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Increasing the effectiveness of heat exchanger using Al_2O_3 nano particle mixed working fluid

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ABSTRACT

This article reports an experimental study on the convection type heat transfer and flow characteristics of a nanofluid consisting of water with different volume concentrations (0.5–1.25) % of Al_2O_3. Nanofluid is flowing in a double pipe type heat exchanger with counter-flow under laminar flow. Aluminum Oxide (Al_2O_3) nano-particles of about 20 to 30 nm are used in the present study. From the experiment the results are shown that the convective heat transfer coefficient of nanofluid is slightly higher than that of the base fluid (water) at same mass flow rate and at same inlet temperature. There is an increase in heat transfer coefficient with an increase in nanofluid mass flow rate, also the heat transfer coefficient increases with the increase of the volume concentration of the Al_2O_3 nanofluid. But increase in the volume concentration cause a relative increment in the viscosity of the nanofluid which leads to increase in friction factor.

KEY WORDS: Nano particle, Aluminum Oxide, Nano Fluid, Heat exchanger, Viscosity, Effectiveness

1. INTRODUCTION

Nano particles are relatively advance class material which is used in conventional heat exchanger and enhancing the fluid characteristics. Nanoparticle of size 1-100mm, when suspended along with conventional base fluid is called nanofluid. As solids are better thermal conductivity and heat capacity than fluid, therefore nanoparticles are dilute suspended into conventional base fluid to increase effectiveness of heat exchanger, which is creating a new scope in nano technology. According to new scientific research, nanoparticle suspended base fluid has shown remarkable improvement in its characteristics. Nanoparticles are divided basically two types- (a) Metal-Oxide and (b)Non-Metal Oxide. Nano Particle possessed heat exchanger has effective increase in heat transfer as compared to conventional heat exchanger due to following reasons Choi (1995) a) Due to increase in surface area between nanoparticle and base fluid. b) Brownian motion of nanoparticles make it more stable in high dispersion. c) Remarkable increase in heat transfer causes reduction in pumping power as compare to conventional system to achieve same amount of heat transfer. d) By changing the concentration of addition of nanoparticle with base fluid can adjust heat transfer as well as surface wet ability. Sabareesh, (2012) performed an experiment on refrigerant R12 based vapour compression refrigeration system. In this experiment nanofluid (small concentration TiO_2) was used. According to this experiment nanoparticle suspended refrigerant increase viscosity of refrigerant, but frictional coefficient decreased as increase in volume concentration of nanoparticles. The rate of heat transfer increased by 3.6% with increase in volume fraction of 0.01%. There was a significant increase in COP followed by decrease in compressor work by 11%. Thus it is cleared that by using nanoparticle dispersed refrigerant the performance of vapour compression system increased. An experiment to monitor the behavior of TiO_2 nanoparticle suspended refrigerant R141b during nucleate pool boiling shows reduced the rate of boiling heat transfer by dispersing TiO_2 nano particle increased from 0.03% to 0.05%(vol.). At higher heat flux rate the boiling heat transfer coefficient decreased at an increased volume concentration. Eastman, (1996), Liu (2006), Hwang (2006), Yu (2009), and Mintsa (2009), noticed significant increase of nanofluids thermal conductivity compared to conventional fluid. Improvement of convective heat transfer was investigated by Zeinali Heris (2007), Kim, Jung (2009), and Sharma (2009).

Torii and Yang (2009), studied the convective heat transfer behavior of aqueous suspensions of nano diamond particles flowing through a horizontal tube heated under a constant heat flux condition. Their experimental system consisting of a flow loop, a power supply unit, a cooling device, and a flow measuring and control unit. The flow loop includes a pump, a digital flow meter, a reservoir, a collection tank, and a test section. A straight seamless stainless tube with 1000 mm length, 4.0 mm inner diameter, and 4.3 mm outer diameter was used as the test section. The whole test section was heated with the aid of the Joule heating method through an electrode linked to a dc power supply. They reported that (i) significant enhancement of heat transfer performance due to suspension of nano diamond particles in the circular tube flow was observed in comparison with pure water as the working fluid, (ii) the enhancement was intensified with an increase in the Reynolds number and the nano diamond concentration, and (iii) substantial amplification of heat transfer performance is not attributed purely to the enhancement of thermal conductivity due to suspension of nano diamond particle.

Preparation of Nanoparticle Blended Fluid:

Preparation of nano particle: The method implemented in the synthesis of Al_2O_3 by sol-gel method were of two different ways: (a) inorganic – aluminum chloride ($AlCl_3$) and (b) organic – aluminum tri-isopropylate $(C3H7O)_3Al$.

First method: In this case the solution-gel synthesis can be prepared by 0.1M $AlCl_3$ ethanolic solution. Solution gel was formed by adding a 28% NH_3. The formed gel was let to prepare for 30 hours at room temperature and then dried at 100° C for 24 hours.

Second method: In this method $C_9H_21AlO_3$ used as precursor, the sol-gel synthesis consisted in the preparation of a 0.1 M $(C_3H_7O)_3Al$ ethanolic solution. Solution gel was formed by adding a 28% NH_3. Mild shaking at 90° C for10 hours was utilized. The gel was let to prepare at room temperature for 24 hours, and then dried at 100° C for 24 hours. The resulting gels were introduced for calcination in a furnace for 2 hours (heating rate 20° C/min.), at temperature of 1000° C and 1200° C.

Confirmation of size of nano-particle using SEM test: Alumina possesses strong ionic inter atomic bond, it can exist in several crystalline phases which all near to the most stable hexagonal alpha phase at high temperature. Due to this alpha phase aluminum oxide is the strongest and stiffest to beta phase aluminum oxide ceramics. It possesses high hardness property, good dielectric properties, good thermal properties makes it good for many applications. From SEM test it is found that the size of nano-particle is 20~30nm as shown in the Figure 1.

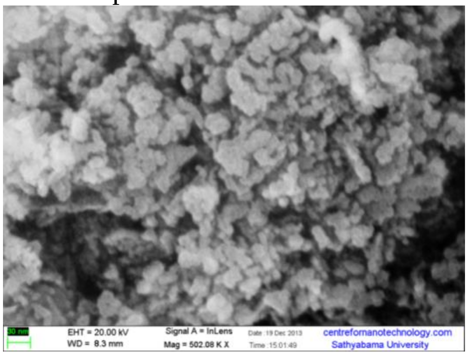

Figure.1.SEM images of aluminum oxide nanoparticles

Testing of element present in nano particle using XRD test: As shown in Figure 2. It is confirmed that nano powder is containing 99.99% pure aluminum oxide. The XRD analysis spectrograph of aluminum oxide shown in Figure 1. The granular size of aluminum oxide nano particle was calculated using Scherrer Formula

$$D = \frac{K\lambda}{\beta \cos\theta} \;\ldots\ldots\ldots\ldots..(1)$$

Here D is the average grain size of the nanoparticles, K is the shape factor, λ is the X-ray refer to wave length denote as the Bragg angle and β is the line broadening at half the maximum intensity.

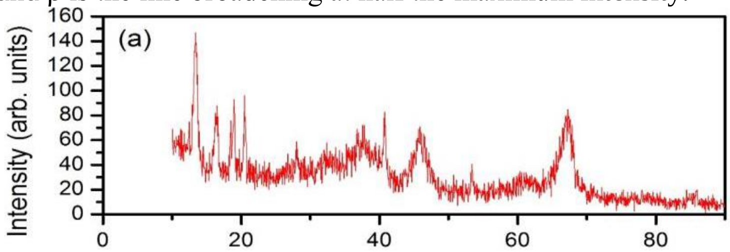

Figure.2.XRD analysis of Aluminum Oxide

Preparation of nano fluid: The amount of nanoparticle required to prepare the nanofluid with different volume concentrations can be calculated from equation (2).

$$\%\ \text{Volume Concentration } (\varphi) = \left[\frac{\frac{W_{nanopaticle}}{P_{nanoparticle}}}{\frac{W_{nanopaticle}}{P_{nanopaticle}}+\frac{W_{water}}{P_{water}}}\right] X\ 100 \qquad \ldots\ldots\ldots(2)$$

To get uniform dispersion of nanoparticles in water, the prepared nanofluids were sonicated for 3 hrs using ultrasonic sonicator. Sonication is the act of applying sound energy for proper mixing of any sample, for various proportion. Ultra sonic frequencies (>30 kHz) are usually used, this process also known as ultrasonication. Then the nanofluid was stirred using magnetic stirrer for 1 hr after preparing the nanofluid. No sedimentation was observed for several hours.

2. EXPERIMENTAL SETUP

The experimental set up as shown in the Figure 3 could be used to transfer heat from nano fluid in a heat exchanger to water stored in a separate tank and make temperature calibrations for the same by employing two thermocouples. Also, Rotameter are installed in the pipes carrying nanofluid and water to check respective flowing rates. The complete system will be very dynamic and easy to use. It consists of two flow loops, a heating unit to heat the nanofluid and temperature measurement system. The two flow loops carries heated nanofluid and the other cooling water. Each flow loop includes a pump with a Rotameter, a reservoir and a by-pass valve to maintain the required flow rate. Thermocouples are inserted on the heat exchanger to measure the bulk temperatures of inlet and outlet fluid streams. The pumps are used with maximum delivery rate of 800 LPH.

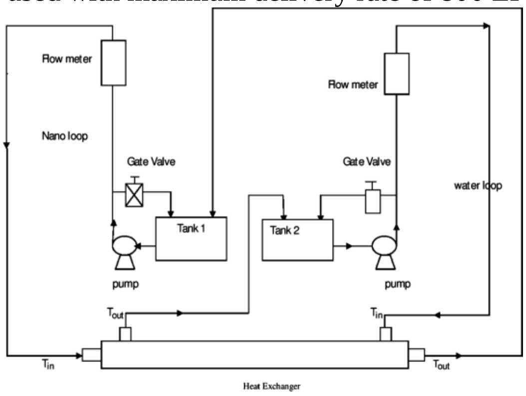

Figure.3. Experimental setup

3. RESULT AND DISCUSSIONS

The results of experimental study by using aluminum oxide nanofluid in different concentration have been discussed as below

Physical propreties: The experiment is conducted with different concentration of nano particle. As there is an increase in volume percentage of nano particle which also affect the physical properties of nano fluid. From the Figure 4, it is clearly shown that there is an increase in density of nano fluid with an increase in volume concentration. There is also increase in viscosity by adding nano particle to the base fluid. From the Figure 6, it is clearly shown an increase in kinetic viscosity. In this experiment investigation, density and kinematic viscosity of nanofluid are reduced to the nearest value of base fluid by adding surfactant which are shown in Figures 5 & 7.

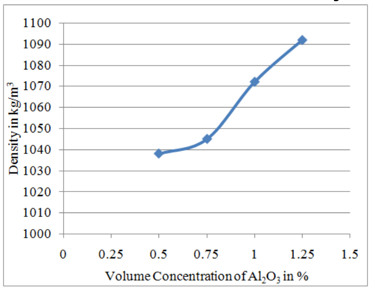

Figure.4.Variation of density of nanofluid without surfactant at different volume concentration of Al_2O_3

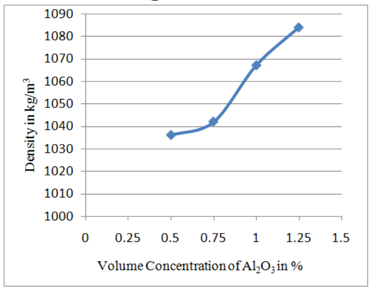

Figure.5.Variation of density of nanofluid with surfactant at different volume concentration of Al_2O_3

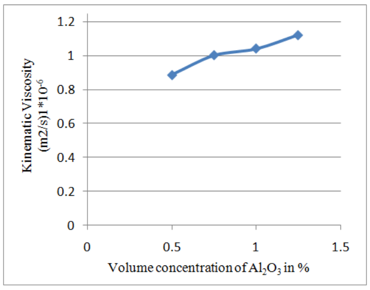

Figure.6.Variation of kinematic viscosity of nanofluid without surfactant at different volume concentration of Al_2O_3

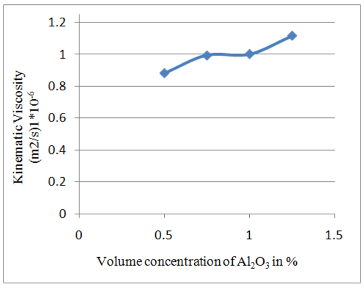

Figure.7.Variation kinematic viscosity with surfactant at different volume concentration of Al_2O_3

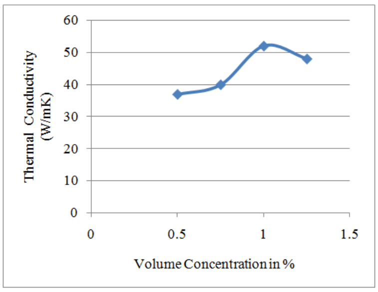

Figure.8.Variation thermal conductivity without surfactant at different volume concentration of Al_2O_3

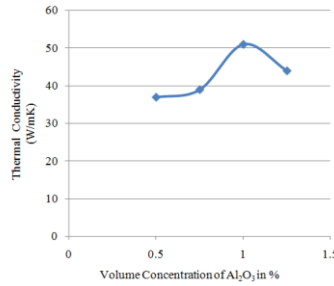

Figure.9.Variation thermal conductivity with surfactant at different volume concentration of Al_2O_3

As from the above Figure 8 it is clearly shown that thermal conductivity increases with increase in volume concentration of nano fluid. From the Figure 8, 0.5% volume concentration shows the lowest thermal conductivity while the highest is shown by 1.0%; while for higher volume concentration of 1.25% thermal conductivity is start decreasing. Addition of surfactant doesn't affect much on the thermal conductivity of nano fluid as shown Figure 9.

Frictional factor: Addition of more nano particle leads to increase in frictional factor as viscosity increases. Frictional factor plays a vital role in heat transfer. If friction factor is more then heat transfer decreases. By addition of nano particle in different concentration varies frictional factor. But to find optimum value it is experimented under different flow rate. Frictional factor calculated by Gnielinski equation as given below

$f = [1.58 \ln Re - 3.82]^{-2}$

where f is the friction factor and Re is Reynolds number

Reynold's Number $Re = VD/\upsilon$

where V is the fluid velocity, υ is kinematic viscosity and D is the tube diameter.

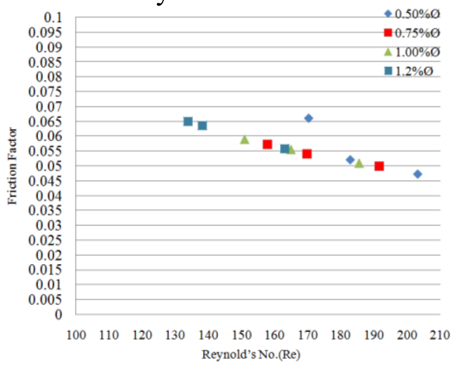

Figure.10. Variation of Friction factor with Reynold's number

From the Figure 10, it is clear that as frictional factor decreases with increase in Reynold's no. So 0.5% concentration of nano particle mixed fluid shows the lowest frictional factor and highest Reynold's number. But 0.5% has the lowest heat transfer rate as compare to other nano particle concentration. From the above graph 1.0% shows the optimum value of Reynold's no. with comparison to friction factor.

Sedimentation effect: After sufficient analysis by comparing the time taken for complete sedimentation of nano particle, the combinations of surfactant and nano particle which have larger time of sedimentation were identified which are shown in the Table 1. The combination selected for aluminum oxide nano fluid and surfactant, which not having significant effect on density and viscosity of nano-fluid compared to base fluid.

Table.1. Time taken for complete sedimentation of nano particle

Exp. No	Concentration of Al_2O_3 in (%)	Mass of surfactant added in (gm)	Time taken for sedimentation in min
1	0.5	0.15	50
2	0.75	0.25	55
3	1.0	0.5	65
4	1.5	0.75	75

Heat transfer rate: In order to evaluate increase in effectiveness of heat exchanger system the increase in heat transfer rate is used to quantify the performance. Increase in heat transfer is defined as the ratio between changes in heat transfer rate of nano fluid with respect to base fluid divided by base fluid (water). In this study, increase in heat transfer has been calculated with help of experimental data. There are several time experiment is carried out with different concentration and mass flow rate.

As shown in Figure 11. experiment is conducted at cold fluid inlet temperature 30^{0}C and inlet of hot fluid at 57.5^{0}C,the change in heat transfer rate at 0.5%,0.75%,1.0%,1.25% are found to be 13.84%,18.23%,20.5%,20.46 % respectively. So there is optimal value can be obtain in 1% volume concentration.

Experiment is then performed at an increase in mass flow rate as shown in Figure 12, at same inlet condition of hot and cold fluid, the heat transfer rate is evaluated 19.28%,25.49%,29.79% and 26.33% with volume concentration of 0.5%,0.75%,1.0%,1.25%.

As mass flow rate further increased to 0.0375Kg/s, there is a significant change is observed in heat transfer rate 20.07%, 25.77 %, 26.57%, 29.80% with volume concentration with 0.5%, 0.75%, 1.0%, and 1.25% respectively as shown in the Figure 13.

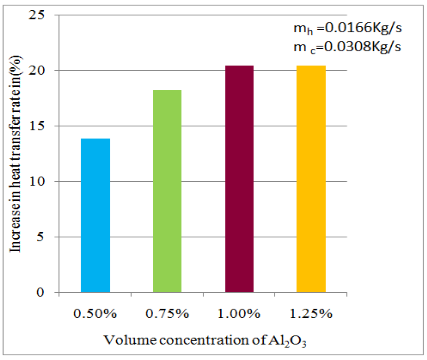

Figure.11.Variation of heat transfer rate with volume concentration of aluminum oxide for 0.0308Kg/s of cold fluid

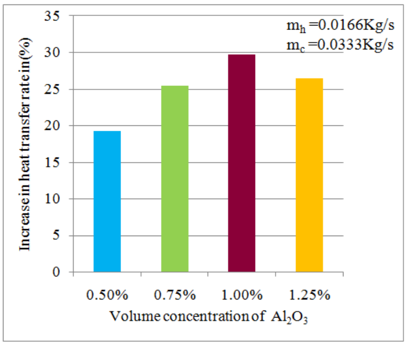

Figure.12. Variation of heat transfer rate with volume concentration of aluminum oxide for 0.0333Kg/s of cold fluid

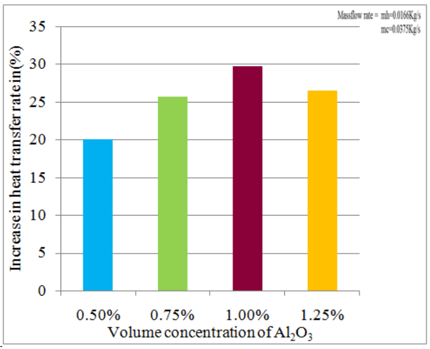

Figure.13. Variation of heat transfer rate with volume concentration of aluminum oxide for 0.0375Kg/s of cold fluid

From above results it is cleared that 1% volume concentration shows an optimal percentage of heat transfer rate at different flow rate of cold fluid. As the mass flow rate increase but still then in other concentration there is not a significant increase in heat transfer other than 1.0%.

Effectiveness: From the experimental results the effectiveness at different volume concentration and different mass flow rate has been calculated and are discussed in following section. T1 and t1 refer the temperatures at hot fluid inlet and cold fluid inlet respectively. Whereas T2 and t2 are temperatures of hot and cold fluids at outlet.

Figures 14-16 show the variation of effectiveness with volume concentration of aluminum oxide at different flow rate of cold fluid. On adding nanoparticle at different volume concentration it is found that an increase in effectiveness. Optimum value is found at 1% addition of volume concentration of nano fluid at all flow rate of cold fluid. There is a higher increment in effectiveness. It is also seen that with the increase in mass flow rate there is an increase in effectiveness of heat exchanger at all volume concentration of Al_2O_3. The Figure 16 shown here is between effectiveness and different volume concentration at 0.0375 kg/s of mass flow rate. In a normal operating condition it is found that the effectiveness for base fluid (water) is 43%.whereas it is observed as 55% for 1% volume concentration of nano fluid.

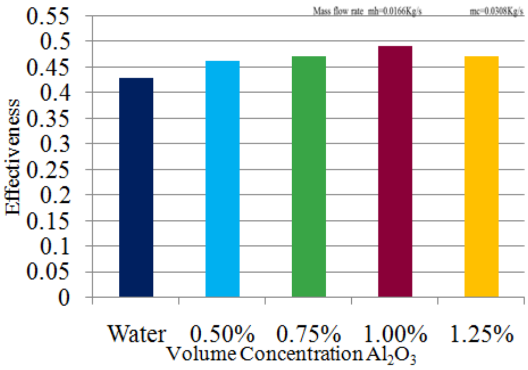

Figure.14. Variation of effectiveness with volume concentration of aluminum oxide for 0.0308Kg/s of cold fluid

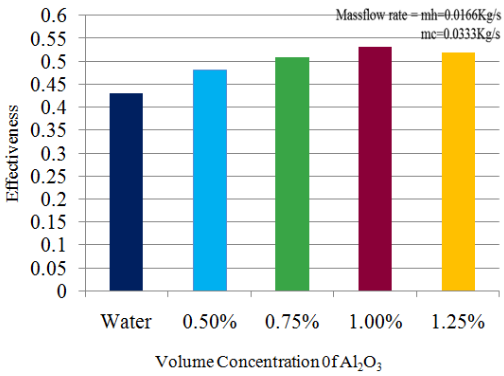

Figure.15. Variation of effectiveness with volume concentration of aluminum oxide for 0.0333Kg/s of cold fluid

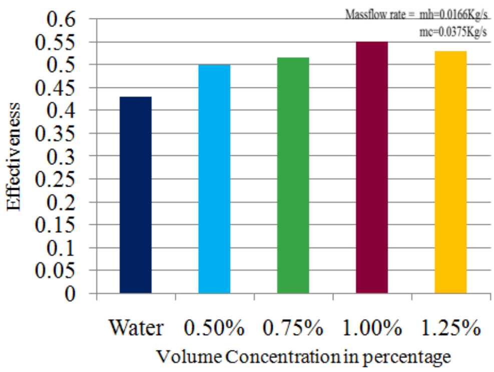

Figure.16. Variation of effectiveness with volume concentration of aluminum oxide for 0.0375Kg/s of cold fluid

4. CONCLUSIONS

In this work, nanofluid (Al_2O_3/water) with four different concentrations (0.5%, 0.75%, 1% and 1.25%) were prepared by using ultrasonicator. The effects of nanoparticle volume concentrations and temperature on thermal conductivity enhancements were studied.

The key findings of this experimental study were summarized as follows:

- A significant thermal conductivity enhancements were observed in aluminum oxide based nanofluid. This shows the nanofluid will be the promising next generation heat transfer fluids.
- Thermal conductivity of nanofluid was increased with the increase of particle volume concentrations in base fluids and mass flow rate. In other words thermal conductivity of nanofluid is a function of nanoparticle volume concentrations and mass flow rate.
- The enhancement of thermal conductivity for Al_2O_3 and water were about 17.2%, 27.3%, 29.8% and 28.73% compared with base fluids respectively with 0.5, 0.75, 1.0, 1.25 volume percentage at 30^0C.
- It is clearly shown that 1% volume concentration of aluminum oxide and flow rate of 0.0375 Kg/s can produce highest increment in percentage of heat transfer rate of about 29.83%.
- There is a 27.9% increase in effectiveness of heat exchanger at 1% volume concentration and flow rate of 0.0375 Kg/s compared to base fluid (water).

REFERANCE

Choi SUS, Singer DA, Wang HP, Development and application of Non-Newtonian flows, ASME, New York 231, 1995, 99–105.

Eastman JA, Choi US, Thompson LJ, Lee S, Enhanced thermal conductivity through the development of nano fiuids. Mater Res Soc Symp Proc, 457, 1996, 3–11.

Hwang Y, Par HSK, Lee JK, Jung WH, Thermal conductivity and lubrication characteristics of nano fluids. Curr Appl Phys, 6S1, 2006, 67–71.

Kim D, Kwon Y, Cho Y, Li C, Cheong S, Hwang Y, Convective heat transfer characteristics of nano fluids under laminar and turbulent flow conditions, Curr Appl Phys, 9(2, Supplement 1), 2009, 119–923.

Liu M-S, Lin MC-C, Huang I-Te, Wang C-C. Enhancement of thermal conductivity with CuO for nano fluids. Chem Eng Technol, 29(1), 2006, 72–77.

Mintsa HA, Roy G, Nguyen CT, Doucet D. New temperature dependent thermal conductivity data for water-based nanofluids. Int J Therm Sci, 48(2), 2009, 363–371

Sabareesh R.K, Gobinath N, Sajith V, Das S, Sobhan C.B. Application of TiO2 nano particles as a lubricant additive for vapor compression refrigeration systems-An experimental investigation, International Journal of Refrigeration, 35, 2012, 1989 – 1996.

Sharma KV, Sundar LS, Sarma PK. Estimation of heat transfer coefficient and friction factor in the transition flow with low volume concentration of Al2O3 nanofluid flowing in a circular tube and with twisted tape insert. Int Commun Heat Mass Transfer, 36(5), 2009, 503–507.

Torii S and Yang W.J, Heat transfer augmentation of aqueous suspensions of nano-diamonds in turbulent pipe flow, J. Heat Transf, 131, 2009, 1-5.

Yu W, Xie H, Chen L, Li Y, Investigation of thermal conductivity and viscosity of ethylene glycol based ZnO nanofluid. Thermo chim Acta, 491(1–2), 2009, 92–96.

Zeinali Heris S, Nasr Esfahany M, Etemad SG, Experimental investigation of convective heat transfer of Al2O3/water nanofluid in circular tube. Int J Heat Fluid Flow, 28(2), 2007, 203–210.