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Experimental investigation of single phase Al_2O_3-polyethylene glycol and TiO_2-polyethylene glycol nanofluids flow through a minichannel heat sink

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Abstract

Heat dissipation becomes a significant issue in the performance of electronic components. Nanofluids are proposed as a promising challenger for advanced heat transfer fluids in a variety of important engineering applications. In the present work, the forced convective heat transfer performance of copper mini channel heat sink has been carried out experimentally using Al_2O_3 polyethylene glycol and TiO_2 polyethylene glycol nanofluids. The Al_2O_3 and TiO_2 are converted into nanoparticles by using planetary ball mill and its shape was analysed. The thermophysical properties density, viscosity, thermal conductivity, the heat transfer coefficient of Al_2O_3 polyethylene glycol and TiO_2 polyethylene glycol based nanofluid is evaluated. The comparative heat transfer performance of these two types of nanofluids for different volume concentration 0. 5%, 1%, 1. 5%, 2%, 2. 5% is analysed by passing it at a constant inlet velocity of 0. 058m/s through a square shape copper mini channel heat sink (30x30mm) with seven passages by maintaining at constant heat supply. The results showed that the Al_2O_3 polyethylene glycol nanofluid thermal performance increased significantly and out performs the TiO_2 polyethylene glycol nanofluid. The highest improvement in the heat transfer occurred was 26% for 2. 5 volume% Al_2O_3 polyethylene glycol nanofluid when compared to TiO_2 polyethylene glycol nanofluid.

Keywords: Nanofluid, Al_2O_3-polyethylene glycol, TiO_2-polyethylene glycol, Minichannel, Heat sink, Thermophysical properties, Heat transfer.

1. Introduction

In recent years the researchers are trying to use the nanofluids to develop the energy efficient heat transfer equipments. Nanofluids are novel suspensions of nanosolid particles in base fluids. Nanofluids possess impense potential applications to improve heat transfer and energy efficient in different fields including micro electrical and electronics, mechanical systems, automobile, biomedical, nuclear and energy sector. Nanofluid is a mixture of continous base fluid and discontinuous suspended nanoparticles in base fluid. The base fluid used may be water, vegetable oil, engine oil, castor oil or organic liquid (Eg: ethylene glycol) or polymeric solution (ethanol, methanol). The nanoparticle may be metallic (Eg: Aluminium, copper, Fe), non-metallic (Al_2O_3, ZnO, CuO) or different forms of carbon. Stephen U. S. Choi and J. A. Eastman (1) introduced the term Nanofluid having superior thermal properties to those of conventional fluids. The addition of nanometer sized particles into the base fluid even at very low concentration has significant improvement in thermal performance. Masuda et al (2) conducted an experiment and this study shows that the maximum enhancement of thermal conductivity can be achieved on nanofluid of TiO_2 (27nm), Al_2O_3 (13nm) and SiO_2(12nm) where water was used as the base fluid. S. Lee et al (3) conducted an experimental analysis and the results shows that nanofluids containing a small amount of Al_2O_3 nanoparticles, posses substantially higher thermal conductivities than the same liquids without nanoparticles. This suggests that not only particle shape but size is considered to be dominant in enhancing the thermal conductivity of nanofluids. Yimin Xuan and Qiang Li (4) conducted experiment on Cu nanoparticles with water as base fluid suspension found that the shape, volume fraction, dimensions and properties of the nanoparticles affect the thermal conductivity of nanofluids. It also shows great potential in enhancing the heat transfer process. M. R. Sohel et al (5) conducted an experimental investigation of heat transfer enhancement of a copper minichannel heat sink of height 0. 8 mm and width 0. 5 mm using Al_2O_3-H_2O nanofluids, with volume fraction ranging from 0. 10 to 0. 25 vol. %, the experimental results showed higher improvement of thermal performances using nanofluids enhanced up to 18% instead of pure distilled water. P Selvakumar et al(6) conducted an experiment in a copper heat sink consists of 15 parallel rectangular mini-channels of length 50mm with a cross-sectional area of 0. 8 mm width by 3mm in height by using Al_2O_3water nanofluid 0. 1% volume fraction with a mass flow rate from 0. 003 to 0. 02 Kg/s. The study shows that the convective heat transfer rate has improved to a great extent and gradual reduction of heat sink temperature against increase in volume flow rates. Bayram Sahin et al (7) investigated the pressure drop and laminar convection heat transfer characteristics of CuO-water nanofluids for four different volume fractions of 0%, 0. 5%, 1%, 1. 5% and 2% in microchannel heat sink with square duct. Analysis showed that the nanofluids best enhanced heat transfer was obtained at 2% while the Reynolds number and the volume fractions are increasing. Ali Ijam et al (8) analysed the heat transfer performance of Al_2O_3-water nanofluid and TiO_2-water nanofluid in a copper minichannel heat sink with the bottom of 20 × 20 mm laminar flow as a coolant, through hydraulic diameters and this study showed that the thermal conductivity is directly proportional to the heat transfer coefficient. It was found that by using nanofluid such as Al_2O_3-water instead of water, improved the cooling by 2. 95% to 17. 32% and by using TiO_2-water, 1. 88% to 16. 53% was achieved. N. A. Roberts and D. G. Walker (9) used water-based alumina nanofluids of size 20-30 nm and volume loadings up to 1. 5% in a water block used for liquid cooling of a computational processing unit. The results observed showed an enhancement in convective heat transfer due to the addition of nanoparticles. M. R. Sohel et al (10) evaluated the thermal performance of the Al_2O_3-H_2O nanofluid at different volume fraction varied from 0. 05 vol. % to 0. 2 vol. % and the volume flow rate from 0. 50 L/min to 1. 25 L/min. The experimental results showed that the nanofluid successfully has minimized the heat sink temperature compared to the conventional coolant. Paisarn Naphon and Lursukd Nakharintr (11) studied the heat transfer characteristics of TiO_2 with de-ionized water nanofluids cooling in the mini-rectangular fin aluminum heat sink with the length, width and base thickness of 110, 60, and 2 mm respectively and found that average heat transfer rates for nanofluids as coolant are higher than those for the de-ionized water as coolant. S. S. Khaleduzzaman et al (12)experimentally performed analysis on a rectangular shape minichannel using Al_2O_3-water nanofluid with nanoparticle concentrations of 0. 10 to 0. 25 vol. % changing the flow rate ranging from 0. 375 to 1. 0 Lit/min. The highest energy efficiency was found to be 94. 68% for 0. 25 vol. % of Al_2O_3-water nanofluid and flow rate of 0. 375 Lit/min. C. J. Ho and W. C. Chen (13)conducted an experiment on copper minichannel heat sink consists of 10 parallel rectangular minichannels of length 50 mm with a cross-sectional area of 1 mm in width by 1. 5 mm in height using Al_2O_3water nanofluid. their results showed that nanofluid cooled heat sink has significantly higher average heat transfer coefficients and hence outperforms the water cooled heat sink. Minichannel heat sinks are ideal for use in compact and light weight electronic devices, equipments. Nano fluid plays a vital role in heat dissipation of microelectronic devices. This paper reports the analysis of Al_2O_3 and TiO_2 nanofluids characteristics and investigation of its performance as a working fluid in a copper minichannel heat sink. Al_2O_3 and TiO_2 nanoparticles are dispersed in polyethylene glycol. The nanoparticles are suspended in polyethylene glycol base fluid with five different volume concentration ranging from 0. 5%, 1%, 1. 5%, 2% and 2. 5% Volume for studying its convective heat transfer performance.

2. Methods of Nanofluids Preparation

In experimental studies with nanofluids, preparation of the nanofluid is the first key step. Nanofluids are not just dispersion of solid particles in a fluid. The essential requirements of a nanofluid is an even and stable suspension, adequate durability, negligible clogging of nanoparticles and no chemical changes of both particles and base fluid. The nanofluids are mainly prepared by two techniques, one step method and two step method.

2. 1 One step method

Various methods have been tried to produce different kinds of nanofluids. The one-step process consists of simultaneously making and dispersing the particles in the fluid. In this method the various processes like drying, storage, dispersion of nanoparticles and transportation are avoided, so the stability of fluids is increased by minimizing the agglomeration of nanoparticles. Nanoparticles can be uniformly dispersed and the particles can be stably suspended in the base fluid by this one-step process.

2. 2 Two step method

Two-step method is the most widely used method for preparing nanofluids. Nanoparticles or other nanomaterials used in this method are first produced as dry powders by chemical or physical methods. The preparation of nanoparticles mainly involves the following methods such as vapour route (physical vapour deposition method, chemical vapour deposition method and Aerosol spraying), Liquid route (sol—gel and wet chemical method) and Solid sate route (mechanical milling and mechanochemical synthesis). Then the nano sized powder will be dispersed into a base fluid in the second processing step with the help of intensive magnetic force agitation, high-shear mixing, ultrasonic agitation etc.

2. 3 Preparation of Nanofluids

For this investigation the preparation of nanofluid involves the two step method. The TiO_2 and Al_2O_3 particles are converted into nanoscale with the help of ball mill. In this work Planetary ball mill is used to convert the Al_2O_3 (82 nm) and TiO_2 (69 nm) particles into nanoscale. The particle shape is spherical and the size of Al_2O_3nanoparticles is 82nm and that of TiO_2 nanoparticle is 69nm confirmed by particle size analyser. The magnetic stirrer is used for the thorough mixing of the nanoparticles with the base fluid polyethylene glycol to form the nanofluid. In this process of nanofluid preparation no surfactants is added. For the effective comparison and results different volume concentrations with 0. 5%, 1%, 1. 5%, 2% and 2. 5% are prepared.

3. Experimental Setup and Procedure

Air cooled heat sink sometimes unable to dissipate heat due to excess temperature produced in the system, thus by making chances to choose liquid cooling system. In this paper a copper minichannel heat sink with seven passages is shown in figure 2 has been inspected by flowing the two different nanofluids Al_20_3-polyethylene glycol and $Ti0_2$-polyethylene glycol of different concentrations ranging from 0. 5%, 1%, 1. 5%, 2% and 2. 5% Vol. Figure 1 shows the schematic diagram of the Experimental setup with its important parts.

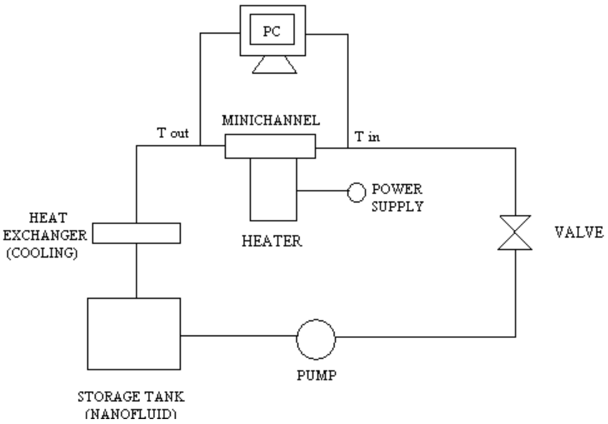

Fig. 1. Schematic Diagram of the Experimental Setup

The working fluid enters the loop from the reservoir through a filter and is continuously circulated by a pump. The experimental setup consists mainly of a copper minichannel heat sink, housing, contact type plate heater and a cover plate is shown in figure 1. The geometric structure of the heat sink fabricated is depicted schematically in fig. Seven parallel square minichannels (N=7) were machined into a copper block to form the minichannel heat sink.

The minichannels are equidistantly spaced with a fin width of 2mm and each has a length of 30mm with across sectional area of 2mm in width and 2mm in height. The inlet and outlet pendulums were fabricated at two ends of the minichannels to provide relative uniform flow distribution and the thermocouple is used for the temperature measurement.

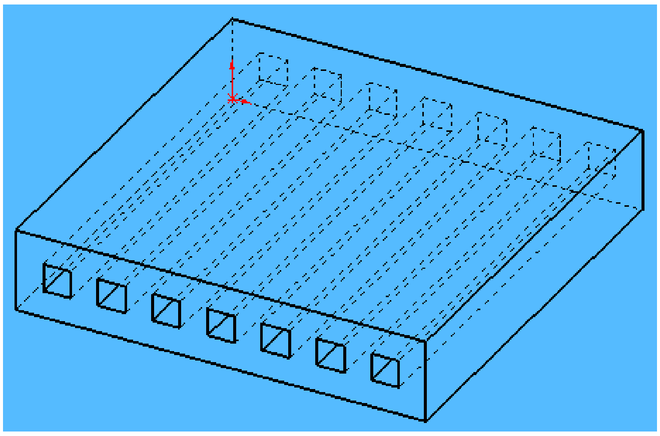

Fig. 2. Schematic diagram of Minichannel Heat Sink

The heat sink is given controlled heat input by using the contact type plate heater and the temperature is maintained constant**.** In this paper the temperature of the heat sink varied from 40°C to 80°C. At first Al_2O_3 polyethylene glycol nanofluid is passed through the heat sink and its heat transfer performance is analyzed for different volume concentration, secondly the TiO_2 polyethylene glycol nanofluid is used and its performance is evaluated.

3. 1 Data Reduction

In the present study Al_2O_3 polyethylene glycol and TiO_2 polyethylene glycol based nanofluids with particle fraction of 0. 5%, 1%, 1. 5%, 2% and 2. 5% are used as coolant in the copper minichannel heat sink to calculate the heat transfer performance. The steady state quantities measured in the experiment primarily include the volumetric flow rate, nodal temapratures of the thermocouple connected to the base of the heat sink as well as the inlet and the outlet fluid temparatures. The heat transfer of the nanofluid when passed through the minichannel is calculated by using the following equation

$$Q_{nf} = \dot{m}_{nf} \, C_{p_{nf}} \, (T_{out} - T_{in})_{nf}$$

Where Q_{nf} is the heat transfer rate of the nanofluid, $\dot{m}_{nf}$ is the mass flow rate of the nanofluid and T_{in} and T_{out} are the temperature of the nanofluid at inlet and exit to the test section. From the volumetric flow rate Q, the mean velocity Um is calculated based on the cross sectional area of the single minichannel.

Thereby the corresponding Reynolds number is defined by

$$Re = \rho_{nf} V_m D / \mu_{nf}$$

Where ρ_{nf} the density of the fluid, Vm is is the mean velocity of the nanofluid and μ_{nf} is the viscosity of the nanofluid.

The thermal conductivity of the nanofluids is determined by the equation

$$k = \frac{kp + (n-1)kf - (n-1)\varphi(kf - kp)}{kp + (n-1)kf + \varphi(kf - kp)} \times kf$$

The coefficient of heat transfer and Nusselt number of the nanofluid are calculated from the following equation

$$h_{nf} = Q_{nf} / [NA\,(T_s - T_{nf})]$$

$$Nu_{nf} = h_{nf} D_h / k_{nf}$$

Where h_{nf} is the heat transfer coefficient of the nanofluid, Ts is the average temperature of the heated surface of minichannel heat sink, T_{nf} is the bulk temperature of the nanofluid which is the average fluid temperature across the test section, Nu_{nf} is the Nusselt number of the nanofluid, Dh is the hydraulic diameter of the channel and k_nf is the thermal conductivity of the nanofluid.

4. Results and Discussion

The experimental result shows the thermal performance comparison of Al_2O_3 polyethylene glycol nanofluid and TiO_2 polyethylene glycol nanofluid passed in a copper minichannel heat sink. From the theoretical study the base fluid having poor thermal conductivity and heat transfer characteristics. In order to increase the thermal conductivity and heat transfer characteristics the nanoparticles are added to the base fluid. It is found that the thermal conductivity is directly proportional to the volume concentration the thermal conductivity of the Al_2O_3 polyethylene glycol nanofluid is 0. 2644W/mK at 2. 5%

volume concentration and for TiO_2 polyethylene glycol nanofluid the thermal conductivity at the same volume concentration is 0. 2638W/m-K.

The figure 3 shows the thermal conductivity of Al_2O_3 polyethylene glycol nanofluid and TiO_2 polyethylene glycol nanofluid with different volume concentrations. It is observed that the thermal conductivity of the Al_2O_3 polyethylene glycol nanofluid having more thermal conductivity than the TiO_2 polyethylene glycol nanofluid for the same volume concentration.

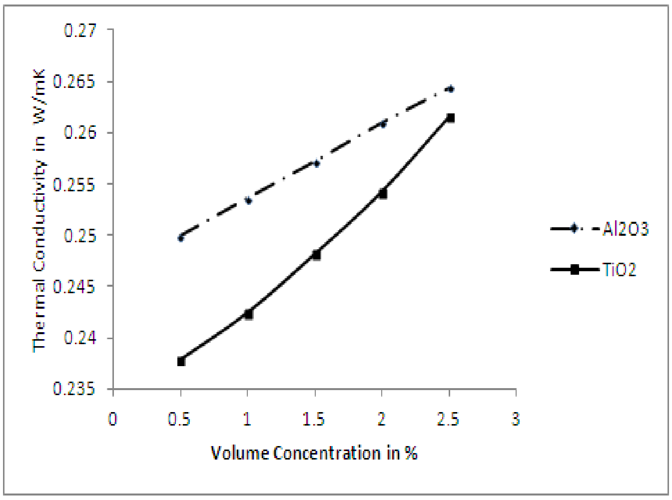

Fig. 3. Thermal conductivity of nanofluids

The figure 4 shows the comparison of heat transfer of Al_2O_3 polyethylene glycol nanofluid and TiO_2 polyethylene glycol nanofluid at various volume concentrations. From the study it is found that the heats transfer of Al_2O_3 polyethylene glycol nanofluid having higher performance than the TiO_2 nanofluid at 2. 5% volume concentration. Thermal conductivity of the nanofluid depends on the heat transfer coefficient.

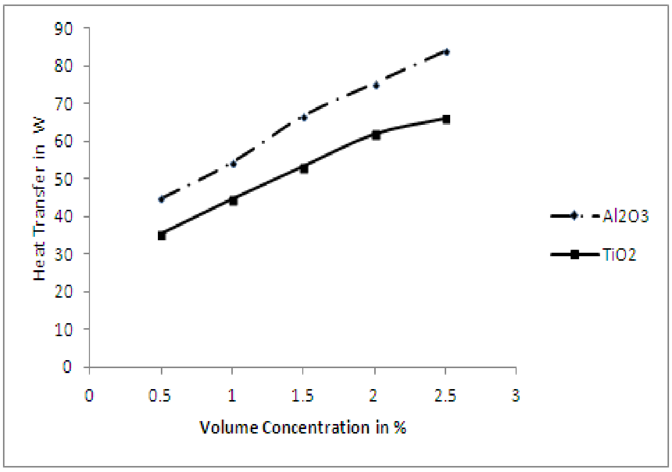

Fig. 4. Heat transfer by the nanofluids

It is obviously found that the heat transfer coefficients of the nanofluids are higher than those of the base fluids and increase with particle concentrations is shown in figure 5. This behavior due to nanoparticles presented in the base fluid increase the thermal conductivity which leads to an increase in the heat transfer performance. The heat transfer coefficient depends on the Reynolds number and the thermal conductivity.

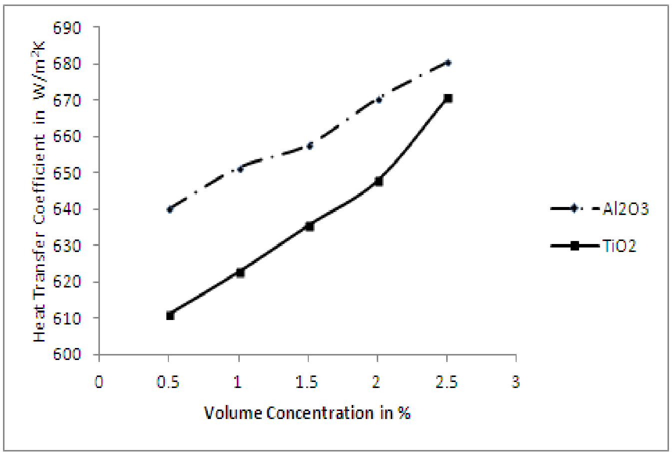

Fig. 5. Heat transfer coefficient of the nanofluids

Figure 6 shows the comparison of density of Al_2O_3 polyethylene glycol nanofluid and TiO_2 polyethylene glycol nanofluid at various volume concentrations. From the observation it is found that the TiO_2 polyethylene glycol nanofluid having more density than the TiO_2 polyethylene glycol nanofluids.

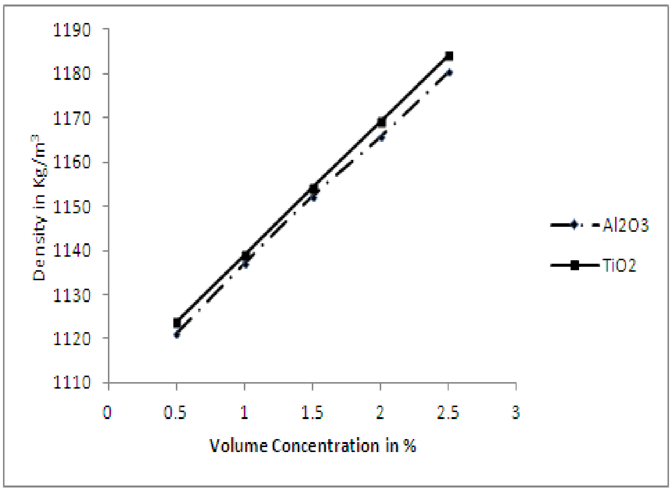

Fig. 6. Density of the nanofluids

The figure 7 is shown represents the comparison of viscosity of the Al_2O_3 polyethylene glycol nanofluid and TiO_2 polyethylene glycol nanofluid at various volume concentrations

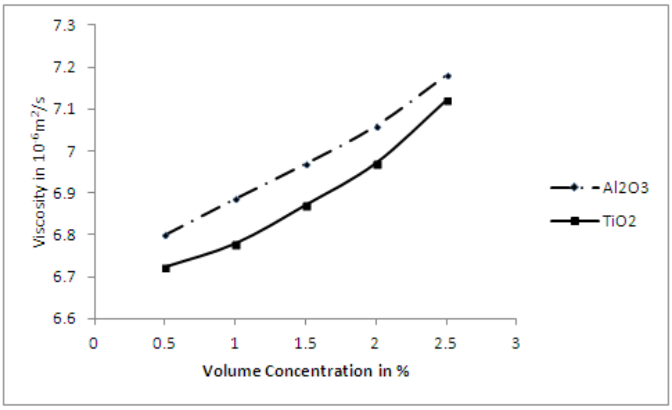

Fig. 7. Viscosity of the nanofluids

The specific heat of Al_2O_3 polyethylene glycol nanofluid and TiO_2 polyethylene glycol nanofluid at various volume concentrations is shown in figure 8. It is found that the specific heat decreases with increase in the volume concentration and the Reynolds number increases at the same time.

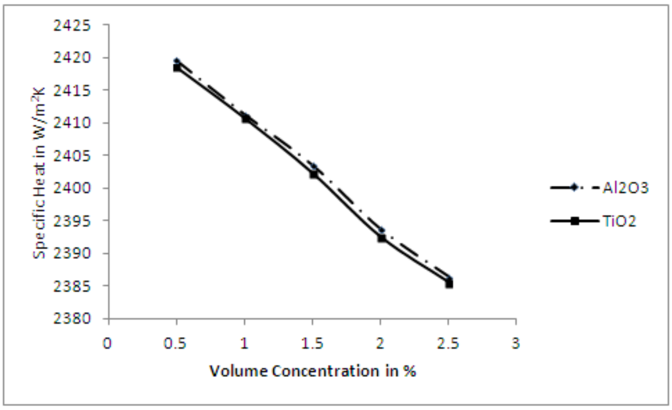

Fig. 8. Specific heat of the nanofluids

Figure 9 shows the comparison of heat flux among the Al_2O_3 polyethylene glycol nanofluid and TiO_2 polyethylene glycol nanofluid at various volume concentrations. It is found that the heat flux is directly proportional to the volume concentration and depends on the volumetric flow rate.

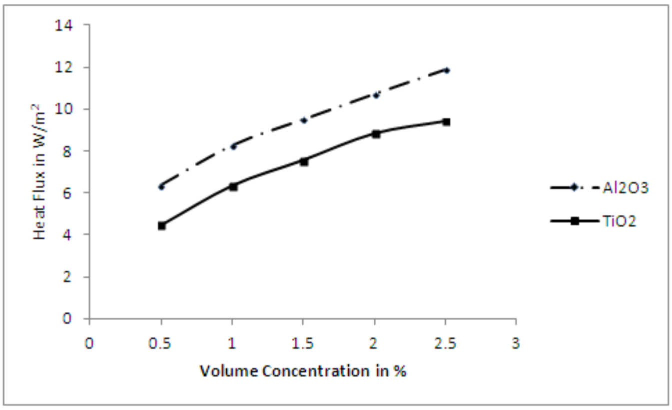

Fig. 9. Heat Flux of the nanofluids

5. Conclusion

In this paper the physical properties of Al_2O_3 polyethylene glycol and TiO_2 polyethylene glycol nanofluids is experimentally investigated. These two types of nanofluids of different volume concentrations were used as the working fluid flowing through a copper minichannel heat sink and the experimental results were compared and the following conclusions have been obtained.

1. The Specific heat and the density of the two different nanofluids were calculated
2. By the dispersion of Al_2O_3 nanoparticles and TiO_2 nanoparticles into the polyethylene base fluid at different volume concentration results in increasing the thermal conductivity of the base fluid.
3. The heat transfer is increased by using Al_2O_3 Polyethylene glycol and the maximum heat transfer obtained at 2. 5 % volume concentration for Al_2O_3 polyethylene glycol based nanofluid is 83. 88W and for TiO_2 polyethylene glycol nanofluid at the same volume concentration is 66. 1W.
4. The heat flux of the Al_2O_3 polyethylene glycol nanofluid and TiO_2 polyethylene glycol nanofluid at 2. 5% volume concentration are 11. 902 W/m^2 and 9. 446 W/m^2 respectively.

Nomenclatures

Cp	-Specific heat (J/Kg K)
Dh	-Hydraulic diameter of the Fluid flow(m)
f	-Friction factor
h	-Heat transfer coefficient ($W/m^2 K$)
k_{nf}	-Thermal conductivity of Nanofluid (W/m K)
k_f	-Thermal conductivity of base fluid (W/m K)
ks	-Thermal conductivity of heat sink (W/m K)
L	-Channel length (m)
Nu	-Nusselt number
N	-Number of cooling channels
P	-Pressure (K Pa)
ΔP	-Pressure drop (K Pa)
Q	-Heat generation (W)
q	-Heat flux(W/cm^2)
Re	-Reynolds number
Wc	-Channel width (m)
Ww	-Channel wall thickness (m)
Vm	-Inlet velocity (m/s)
V	-Volumetric flow rate (m^3)
Pp	-Pumping power (W)
m	-Total mass flow rate of fluid (kg/s)

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