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Experimental Investigation of Heat Transfer Characteristics of Plate Heat Exchanger using Alumina - Water based Nanofluids at Different Orientations

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Abstract

Objectives: Fluids like nanofluids which are rich in thermal conductivity have very good impact on the heat transfer rate of any device. The main aim of this study is to carry out research on the heat transfer characteristics of plate heat exchanger with different orientations using Al2O3/nanofluids. **Methods**: Two different concentration (0.1% v/v and 0.2% v/v) of nanofluids have been used in this research. Inclination angles 0°, 30°, 60°, 90° have been used in this experiment. Experiments firstly carried out with double distilled water then with 0.1% and 0.2% v/v nanofluids. Performance of plate heat exchanger with use of nanofluids compared with water to check the effects of use of nanofluids. **Findings**: Results addresses that the overall performance of the plate heat improve by using nanofluids as a working fluid in a plate heat exchanger. Average increment of approximately 28% has been noticed in case of the nanofluids. Results also addresses that the average decrement of approximately 10- 15% has been observed when the orientation of plate heat exchanger changes from horizontal to inclined (30°). **Improvements/Applications:** This technique can be used in industries to improve the performance of heat exchange device.

Keywords: Al_2O_3/Water Nanofluids, Heat Transfer Characteristics, Plate Heat Exchanger

1. Introduction

The plate heat exchanger is conventionally used in many engineering applications. Because of their compactness, ease of use and thermal performance most of the industries prefer plate heat exchangers over the other heat exchangers. In today's world the performance of any device is a very big issue. Many studies have been done to improve the overall performance of plate heat exchanger. Researchers have found that the performance of the plate heat exchangers is not only depend upon its geometric configuration but also on the type of working fluid used in it. In order to achieve this, it has been found that by dispersing nano sized particles in to the base fluid, results to have the better thermal conductivity[1]. In[2] was the first person to use the term nanofluids. Nanofluids is a fluid which contains nano sized particle in it.

As we know that the heat transfer rate basically depends upon the conductivity of the working fluids. So 1995 found out the nano sized particles having high ther-

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mal conductivity. Author noticed that for heat transfer enhancement thermal conductivity play the important role. He compares the thermal conductivity between the two fluids, the one is made by dispersing the nano sized particle in the base fluid and the other is just a base fluid and noticed that the first fluid which have nano sized particles have the high thermal conductivity than the base fluid. After that many a researcher has studied about the nanofluids technology and its application in the heat transfer devices. Many researchers have studied about the thermophysical properties of the nanofluids in which the thermal conductivity was the major aspect. In found that the thermal conductivity of the nanofluids depends upon the three basic parameters the first one is temperature, the second one is the particle volume concentration and the last one is the nanoparticle size. In[3–8] found that with increase in particle volume concentration, temperature and the particle size the thermal conductivity of the nanofluids increases. In[9] investigated the dispersion behavior and the thermal conductivity of the Al_2O_3 water based nanofluids. The dispersion behavior and thermal conductivity has been investigated under different PH values and different sodium dodecylbenzenesulfonate (SDBS) concentration. The author observed that the stability and thermal conductivity of Al_2O_3/water nanofluids are highly dependent on PH values and is different for different SDBS dispersant concentration. The author observed that good dispersion of alumina particle has been found when the PH is 8.0. In[10] investigated the behavior of alumina- water nanofluids in a pipe with different power input. Author found out that with increase in the density, thermal conductivity and viscosity of nanofluids increases with increase in the nanoparticle concentration and has the reverse effect on the specific heat. i.e. specific heat decreases with increase in nanoparticle concentration. Author also concluded that with increase in the power input the heat transfer coefficient increases while there is slightly decrease have been shown in case of pressure drop. In[11] experimentally investigated the heat transfer and pressure drop characteristics of ammonia in un-symmetrical $30^0/60^0$ chevron plate heat exchanger. It has been found that heat transfer and pressure drop characteristics increases with increase in saturation temperature. Results also shows that $30^0/60^0$ type chevron plate configuration have highest heat transfer rate than that of $30^0/30^0$ and $60^0/60^0$ type chevron plate configuration. In[12] presents an experimental research on heat transfer and fouling studies of multiwalled carbon nanotubes nanofluids in plate heat exchanger. About 68% of enhancement has been noticed in thermal conductivity of carbon nanotubes in comparison with the base fluid. In revealed that the concentration was the two important factor responsible for the enhancement in thermal conductivity value. Among the three different concentration, with 1% v/v concentration best results has been obtained. In[13] used CuO water based nanofluids to investigate numerically the heat transfer characteristics in water nuclear reactor and found that the heat transfers characteristic increase with increase in nanoparticle concentration and Reynolds number. In[14] experimentally studied the heat transfer performance of rectangular plate type heat pipe. From the study, the authors concluded that the best heat transfer rate observed when the heat source was at 100°C. In[15] studied the effect of water silver nanofluid with in the rectangular two dimensional micro channel. The authors noticed that with increase in the flow rate and the nanoparticle concentration the greater temperature drop occurs.

In the present research an investigation has been done on the plate heat exchanger with different orientation using Al_2O_3/water nanofluids. Literature shows that most of the work has been done using horizontal arrangement. A very less work has been done on the other orientation. So this work addresses the effect of inclination of plate heat exchanger on the heat transfer characteristics using Al_2O_3/water nanofluids. Before experiments the thermophysical properties of nanofluids have been measured. Nanofluids have been prepared with the two different nanoparticle concentration 0.1% v/v and 0.2%v/v. The acquired results from the horizontal orientation have been compared with the result from the different inclination of plate heat exchanger.

2. Nanofluids Preparation

Aluminum nanoparticles of size 20nm were used in this research. Two sets of same sample of water based Al_2O_3

nanofluids has been prepared with the help of two step method. The first set contains 0.1% v/v particle concentration while in the second set 0.2%v/v particle concentration is used. Equation 1 has been used to calculate the required volume concentration of the nanoparticles. The Al_2O_3 nanoparticles used in this research were purchased from

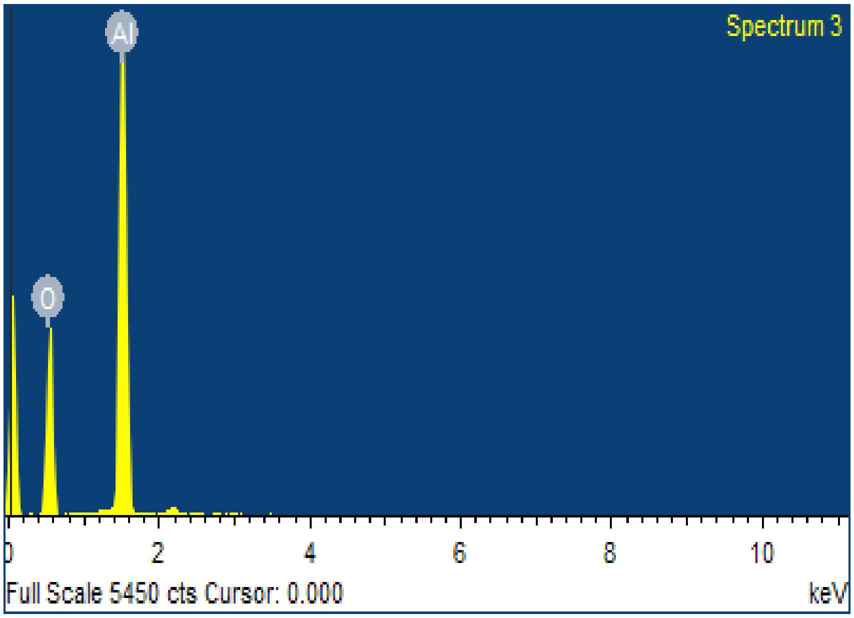

Figure 1. EDX image of Al_2O_3 nanoparticles.

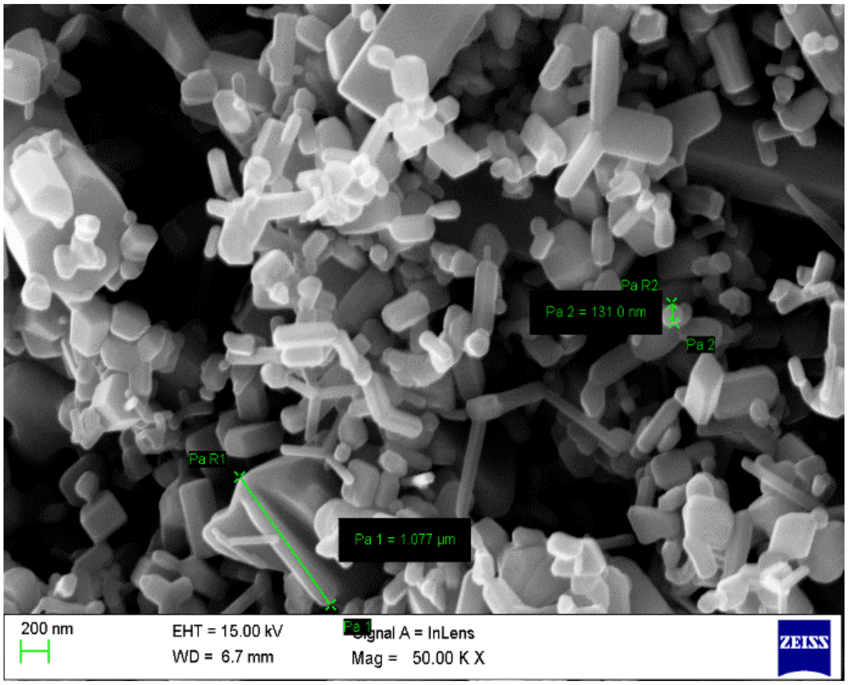

Figure 2. SEM image of Al_2O_3 nanoparticles.

Nanoshells, DerraBasi, India. To prepare the nanofluids required amount of nanoparticles were dispersed in the base fluid (distilled water). For completely mixing the nanoparticles with the base fluid a magnetic stir has been used. After that the complete mixture of the nanoparticles with the base fluid placed in ultrasonicator for 2 hours to remove the agglomerations. As the nanoparticles completely mixed with the base fluid so no surfactant is required to stable the nano fluids. The EDX, SEM, TEM and XRD images has been shown in Figures 1 to 4.

$$\phi = \frac{\frac{m_{np}}{\rho_{np}}}{\frac{m_{np}}{\rho_{np}} + \frac{m_{bf}}{\rho_{bf}}} \tag{1}$$

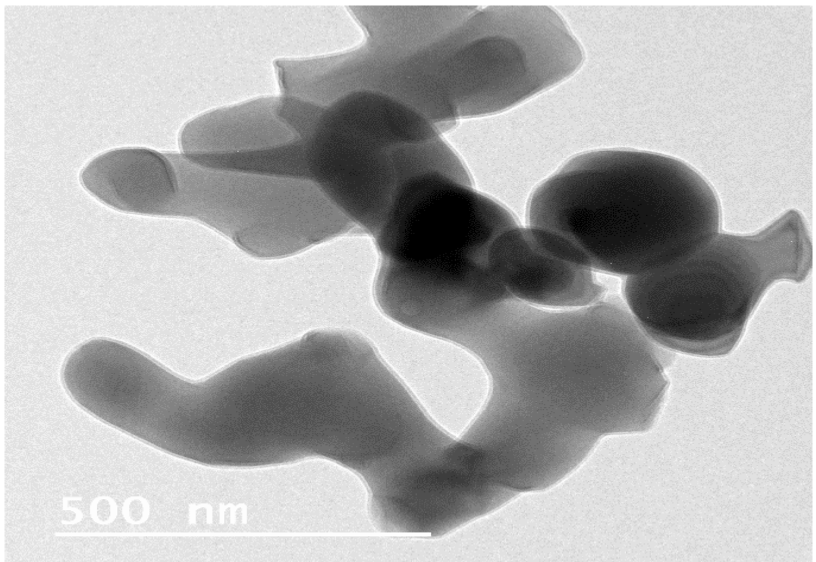

Figure 3. TEM image of Al_2O_3 nanoparticles.

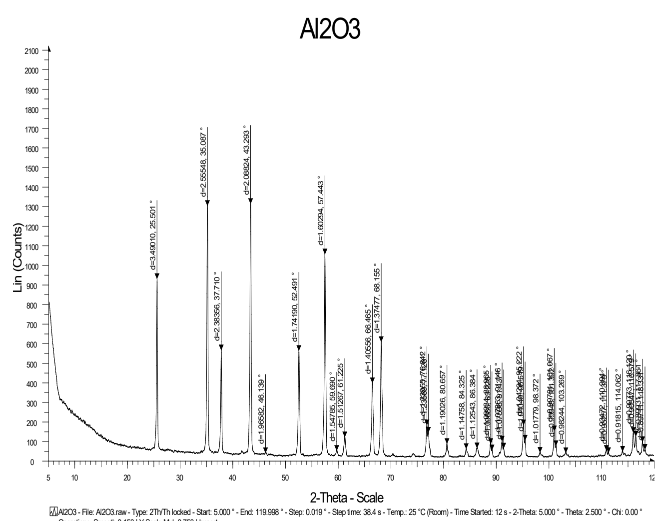

Figure 4. XRD image of Al_2O_3 nanoparticles.

Once the both the set of nanofluids have completely prepared then the thermophysical properties of nanofluids have determined. The following steps have been used to determine the thermophysical property of nanofluids. Firstly, with hot wire transient method the thermal conductivity of nanofluids have been measured. KD-2 Pro thermal property analyzer has been used to measure the thermal conductivity of the nanofluids. After thermal conductivity measurement, viscosity of nanofluids have measured with the help of viscometer. The density of the nanofluids have measured with the help of density meter. Figure 7 to Figure 9 shows the effect of temperature on the thermal conductivity ratio, density ratio and the viscosity ratio of the nanofluids with base fluid.

3. Experimental Setup

An experimental set up was designed to carry out the heat transfer characteristics of the plate heat exchanger using Al_2O_3 water based nanofluids. The schematic and photographic view of test section has been shown in Figures 5 and 6. The experimental set up composed of a plate heat exchanger having 20 plates, two flow meters which are used to maintain the flow of the hot and cold fluids, two U- tube manometer for measuring the pressure drop on both the sides, two water tanks which are used to store hot and cold fluids, two magnetic pumps were also used to pump the fluids into the plate heat exchanger, a heater has also been installed at the bottom of one tank to heat

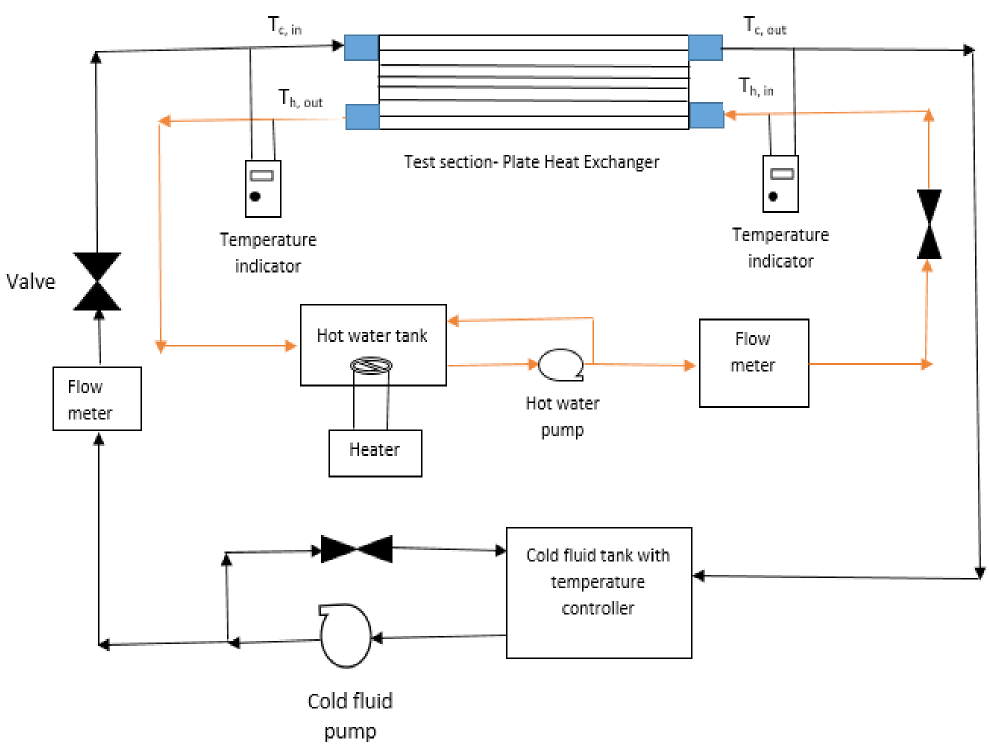

Figure 5. Schematic diagram of experimental setup.

Figure 6. Photographic view of experimental setup.

the water and five thermocouples have been installed at different location of heat exchanger to find out the temperature of hot and cold fluids. To maintain the cold fluid inlet temperature at the constant value a heat exchanger has been installed. A PID controller has been also installed to control the temperature of the hot fluid. Total uncertainty of ±2°C has been noticed.

4. Data Processing

Based on the experimental data the set of equations has been used to calculate the heat transfer characteristics of nanofluids in plate heat exchanger. Equation (1) and (2) written given below used to calculate the heat lost by the hot fluid (base fluid) and heat gained by the cold fluid.

$$Q_h = m_h C_{ph}(T_{h,i} - T_{h,o}) \quad (2)$$

$$Q_c = m_c C_{pc}(T_{C,O} - T_{C,i}) \quad (3)$$

Equation (3) is used to calculate the Reynolds number of the fluid. Mass velocity and hydraulic diameter has been used to calculate the Reynolds Number of fluids which is defined in equation (4) and (5).

$$Re_h = \frac{G_h D_H}{\mu_h} \quad (4)$$

$$G_h = \frac{m_h}{N_{cp} b L_W} \quad (5)$$

$$D_H = \frac{2b}{\phi} \quad (6)$$

Equation (6) is used to calculate the average value of heat transfer of hot and cold fluid. Which is defined:

$$Q_{avg} = \frac{Q_h + Q_c}{2} \quad (7)$$

Based on experimental data the heat transfer coefficient has been calculated by equation (7). The value of heat transfer coefficient is based upon the value of value of bulk mean temperature and area of heat exchanger. The bulk mean temperature is defined in equation (8).

$$h = \frac{Q_{avg}}{A(T_b - T_w)} \tag{8}$$

$$T_b = \frac{T_i + T_O}{2} \tag{9}$$

The Nusselt number can be calculate based on the heat transfer coefficient and conductivity of the working fluid as follows:

$$Nu = \frac{hD_H}{k} \tag{10}$$

The dimensionless exergy loss of nanofluids has been found from the relationship given below:

$$e = \frac{E}{T_e \times c_{\min}} \tag{11}$$

where,

$$E = E_c + E_h E = E_c + E_h \tag{11.1}$$

$$E_c = T_e \left\{ m_c c_{pc} LN \left(\frac{T_{co}}{T_{ci}} \right) \right\} \tag{11.2}$$

$$E_h = T_e \left\{ m_h c_{ph} LN \left(\frac{T_{hi}}{T_{ho}} \right) \right\} \tag{11.3}$$

5. Results and Discussions

The experimentations were carried out on four different temperatures ranging from 30°C to 60°C. The experimentation has been conducted for the laminar flow regimes in which the range of the Reynolds number of hot fluids varied between 300<Re<2000. The experiment was carried out in three different stages. In first stage base fluid is used as the working fluid, while in the second and third stage nanofluids with different concentration has been used. The inlet temperature and the flow of the cold fluid maintained at constant value with the help of heat exchanger and flow meter.

5.1 Thermophysical Properties of Nanofluids

Figure 7 shows the variation of the thermal conductivity ratio of nanofluids with the increase in temperature. The range of the temperature in which the thermophysical properties of nanofluids has been measured was 30°C, 40°C, 50°C and 60°C. It has been noticed that the thermal conductivity of nanofluids increases with increase in temperature. And it attains the maximum value when the nanofluids concentration is 0.2% v/v at 60°C. Maximum enhancement of 32% has been observed at 0.2% v/v at 60°C as comparison with the base fluid. Figure 7 presents the thermal conductivity ratio at the four different temperatures. It has been observed that the temperature from 30°C to 60°C, there is total enhancement of approximately 6.5% to 15% has been observed in thermal conductivity ratio. The results show that the temperature plays an important role in the thermal conductivity ratio enhancement. The main reason behind the thermal conductivity enhancement is the excitation of the nanoparticles at higher temperatures. When the temperature increases the movement of particles increases due to which the chances of collision increases which results to improve in the thermal conductivity of nanofluids.

Figure 8 shows the effect of temperature on the density ratio. The density ratio of the nanofluids is maximum at 60°C with 0.2% v/v concentration. The Figure 8 shows that the density ratio increases with increase in the temperature and particle volume concentration. The density of Al_2O_3/water nanofluids is quite higher than that of water.

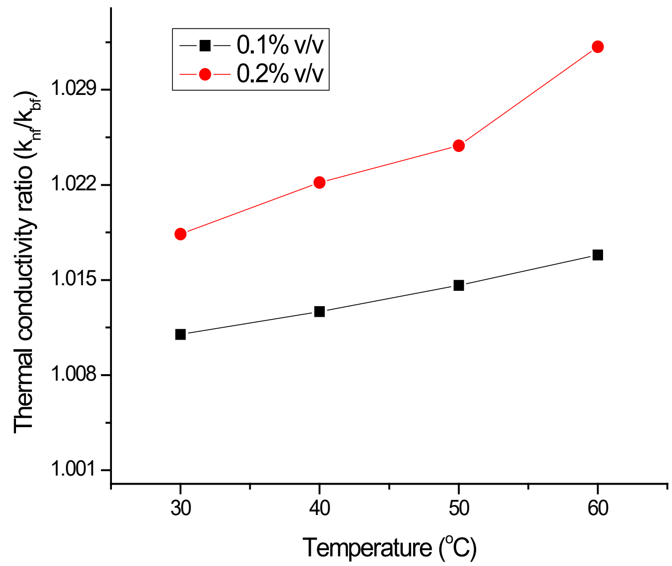

Figure 7. Variation in thermal conductivity ratio with temperature.

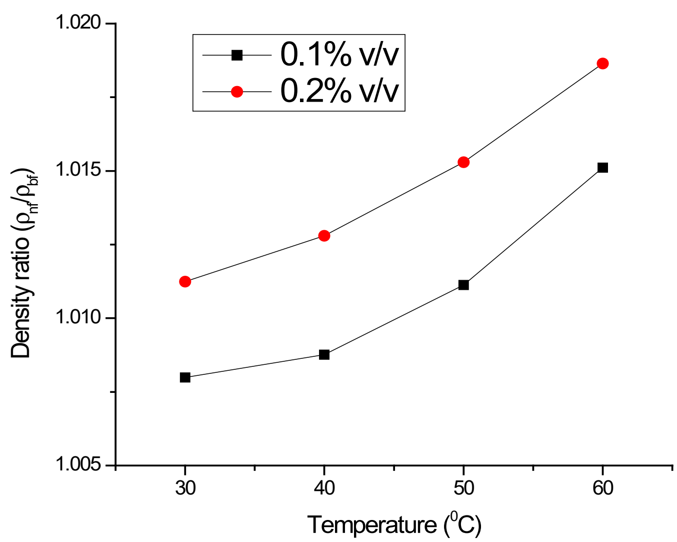

Figure 8. Variation in density ratio with the temperature.

Figure 9 shows the effect of the temperature on the viscosity ratio of nanofluids. In this case viscosity it has been observed that viscosity decreases with increase in temperature. Figure 9 shows that the viscosity ratio increases with increase in temperature. In has also investigated on thermophysical properties of Al_2O_3 water based nanofluids and concluded the same results.

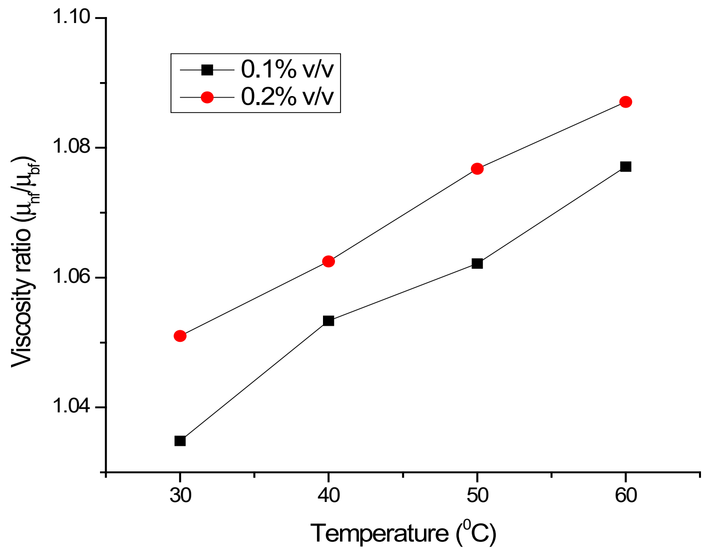

Figure 9. Variation in viscosity ratio with the temperature.

5.2 Effect of Reynolds Number on Heat Transfer Coefficient Ratio

Figure 10 shows the effect of Reynolds number on the heat transfer coefficient ratio of the plate heat exchanger. The experimentation has been carried out with the specific range of Reynolds number (300<Re<2000). The Figure 10 addresses that the heat transfer ratio is maximum for 0.2% v/v concentration. The heat transfer ratio with its base fluid vary "between" 1.3 to 1.6 with the

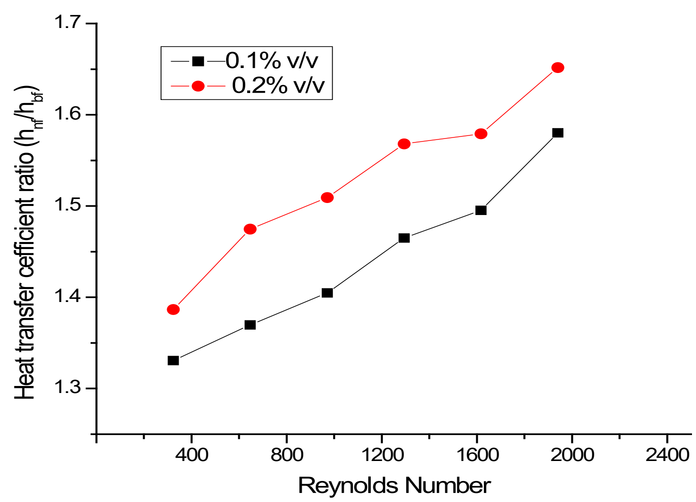

Figure 10. Effect of Reynolds number on heat transfer coefficient ratio.

respective Reynolds number. Overall enhancement of approximately 29% has been observed when nanofluids was used as the working fluid. To calculate the heat transfer coefficient of nanofluids equation (8) has been used. The results addresses that the heat transfer characteristics strongly depends on the thermal conductivity and density of the working fluid.

Effect of inclination of base of the plate heat exchanger on the heat transfer coefficient ratio has been shown in Figure 11. Decrement of approximately (8-10) % has been observed in the heat transfer coefficient ratio when the base plate of plate heat exchanger was made inclined at 30° from 0°. Maximum heat transfer coefficient ratio of 1.56 have been observed at 60°C at 0.2% v/v concentration. This is due to the fact that with increase in the particle concentration of nanofluids the tendency of the collision of particles increases which results increase in heat transfer characteristics.

5.3 Variation of Nusselt Number Ratio with the Reynolds Number

Figure 12 shows the variation of Nusselt Number ratio with the Reynolds Number. It has been concluded that theNusselt Number increases with increase in thermal conductivity and particle volume concentration of the working fluid. Maximum increment of 30% has been found out in case of the Nusselt number. In case of Nusselt numberratio enhancement average increment of (7 - 8) % has been observed. It is clear from the equation (10) that the Nusselt number purely depends upon the heat transfer coefficient and the thermal conductivity of the

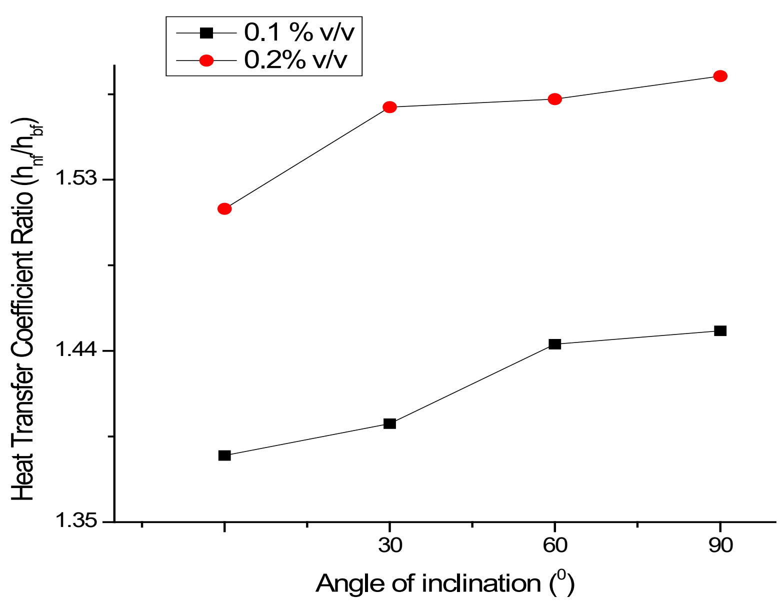

Figure 11. Effect of inclination on heat transfer coefficient ratio.

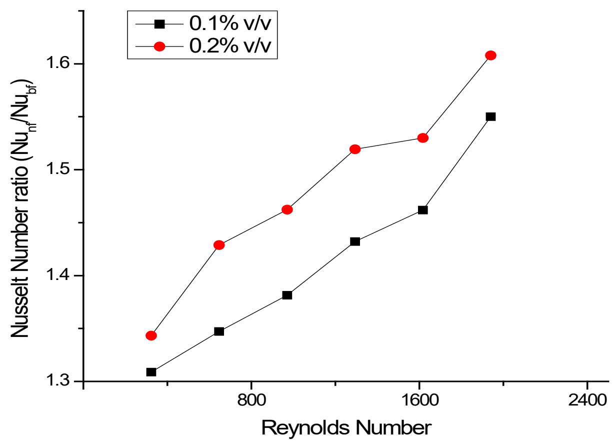

Figure 12. Effect of Reynolds number on Nusselt number ratio.

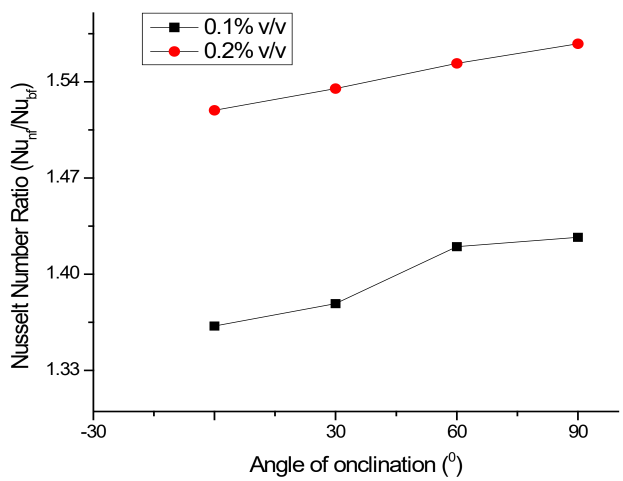

Figure 13. Effect of inclination on Nusselt number ratio.

working fluid. More the heat transfer coefficient more the Nusselt number.

Figure 13 shows the effect of inclination on the Nusselt number ratio. It has been concluded that when the plate heat exchanger used horizontally they gives the best results. The enhancement of approximately 15-16% has been observed when the plate heat exchanger used horizontally from the inclined (30°) position.

5.4 Variation of Dimensionless Exergy Loss with the Reynolds Number

Figure 14 shows the variation of exergy loss ratio with respective Reynolds number. From the Figure 14 it has been clear that the value of exergy loss varies between "0.5 to 1.5" respectively for the given Reynolds number. In case of the exergy loss ratio analysis the value is maximum for the 0.1% v/v concentration. Equation (11) is used to calculate the exergy loss of nanofluids in plate heat exchanger. And it is clear from the equation (11.1), exergy loss purely depends upon the specific heat of the fluid. So with increase in particle volume concentration the specific heat decreases so there is decrease in exergy loss has been observed when the particle volume concentration changes from 0.1% to 0.2%.

6. Conclusion

Experiments have been carried out to find out the heat transfer characteristics of plate heat exchanger under different orientations using Al_2O_3/water nanofluids. It was observed that the heat transfer characteristics strongly depends on the type of working fluid used in it and the orientation of plate heat exchanger i.e how heat exchanger has been placed. The present research concluded that the heat transfer characteristics increases with increase in thermal conductivity of the fluid and thethermal conductivity of the fluid increases with increase in nanoparticle concentration. So, better heat transfer rate has been observed with the 0.2% v/v concentration. It has been also concluded that plate heat exchanger gives maxi-

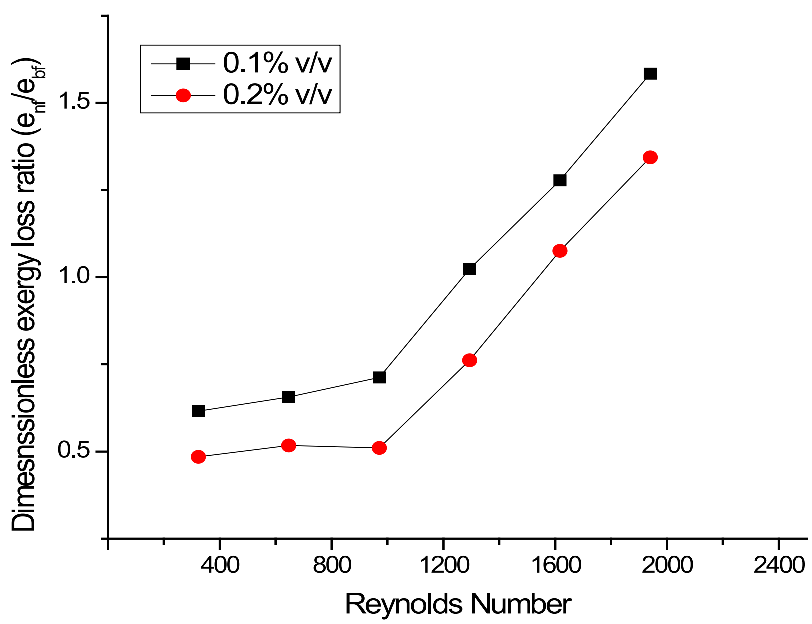

Figure 14. Effect of Reynolds number on dimensionless energy loss ratio.

mum heat transfer rate when placed horizontally. Results addresses that there is diminution of approximately 15% observed in the heat transfer characteristics when the orientation of the plate heat exchanger changes from 0° of inclination to 30°.

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Nomenclature

D_H	Hydraulic diameter (mm)
A	Area (m^2)
C_p	Heat capacity (J/kg-k)
k	Thermal conductivity (W/m-k)

L_w	Plate width (mm)
N_{cp}	Number of channels per pass
m	Mass flow rate (Kg/s)
Q	Heat transfer rate (W)
R_e	Reynolds number
T	Temperature (°C)
T_w	Wall temperature (°C)
T_b	Bulk mean temperature (°C)
θ	Enlargement factor
μ	Viscosity (N-s/m^2)
Φ	Particle volume concentration.
ρ	Density (Kg/m^3)
bf	Base fluid
nf	Nanofluids