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RESEARCH ARTICLE

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HEAT TRANSFER ANALYSIS ON PLAIN TUBE HEAT EXCHANGER USING TiO_2 NANOFLUID

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ABSTRACT

Now a day, heat transfer has become an important problem for thermal equipment. In this project work, the base fluid (water) will be changed into nanofluids (TiO_2). The heat transfer will be analyzed on the plain tube heat exchanger using nanofluids (TiO_2) for various volume flow rates and a wide range of concentration. In this project, the work will be carried out at various Reynolds numbers. The performance is made on the basis of the rate of flow using the Reynolds number and wide range of concentration. This gives the flow of the fluid in laminar or turbulent. And also, the project will be carried out on both the direction.

INTRODUCTION

Forced convection heat transfer in a circular tube had been a subject of interest in many research studies over the past decades. In terms of reducing the size and the cost of the heat exchanger devices and saving up the energy, many engineering techniques had been devised to enhance the heat transfer rate from the wall in heat exchangers. The thermal conductivity of fluids has significant effect in heat transfer equipments. Traditional heat transfer fluids including Oil, Water and Ethylene glycol (EG) are poor heat transfer fluids. Water is the most cost effective and widely used thermal fluid available with high heat transfer efficiencies and easy to control. However, its main limitation is that at a temperature above 100ºC it starts to boil, become steam and hence can only be used as a pressurized system – imposing restrictions upon its handling and use to ensure safe operation. The introduction of nano-sized particles to heat transfer fluids (nanofluids) is an emerging thermal management concept with implications in many disciplines including power generation, transportation, micro-electronics, chemical engineering, aerospace and manufacturing.

Convective heat transfer can be improved by the addition of nanoparticles to the conventional heat transfer fluids. The concept of nanofluid was proposed by Choi in 1995. Nanoparticles have thermal conductivities that are significantly higher than base fluids. They also remain in suspension and contribute to the thermo-physical properties of the system while mitigating problems associated with erosion, sedimentation and clogging, observed for suspensions of micron size particles. A large variety of nanoparticle suspensions with different nanoparticle materials, shapes, sizes and concentrations have been extensively studied in last decade; the majority of studies have been conducted in polar base fluids such as water, ethylene glycol (EG) and their mixtures.

Many nanoparticles are being dispersed in the basefluids to get the nanofluids. Of these the commonly used materials are Alumina, copper oxide, titanium oxide etc. Nanopowders are produced by physical or chemical methods. Physical methods include inert gas condensation and mechanical grinding. Chemical methods include thermal spray, spray pyrolysis, chemical vapor deposition and arc sputtering.

Nanofluid preparation can be done in two methods. They are one step method and two step method. In one step method, preparation of nanofluid and their dispersion in the base fluid will take place simultaneously. In two step method, the nanopowder is prepared in the first step using any of the methods mentioned above. The nanofluid is prepared by magnetic stirring and ultrasonicating the nanoparticle with the base fluid.

Where *v* is the sedimentation velocity of the particles; R is the radius of spherical particles; µ is the viscosity of the liquid medium; ρs and ρ are the density of particles and liquid mediums; g is the gravitational acceleration. So the factors affecting settling velocity are radius of the particle, viscosity of the fluid and density difference.

The main reasons for heat transfer enhancement are:

- The suspended nanoparticles increase the effective thermal conductivity of the fluid.
- The suspended nanoparticles increase the surface area and the heat capacity of the fluid.
- The interaction and collision among particles, fluid and the flow passage surface are intensified.
- The mixing fluctuation and turbulence of the fluid are intensified. The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid.

In the case of heat exchanger applications, heat transfer enhancement has been achieved by a variety of ways. Heat transfer enhancement in heat exchangers is gaining industrial importance because it gives one the opportunity to reduce the heat transfer surface area required for a given application and thus reduce the heat exchanger size and cost, increase the heat duty of the exchanger for fixed surface area, reduce logarithmic mean temperature difference (LMTD) for fixed heat duty and surface area, and reduce pumping power for fixed heat duty and surface area.

SYNTHESIS OF TiO_2 NANO FLUIDS

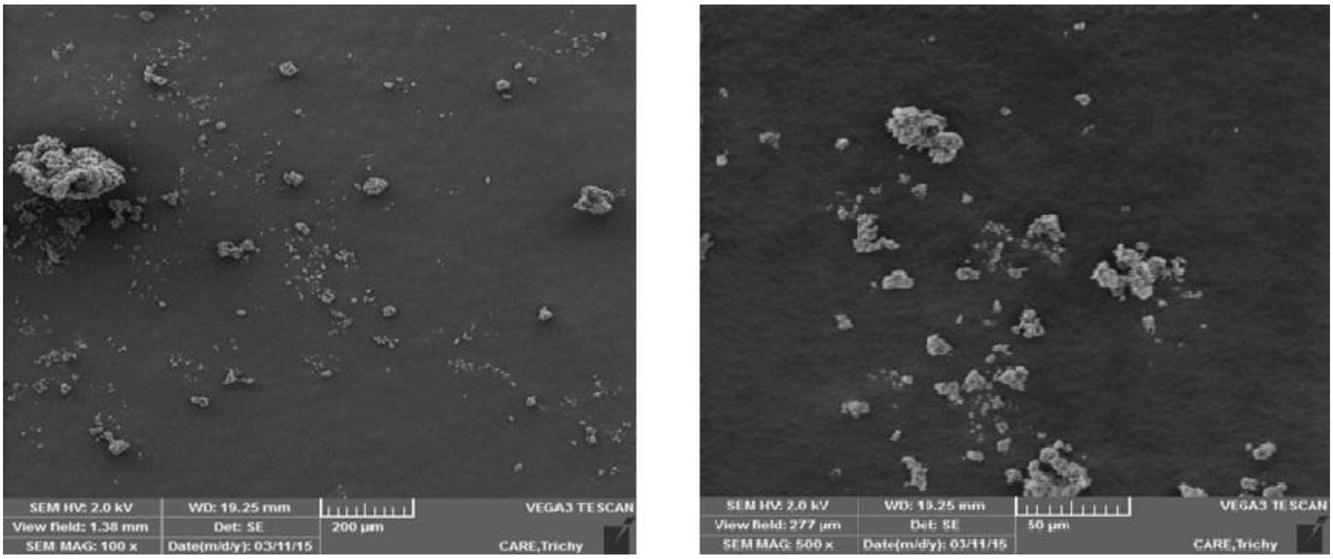

Figure 1: SEM image of TiO_2 nanoparticle

PREPARATION OF NANO-FLUID:

Figure 2: Ultrasonic bath

THERMAL CONDUCTIVITY MEASUREMENTS

The thermal conductivity of TiO_2 nanofluid was carried out using KD2 Pro thermal properties analyzer (Deccagon Devices, Inc, USA). The KD2 Pro is a battery operated, menu driven device that measures thermal conductivity and resistivity, volumetric specific heat capacity and thermal diffusivity.

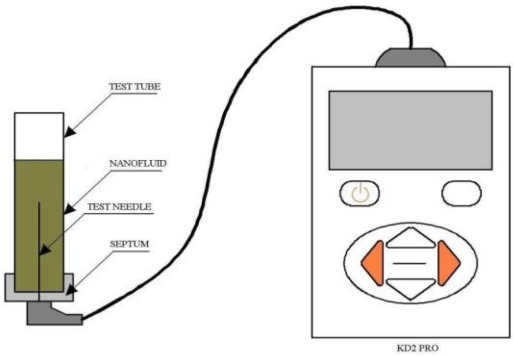

Figure 3: Schematic Diagram of thermal conductivity measurement arrangement

It consists of a handheld microcontroller and sensor needles. The sensor needle used was KS-1 which is made of stainless steel having a length of 60 mm and a diameter of 1.3 mm, and closely approximates the infinite line heat source which gives least disturbance to the sample during measurements. The sensor needle can be used for thermal conductivity of fluids in the range of 0.2 – 2 W/mK with an accuracy of ± 5%.

EXPERIMENTAL SETUP

The schematic diagram of experimental setup for the heat transfer and friction factor study is shown in *figure 4*. The experimental setup consists of a calming section, test section, pump, cooling unit, a fluid reservoir and temperature and pressure drop measurement arrangements. The fluid is directed from the reservoir using a centrifugal pump. A valve and by pass valve arrangement is used for controlling the flow rate. The flow rate is measured by using a rotameter. The fluid after passing through the heated section flows through a riser section and then through the cooling unit and finally it is collected in the reservoir.

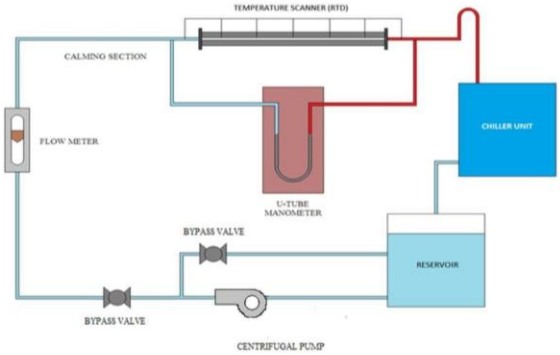

Figure 2: Schematic diagram of Experimental setup

The test section is heated uniformly by the electrical heating wire, attached to an auto-transformer, by which the heat flux can be varied by varying the voltage. Calibrated RTD sensors are used to measure the inlet, outlet and surface temperatures at five different locations. An indicator panel is provided to display the temperatures. The pressure drop across the system is measured by a U tube manometer connected.

EXPERIMENTAL PROCEDURE

All RTDs used for temperature measurements were calibrated.

- Validation of experimental setup was done with water as the working fluid in laminar flow conditions.
- The experiment was conducted in the Reynolds number range of 800 to 2300 and in the range of 9000 to 23000

For heat transfer study

- Centrifugal pump was used to pump nanofluid from the reservoir. The heater was switched on and autotransformer was adjusted to 140 volts.
- A valve is used to control the flow rate of the nanofluid. The heat flux was set by adjusting the electrical voltage with the help of an auto

transformer, and constant heat flux was allowed to continue till the steady state is reached.

For pressure drop study

- Centrifugal pump was used to pump nanofluid from the reservoir.
- The pressure drop was measured for each flow rate without switching on the heater with the help of a U-tube manometer.
- The flow rates are varied and the pressure drop readings are noted after the steady state is reached.
- Experiments were conducted for heat transfer and pressure drop studies in plain tube using TiO_2 nanofluids of 0.25%, and 0.5% volume concentrations under Laminar and Turbulent flow condition.

Heat Transfer Calculation

The total heat generated by the electrical winding is calculated as,

$Q_1 = VI$

Where V is the heater input voltage and I is the heater input current.

The heat absorbed by the fluid is calculated as,

$Q_2 = \dot{m}C_p(T_{out} - T_{in})$

$\dot{m}$ - mass flowrate of fluid Tin and Tout are the fluid inlet and exit temperatures

$$Q = \frac{Q_1+Q_2}{2} \qquad (3)$$

$$q = \frac{Q}{\pi DL} \qquad (4)$$

The measured local wall temperature and heat flux are used to calculate the local heat transfer coefficient defined by the following formula:

$$h = \frac{q}{(T_w - T_f)} \qquad (5)$$

Where, q is the heat flux, Tw is the average wall temperature, and Tf is the average fluid temperature

The average Nusselt number is calculated as,

$$Nu = \frac{h\,D}{k} \qquad (6)$$

Where D is the diameter of the test section, h is the average heat transfer coefficient, and k is the thermal conductivity of the working fluid.

Friction Factor Calculation

The pressure drop (Δp) measured across the test section under isothermal condition is used to determine the friction factor (f) using the following relation

$$f = \frac{\Delta p}{\frac{1}{2}\rho v^2}\,\frac{D}{L} \qquad (7)$$

Where v is the fluid velocity, ρ is fluid density, D is the test section diameter and L is the test section length.

RESULT AND DISCUSSION:

Validation of experiment setup:

To validate the experimental setup in Laminar flow, experiments were conducted with pure Water in plain tube with Reynolds numbers in the range 800 to 2300 for laminar flow. The validation of experimental setup was done under constant heat flux conditions in the laminar flow conditions.

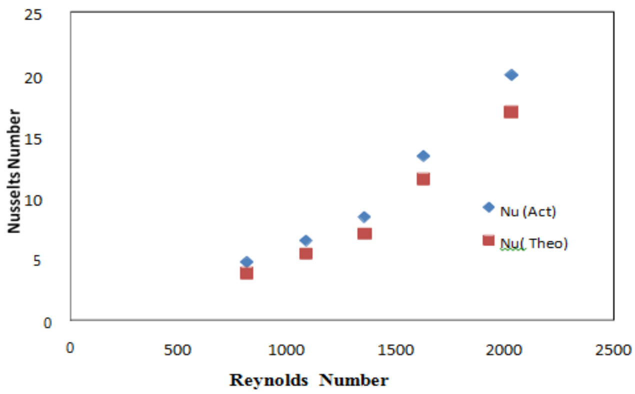

Figure 4: Comparison of Experimental and Theoretical Nusselts Number values in Laminar Flow

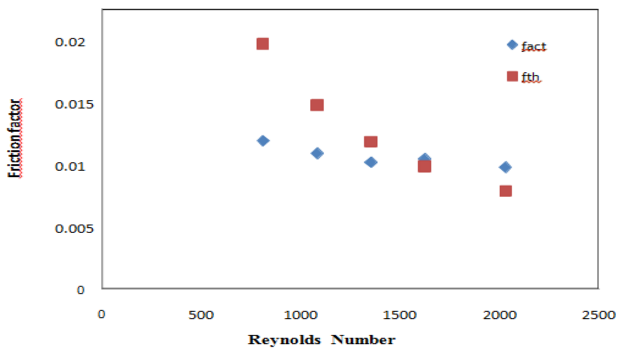

Figure 5: Comparison of Experimental and Theoretical Pressure drop values in Laminar flow

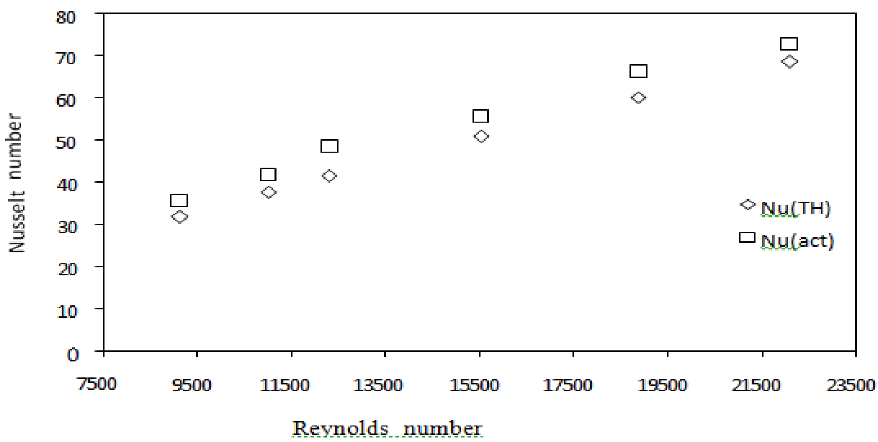

Figure 6: Comparison of Experimental and Theoretical Nusselts values

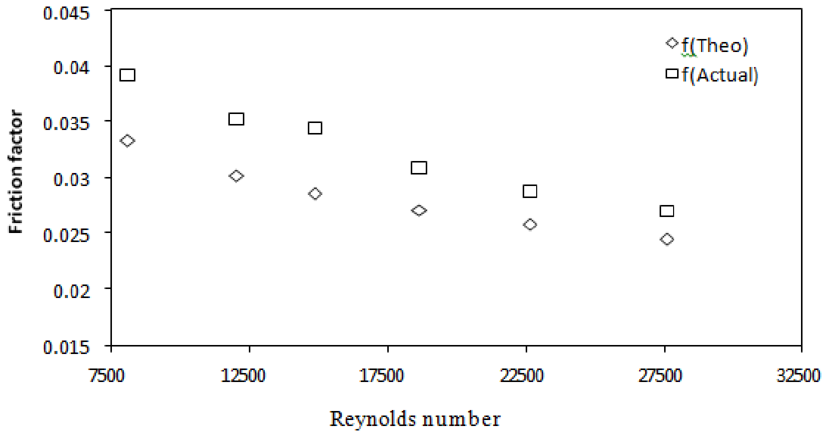

Figure 7: Comparison of Experimental and Theoretical Pressure drop values

Heat transfer characteristics of TiO_2 nanofluids:

The experimental data of TiO_2 nanofluids of 0.25% and 0.5% volume fraction were used to deduce the Nusselt number in laminar and turbulent flow regime. It is compared with Plane tube with water. The Nusselt numbers are calculated from the measured values of mean wall temperature and bulk mean temperature and the actual heat flux. The reasons for such increases in Nusselt number may be due to mixing effects of particles near the wall, thermal conductivity enhancement, Brownian motion of particles, particle shape, particle migration and re-arrangement, reduction of boundary layer thickness etc.

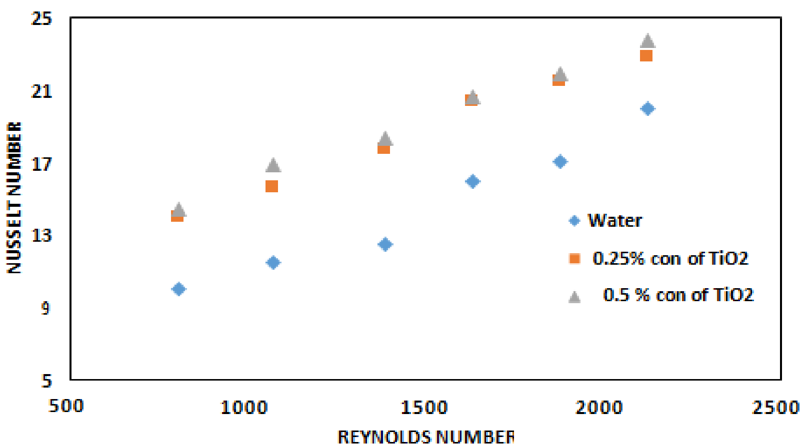

Figure 8: Reynolds number vs Nusselt number in plane tube in laminar regime with water and nanofluids

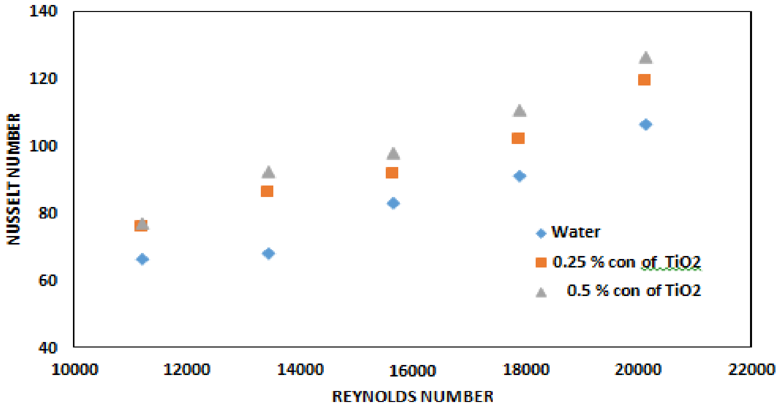

Figure 9: Reynolds number vs Nusselt number in plane tube in turbulent regime with water and nanofluids

The figure 6 shows that show the experimental results for the laminar flow showed average enhancements of 30.66%, and 35.8% for 0.25% and 0.5% of nanofluids compared to Plain tube with water. The figure 5.4 shows that show the experimental results for the turbulent flow showed average enhancements of 15.41% and 22.11% for 0.25% and 0.5 % of nanofluids compared to Plain tube with water, across the test section, which uses mercury as the manometric fluid.

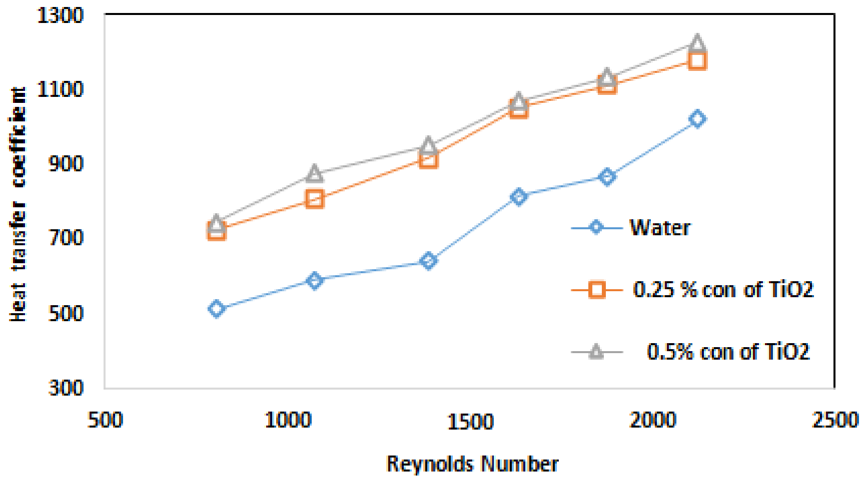

Figure 10: Heat transfer coefficient enhancement in plane tube with nanofluids in laminar regime

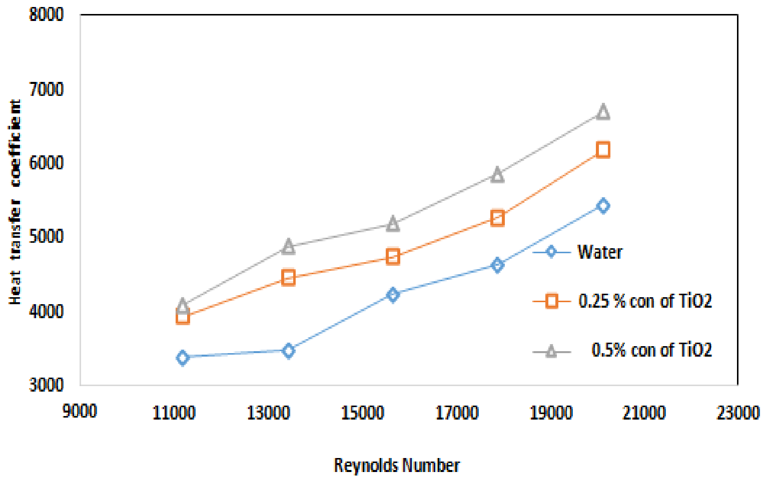

Figure 11:Heat transfer coefficient enhancement in plane tube with nanofluids in turbulent regime.

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The figure 8 shows that show the experimental results for the laminar flow showed average enhancements of heat transfer coefficient by 32.36% and 37.53% for 0.25% and 0.5 % of nanofluids insert compared to Plain tube in laminar flow regime. The figure 5.6 shows that show the experimental results for the turbulent flow showed average enhancements of 16.92%,and 26.91% for 0.25% and 0.5 % of nanofluids compared to Plain tube with water in turbulent flow regime.

Friction Factor Characteristics of TiO_2Nanofluids:

It is necessary to measure the pressure drop of nanofluid besides the heat transfer performance in order to apply nanofluids in industrial units. Hence, the $_2$pressure drops of the nanofluid in a tube at different flow rates are experimentally measured for laminar turbulent flow under isothermal conditions. The pressure drop (Δp) measured across the test section is used to calculate the friction factor.

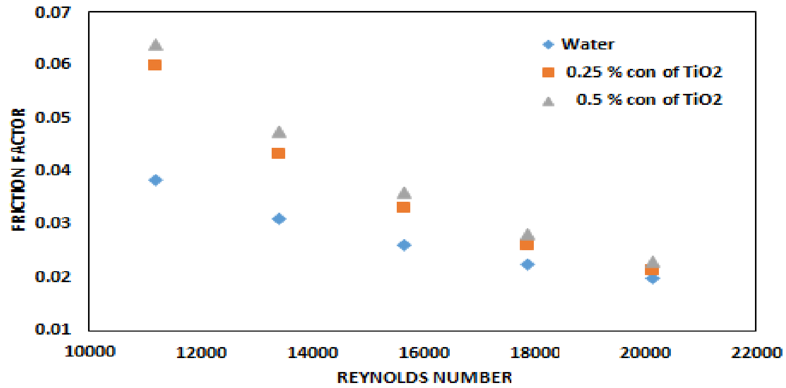

Figure 11: Reynolds number vs Friction factor in plane tube in laminar regime with water and nanofluids

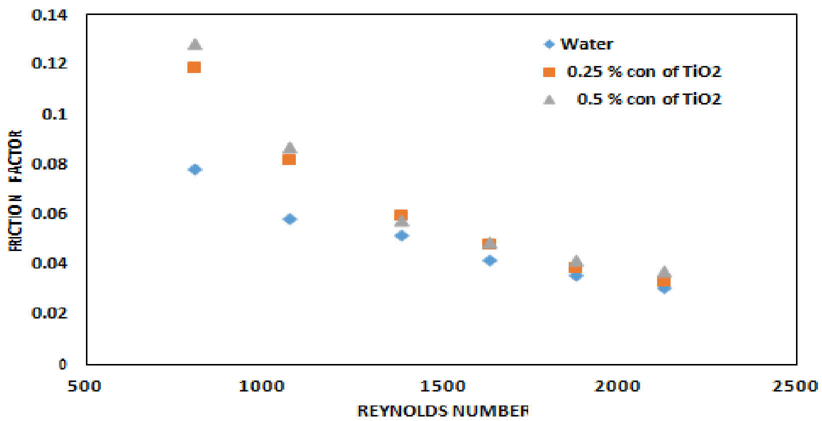

Figure 12: Reynolds number vs friction factor in plane tube in turbulent regime with water and nanofluids

CONCLUSIONS

- From the detailed analysis of the data presented in discussion the following conclusions were obtained. Experimental results for the laminar flow showed average enhancements of 30.66%, and 35.8% for 0.25% and 0.5% of nanofluids compared to Plain tube with water.
- Experimental results for the turbulent flow showed average enhancements of 15.41% and 22.11% for 0.25% and 0.5 % of nanofluids compared to Plain tube with water. Experimental results for the laminar flow showed average enhancements of heat transfer coefficient by 32.36% and 37.53% for 0.25% and 0.5% of nanofluids insert compared to Plain tube in laminar flow regime.
- Experimental results for the turbulent flow showed average enhancements of 16.92%,and 26.91% for 0.25% and 0.5 % of nanofluids compared to Plain tube with water in turbulent flow regime. The average increase in friction factor is 30.66 % and 35.8% for 0.25% and 0.5 % of nanofluids compared to Plain tube in laminar regime The average increase in friction factor is 29.51 % and 39.82% for 0.25% and 0.5% of nanofluids compared to Plain tube in turbulent

regime.

- Main reasons for heat transfer enhancement may be increased thermal conductivity of fluid, increased surface area and heat capacity of fluid, increased turbulence and fluctuations in fluid due to the presence of nanoparticle etc.

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