Research Article **ISSN: 2395 – 5597**

International Journal of Engineering and Robot Technology

EFFECTIVENESS STUDY ON Al_2O_3-TiO_2 NANOFLUID HEAT EXCHANGER

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ABSTRACT

Conventional coolants have poor thermal conductivity which makes them inadequate for high cooling applications**.** Due to the high thermal conductivity of metals, it is suspended in the base fluid in order to improve the thermal conductivity. Nanofluids is defined as the dispersion of the nanoparticles in the conventional heat transfer such as water, ethylene glycol etc. which enhances the heat transfer performance compared to conventional fluids. This article focuses on the synthesis and analysis of Al_2O_3-TiO_2nanofluids using two step method and an experimental study on heat transfer analysis using tubular heat exchanger. The results show that the heat transfer characteristics and effectiveness of the nano fluid is higher than that of the conventional heat transfer fluids. The thermal conductivity of then a nofluid also increases with increase in volume concentration of nanofluid.

KEYWORDS

Al_2O_3-TiO_2 Nanofluid, Heat transfer enhancement, Nanofluid, Tubular heat exchanger and Thermal conductivity enhancement.

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INTRODUCTION

Thermal properties of coolants play an important role in heating and also in cooling applications. Conventional coolants such as water, engine oil, and ethylene glycol have inherently poor thermal conductivity which makes them inadequate for high cooling applications. Due to the low heat transfer properties of conventional coolants, the performance enhancement and the compactness of heat exchangers is affected. So, there is a need for the improvement of heat transfer properties of conventional coolants. The heat transfer properties of the conventional coolants can be improved by suspending the solid particles. The recent studies have proven that the suspension of the nano particles in the base fluid will alter the heat transfer properties of the coolants.

MATERIAL AND METHODS

Nanofluids

Nanofluids are liquids that contains solid nanoparticles with size typically of 1 to 100 nm suspended in liquid. Nanofluids have become the point of interest due to the reports of improved heat transfer properties. When compared to the larger size particles, the resistance to the sedimentation shown by the nanoparticles is higher because of the Brownian motion. The nanofluidis with stable suspension for long durations can be achieved by reducing the density between solids and liquids or by increasing the viscosity of the liquid.

Preparation of Nanofluids

The nanofluids can be prepared by two methods, they are,

Single-Step Direct Evaporation Method

In this method, the direct evaporation and condensation of the nanoparticles in the base liquid are obtained to produce stable nanofluids. Moreover, nanofluids made using this method showed higher conductivity enhancement than the ones made using 2-step method. But a disadvantage of the method is that only low vapor pressure fluids are compatible with the process[1]. It limits the applications of the method.

Two-Step Method

In this method, nanoparticles are first prepared in a form of powders by physical or chemical methods, e.g. grinding, laser ablation, inert gas condensation, chemical vapor deposition, sol-gel processing, etc. and then suspended in base fluid. Nanopowders were mixed with water and stabilizers and then sonicated by ultrasonic mixer for a set period of time. This method of production is cheaper, because nanopowders are produced on large scale.

However, due to large and active surface area nanoparticles tend to agglomerate and settle down in the base fluid. Therefore, in order to prepare a stable nanosuspension sonication, stabilizers/surfactant are added. In this method a small amount of suitable surfactant is added to the base fluid and stirred continuously for few hours. The nanoparticles remain in suspension state for a long time without settling down at the bottom of the container. Some of the surfactant are sodium lauryl sulfate, Triammonium citrate, diammonium hydrogen citrate, sodium hexametafosfate (SHMP), sodium dodecyl benzene sulfonate (SDBS), acetic acid and formic acid.

Properties of Nanofluid

Three properties that make nanofluids promising coolants are:

- Increased thermal conductivity,
- Increased single-phase heat transfer,
- Increased critical heat flux.

Therefore, exploiting the unique characteristics of nanoparticles, nanofluids are created with two features very important for heat transfer systems: (i) high stability, and (ii) high thermal conductivity.

Effect of Nanoparticles in Base Fluid

Compared to micrometer sized particles, nanoparticles possess high surface area to volume ratio due to the occupancy of large number of atoms on the boundaries, which make them highly stable in suspensions. Since the properties like the thermal conductivity of the nano sized materials are typically an order of magnitude higher than those of the base fluids, nanofluids show enhancement in their effective thermal properties. Due to the lower dimensions, the dispersed nanoparticles can behave like a base fluid molecule in a suspension, which helps us to reduce problems like particle clogging, sedimentation etc. found with micro particle suspensions. The combination of these two features; extra high stability and high conductivity of the nanofluids make them highly preferable for designing heat transfer fluids. The stable suspensions of small quantities of nanoparticles will possibly help us to design lighter, high performance thermal management systems.

Applications

Nanofluids can be used as coolants in various application such as electronic power circuits, car engines, HVAC, high power lasers, X-ray generators, boilers, nuclear reactor, powerplants, microelectronics, manufacturing, metrology, defence etc. So the enhanced heat transfer characteristics of nanofluids may offer the development of high performance, compact, cost effective liquid cooling.

SYNTHESIS OF NANOFLUID

Characterization of the nanoparticles

The average size of the nanoparticles in characterized using SEM (Scanning Electron Microscope). The SE Mmicrograph of the Al_2O_3 and TiO_2 nanoparticles are shown in Figure No.1 and 2 respectively. The size of Al_2O_3 nanoparticle is around 40 nm and the size of TiO_2 nanoparticle is around 30 nm. The shape of both Al_2O_3 and TiO_2 is spherical.

Preparation of Al_2O_3 and TiO_2 nanofluid

In this paper, a new combination of Al_2O_3-TiO_2 nanofluid with water as base fluid is synthesized by using Two step method with Sodium lauryl sulfate (SLS) as surfactant. Three different volume concentrations (0.15%, 0.22% and 0.29%) of Al_2O_3-TiO_2hybrid nanofluid is produced. Aluminium oxide (Al_2O_3) and Titanium oxide (TiO_2) nanoparticles are taken in the 2:1 weight proportions and mixed in water (Base fluid).Nanoparticles were mixed with water along with required amount of stabilizers (surfactant) and then sonicated by using an ultrasonic vibrator generating ultrasonic pulses of 180 W at 40 kHz as shown is Figure No.3. Uniform dispersion and stable suspension of nanofluids can be achieved by keeping it in ultrasonic vibrator continuously for 3-4 hours. The properties of Aluminum oxide (Al_2O_3) and Titanium oxide (TiO_2) nanoparticles are given in Table No.1.

Measurement of thermo physical properties of nanofluid

Some of the thermo physical properties of a fluid are thermal conductivity, viscosity, specific heat, density etc. The thermal conductivity of Al_2O_3-TiO_2hybrid nanofluid was measured by using a Nanofluid interferometer. The viscosity of the nanofluid was measured using DV1 digital Brookfield viscometer, which has an accuracy of +/- 1.0%. A simple calorimeter shown in Figure No. 4 is designed and fabricated to measure the specific heat of the nanofluid. It has an accuracy of about +/-5.4%. It consists of 7.5 ohm resistor, a digital thermocouple, variable power supply and well insulated container. In this experiment, the specific heat of nanofluid was measured by heating a small quantity of nanofluid with a known power input, and measuring the temperature change over a period of time. Experimental error due to heat transfer to or from the surroundings was minimized by taking measurements an equal amount of time before and after the ambient temperature was reached.

Mathematical modelling of Nanofluid properties

Volume fraction

The volume fraction (φ) is the percentage of volume of nanoparticles to the mixture volume of base fluid (water) with nanoparticles. This is obtained from law of mixture [1].

$$\text{Volume concentration} = \frac{\frac{W_{Al_2O_3}}{\rho_{Al_2O_3}}+\frac{W_{TiO_2}}{\rho_{TiO_2}}}{\left(\frac{W_{Al_2O_3}}{\rho_{Al_2O_3}}+\frac{W_{TiO_2}}{\rho_{TiO_2}}\right)+\frac{W_b}{\rho_b}} \quad (1)$$

Density

The nanofluid density is calculated by Pak and Cho correlations [3],

$$Density = (1-\emptyset)\,\rho_b + \left(\frac{\emptyset * N_1}{2} * \rho_{Al_2O_3} + \frac{\emptyset * N_2}{2} * \rho_{TiO_2}\right), kg/m^3 \quad (2)$$

Specific heat

The specific heat of nanofluid is calculated from Xuan and Roetzel as following [3],

$$Specific\ heat = (1-\emptyset)\,Cp_b + \left(\frac{\emptyset * N_1}{2} * Cp_{Al_2O_3} + \frac{\emptyset * N_2}{2} * Cp_{TiO_2}\right), \frac{J}{kg\,K} \quad (3)$$

Thermal conductivity

Maxwell formulated the expression to calculate the thermal conductivity [3],

$$k_{nf} = \left(\frac{((N_1 * k_{Al_2O_3} + N_2 * k_{TiO_2}) + (2 * k_b) - 2 * (k_b - (N_1 * k_{Al_2O_3} + N_2 * k_{TiO_2})) * \emptyset)}{((N_1 * k_{Al_2O_3} + N_2 * k_{TiO_2}) + 2 * k_b + (k_b - (N_1 * k_{Al_2O_3} + N_2 * k_{TiO_2})) * \emptyset)}\right) * k_b, \frac{W}{m\,K} \quad (4)$$

Viscosity

The viscosity can be calculated using the Drew and Passman relation [3],

$$viscosity = (1 + 2.5 * \emptyset) * \mu_b, \frac{N.s}{m^2} \quad (5)$$

EXPERIMENTAL TEST RIG

Modelling Of Experimental Setup

The below figure 5 shows the model of the experimental setup that is being fabricated. Tubular heat exchanger is modelled using Auto CAD software.

Tubular heat exchanger

Tubular heat exchanger is a device used to transfer heat from hot nanofluid to the cold water. It consist of five k- type thermocouples to measure the inlet and outlet temperature of nanofluid and water. The control valves can be controlled to vary the flow of cold water either as parallel flow or counter flow. The rota meter is used to measure and adjust the flow rate of water and nanofluid. The heating unit is placed in nanofluid reservoir to heat the nanofluid. Pumps with maximum delivery of 15 lpm is used to deliver the water and nanofluid in the heat exchanger. The complete system will be very dynamic and easy to use. It is used to calculate the heat transfer characteristics of the nanofluid.

Heat transfer equations

Heat transfer rate can be defined as [4]

$$Q=m*Cp*\Delta T \quad (6)$$

Where, Q is the heat transfer rate, m is the mass flow rate and ΔT is the temperature difference of the nanofluid.

The logarithmic mean temperature difference [4],

$$\Delta T_{lm} = \frac{(T_{ci}-T_{no})-(T_{co}-T_{ni})}{Ln((T_{ci}-T_{no})/(T_{co}-T_{ni}))} \quad (7)$$

Where, $\Delta T_{lm}$is the logarithmic temperature difference, $T_{ci}$is the inlet temperature of the water, $T_{co}$is the outlet temperature of water, $T_{ni}$is the inlet temperature of the nanofluid and $T_{no}$is the outlet temperature of the nanofluid.

The overall heat transfer coefficient is [4],

$$Q = U * A_s * \Delta T_{lm} \quad (8)$$

Where, U is the overall heat transfer coefficient and As is the surface area.

The effectiveness of nanofluid is given by

$$\varepsilon = \frac{m_h * C_{pn} * (T_{ni} - T_{no})}{C_{min} * (T_{ni} - T_{ci})} \quad (9)$$

Where, $Cmin$ is the minimum of Cpn and Cpc.

RESULTS AND DISCUSSION

The thermo physical properties such as thermal conductivity, viscosity, specific heat, density etc. of Al_2O_3-TiO_2hybrid nanofluid are measured and compared with theoretical results. The heat transfer analysis of different volume concentration (0.15%, 0.22% and 0.29%) of Al_2O_3-TiO_2 nanofluid using the tubular heat exchanger had been completed and the results of Al_2O_3-TiO_2 nanofluid are compared with values of distilled water.

Thermal conductivity

Thermal conductivity is the property of the material to conduct heat. As the volume concentration of the Al_2O_3-TiO_2 nanofluid (0.15%, 0.22% and 0.29%) increases, the thermal conductivity of the Al_2O_3-TiO_2 nanofluid increases. The increase in thermal conductivity of the Al_2O_3-TiO_2/water nanofluids for volume concentrations 0.15%, 0.22% and 0.29% are 21%, 40%, 67% respectively when compared to thermal conductivity of distilled water. The actual thermal conductivity of the Al_2O_3-TiO_2 nanofluid is lesser than the theoretical thermal conductivity which is calculated using Maxwell relation. The decrease in actual thermal conductivity of the Al_2O_3-TiO_2water nanofluids is 6% when compared to the theoretical thermal conductivity.

Viscosity

Viscosity is a measure of the tendency of a liquid to resist flow. As the volume concentration of the Al_2O_3-TiO_2 nanofluid (0.15%, 0.22% and 0.29%) increases, the viscosity of the Al_2O_3-TiO_2 nanofluid increases. The increase in viscosity of the Al_2O_3-TiO_2/water nanofluids for volume concentrations 0.15%, 0.22% and 0.29% are 17%, 38%, 55% respectively when compared to viscosity of distilled water at 25^0C. The actual viscosity of the Al_2O_3-TiO_2 nanofluid is lesser than the theoretical viscosity which is calculated using Drew and Passman relation. The decrease in actual viscosity of the Al_2O_3-TiO_2/water nanofluids is 5% when compared to the theoretical viscosity.

Specific heat

Specific heat is defined as the amount of heat required to raise the temperature of 1 gram of substance by 1^0C. As the volume concentration of the Al_2O_3-TiO_2 nanofluid (0.15%, 0.22% and 0.29%) increases, the specific heat of the Al_2O_3-TiO_2 nanofluid decreases. The decrease in specific heat of the Al_2O_3-TiO_2/water nanofluids for volume concentrations0.15%, 0.22% and 0.29% are 5.13%, 9.14%, 12.66% respectively when compared to specific heat of distilled water. The actual specific heat is around 1.5% lesser than the theoretical viscosity which is calculated using Xuan and Roetzel relations.

Density

Density of a fluid is defined as the mass per unit volume. As the volume concentration of the Al_2O_3-TiO_2 nanofluid (0.15%, 0.22% and 0.29%) increases, the density of the Al_2O_3-TiO_2 nanofluid increases. The increases in density of the Al_2O_3-TiO_2/water nanofluids for volume concentrations 0.15%, 0.22% and 0.29% are 12.22%, 25.86%, 38.2% respectively when compared to density of distilled water. The actual density is around 7% more than the theoretical density which is calculated using Pak and Cho relations.

Effectiveness

Effectiveness is defined as the ratio of the actual heat transfer to the maximum possible heat transfer. As the volume concentration of the Al_2O_3-TiO_2 nanofluid (0.15%, 0.22% and 0.29%) increases, the Effectiveness of the Al_2O_3-TiO_2 nanofluid increases. The increases in Effectiveness of the Al_2O_3-TiO_2/water nanofluids for volume concentrations 0.15%, 0.22% and 0.29% in parallel flow are 7%, 10%, 14% respectively when compared to density of distilled water.

The increases in Effectiveness of the Al_2O_3-TiO_2/water nanofluids for volume concentrations 0.15%, 0.22% and 0.29% in counter flow are 5%, 9%, 13% respectively when compared to Effectiveness of distilled water.

Table No.1: Properties of nanoparticles

S.No		Aluminium oxide (Al_2O_3)	Titanium oxide (TiO_2)
1	Thermal conductivity, W/ m K	$K_{Al_2O_3}$ = 38	K_{TiO_2}=12
2	Specific heat,J/ kg K	$Cp_{Al_2O_3}$ = 765	Cp_{TiO_2} = 685
3	Density, kg/m^3	$\rho_{Al_2O_3}$ = 3970	ρ_{TiO_2}= 4230

Table No.2: Symbols used

S.No	Symbol	Nomenclature	Unit
1	ϕ	Volume concentration	%
2	V	Voltage	Volt
3	I	Current	Ampere
4	$W_{Al_2O_3}$	Weight of Al_2O_3 nanoparticle	Grams
5	W_{TiO_2}	Weight of TiO_2 nanoparticle	Grams
6	$\rho_{Al_2O_3}$	Density of Al_2O_3 nanoparticle	kg/m^3
7	ρ_{TiO_2}	Density of TiO_2 nanoparticle	kg/m^3
8	W_b	Weight of distilled water	Grams
9	ρ_b	Density of distilled water	kg/m^3
10	N_1	Proportion of Al_2O_3 nanoparticle added	_
11	N_2	Proportion of nanoparticle added	_
12	$Cp_{Al_2O_3}$	Specific heat of Al_2O_3 nanoparticle	J/ kg K
13	Cp_{TiO_2}	Specific heat of TiO_2 nanoparticle	J/ kg K
14	$k_{Al_2O_3}$	Thermal conductivity of Al_2O_3 nanoparticle	W/ m K
15	k_{TiO_2}	Thermal conductivity of TiO_2 nanoparticle	W/ m K
16	μ_b	Viscosity of water	Ns/m^2

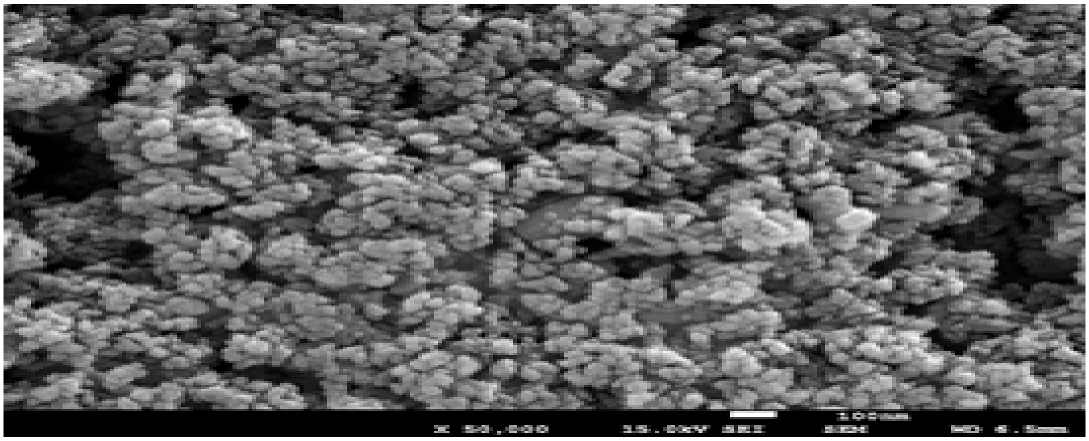

Figure No.1: SEM image of Al_2O_3 nanoparticles

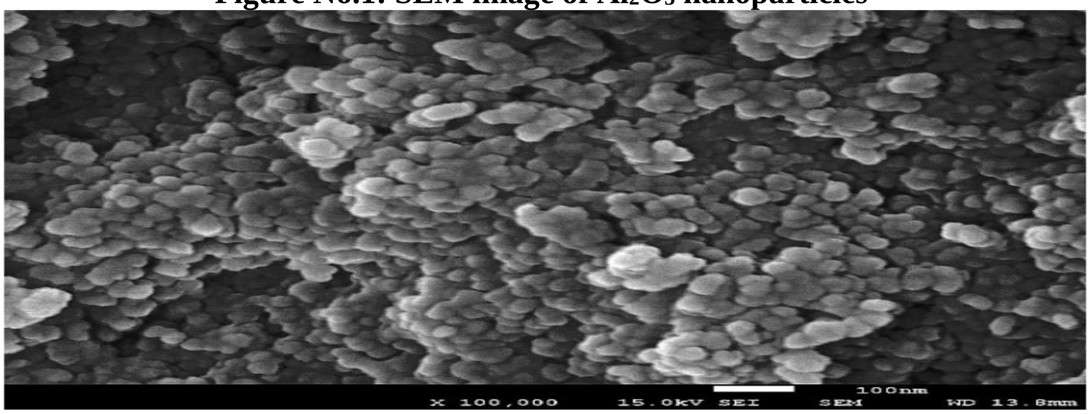

Figure No.2: SEM image of TiO_2 nanoparticles

Figure No.3: Al_2O_3–TiO_2nanofluid

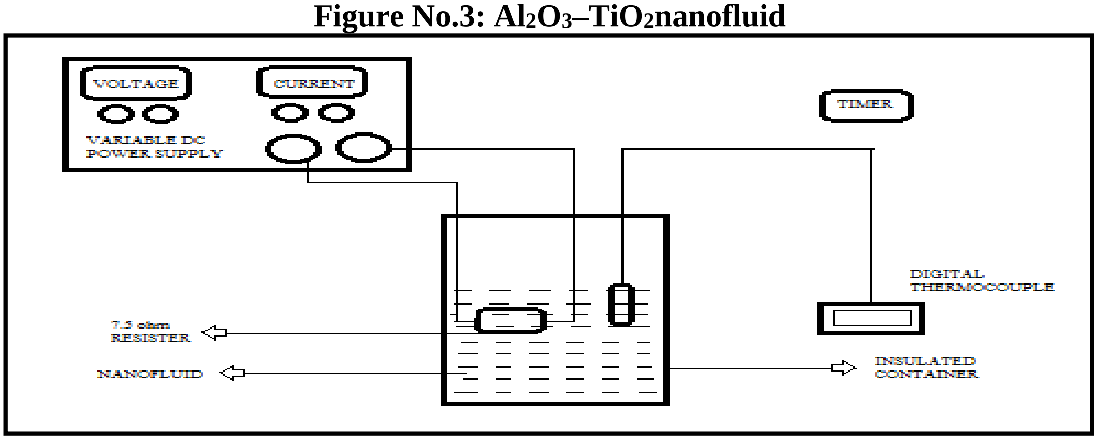

Figure No.4: Experimental setup of simple Calorimeter

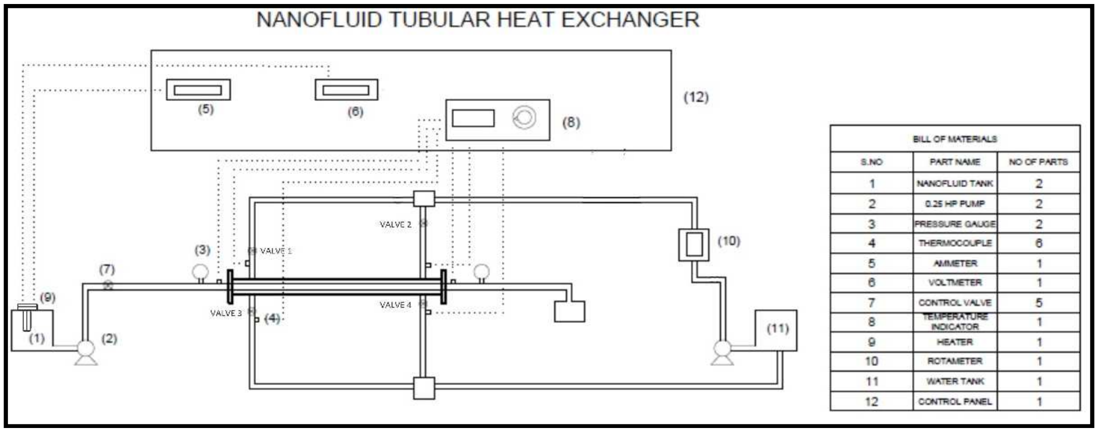

Figure No.5: Autocad model of Tubular heat exchanger

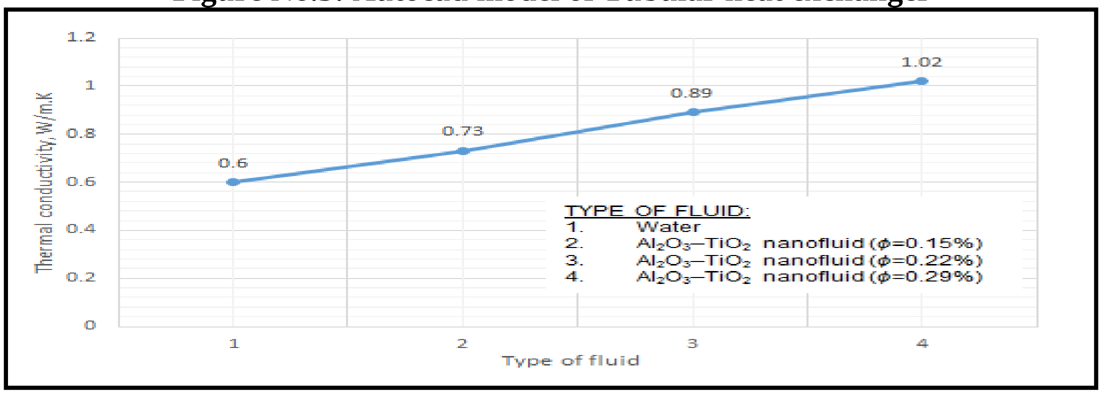

Figure No.6: Thermal conductivity of various fluids

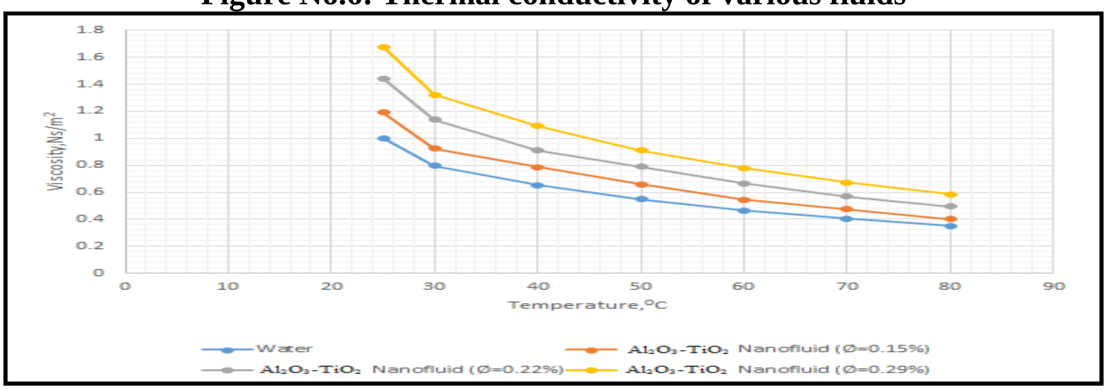

Figure No.7: Viscosity as the function of temperature for different fluids

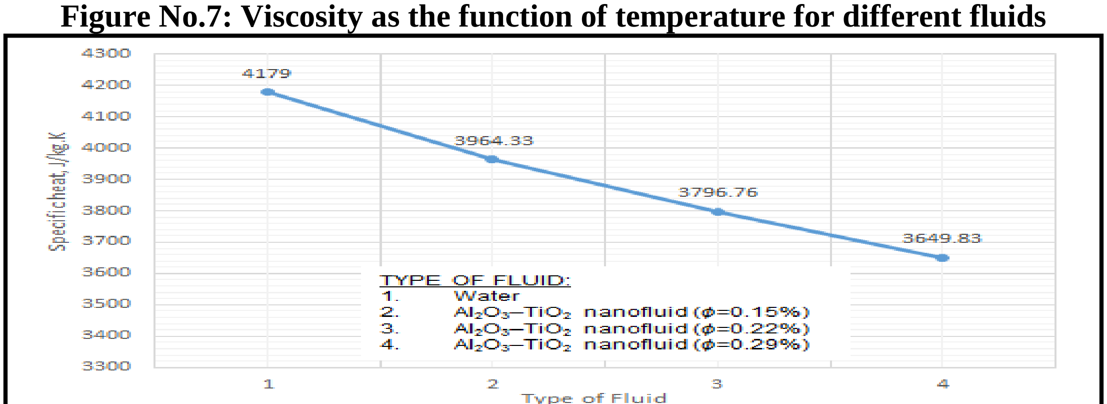

Figure No.8: Specific heat of various fluids

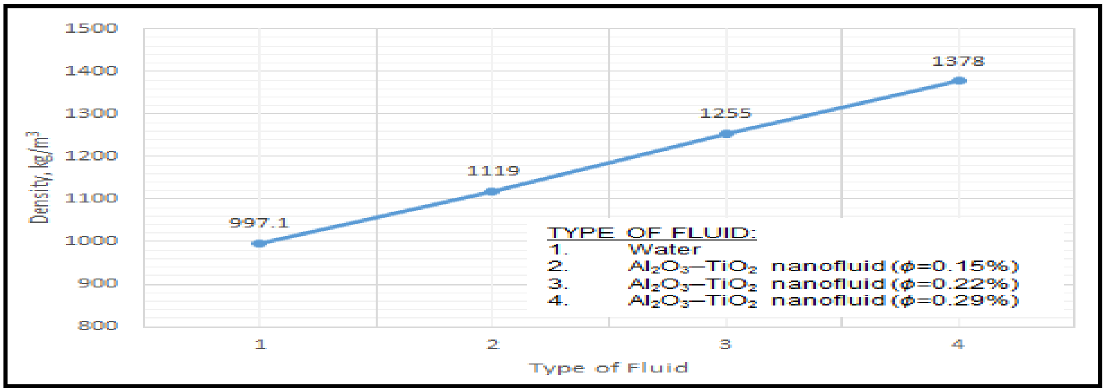

Figure No.9: Density of various fluids

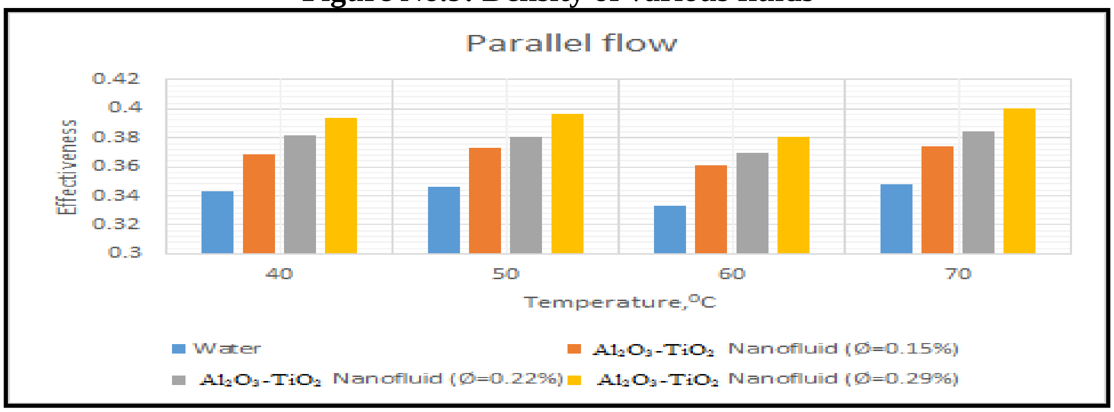

Figure No.10: Effectiveness of various fluids in parallel flow

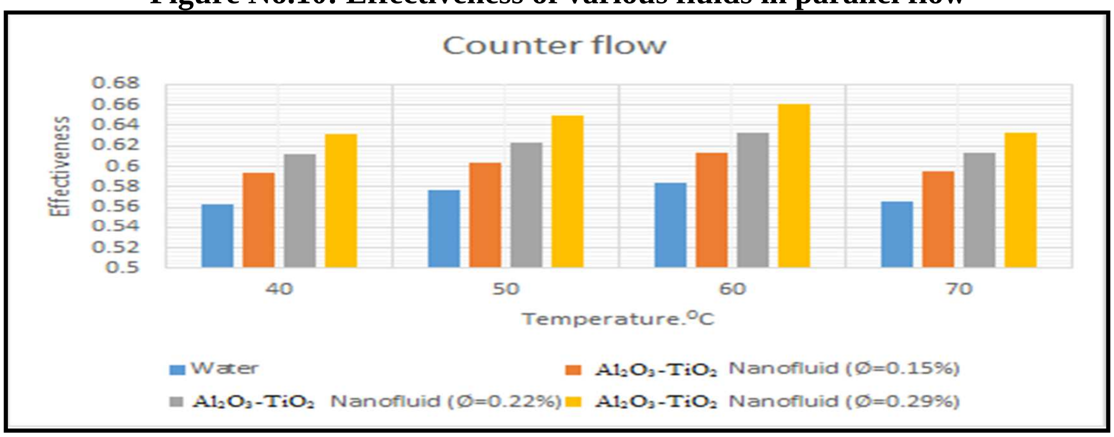

Figure No.11: Effectiveness of various fluids in counter flow

CONCLUSION

From the experimental investigation, it is evident that there is a significant enhancement in thermal conductivity of the Al_2O_3-TiO_2 nanofluids compared with deionized water. It has also been observed that the thermal conductivity Al_2O_3-TiO_2 nanofluids increases remarkably with increasing volume concentration of nanofluids. The viscosity values for Al_2O_3-TiO_2 nanofluids are higher when compared to the viscosity of water. It is observed that specific heat of the Al_2O_3-TiO_2 nanofluids decreases with increase in volume concentration. The experimental results have been compared with the existing theoretical models. It has been found that the experimental results are slightly less than those predicted by existing models. It is found that heat transfer rate and effectiveness of the Al_2O_3-TiO_2 nanofluids increases significantly with the increase in volume concentration of nanofluids.

ACKNOWLEDGMENT

We are very thankful to Department of Mechanical Engineering, PSG college of Technology, who supported us throughout the work and we would also like to thank the College Management, for providing the fund and the necessary facilities to carry out this work.

CONFLICT OF INTEREST

We declare that we have no conflict of interest.

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Please cite this article in press as: Senthilkumar A P *et al.* Effectiveness study on Al_2O_3-Tio_2 nanofluid heat exchanger, *International Journal of Engineering and Robot Technology*, 3(2), 2016, 73 - 81.