981. Many researchers diverted their concentration to the new

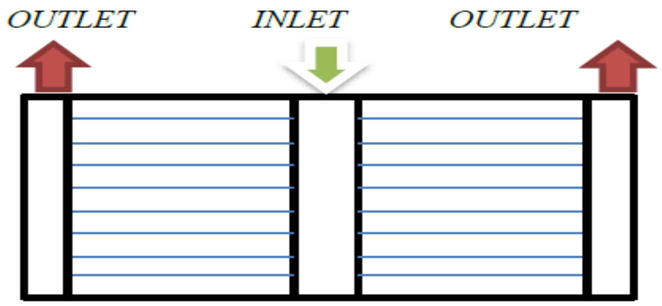


Fig.1 Microchannels

means of 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 [30], 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 [31], 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 [32], 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

In research presented here, experimental work was carried out using microchannels as heat exchangers and nanofluids as coolant. Al_2O_3 particles were used to make nanofluids by two-step method. Experimental setup consist of microchannels, syringe pump, syringe, PT-100 temperature sensors, temperature displays, heater, voltage and current display, reservoir, inclined manometer, controller system of syringe pump, computer. Fig.2 (a) shows the layout of fabricated setup and fig. 2 (b) shows the pictorial view of the setup. Flow rate through the setup was regulated by the computer controlled syringe pumps, as syringe pumps are highly accurate there is no need of installing any flow meter in flow passage to double check the flow rate. The given heat to the microchannels is regulated by varying the current and voltage to the heater with the help of a dimmerstat. A reservoir is used to collect heat extracted nanofluids which has passed from microchannels. The whole setup is single pass flow type. Temperature sensors T1, T2, T3 are inlet and outlet temperature sensors, T4 is temperature of bottom wall which is in contact with heater. T5 shows the temperature of nanofluids collected in reservoir. However the detail of every essential component is given in detail as follows.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

A. Fabrication of test section and setup.

a) Syringe pump: Pumps are the major component in the setup since they are the driving force in an experiment. The accuracy of pumps is the utmost consideration in accuracy of overall experiment. Here the pumps used are syringe pump. Due to very low flow rate required in microchannels, syringe pumps have been selected for the purpose of pumping. Also to incorporate any flow meter in the flow passage can disturb the distribution and concentration of nanofluids used. Highly accurate syringe pumps purchased from E-Spin Nanotech, IIT Kanpur, Uttar Pardesh has been used here.

b) Heaters: 35W heaters were used to supply heat to the channels, whose heating capacity can be variate by dimmerstat fixed in the circuit.

c) Temperature sensors: Highly sensitive PT-100 temperature sensors are used in the experiment; the total six sensors were used three for flow temperature measurement, two for heated base wall temperature, and one to measure the temperature of nanofluids at the reservoir. Pt-100 sensors work on principle of resistance thermometers, with change in temperature the resistivity of element changes, this change in resistivity correlates to the temperature change of fluid. Pt-100 sensors are used over thermocouples because of their higher accuracy and quick response than thermocouples. In Pt-100, Pt stands for platinum and 100 stands for the resistance 100**Ω** at 0°C. Another model Pt-1000 is also available in the market.

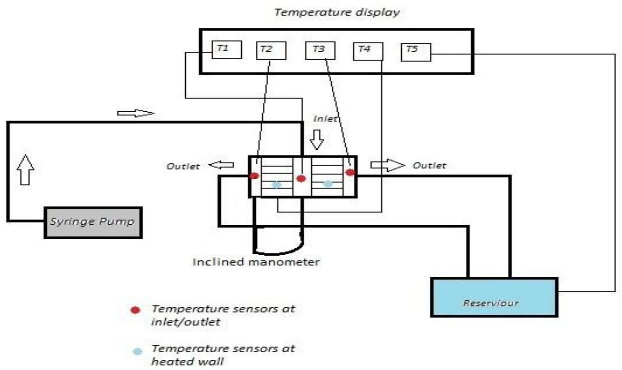


Fig. 2. A) Experimental setup layout

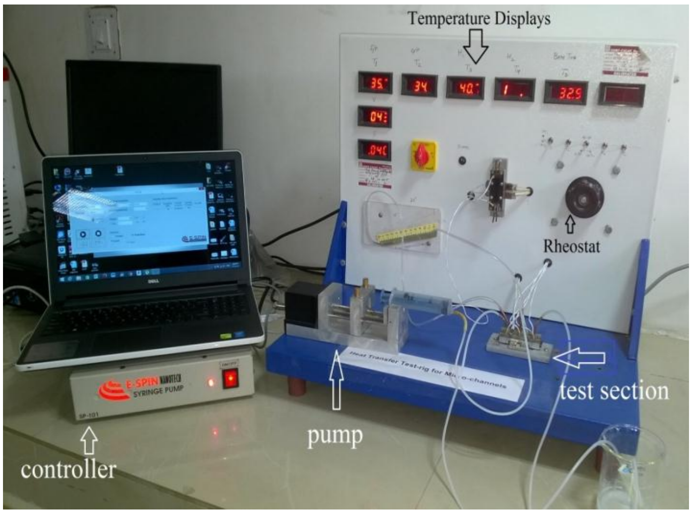


Fig.2. B) Pictorial view of setup

The calibration of the temperature sensors was done by NIIRT-Centre for Calibration, Analysis, and Testing, Industrial area, Panchkula, Haryana.

d) Microchannels: have been shown in Fig. 1 we can see the small slots which have hydraulic diameter in range of 10 to 400 nm. Microchannels are made generally on silicon wafer due to ease in manufacturing by simple process of stereo lithography. This method has drawbacks of manufacturing accuracy which leads to deviation in experimental and theoretical results. Hence by avoiding this method a new idea to use CNC wire cutting on aluminium has been incorporated. This CNC wire cutting is cheaper, easily available, takes less time in manufacture. CNC wire cut uses the wire of 0.018mm to produce the cut of 0.025mm. The microchannels were cut at S.R. Engineers, Chandigarh, India. In the experimental setup beneath the microchannels a low capacity heater is fitted to heat the microchannels. To make the upper surface as adiabatic wall, transparent acrylic sheet has been used with grease paper to make it leak proof. However, other methods like using rubber sheet between channels upper surface and acrylic sheet can be used. The physical description of microchannels are given in Table 1.

Table 1.

Cross section	Material	Type of flow	Type of channels	Process of manufacturing
Rectangular	Aluminum	Single pass	Split flow type	CNC wire cutting

The cross sectional view with dimensions of channels is shown as

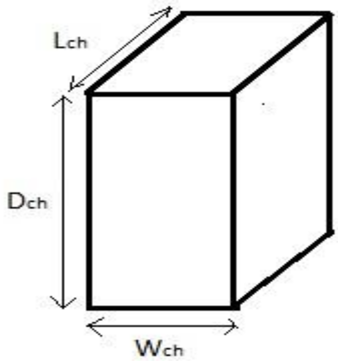


Fig. 3.Cross sectional view of microchannel

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

Table 2. Dimensions of microchannels.

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

The process of designing starts with the industrial, manufacturing and economical constarints. The least dimension of microchannel which can be made with the help of CNC wire cutting is 0.25mm. Hence the width gets fixed due to manufacturing constraint of wire and machining facility. Since CNC wire cutting can only produce rectangular cross sectional, hence shape of microchannel is selected. From Kandlikar et al [24] microchannels with aspect ratio of 8 shows maximum convective heat transfer, hence the depth of 2mm is selected. The minimum size of pipe for inlet and

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

outlet manifolds available in market is 2.5 mm. This constraint of pipe diameter has fixed the width of inlet and outlet plenums. However, three holes in the acrylic sheet for insertion of temperature sensor, inlet/outlet manifold and pressure manometer which should have considerable amount of gap of at least 1.5 mm if sheet material between them to avoid the leakages from these points. Hence the length of plenums is kept 15mm. this is the little glimpse of designing procedure has been given here.

B. Flow loop and working

The pumps serve as a driving force for nanofluids in the whole flow path. Syringe pumps fitted with a syringe of 20 ml are driven by the computer controlled controller and flow can be varied according to the need. Syringe pumps are constant and accurate in working and hence there are no fluctuations in the flow. After fitting the pump arrangement in the loop DC supply was switched on this heat the aluminum microchannels. The fluid flows from syringe to reservoir through microchannels. The heating is controlled by the dimmerstat fitted in the electric circuit. Heat is dissipated by the microchannel and once the steady state is reached reading of the temperature sensors at different points were measured. As the syringe empties the pump operation was stopped. The syringe is then again withdrawl to fit the next syringe in it.

C. Preparation and properties of nanofluids of nanofluids

Nanofluids were prepared by two step method. It is most widely used method to prepare nanofluids. In this method two-steps are followed; this is why it is called two-step method. Nanofibers, nanoparticles, nanotubes etc. produced by this method are first prepared as dry powders by different means of physical and chemical methods, this formation of nanoparticles ends the first step. Now the powdered form nanoparticles are dispersed into base fluid with the help of high shear mixing, ultrasonic agitation, force agitation and ball mixing. This is the most economical technique to make nanofluids due to cheaper method to synthesize nanoparticles in industry. However nanoparticles have the tendency to agglomerate. Due to lesser stability of nanofluids by this method new method has been developed: one-step method. However the one step method is simultaneously making and dispersing the particles into fluid is carried out. Many processes like transportation, drying and dispersion has been avoided hence the problem of agglomeration has been minimized. One-step physical method is not so efficient and we cannot make nanofluids on large scale because of high cost of preparation. Thermophysical properties: thermal conductivity, viscosity are measured by KD2-Pro and Brookfield viscometer respectively.

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

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

SEM (spectral electron microscopy) was done on nanoparticles in SAI labs at Thapar University. The report of which is shown in Fig. 4. In SEM 80 nm size has been detected

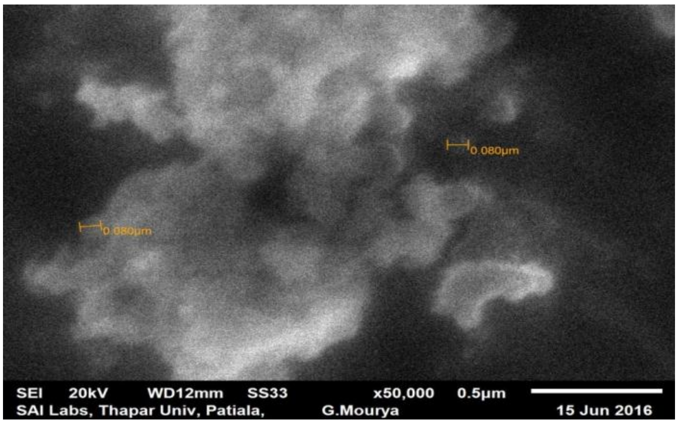


Fig. 4. SEM of nanoparticles

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_2O 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:

Hydraulic diameter is the first parameter to be calculated to decide other parameters in microchannels and it 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 represents 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, ϑ 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, φ 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. Thermal conductivity

Thermal conductivity of nanofluids at various concentrations was measured and shown in Fig. 5. From figure it is seen that thermal conductivity of nanofluids increases with increase in concentration. With respect to pure water (0%,vol.) thermal conductivity increase by 0.585%, 3.5%, 5.65% for 0.1%, 0.25%, 0.5% vol. concentration respectively. Kamaldeep et al [34] investigated the effect of temperature on thermal conductivity of nanofluids and found that with increase in temperature thermal conductivity increases for all volume fractions of nanofluids.

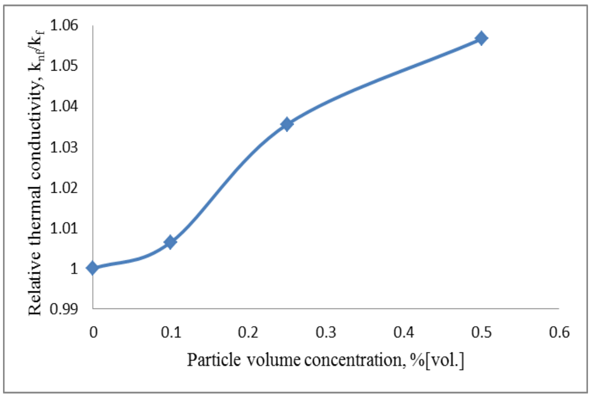


Fig. 5. Relative thermal conductivity with concentration.

Thus from these two observations it can be said that thermal conductivity is the function of temperature and concentration. It is seen from the Fig. 5 that particle concentration of 0.1%,vol. doesn't provide any considerable enhancement in thermal conductivity of nanofluids. To obtain considerable enhancement in thermal conductivity the particle volume concentration was increased, therefore by increasing the particle volume concentration the thermal conductivity increased by 5.65% and this is due to presence of higher number high conductivity nano particles in base fluid and higher number of contacts between the particles.

B. Viscosity

Viscosity of nanofluids was measured at different temperature from 25ºC – 50ºC and the behavior was studied. It can be seen that with increase in temperature from 25 to 50ºC the viscosity decreases because of more Brownian motion among particles due to energy gained by heating. Nanofluids have slightly higher viscosity than pure water due to presence of solid particles in them. However the increase in viscosity was overcome by heat transfer gains by nanofluids. Fig. 6 shows the comparison of viscosity among pure water, nanofluids, and mathematical value calculated by Newton's model.

Kamaldeep et al [34] also studied the effects of temperature on nanofluids and same pattern is observed i.e. with increase in temperature viscosity of nanofluids decreases and nanofluids shows slight increase in viscosity in comparison to the pure water at same temperature.

Relative viscosity of nanofluids with respect to particle volume concentration was measured. The plot is between relative viscosity and particle volume concentration is shown in Fig. 7 From figure the obvious trend of viscosity increase with particle volume fraction increases

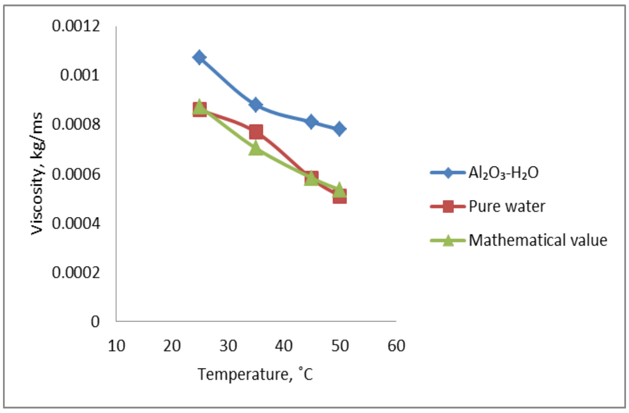


Fig. 6. Viscosity variation with temperature

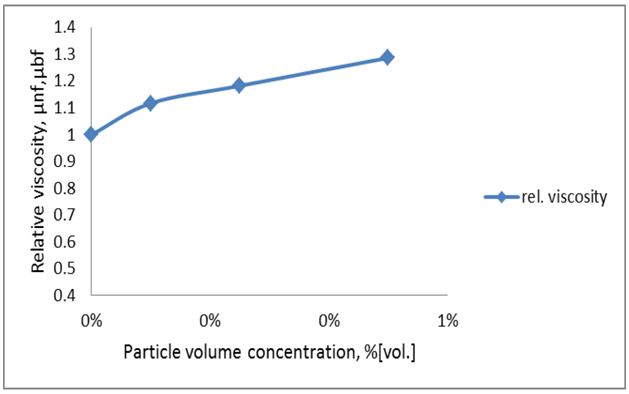


Fig. 7. Relative viscosity with particle vol. concentration

C. *Heat transfer coefficient*

Fig. 8 shows the plot of heat transfer coefficient versus flow rate in ml/min of pure water and Al_2O_3-H_2O nanofluids. Every effort has been made to increase the convective heat transfer coefficient to increase the heat transfer capacity of the coolant. Heat transfer coefficient can be increased either by increasing the flow velocity in the channels and by increasing the coolant heat carrying capacity. Heat capacity has been increased by using nanoparticles and velocity was increased by using syringe pumps. In split flow type microchannels convective heat transfer coefficient of both the sides was calculated and then the overall heat transfer coefficient was calculated for different flow and for different concentrations of nanofluids. Similar trend was noticed with all concentrations.

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.

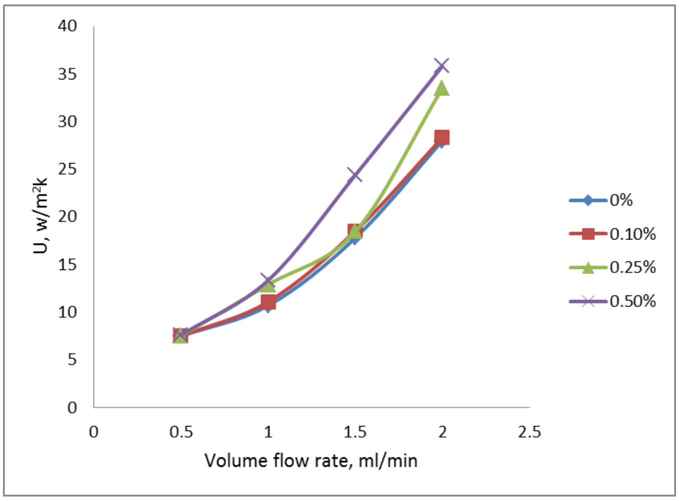


Fig. 8. Variation of Overall heat coefficient with particle volume concentration

D. *Prandlt number*

Prandtl number, Reynolds number these are important function of thermophysical properties of nanofluids, which greatly affect the heat convective heat transfer coefficient. Hence it becomes important to study their variations. Prandtl number is the ratio of momentum diffusivity to the thermal diffusivity of a fluid and it is the only dimensionless number which is a property of fluid and depends on µ, Cp and k, which further depends upon temperature and φ. Fig. 9 shows how Prandtl number behaves on adding different fractions of nanoparticles in base fluid. It is seen from the figure that as the particle concentration increases Prandtl number increases for Al_2O_3-H_2O nanofluids. This backs the utility of nanofluids. From the observations it is seen that by using nanofluids Prandtl number increases by upto 24%. This considerable increase with concentration of 0.5% (vol.) suggests that to get more Prandtl number higher concentrations may be used. With increase in concentration of nanofluids viscosity, thermal conductivity increases but specific heat decreases. The viscosity changes are dominant over all other parameters change, therefore with change in concentration of nanofluids Prandtl number increases, overcoming the increasing effects of thermal conductivity.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 07, July-2016

This suggests that thermal diffusion increases with increase in concentration of nanofluids. Temperature dependency of nanofluids have been studied by [35]. They took CuO, SiO_2, Al_2O_3 nanoparticles at 6% (by vol.) concentration and showed that Prandtl number decreases with increase in temperature (as shown in Fig. 10) because in this case viscosity variation dominates over specific heat capacity and thermal conductivity. This decreases the Prandtl number over temperature increase.

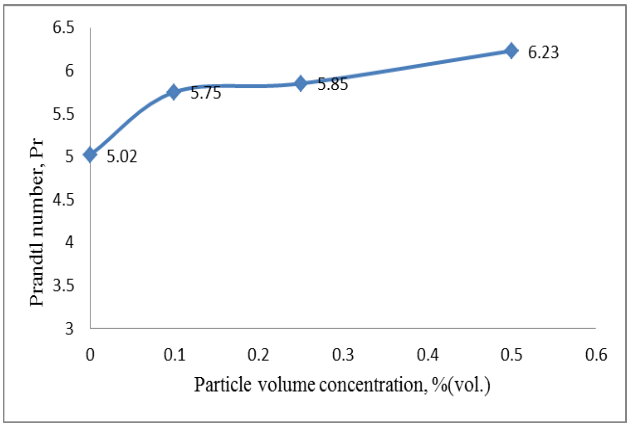


Fig. 9. Prandtl number variation with particle volume concentration

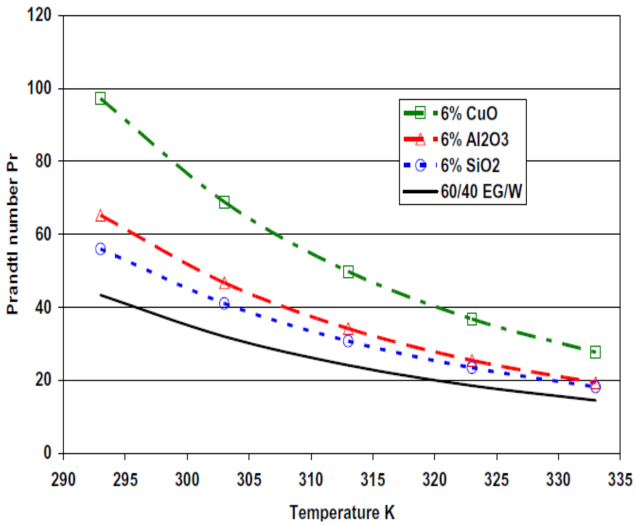
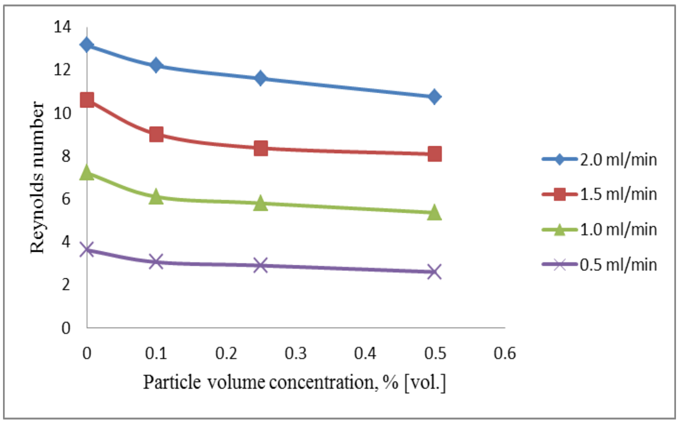


Fig. 10. Temperature dependency of Prandtl number

E. Reynolds number

Reynolds number is the ratio of inertial force to the viscous force. The behavior of Reynolds number is studied with different flow rates. Fig. 11 shows the variation of Reynolds number of different flow rates with particle volume concentration. The diameter and velocity are kept constant for different particle volume concentrations, to ensure same parameters. From the Fig. 11 it is seen that there is gradual decrease in Reynolds number with increase in particle volume concentration for every flow rate. However maximum drop of 28% is seen for the flow rate of 0.5ml/min and least drop of 185 for 2ml/min flow rate. Increase in particle volume concentration in the base fluid increases viscosity and density of nanofluids. However there is less increase in density and considerable increase in viscosity of nanofluids, the viscous forces increases more than the inertial forces. Therefore at the end there is decrease in Reynolds number with increase in concentration of nanofluids could be encountered.

The analyses under the previous sections show that thermophysical properties of nanofluids influences the Prandtl number and Reynolds number in contradicting manner. Higher concentrations of nanofluids are better for higher Prandtl number and heat transfers, whereas lower concentrations are desirable for higher Reynolds number to enhance heat transfers. Hence designing the equipment optimization of both the numbers should be done to get better results from nanofluids.



V CONCLUSION

Experimental work was performed on split flow microchannels to study the effects of Al_2O_3-H_2O nanofluids on thermophysical properties and performance of microchannels heat sink. Experimental work was performed using distilled water and Al_2O_3-H_2O nanofluids with different concentrations, 0.1%, 0.25% and 0.5% (vol.) as a coolant in microchannels. Experiments were carried out at 0.5 ml/min, 1.0 ml/min, 1.5 ml/min, 2.0 ml/min flow rates in laminar regime. Following conclusions were made from the experimental work.

A. Thermophysical properties of nanofluids

1) Thermophysical properties of nanofluids got improved in comparison with the pure water. Thermal conductivity of nanoparticles got increased, which is the main focus of every study done on nanofluids. Enhancement of 5.65% with respect to pure water with concentration of 0.5% (vol.) of Al_2O_3-H_2O is reported.

2) Viscosity of nanofluids increases with increase in particle volume concentration i.e. least with pure water and maximum with 0.5% concentration. The viscosity increases leads to increase in pumping power. However, with increase in temperature viscosity of nanofluids decreases due to increased Brownian motion in particles.

3) Specific heat capacity calculated by model quoted by Wu et al [22] in his research work, and it has been seen nanofluids have lesser specific heat than pure water due to presence of low heat capacity nanoparticles in them. It is also seen that specific heat decreases with increase in concentration of nanofluids.

B. Performance of microchannels

The performance of microchannels has been studied at different concentrations and at different flow rates. The parameters: heat transfer coefficient, Prandtl number are studied with respect to concentration and Reynolds number. Reynolds number has been kept in laminar regime.

1) Heat transfer coefficient: the flow rate has been increased from 0.5ml/min to 2 ml/min and concentration is varied from 0.1% to 0.5%. With the increase in concentration of nanofluids heat transfer coefficient has been increased upto 27% with respect to the distilled water. This observation backs the utility of nanofluids in many heat exchanger applications where space and weight is constraint. It has been seen that for 0.1% concentration there is very less increase in heat transfer coefficient with increasing flow rates. However, higher concentrations of 0.25% and 0.5% show the considerable increase in heat transfer coefficient.

2) Prandtl number: Prandtl number the ratio of momentum diffusion to thermal diffusion depends on φ and temperature. With increase in concentration Prandtl number increases, with respect to distilled water. Prandtl number increased with increase in concentration in almost same proportion for every concentration change. Increase of Prandtl number upto 22% for Al_2O_3-H_2O nanofluids shows the expected results [24]. Das et al [24] also studied the change of Prandtl number with different nanofluids and concluded that Prandtl number increases with increase in concentration for every nanofluid he used. With temperature Prandtl number increases due to viscosity dominance at higher temperatures.

3) Reynolds number: Reynolds number with increase in particle volume concentration decrease. The decrease in Reynolds number by 18% from pure water to 0.5% (vol.) shows the considerable increase in viscosity overcoming the density effects.

4) The results obtained showed that microchannels are proved vital in the field of heat transfer. Their higher surface to volume ratios gives high heat transfer coefficients, which carries more heat from small places.

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