International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com || Volume 03 - Issue 12 || December 2018 || PP. 14-22

Heat Transfer Enhancement Using Magnetite Nano Fluid in a Double Pipe Heat Exchanger

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Abstract: As many of industries required the transfer of heat energy for its propagation. Heat exchanger is an adiabatic device which is used for heat addition/heat rejection from the process. Double pipe heat exchanger comprising of inner and outer pipes of different diameter with counter flow arrangement was chosen due to its high performance. Present experiment deals with a study on heat transfer enhancement using magnetite (Fe_3O_4) nanofluid. A nano-fluid comprises of nano-meter sized particles that are less than 100nm and these are colloidal dispersions of nano particles in common base fluids such as water, ethylene glycol and engine oil. The hot water/ hot nano fluid passes through the inner tube with different flow rates, while the cold water at constant flow rate passes through the annulus. The volume concentration of nanofluid is varied from 0 to 0.004%, 0.006% and 0.008% under turbulent flow conditions, with the Reynolds number varying in the range of 15000 to 28000.The effects of various concentrations of Iron oxide nano fluid on heat transfer coefficient, friction factor and pressure drop in a double pipe heat exchanger are investigated. The thermal performance of the nanofluid is observed to increase with the increase of volume concentration and at low flow rates, within the experimental parameters considered. Experimental results are compared with the correlations and there is a good agreement between experimental and theoretical data. Finally, the conclusions derived that convective heat transfer coefficient increased up to 20%-35% and pressure drop has increased up to 25% - 38% compared to water, based on the Reynolds number and volume concentration of Iron oxide nano particles.

Keywords: Heat exchanger, Heat transfer enhancement, Nano fluid,

1. Introduction

A heat exchanger is an engineering device in which heat exchange takes place between two fluids (i.e. hot and cold fluids) at various temperatures. The main objective of heat exchanger may be either to add heat to a fluid or to remove heat from a fluid. Thermal properties of fluids play a vital role both in heating and cooling applications in industrial aspects. Generally water, engine oil, and ethylene glycol are used as heat transfer fluids. There are many techniques which are applied and are to be applying for enhancement of heat transfer rate. The addition of nano particles to the base fluid (water) is selected for the heat transfer enhancement. Heat transfer characteristics mainly depend on thermal conductivity of solid particles. Nano particles having high thermal conductivity are added to the base fluid to increase thermal conductivity. The enhancement of thermal conductivity of conventional fluids by the suspension of solid particles, such as millimeter or micro meter sized particles, has been well-known for many years. But, in real for practical applications they may cause problems such as sedimentation which leads to increase in pressure drop of a certain flow channels. The recent material technology has made a possible solution to produce an alternate heat transfer fluids by suspending Nano-sized particles in base fluids which can change the thermal properties of the base fluid.

An experimental study on heat transfer enhancement and pressure drop characteristics in a double pipe counter flow heat exchanger by titanium oxide/water nanofluid (0.2% titanium oxide nano particles of size 21nm). As per the experiment, they have found that there is a slight increase in heat transfer coefficient of the nanofluid about 6 % to 11% compared to the base fluid and stated that theoretical heat transfer coefficient Gnielinski equation had failed to predict[1].

A comparative study on thermal conductivity of Al_2O_3/water, CuO/water and Al_2O_3-CuO/water nano fluid of three different volume concentrations (0.05, 0.1 and 0.2%) were prepared by dispersion process. The experimental results showed that by overall performance comparison the maximum of 9.8% enhancement of thermal conductivity was observed for 0.2% of particle volume concentration [2].

An experimental investigation on enhancement of convective heat transfer coefficient using aluminum oxide/water nanofluid under laminar flow conditions which is passing through the copper tube from the results, they have found that increase in heat transfer coefficient was particularly significant in entrance region due to random motion of nano particles and resulting disturbance of the boundary layer [3].

A study on convective heat transfer coefficient in horizontal tube heat exchanger using graphite nano particles dispersed in a base fluid under laminar flow condition. In this study, disc shaped nano particles of various aspects ratio were used. From the results, they concluded that heat transfer coefficient increases with the mass flow rate and particle volume concentration [4].

The performance of heat transfer using CNT nanofuids flowing through an inner tube of diameter 4.5mm from the experimental data stated that CNT Nano fluids heat transfer coefficient is greater than that of pure water and its enhancement depends on the CNT particle concentration flow conditions and PH value, From the observations, they suggested that aspect ratio should be associated with high enhancement of heat transfer performance of CNT Nano fluids [5].

2. Experimental Procedure:

To experimentally determine the heat transfer coefficient of Iron oxide nanofluid at low volume concentrations of 0.004%, 0.006% and 0.008% in a Double pipe heat exchanger for counter flow arrangement.

2.1 Preparation of Iron Oxide Nanofluid

In this present work, Iron oxide having <50nm was used. The colour of nano particles is black.

Fig: 2.1 Iron oxide Nano particles

The amount of Iron oxide to be mixed in base fluid i.e. water for various volume concentrations. Initially high concentrations are selected for doing experiment but at high volume concentration sedimentation was occurred , so low concentrations are selected for this study. There are two methods to prepare nano fluids – one step process and two step process. Two step processes has been selected to prepare Iron oxide-water nano fluid.

Nano fluids at various concentrations in the range of 0.004% - 0.008% is prepared for this experimental study.

To prepare nano fluid of specific volume concentration, samples are first prepared by adding surfactant in different proportions to water and then mixture is stirred in a conical flask by magnetic stirrer for 10minutes.

Fig: 2.2: Nano fluid preparation using mechanical stirrer

The Iron oxide nano particles are then added and stirred continuously for 24 hours using mechanical stirrer as shown in Fig. the nanofluid observed for dispersion and stability. It is observed that surfactant weighing 1/10th the mass of Iron oxide nano particles added to base fluid gives uniform dispersion without sedimentation. Hence nanofluid preparation is done by using this procedure to obtain a specific volume concentration.

2.2 Sedimentation test:

In order to get stability of nano particles, surfactants must be added for two step process depending on type of nano particles otherwise it causes particle sedimentation problem.

In this present work, sedimentation test is carried out to know the behavior of nano particles in the base fluid which means how much time the nano particles are uniformly dispersed in base fluid using surfactant. Fig shows the preparation of Iron oxide nanofluid using magnetic stirrer.

Fig: 2.3 Magnetic stirrer

The following steps are conducted for sedimentation test:

- Firstly, 250ml of distilled water is taken in conical flask.
- Conical flask is mounted on magnetic stirrer equipment and surfactant weighing one-tenth the mass of nano particles concentration is mixed in distilled water and continuously stirred for 10 minutes using stir bead.
- After stirring process, it is observed how much time the particles are uniformly dispersed in the base fluid.
- The Iron oxide nano fluid before sedimentation and the Iron oxide nano fluid after sedimentation were shown in fig.

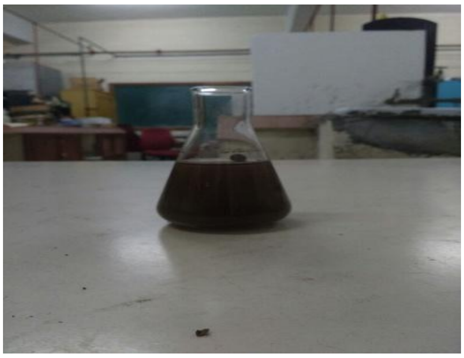

Fig: 2.4 Before sedimentation

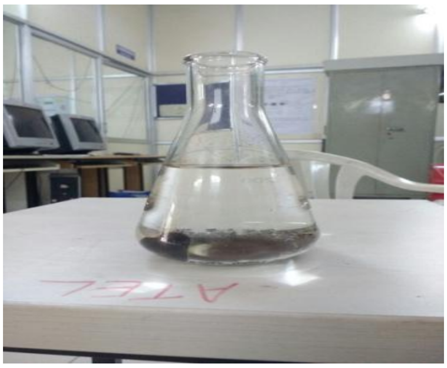

Fig: 2.5 After sedimentation

3. Results And Discussion

3.1 Heat transfer coefficient of pure water as Hot Fluid:

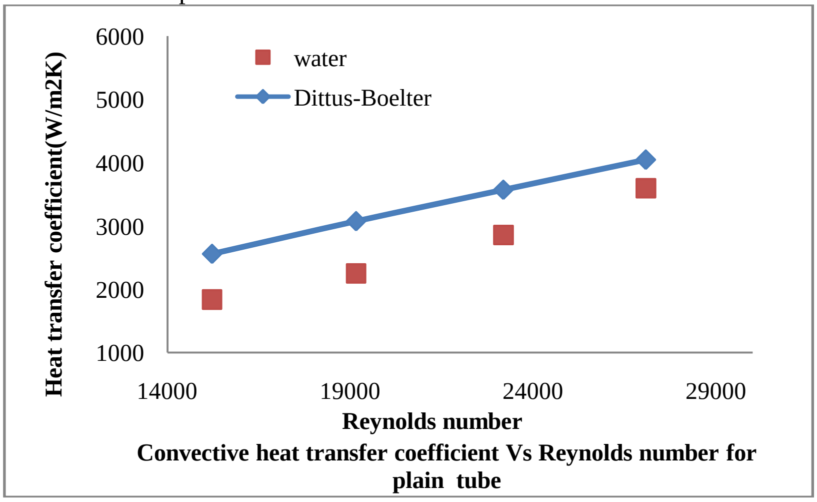

Fig 3.1 Convective heat transfer coefficient Vs Reynolds number for plain tube

Fig.3.1 shows the variation of convective heat transfer coefficient with Reynolds number for a Double pipe heat exchanger with plain tube. As the mass flow rate of hot water increases, Reynolds number increases. As the Reynolds number increases, the degree of turbulence increases which enhance the Nusselt number. From the experimental results, it is found that convective heat transfer coefficient increases from 1840 to 3600 with increasing Reynolds number from 15000 to 27000.Dittus-Boelter equation is used to compare the experimental data.

3.2 Friction Factor for Pure Water:

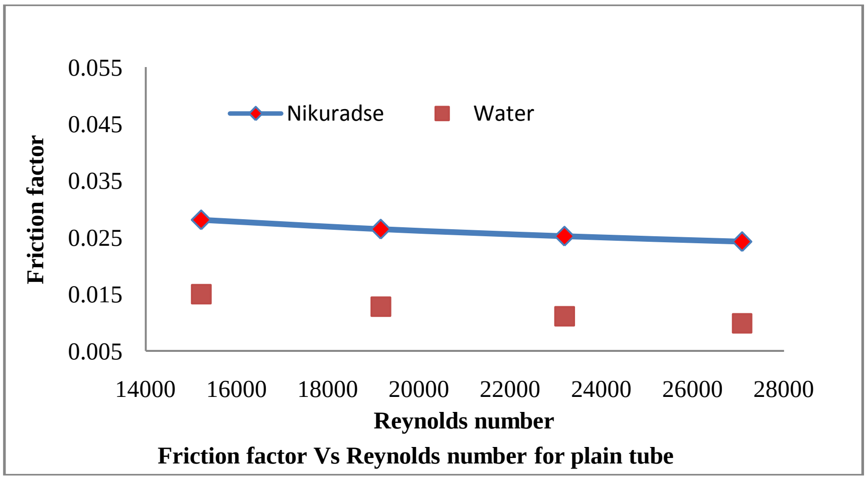

Fig 3.2 Friction factor Vs Reynolds number for plain tube

Figure shows the variation of friction factor with Reynolds number for plain tube (water). It is observed that the friction factor of both experimental and analytical are found to decrease with increasing Reynolds number. Nikuradse correlation has more friction factor than with experimental data. This is because of the increasing turbulence which reduces the frictional forces between the moving fluid and plain tube.

3.3 Heat Transfer Coefficient of 0.004% as Hot Fluid:

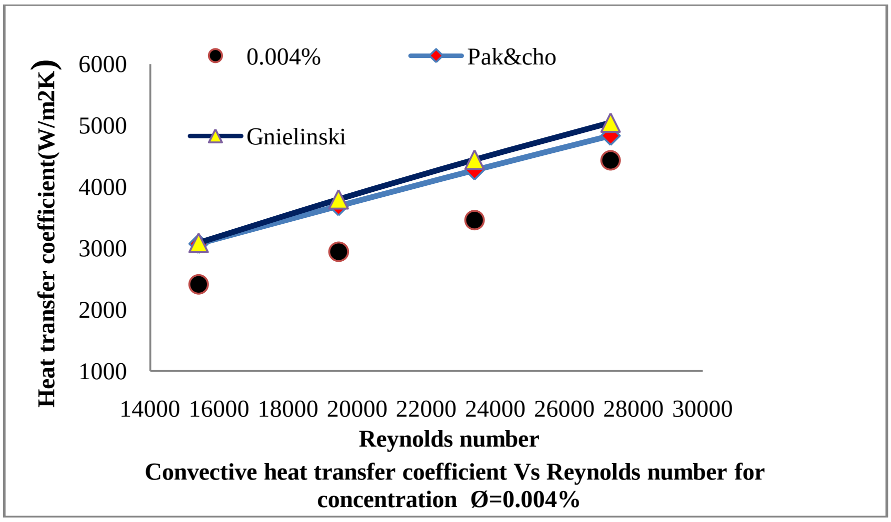

Fig 3.3 Convective heat transfer coefficient Vs Reynolds number for concentration (Ø=0.004%).

Figure 3.3 Shows the variation of experimental values are found to be in close agreement with the values determined by other correlations. As the mass flow rate of hot water increases, Reynolds number increases. It is found that convective heat transfer coefficient increases from 2410 to 4430 with increasing Reynolds number from 15000 to 27000.Pak & Cho and Gnielinski equations are used to find out the theoretical convective heat transfer coefficients and compared with .004% concentration data. The difference between the heat transfer coefficient obtained from experimental data and that of Pak & Cho and Gnielinski correlations is observed to decrease from 21.5% to 8.4% and from 21.9% to 12% respectively.

3.4 Friction Factor of .004% as hot fluid:

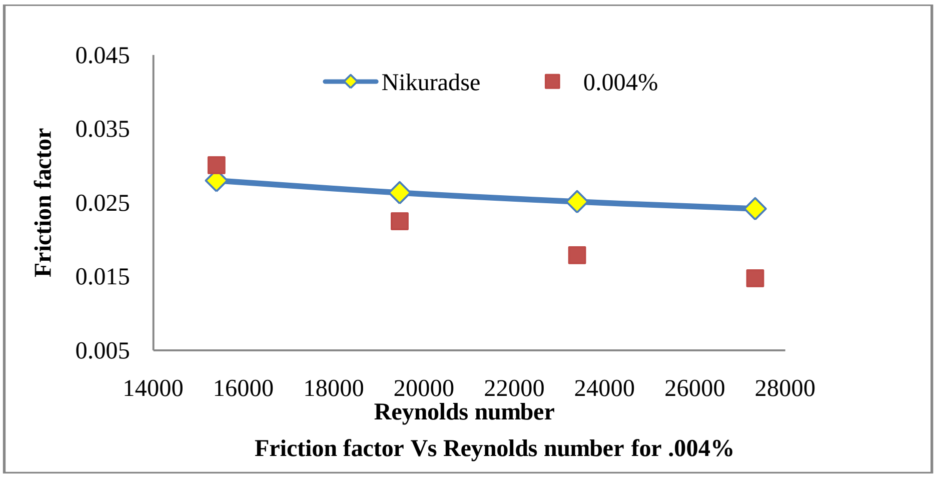

Fig 3.4 Friction factor Vs Reynolds number for .004%

Figure shows the variation in friction factor of Iron oxide-water nanofluid in terms of Reynolds number and volume concentration of .004%. Nikuradse correlation is selected for determining the friction factor of nanofluids flowing inside the tube, as this correlation is more accurate than the Blasius correlation. It can be clearly seen that the friction factor of Nikuradse and experimental are nearly equal at Reynolds number 15000, as Reynolds number increases, the deviation between theoretical and that of experimental data varies from 0% to 35%, within the range of Reynolds number considered in the present study.

3.5 Heat Transfer Coefficient of 0.006% as Hot Fluid

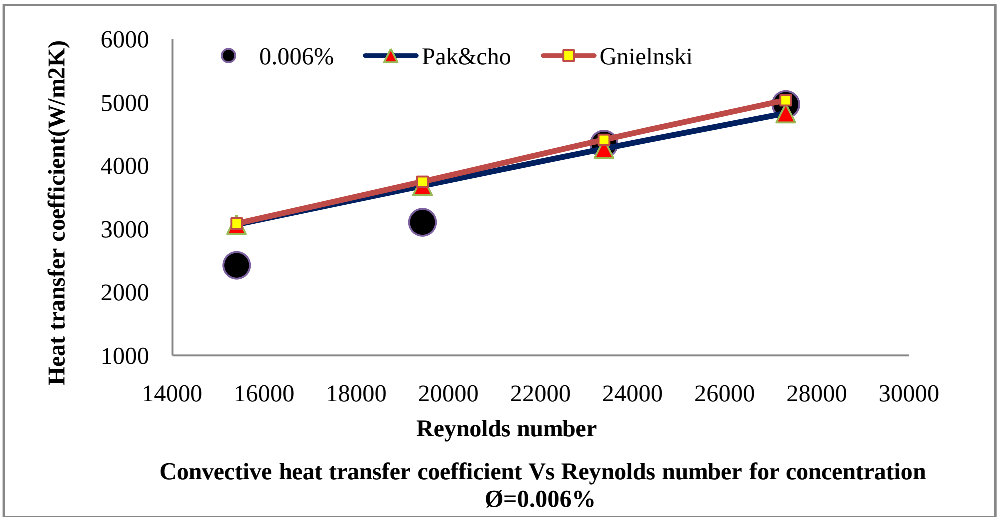

Fig: 3.5 Convective heat transfer coefficient Vs Reynolds number for concentration (Ø=0.006%).

The experimental values are found to be in close agreement with the values determined by other correlations. From the experimental results, it is found that the increasing Reynolds number from 15400 to 27300, convective heat transfer coefficient increases from 2430 to 5000. Pak & Cho and Gnielinski equations are used to find out the theoretical convective heat transfer coefficients and compared with .006% concentration data. As the Reynolds number increases 15400, 19400 the difference between heat transfer coefficient of experimental data and that of Pak& Cho and Gnielinski correlations is found to decrease from 20.8% to 15.7% and from 21.2% to 1.2% respectively.

3.6 Friction Factor of .006% as hot fluid:

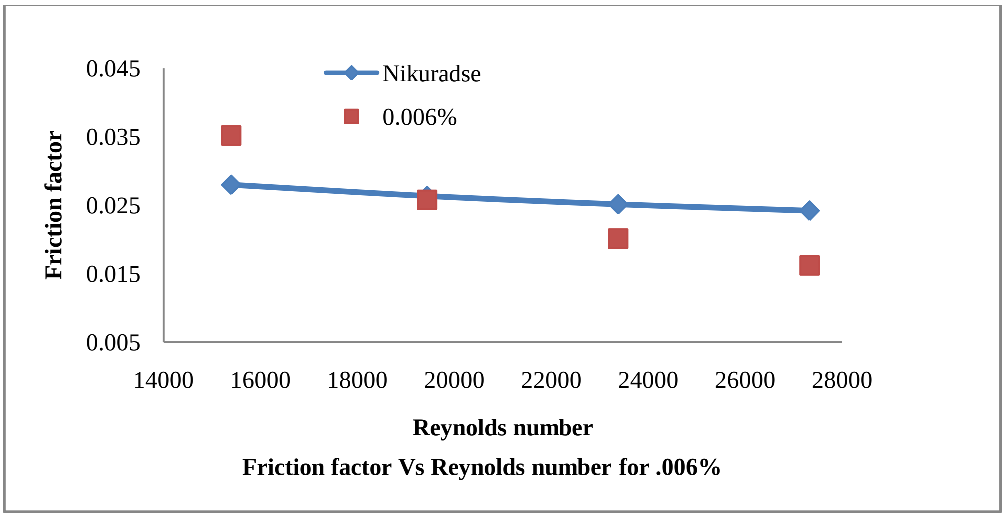

Fig 3.6 Friction factor Vs Reynolds number for (0 .006%)

The variation in friction factor of Iron oxide-water nano fluid in terms of Reynolds number and 0.006% volume concentration. It is observed that the friction factor for analytical and experimental is found to decrease with increasing Reynolds number. The deviation between theoretical and that of experimental data varies from -20.4% to 32.17%, within the range of Reynolds number considered in the present study.

3.7 Heat Transfer Coefficient of 0.008% as Hot Fluid:

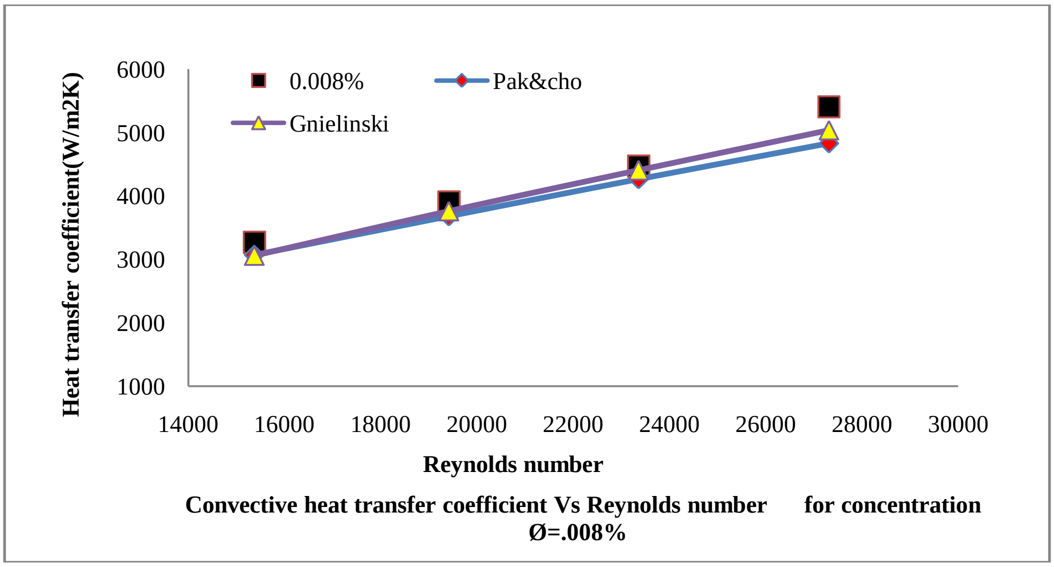

Fig 3.7 Convective heat transfer coefficient Vs Reynolds number for concentration (Ø=.008%)

From fig 3.7 it is explained that As the mass flow rate of hot water increases, Reynolds number increases. From the experimental results, it is found that the increasing Reynolds number from 15370 to 27310,convective heat transfer coefficient increases from 3273 to 5409.Pak & Cho and Gnielinski equations are used to find out the theoretical convective heat transfer coefficients and compared with .008% concentration data. As the Reynolds number increases, the difference of experimental (.008%) heat transfer coefficient and Analytical heat transfer coefficient increases from 6.2% to 10.6%.

3.8 Friction Factor of .008% as hot fluid:

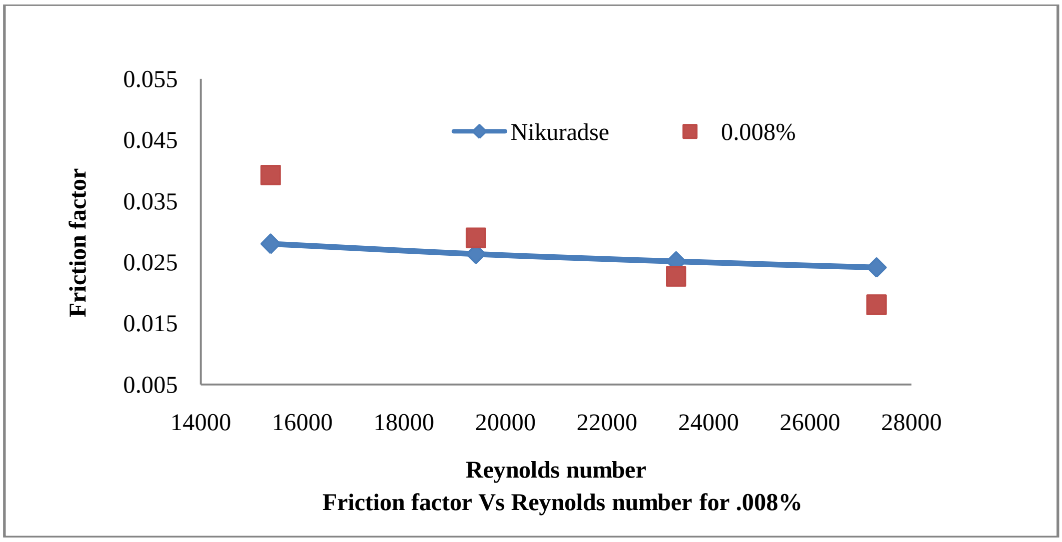

Fig 3.8 Friction factor Vs Reynolds number for .008%

The variation in friction factor of Iron oxide-water nanofluid in terms of Reynolds number and .008% volume concentration. The deviation between theoretical and that of experimental data varies from -28.5% to 25.33%, within the range of Reynolds number considered in the present study This is because of the increasing turbulence which reduces the frictional forces between moving fluid and tube. It can be clearly seen that initially friction factor of Nikuradse is less than that of experimental, later as mass flow rate, Reynolds number increases experimental friction factor decreases because of the increasing turbulence which reduces frictional forces between the moving fluid and the tube.

3.9 Comparative results of heat transfer coefficient for different volume concentrations of Iron oxide Nanofluid:

Figure 3.9 shows the comparison of experimental convective heat transfer coefficient of Iron oxide nanofluid and water in terms of Reynolds number at various volume concentrations. The results shows that the convective heat transfer coefficient increases with increasing volume concentration of nano particles and Reynolds number of range 15000 to 27500 compared to the base fluid The average enhancement of the heat transfer coefficient compared to that of base fluid is 26.27%, 40% and 64.4% for a volume concentration of 0.004 %, 0.006% and 0.008% respectively. The maximum increase of 30.9% is observed in case of 0.004% volume fraction at a Reynolds Number of 15401, 52% is observed in case of 0.006% volume fraction at a Reynolds Number of 23373and 77% is observed in case of 0.008% volume fraction at a Reynolds Number of 15374.

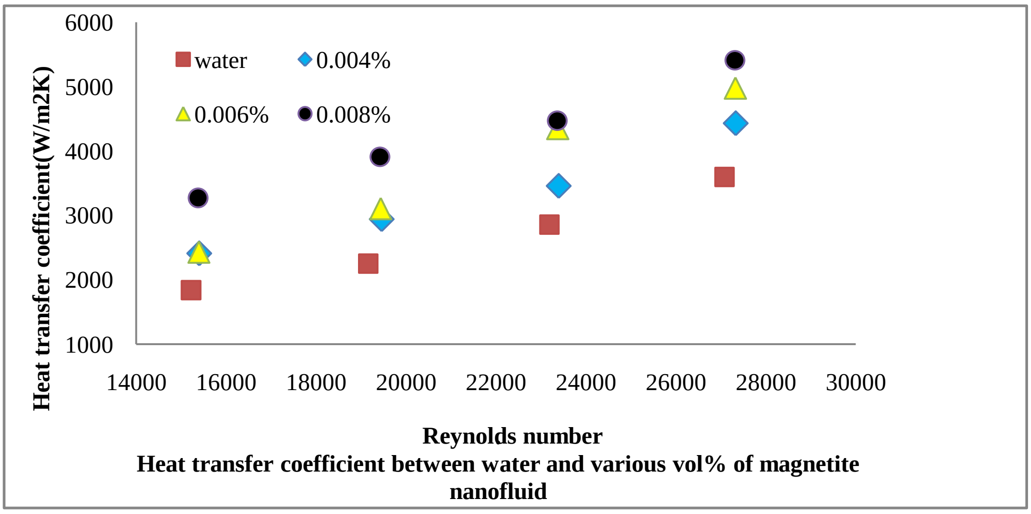

Fig: 3.9 Heat transfer coefficient between water and various vol% of magnetite nanofluid

The enhancement of heat transfer coefficient might be due to following reasons – (1) increased heat transfer surface between the suspended particle and the fluid. (2) Uncontrolled movement of nano particles in the base fluid.

3.10 Comparative results of Enhancement ratio for different Reynolds number:

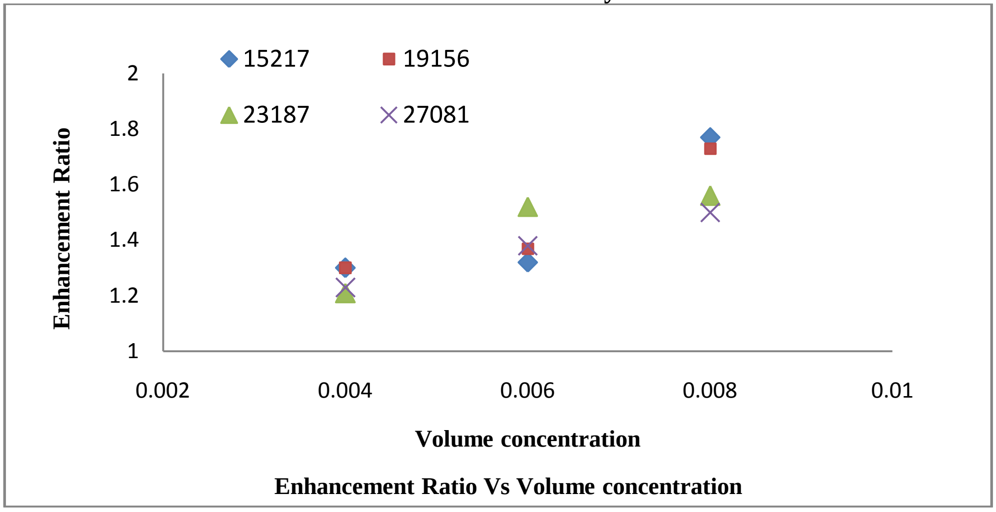

Fig 3.10 Enhancement Ratio Vs Volume concentration

Fig.3.10 shows the Enhancement of heat transfer coefficient graph for different Reynolds number. From the above graph, it is found that higher enhancement is observed at 0.008% volume concentration at low Reynolds number i.e.15217. The enhancement of heat transfer coefficient is lower at 0.004% volume concentration at Reynolds number 23187. With the increase of nano particles concentration, the heat transfer surface area between the suspended nano particles and the base fluid increases. This might be responsible for higher enhancement in heat transfer coefficient at 0.008% volume concentration. At .008% volume concentration and Reynolds number of 15217, enhancement ratio is nearly 1.8 times of the original value.

3.11 Comparative results of Thermal performance factor for different Volume Concentrations of Iron Oxide Nanofluid:

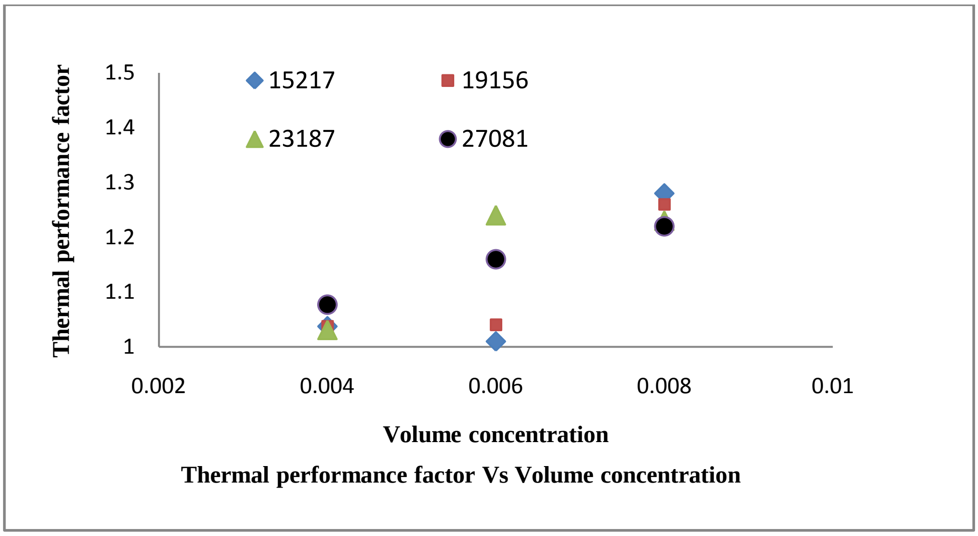

Fig. 3.11 Thermal performance factor Vs Volume concentration

From the above graph, it is found that the thermal performance is generally increased with increase of volume concentration. Higher thermal performance factor of 1.28 is observed at 0.008% volume concentration at low Re. With minor experimental deviations at high Re, in general, the thermal performance factor decreased with the increase of Re. Thus, based on the combined effect of heat transfer enhancement and friction factor enhancement, it is clear that nanofluid has shown higher thermal performance at higher volume concentrations and at low flow rates, as compared to the high flow rates.

4. Conclusions

- The addition of Iron oxide nano particles, even at low volume concentrations has resulted into the enhancement of heat transfer coefficient, with an average enhancement of the heat transfer coefficient compared to that of base fluid as 26.2%, 40% and 64% for corresponding volume concentration of 0.004 %, 0.006% and 0.008% respectively.
- Higher heat transfer enhancement is observed at low Reynolds number, for example, at a volume concentration of 0.008%, the enhancement in the heat transfer coefficient is 1.8 times that of base fluid at low Re as compared to approximately 1.4 times at high Re. Similar results are observed at other volume concentrations also.
- The heat transfer coefficient is increased with the increase of volume concentration, with a maximum enhancement of nearly 77% is observed at 0.008%.
- Owing to higher values of heat transfer enhancement and pressure drop, the thermal performance factor is evaluated, which suggests that the thermal performance is increased with increase of volume concentration. For example, at a given Reynolds number of 15000, the thermal performance factor is 1.037 for a volume concentration of 0.004% compared to 1.28 at a volume concentration of 0.008%.
- At any given volume concentration, thermal performance is higher at low Reynolds number and reduced with the increase of Reynolds number. For example, in case of 0.008% Iron oxide nanofluid, the thermal performance factor is highest i.e., 1.28 at low Reynolds number and is 1.22 at high Reynolds number.
- Based on the experimental results, within the range of Reynolds number considered, the addition of Iron oxide nano particles has enhanced the heat transfer coefficient and the increased enhancement in thermal performance is observed at increased volume fractions and at low flow rates, within the range of volume fractions and Reynolds number considered in the analysis.

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