



AN EXPERIMENTAL INVESTIGATION ON THERMAL PERFORMANCE OF NANOFLUIDS IN A MINICHANNEL HEAT SINK

R.NandhaKumar*,D.SenthilKumar**

* Assistant Professor, Department of Mechanical Engineering, Mahendra College of Engineering, Salem, India.
e-mail:ernandha2003@gmail.com

** Professor & Head, Department of Mechanical Engineering, Sona College of Technology, Salem, India.
e-mail:dskumar33@yahoo.com

ABSTRACT

In the present work, experimental investigation has been undertaken to analyze the heat transfer performance of nanofluids used as alternate coolant to conventional fluid in a copper minichannel heat sink. Al_2O_3 -water, Al_2O_3 -ethylene glycol, TiO_2 -ethylene glycol, MgO -water and ZnO -water nanofluids were used to evaluate their comparative thermal performances. The copper minichannel heat sink 30mmx30mmx4mm consists of seven parallel minichannels of length 30mm with a cross section area of 2mm in width and of channel height 2mm for each channel was used in this investigation. Nanofluids as coolant were tested at different volume concentration ranging from 0.5% to 2.5% was passed through the minichannel heat sink attached with a heat source. The results showed that the thermal conductivity of nanofluids enhanced significantly by increasing the volume concentration of nanoparticles in the base fluid. From the comparative results, the Al_2O_3 -water nanofluid cooled heat sink showed better heat transfer and hence outperforms the other nanofluids. This nanofluid can be recommended for electronic cooling system as an alternate coolant to conventional fluid.

Keywords: Nanoparticles, Nanofluids, Minichannel, Thermo physical properties, Heat transfer.

1. INTRODUCTION

For effective heat dissipation liquid cooling system requires advance technologies to replace conventional coolant. Nanofluids are being considered as an promising alternative coolant formulated by the suspension of metallic or non-metallic nanoparticles with the conventional base fluid like water, ethylene glycol and different types of oil, was first introduced by Stephen U.S.choi and J.A.Eastman [1] at Argonne National laboratory. The result showed that mixing of nano particles in the base fluid increases the thermal conductivity. The use of different types of nanofluids in micro and minichannel exhibits high heat transfer performance. Masuda et al [2] experimentally inspected the thermal conductivity of TiO_2 (27nm) Al_2O_3 (13nm) and SiO_2 (12nm) water based nanofluids. They concluded that the thermal conductivity enhanced about 32.4% by adding 4.3vol% concentration of Al_2O_3 nanoparticle with the base fluid. S.Lee et al [3] conducted an experimental analysis on Al_2O_3 and CuO nanoparticles and the results shows that nanofluids possess substantially higher thermal conductivity than the base fluid without nanoparticles. Yimin xuan and Qiang Li [4] examined Cu -water nanofluids and found that the nanoparticle volume fraction, dimensions, shape and its properties can affect thermal conductivity of the coolant. N.A.Roberts and D.G.walker [5] showed the addition of alumina nanophase powder in water enhanced the convective heat transfer performance in the commercial cooling system with increasing volume loading. Ali Ijam et al [6] studied Al_2O_3 -water and TiO_2 -water nanofluids for cooling of copper minichannel heat sink. They reported that the thermal conductivity of coolant improved 11.98% by adding Al_2O_3 nanoparticles and 9.97% by adding TiO_2 nanoparticles in the base fluid at 4% particle volume concentration. Bayram sahim et al [7] used CuO -water nanofluids of four different volume fractions 0.5%, 1%, 1.5% and 2% to investigate its thermal performance in a microchannel heat sink with square duct. C.J.Ho and W.C.chen [8] experimentally analyzed the convective heat transfer of Al_2O_3 -water nanofluid in a copper minichannel heat sink. The nanofluid heat transfer co-efficient was significantly higher than the water cooled heat sink. Paisarn Naphon and Lursukd Nakharintr [9] investigated the heat transfer characteristics of TiO_2 -deionized water nanofluid in the mini-rectangular fin heat sink made up of aluminum and found the heat transfer rate of nanofluids are higher than that of using de-ionized water as coolant. M.R.Sohel et al [10] also investigated analytically the heat transfer performances of Al_2O_3 -water, CuO -water, Cu -water and Ag -water nanofluids at different volume concentrations ranging from 0.5vol% to 4vol% flow through a circular shaped copper minichannel heat sink. The comparative result showed that Ag -water nanofluid exhibits higher heat transfer performance. S.S.Khaleduzzaman et al [11] made analysis in a rectangular shape minichannel using Al_2O_3 -water nanofluid as a coolant with particle fraction of 0.10 to 0.25vol% and changing the flow rate ranging from 0.375 to 1.0L/min. The result showed that the highest efficiency obtained was 94.68% for 0.25vol% at the flow rate of 0.375 L/min.



Nomenclature

C_p	Specific heat (J/kgK)
K	Thermal Conductivity (W/mK)
T	Temperature ($^{\circ}\text{C}$)
Re	Reynold's number
Nu	Nusselt number
u_m	Inlet velocity (m/s)
D_h	Hydraulic diameter (m)
W_c	Channel width (m)
H_c	Channel height (m)
L	Channel length (m)
A	Area (m^2)
ΔT	Temperature difference ($^{\circ}\text{C}$)
N	Number of cooling channels
h	Heat transfer co-efficient ($\text{W}/\text{m}^2\text{K}$)
Q	Heat transfer (W)

Greek symbols

ρ	Density (kg/m^3)
μ	Viscosity (Ns/m^2)
η	Efficiency
\emptyset	Particle volume fraction

Subscript

f	Base fluid
p	Particle
nf	Nanofluid
In	Inlet
Out	Outlet
b	base of the heat sink
eff	effective
LMTD	Logarithm mean temperature difference

P.Selvakumar et al [12] experimentally studied the convective heat transfer performance of Al_2O_3 -water nanofluid flow through a rectangular minichannel. The result shows improvement in the heat transfer and gradual reduction of heat sink temperature against increase in volume flow rate. M.R.Sohel et al [13] experimentally investigated the thermal performance of a copper minichannel using Al_2O_3 - H_2O nanofluid as coolant instead of pure water. The volume fraction ranging from 0.10 to 0.25 vol% was used and the heat transfer co-efficient enhanced up to 18% successfully. He also studied the

cooling performance of electronics cooling system using $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$ nanofluid at different volume fraction of nanoparticle varied from 0.05 vol% to 0.2vol% and volume flow rate from 0.50 L/min to 1.25L/min, this study showed that the nanofluid minimized the heat sink temperature considerably than the conventional fluid.

In recent years, many investigators are using nanofluids to analyze its heat transfer performance in a minichannel heat sink but till now nanofluids have not been used practically as a coolant for the liquid cooling system in the electronic devices. This research article investigates the nanofluids thermo physical properties, its heat transfer performance as a coolant in a copper minichannel heat sink and pumping power.

2. METHODOLOGY

2.1 Experimental Setup

The schematic of a close loop experimental setup constructed for the cooling system is shown in Figure1. The fabrication consists of a minichannel heat sink, housing, storage tank, pump, contact type plate heater and heat exchanger. The pump is used to force the nanofluid used as coolant from the storage tank to circulate through the minichannel heat sink. The heat input was given to the minichannel by using a contact type plate heater, placed below the heat sink. Proper housing facility was provided with insulation to avoid heat loss.

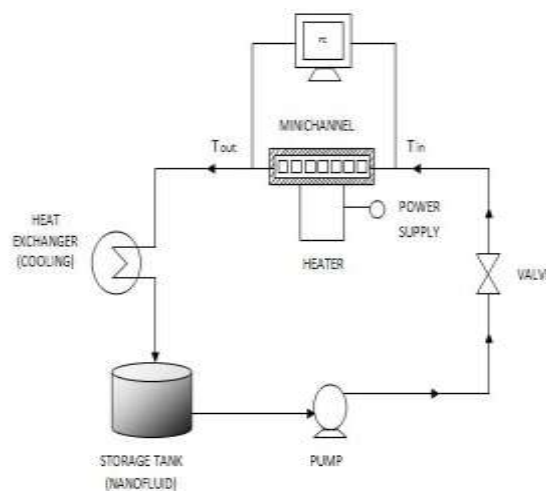


Figure 1: Schematic of the experimental setup

The coolant absorbs the heat while passing through the minichannel and reject heat into the heat exchanger. In this way the temperature of the heat sink gets reduced, the coolant reaches back the storage tank and recirculates into the cooling system. The dimension of rectangular minichannel heat sink was 30mmx30mmx4mm consists of seven parallel minichannel and it is fabricated by electric discharge machining, machined equidistantly spaced with 2mm width, 2mm height each of 30mm length. The inlet and outlet pendulums were fabricated at the two ends of the minichannel to provide uniform flow distribution and the thermocouples was used at different points for the temperature measurement.

2.2 Nanofluid Preparation

There are mainly two methods used for preparing nanofluids one step method and two step methods. In this present work the preparation of nanofluid was done by two step method. At first the Al_2O_3 , TiO_2 , MgO and ZnO particles are converted into nano sized particles with the help of planetary ball mill. The particles shape is spherical and the size of Al_2O_3 nanoparticles is 82nm, TiO_2 nanoparticles is 69nm, MgO nanoparticles is 20nm and ZnO nanoparticles is 29nm confirmed by particle size analyzer. In the second step the nanoparticles were dispersed properly in the base fluids water and ethylene glycol to form stable nanofluids. The nanofluids of five different volume concentrations were prepared by this two step method.

2.3 Experiential data calculation

The nanoparticles with 0.5%, 1%, 1.5%, 2% and 2.5% of volume fractions were used to find the thermo physical properties of $\text{Al}_2\text{O}_3\text{-water}$, $\text{Al}_2\text{O}_3\text{-ethylene glycol}$, $\text{TiO}_2\text{-ethylene glycol}$, MgO-water and ZnO-water nanofluids. The density, specific heat, thermal conductivity and viscosity were experimentally measured and have been examined mathematically by using the following equations

Density of the nanofluid is determined by Pak and Cho model [15] by using Eq. (1):

$$\rho_{nf} = (1 - \phi)\rho_{nf} + \phi\rho_{np} \quad (1)$$



The Specific heat can be calculated by using Xuan and Roetzel model [16] by using Eq. (2):

$$C_{p_{nf}} = \frac{(1 - \phi) \rho_f C_{p_f} + \phi \rho_p C_{p_p}}{\rho_{nf}} \quad (2)$$

The model posed by Hamilton and crosser [17] to determine thermal conductivity of the nanofluid is calculated by the following Eq. (3):

$$\frac{K_{nf}}{K_f} = \frac{k_p + (n - 1)k_f - (n - 1)\phi (k_f - k_p)}{K_p + (n - 1)K_f + \phi (k_f - k_p)} \quad (3)$$

Where n is the shape factor, for spherical shape of the nanoparticle $n = 3$.

The viscosity of nanofluid for spherical particles volume fractions less than 5.0vol% suggested by Drew and passman [18] is calculated by using the following Eq. (4):

$$\mu_{nf} = (1 + 2.5 \phi) \mu_f \quad (4)$$

The heat transfer by the nanofluid is calculated from the Eq. (5):

$$Q_{nf} = m_{nf} C_{p_{nf}} (T_{out} - T_{in})_{nf} \quad (5)$$

The Reynold's number is calculated by using Eq. (6):

$$Re = \frac{\rho_{nf} u_m D_h}{\mu_{nf}} \quad (6)$$

Hydraulic diameter is defined as the ratio between cross sectional area to the perimeter of the channel was calculated by using the following Eq. (7):

$$D_h = \frac{4W_c H_c}{2(W_c + H_c)} \quad (7)$$

The convective heat transfer co-efficient is evaluated by the Eq. (8):

$$h = \frac{Q_{nf}}{A_{eff}(\Delta T_{LMTD})} \quad (8)$$

Where $A_{eff} = NL_{ch}(W_{ch} + 2\eta_{fin}H_{ch})$

The logarithm mean temperature difference is calculated by the Eq. (9):

$$\Delta T_{LMTD} = \frac{(T_b - T_{in_{nf}}) - (T_b - T_{out_{nf}})}{\ln \left[\frac{T_b - T_{in_{nf}}}{T_b - T_{out_{nf}}} \right]} \quad (9)$$

The Nusselt number is determined by the Eq. (10):



$$Nu = \frac{hD_h}{k_{nf}} \quad (10)$$

The convective thermal resistance for the nanofluid is evaluated by using the Eq. (11):

$$R_{th} = \frac{1}{h A_{eff}} = \frac{\Delta T_{LMTD}}{Q_{nf}} \quad (11)$$

The pumping power is estimated by the following Eq. (12):

$$P_p = \frac{m}{\rho_{nf}} \times \Delta P \quad (12)$$

3. RESULTS AND DISCUSSION

3.1 Thermo physical properties

Thermo physical properties play a vital role in the heat transfer performance of nanofluids. Adding volume fraction of nanoparticles in the base fluid raises the density value of the coolant. Figure 2 shows that the density value gradually increases with corresponding improvement in particle vol% fraction. In this study the density value is determined by using Pak and Cho model [15]. The density value of different types of coolant was minimum at 0.5vol% and it reaches the maximum value at 2.5vol% concentration. The maximum density at 2.5vol% of Al_2O_3 -water nanofluid was 1066 kg/m^3 , Al_2O_3 - ethylene glycol was 1180 kg/m^3 , TiO_2 -ethylene glycol was 1186 kg/m^3 , MgO -water was 1056 kg/m^3 and ZnO -water was 1107 kg/m^3 . By observation the density value of nanofluids increases proportional to the volume fraction of nanoparticles in the base fluid.

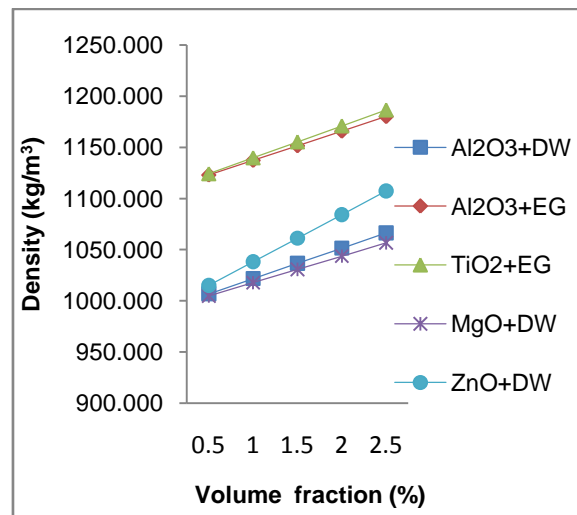


Figure 2: Density vs Volume fraction (%)

The following figure 3 represents the value of specific heat schemed against volume concentration of nanoparticles in the base fluid. The specific heat property does not increase like other thermophysical properties of nanofluids. The value of specific heat decreases with the increases in volume fraction of nanoparticles in the base fluid was calculated by the model proposed by Xuan and Roetzel [16]. The specific heat property value of different types of coolant was maximum at 0.5vol% and the value starts diminishing by increasing the volume fractions of nanoparticles to the base fluid. The specific heat at 2.5vol% of Al_2O_3 -water nanofluid was 3860.852 J/KgK , Al_2O_3 -ethylene glycol was 2324.765 J/KgK , TiO_2 -ethylene glycol was 2308.913 J/KgK , MgO -water was 3905.518 J/KgK and ZnO -water was 3698.718 J/KgK respectively. The specific heat value of all types of nanofluids is minimum when the volume fraction reaches 2.5vol% concentration.

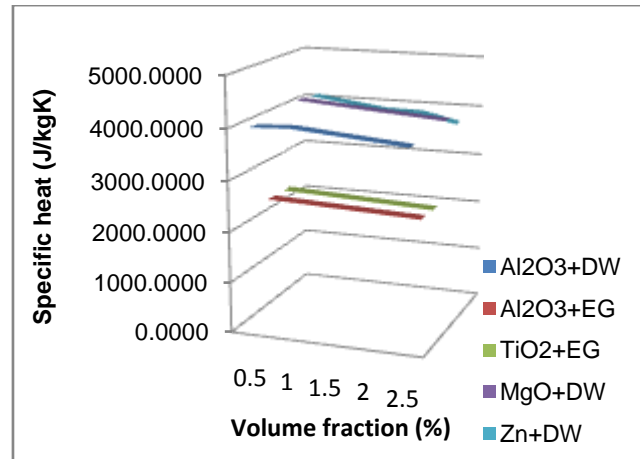


Figure 3: Specific heat vs Volume fraction (%)

The base fluids initially have poor thermal conductivity make it not suitable for using in advance cooling system and high heat loads. The thermal conductivity is one of the important property to improve the thermal performance of the coolant. The thermal conductivity of the base fluid is increased by the suspension of nanoparticles in it. In this investigation the thermal conductivity value is calculated based on model proposed by Hamilton and Crosser [17] considering both the particle volume fraction and shape of the nanoparticles. As shown in figure 4 the maximum thermal conductivity of Al₂O₃-water was 0.6775W/mK, Al₂O₃-ethylene glycol was 0.2649W/mK, TiO₂- ethylene glycol was 0.28478 W/mK, MgO-water was 0.6777W/mK, ZnO-water was 0.67783 W/mK at 2.5% of particle volume fraction. The highest enhancement in the thermal conductivity of Al₂O₃-water was 7.38%, Al₂O₃-ethylene glycol was 7.55%, TiO₂- ethylene glycol was 15.62%, MgO-water was 7.4% and for ZnO-water was 7.42% respectively.

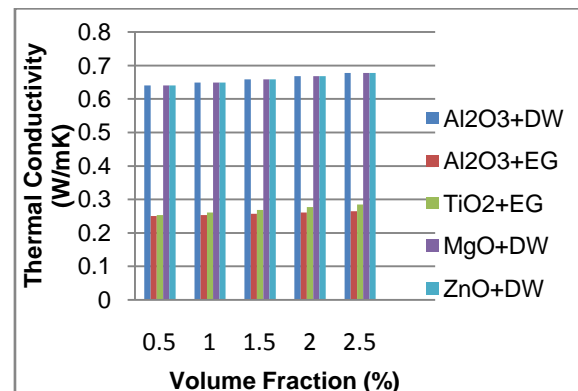


Figure 4: Thermal conductivity vs Volume fraction (%)

The viscosity is one of the important thermophysical property of the nanofluid taken into consideration in a liquid cooling system and it is one of the important parameter used to determine the pumping power of the heat transfer system. The relative viscosity is schemed against the volume fraction was shown in figure 5.

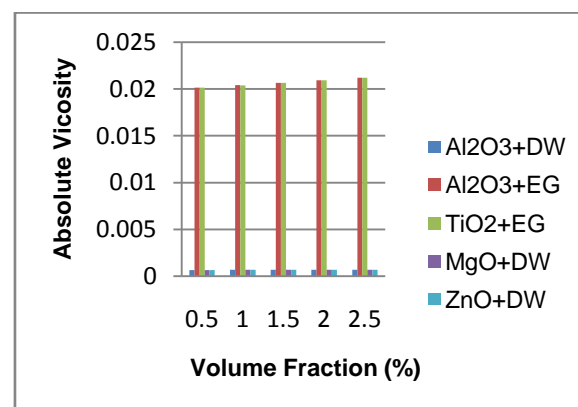


Figure 5: Viscosity vs Volume fraction (%)



From the graph it is observed that the viscosity value rises with the corresponding volume fraction of the nanoparticles. The viscosity of Al_2O_3 -water, MgO -water and ZnO -water shows similar values whereas the Al_2O_3 - ethylene glycol and TiO_2 - ethylene glycol nanofluids values are comparatively high due to their difference in the base fluid.

3.2 Nusselt number, Reynolds number, Heat transfer co-efficient

For a minichannel heat sink, the conduction heat transfer is constant because of heat sink material, dimensions and for a heat source. But the convection heat transfer can change with the type of fluid and its properties used in the cooling system. The Nusselt number and Reynolds number represents the flow characteristics and also the convective heat transfer performance. The Reynolds number used to characterize the laminar flow of nanofluids in this experiment. From the observation, the Nusselt number increases proportional to the volume fraction of nanoparticles in the base fluid. As shown in figure 6 at 2.5vol% the nanofluids show higher Nusselt number over the conventional fluid.

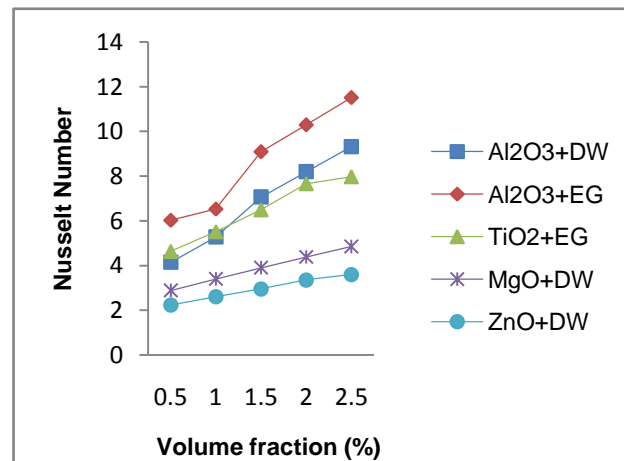


Figure 6: Nusselt Number vs Volume fraction %

The principle objective of this study is to investigate the thermal performance of the nanofluids. The thermal performance of the coolant depends on the heat transfer co-efficient. By adding the volume fraction of nanoparticles in base fluid the heat transfer co-efficient increases as shown in figure 7.

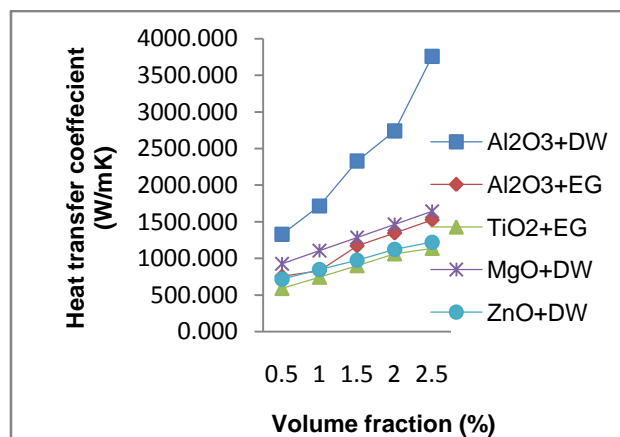


Figure 7: Heat transfer coefficient vs Volume fraction (%)

Equation (8) shows that heat transfer co-efficient inversely related to the log mean temperature difference. The addition of volume fractions of nanoparticles in the base fluids improves the thermal conductivity and it is responsible for increasing the heat transfer performance of the nanofluids over the conventional fluids. The minimum and maximum heat transfer co-efficient of Al_2O_3 -water at 0.5% and 2.5% of particle volume fraction were 1326.104W/mK and 3759.478W/mK, Al_2O_3 -ethylene glycol was 753.459W/mK and 1525.466W/mK, TiO_2 -ethylene glycol was 588.714W/mK and 1135.482W/mK, MgO -water was 923.354W/mK and 1643.2W/mK and for ZnO -water was 716.031W/mK and 220.758W/mK respectively.

Nanofluid is mainly used in liquid cooling system to perform better heat transfer than conventional fluid. By increasing the volume fraction of nanoparticles in the base fluid results in enhancement of heat transfer characteristics when it is used as a coolant in a minichannel heat sink. From the figure 8 it can be observed that the heat transfer rate of nanofluids enhanced by the addition of volume fraction of nanoparticles in the base fluid. The minimum and maximum heat transfer of Al_2O_3 -water at 0.5% and 2.5% of particle volume fraction were 82.02W and 176.054W, Al_2O_3 -ethylene glycol was 45.101W and 81.715W, TiO_2 -ethylene glycol was 36.029W and 64.072W, MgO -water was 58.314W and 99.473W and for ZnO -water



was 45.220W and 73.9W respectively. The highest heat transfer performance was given by Al_2O_3 -water nanofluid compared to Al_2O_3 -ethylene glycol, TiO_2 -ethylene glycol, MgO -water and ZnO -water nanofluids used at different vol% concentrations.

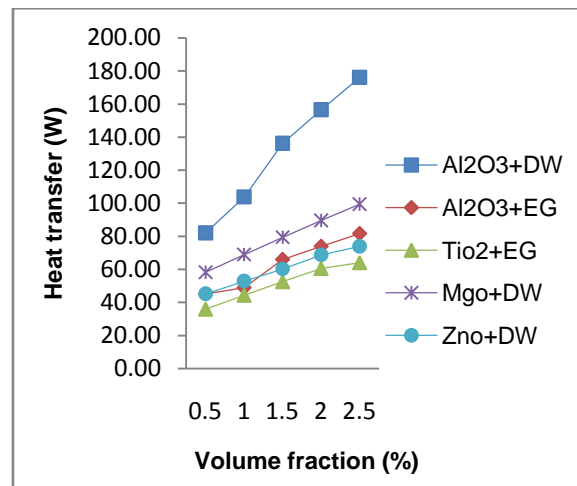


Figure 8: Heat transfer vs Volume fraction (%)

3.3 Friction factor

The heat transfer performance of the nanofluid when flow through the minichannel will be affected by the friction factor. By minimizing this resistive factor the thermal performance of the coolant can be enhanced significantly. The friction factor depends primarily on the coolant velocity, dimensions of the channel, coolant properties such as density and viscosity. As shown in the following figure 9 by increasing the volume fraction of nanoparticles in the base fluid the friction factor will be decreased while passing through the heat sink.

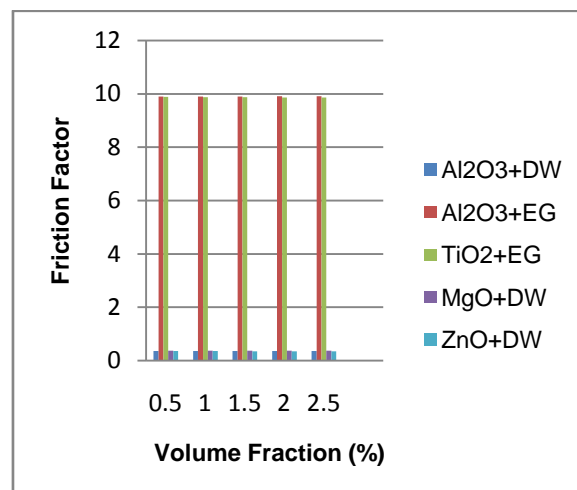


Figure 9: Friction Factor vs Volume fraction (%)

3.4 Thermal resistance

By increasing the volume fraction of nanoparticles in the base fluid results in enhancement of heat transfer co-efficient and diminishing of convective thermal resistance as shown in the figure 10.

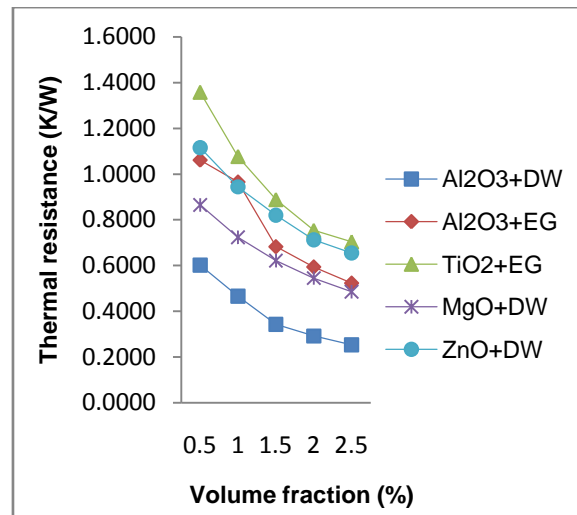


Figure 10: Thermal resistance vs Volume fraction (%)

In this experiment the maximum reduction in convective thermal resistance was obtained at 2.5vol% concentration of nanoparticles in the base fluid. The graph emphasizes that there is an effective reduction of thermal resistance with increasing of the volume fraction from 0.5% to 2.5vol%. The thermal resistance at 0.5% and 2.5% of particle volume fraction of Al₂O₃-water were 0.6024K/W, 0.2529K/W and for Al₂O₃- ethylene glycol was 1.0603K/W and 0.5237K/W. The maximum and minimum thermal resistance of TiO₂- ethylene glycol at 0.5% and 2.5% of particle volume fraction were 1.3571K/W and 0.7035K/W, MgO-water was 0.8652 K/W and 0.4862K/W and for ZnO-water was 1.115K/W and 0.6544K/W respectively. The convective heat transfer co-efficient is inversely related to the thermal resistance.

3.5 Pumping power

When the nanofluids pass through the minichannel heat sink a pressure drop occurs. Some amount of extra pumping power is needed to overcome this pressure drop. Increasing the volume fractions of nanoparticles in the base fluid, density and viscosity is the causes to raise the pumping power. But it can be compromised by considering the overall performance enhancement of nanofluids compared to the conventional base fluids. The pumping power was calculated by using the Eq.(12). The following graph 11 shows the details of gradual increment in pumping power requirement with reference to the vol% concentration of nano particles to the base fluid. The pumping powers of Al₂O₃- water, MgO-water and ZnO-water nanofluids with 0.058m/s inlet velocity, at 0.5% and 2.5% of particle volume fraction were 0.00001502W, 0.00001580W. Also, the pumping powers of Al₂O₃- ethylene glycol and TiO₂- ethylene glycol nanofluids with the same above velocity at 0.5% and 2.5% of particle volume fraction were 0.00045538W, 0.00047901W respectively. The pumping power requirement for Al₂O₃- ethylene glycol and TiO₂- ethylene glycol nanofluids was high compared to Al₂O₃- water, MgO-water and ZnO-water nanofluids due to the usage of ethylene glycol as base fluid.

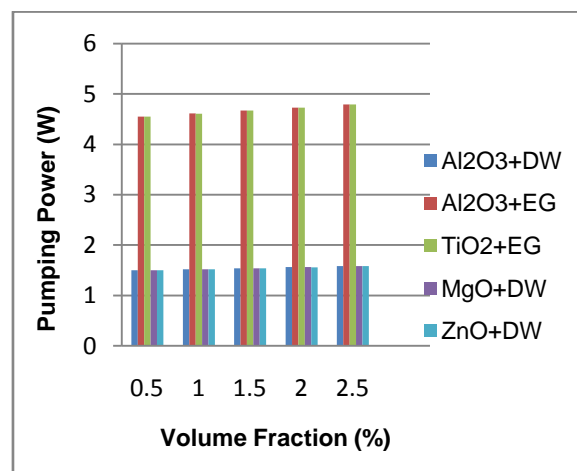


Figure 11: Pumping Power vs Volume fraction (%)

5. CONCLUSIONS

In this present study, the thermo physical such as density, specific heat, thermal conductivity, viscosity, heat transfer co-efficient, heat transfer, thermal resistance, friction power and pumping power have been investigated. Five different kinds of nanofluids at different volume fractions were used as coolant flowing through a cooper minichannel heat sink. The



comparative results obtained show significant enhancement in heat transfer characteristics of the coolant by increasing the volume fraction of nanoparticles in the base fluid. The experimental results are listed as follows:

1. The Al_2O_3 -water nanofluid exhibits better thermal performance compared to the other types of nanofluids. The maximum heat transfer obtained at 2.5% particle volume fractions of Al_2O_3 -water was 176.054W.
2. There is a significant improvement in the thermal conductivity of the base fluids (water, ethylene glycol) by the suspension of nano particles into it. The highest improvement in the thermal conductivity of 7.38% by adding Al_2O_3 nanoparticles, 7.4% by adding MgO nanoparticles, 7.42% by adding ZnO nanoparticles in water and 7.55% by adding Al_2O_3 nanoparticles, 15.62% by adding TiO_2 nanoparticles in ethylene glycol at 2.5% particle volume fractions was observed.
3. The heat transfer co-efficient was increased in addition of nano particles to the base fluid and it was evaluated based on logarithm mean temperature difference. The highest heat transfer co-efficient value was obtained at 2.5% volume fraction concentration of nanoparticles in the base fluids. For Al_2O_3 -water the value was 3759.478W/mK, Al_2O_3 -ethylene glycol was 1525.466W/mK, TiO_2 -ethyleneglycol was 1135.482W/mK, MgO-water was 1643.2W/mK and for ZnO-water 1220.758W/mK was observed.
4. The convective thermal resistance was minimized by the addition of volume fraction of nano particles in the base fluid.
5. Increasing the volume concentration of nano particles in the base fluid cause to raise the pumping power. The pumping power requirement for Al_2O_3 - ethylene glycol and TiO_2 - ethylene glycol nanofluids was high compared to Al_2O_3 - water, MgO-water and ZnO-water nanofluids.

From the above analysis it can be concluded that Al_2O_3 -water nanofluid shows higher heat transfer performances than Al_2O_3 -ethylene glycol, TiO_2 -ethylene glycol, MgO-water and ZnO-water nanofluids and it can be used as an effective alternative coolant to conventional fluid for enhancing the cooling performance in commercial and various industrial applications.

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