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Heat transfer and friction characteristics of metal oxide nanofluids through a circular tubewith small pipe inserts

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***Abstract*—In the past years, an amazing number of heat transfer enhancement techniques have been developed to improve the convective heat transfer through pipes. In that, inserts are the most commonly used enhancement techniques. The low cost, rapid installation and easy maintenance associated with this augmentation technique makes it attractive compared with other enhancement techniques. In the present work a novel type of insert, S shape pipe insert was used to improve heat transfer along with fluid additives. In this work experimental evaluation of heat transfer and friction characteristics on a straight circular tube of inner diameter 16mm fitted with this insert and TiO2/deionized water Nanofluid of different particle volume concentration as working fluid. Insert with arc radius 5mm and different spacer lengths (S = 100, 150 and 225mm) were investigated at Reynolds number range between 800 and 6000. The results show that Nusselt number increases and friction factor decreases with increase in Reynolds number throughout the experiments. The geometry of the small pipe inserts makes the fluid to flow easily from the central region to wall region of the pipe thus it can achieve a high heat transfer by controlling the friction factor. Experiment were conducted using both water and TiO2/deionized water nanofluid as working fluid and TiO2/deionized water Nanofluid showed better heat transfer enhancement than water .Compared with other inserts, pipe inserts can transfer more heat for the same pumping power due to its unique structure.**

***IndexTerms*—Pipe insert,Nano fluid,Titanium dioxide**

1. INTRODUCTION

The technique of improving the performance of heat transfer system is referred to as heat transfer augmentation or intensification. Heat exchangers are devices used to transfer heat from one medium to another efficiently. They are used in different processes ranging from conversion, utilization & recovery of thermal energy in various industrial, commercial & domestic applications. The design procedure of heat exchangers is quite complicated, since it needs analysis of heat transfer rate and pressure drop estimations along with issues such as long-term performance and the economic aspect of the equipment. The major challenge in designing a heat exchanger is to make the device compact and achieve maximum heat transfer rate using minimum pumping power. In recent years, the high cost of energy and material has resulted in an increased effort for producing more efficient heat exchanger equipment. The need to increase the thermal performance of heat exchangers, thereby reducing energy consumption, material & cost savings. Thus Heat transfer enhancement technology has been widely developed and applied to heat exchanger applications; for example, refrigeration, automotive, process industry, chemical industry etc.

Researchers have designed various inserts to achieve a high heat transfer rate and low increase in pressure drop.M. Udayakumar et Al. [1] used Heat Transfer enhancement techniques to increase rate of Heat transfer.S. Liu a,n, M.Sakr[2] studied passive heat transfer technique. These techniques when adopted in Heat exchanger proved that the overall thermal performance improved significantly.A. Hasanpour et Al. [3] studied heat transfer enhancing mechanisms used in many industrial applications like heat exchanger, air conditioning, chemical reactors and refrigeration systems.One of the leading tools used in passive heat transfer methods mainly at turbulence flow is twisted tape inserts. P.K. Sarma et.al. [4] Presents a new approach in predicting the convective heat transfer coefficient in a tube

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with twisted tape inserts of different pitch to diameter ratios. A modification is proposed to the classical van Driest eddy diffusivity expression to respond to the case of swirl flow generated by the tape inserts.Smith Eiamsa-ard [5] presents an experimental study of turbulent heat transfer and flow friction characteristics in a circular tube equipped with two types of twisted tapes: (1) typical twisted tapes and (2) alternate clockwise and counterclockwise twisted tapes (C–CC twisted tapes). Nine different C–CC twisted tapes are tested in the current work.The results reveal that the C–CC twisted-tapes provide higher heat transfer rate, friction factor and heat transfer enhancement index than the typical twisted-tapes at similar operating conditions. P. Murugesan et.al [6] studied the effect of V-cut twisted tape insert on heat transfer, friction factor and thermal performance factor characteristics in a circular tube were investigated The obtained results show that the mean Nusselt number and the mean friction factor in the tube with V-cut twisted tape (VTT) increase with decreasing twist ratios (y), width ratios (WR)and increasing depth ratios (DR).

2. EXPERIMENTAL SETUP

Main parts of experimental set up which completes the fluid flow circuit are reservoir, pump, calming section, test section, riser section, cooling unit, manometer, powersupply and temperature indicators. It is schematically represented as in the figure 2.1

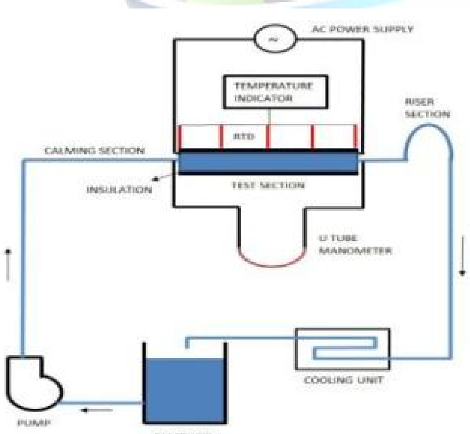

Fig 2.1 Schematic of experimental setup

The pump (here peristaltic pump) takes away fluid (water or TiO_2/water Nano fluid) from the reservoir to the calming section where the irregularities in the flow are minimized. From the calming section fluid passes on to test section which contains RTD for temperature measurement.

Fig2.2 Experimental setup.

The test section is connected to manometer for pressure, measurements and is connected to power supply (through a dimmer stat) to heat the test section. Inserts are placed in this test section. A riser section is provided so that the circuit is completely filled at low Reynolds number flow. Cooling unit cools down the hot fluid from the test section and passes it to the reservoir.The inserts used are small pipe inserts of S shape with different spacer lengths. At first the small pipe inserts is fabricated from copper tubes of 1mm ID and 0.5 mm thickness. A small copper tube 20mm in length was formed into an S-shape small pipe insert. Then three such pipe inserts were mounted on a 1000 mm copper rod with different spacer lengths(S=100, 150 and 225 mm). The pipe insert geometries are shown in Fig 2.3.

Fig 2.3 Fabricated pipe inserts

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The spacer length is the distance between two consecutive pipe insert. The inserts are manufactured by a gold smith. Six inserts are manufactured with different spacer distance and number of wings. The inserts are named as shown in the table 3.1.

Table 3.1 Cases of Inserts considered

NAME	SPACER LENGTH	NUMBER OF WINGS
INSERT A	100mm	3
INSERT B	150mm	3
INSERT C	225mm	3

3. DATA PROCESSING

The total electrical power supplied to the tube wall

$$Q_e = V \times I$$

Actual heat supplied by heater

$$Q_1 = Q_e - Q_{loss}$$

The heat absorbed by the fluid is calculated as,

$$Q_2 = m\, C_p (T_{fout} - T_{fin})$$

Heat transfer rate

$$Q = \frac{Q_1 + Q_2}{2}$$

Heat flux is calculated as

$$q = \frac{Q}{\pi D L}$$

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

The average heat transfer coefficient is $h = \frac{q}{(T_{wavg} - T_{favg})}$

The average Nusselt Number is $Nu = \frac{hD}{k}$

The local heat transfer coefficient is $h_x = \frac{q}{(T_{wx} - T_{fx})}$

Where, $T_{fx} = T_{fin} + \frac{q\, s_x}{\rho\, C_p\, A\, v}$

$S_x = \pi D\, x$

The local Nusselt Number is $Nu = \frac{h_x D}{k}$

The friction factor is $f = \frac{\Delta P\, D}{\frac{1}{2} \rho\, v^2\, L}$

The experimental friction factor was compared with Hagen Poiseuille equation in laminar flow $f = \frac{64}{Re}$

Thermal performance factor equation for the performance evaluation of the inserts at the same pumping power

$$\eta = \frac{\frac{Nu}{Nu_{pt}}}{\left(\frac{f}{f_{pt}}\right)^{0.1666}}$$

4. RESULTS AND DISCUSSIONS

4.1 Experimental setup validation

For validating the experimental setup, experiments were conducted using water at constant heat flux boundary condition. In the laminar flow range the experimental data was compared with Shah Equation.

$Nu = 1.953\,(RePr\, D/x)^{0.333}$ for RePr D/x $\geqslant 33.33$

The Reynolds number used for validation is 1280.714

For low turbulent flow the data was compared with Gnielinskis equation

$$Nu = \frac{\epsilon/2\,(Re - 1000)Pr}{1 + 12.7\left(\frac{\epsilon}{2}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)}$$

where $\epsilon = \frac{1}{(1.58 \ln Re - 3.82)^2}$

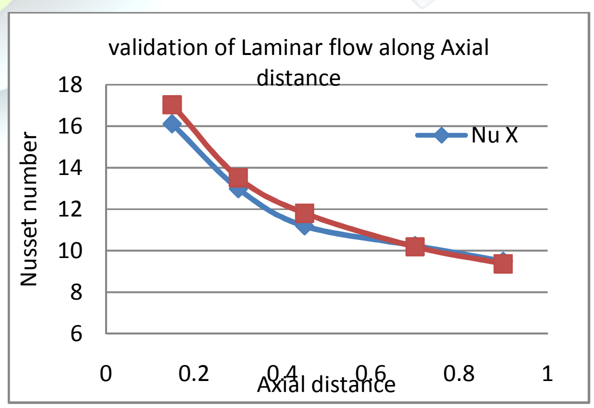

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Fig. 4.1. Validation of the experimental Nusselt number with Shah equation

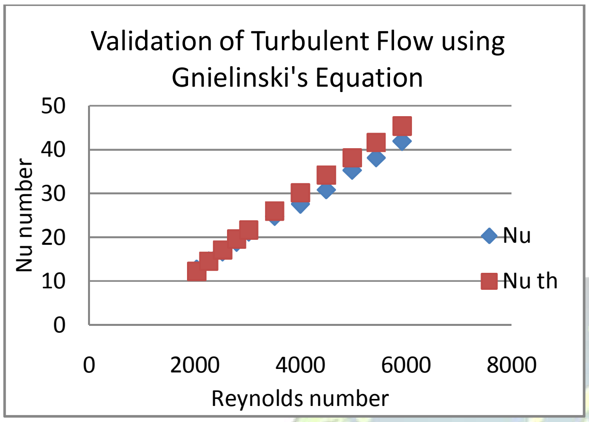

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Fig 4.2 Comparison of experimental Nusselt number with Gnielinskis equation

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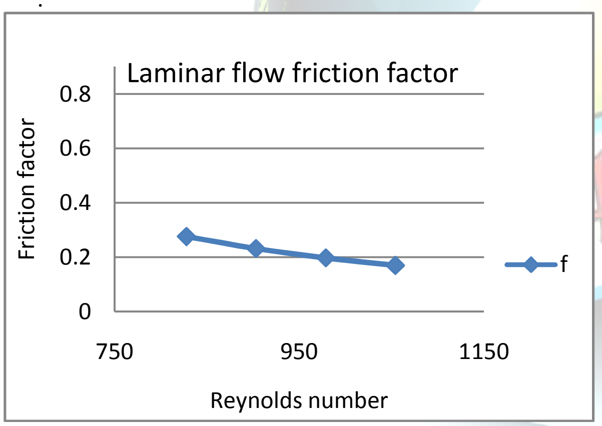

Fig 4.3 Friction factor vs. Reynolds number in plain tube in laminar flow

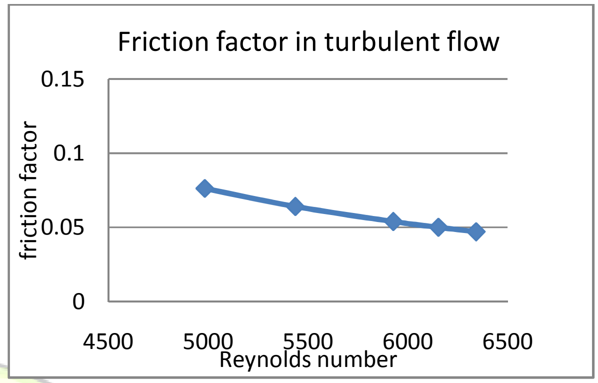

Fig 4.4 Friction factor vs. Reynolds number in plain tube in turbulent flow

4.2 Variation of Nusselt number with Reynolds number of differentinserts with nanofluids.

Experiments were conducted on a straight plain circular tube at constant heat flux boundary using water and TiO_2/water nanofluid of 0.1 % and 0.3 % volume concentration.In all experiments, the Nusselt number increases with the Reynolds number. The insert A has 3 wings and the spacer distance is 100mm. Experiments were conducted by fitting the insert A in the tube and using water and TiO_2/water nanofluid of 0.1 % and 0.3% volume concentration as the fluids. Insert A showed an increase in Nusselt number while comparing against plain tube.

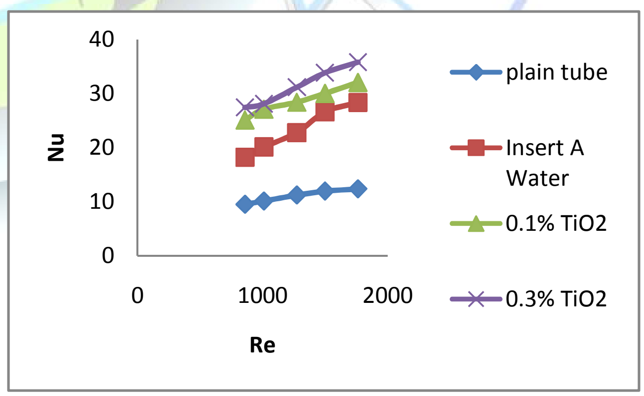

Fig. 4.5 Variation of Nusselt number with Reynolds number of INSERT A in laminar region.

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For 0.1 % volume concentrationthe average increase in nusselt number produced withinsert A is 147% and for0.3 % volume concentrationthe enhancement in nusselt number is about 170%.

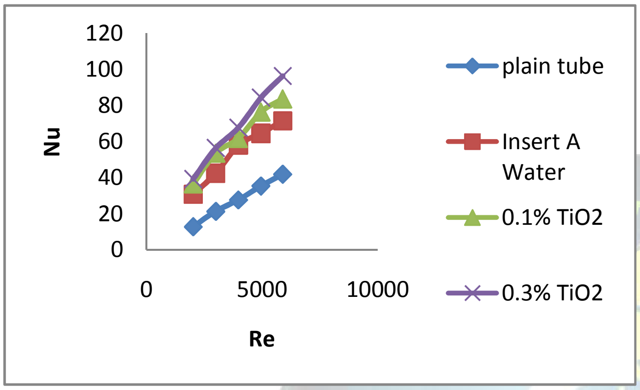
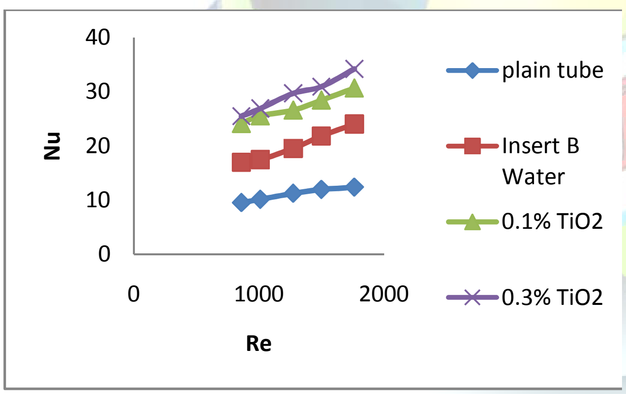


Fig. 4.6Variation of Nusselt number with Reynolds number of INSERT A in low turbulant region.



.Fig. 4.7 Variation of Nusselt number with Reynolds number of INSERT B in laminar region.

Insert Bproduces an average increase in nusselt number by133% with0.1 % volume concentrationand 154% with0.3 % volume concentration.

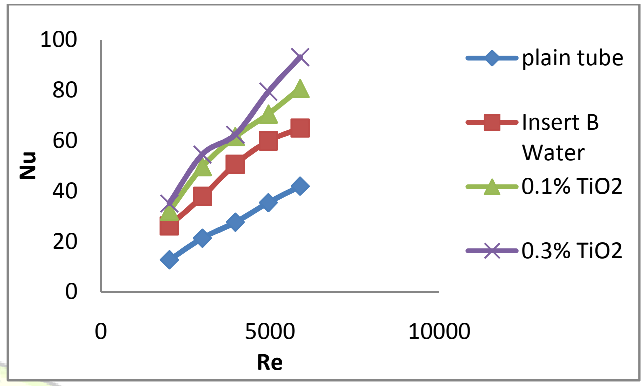


Fig 4.8. Variation of Nusselt number with Reynolds number of INSERT B in low turbulant region.

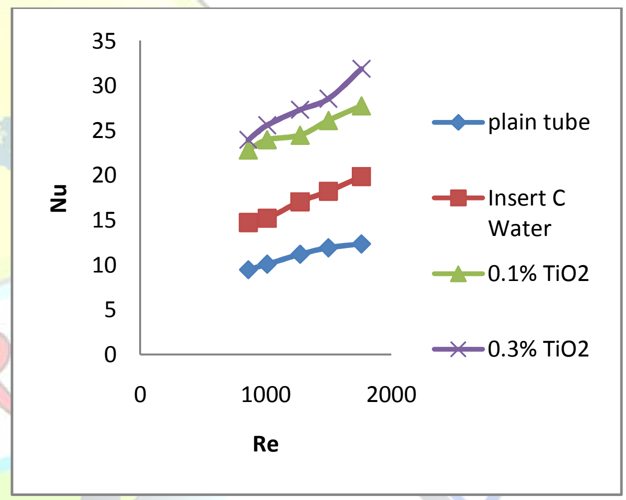


Fig. 4.9 Variation of Nusselt number with Reynolds number for INSERT B in low turbulent region.

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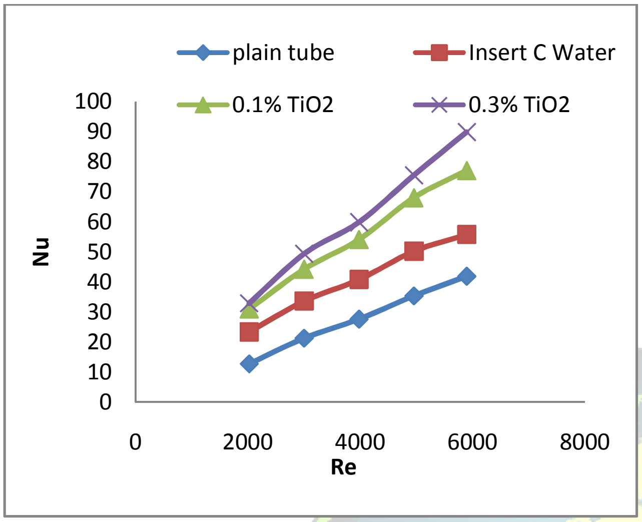

Fig. 4.10 Variation of Nusselt number with Reynolds number for INSERT B in low turbulent region.

The nusselt number increases by with insert Cfor 0.1 % volume concentration and for 0.3 % volume concentration. The experimentalresults show that there is only a slight difference in the friction factor.

4.3 Thermal performance factor.

Thermal performance factor for various inserts are shown in fig the results shows that TPF increases in the laminar region and decreases in the turbulent regionInsert A, B and C shows an average thermal performance factor of 2.19, 2.05 and 1.92 respectively with 0.3% PVC of $TiO_2$and for 0.1% concentration showed 1.98, 1.87 and 1.73 respectively.

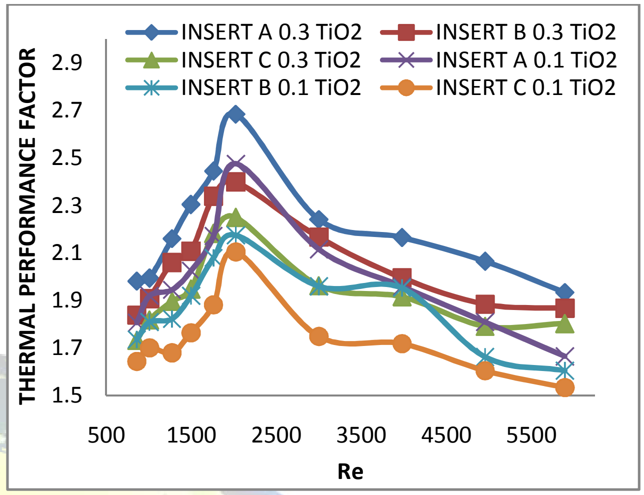

Fig 4.11 Thermal performance factor

5. CONCLUSION

The experiments were conducted with different concentration of titanium dioxide nanofluid and using small pipe inserts.Tubes fitted with pipe inserts affect the heat transfer coefficient and friction factor. The geometry of the small pipe inserts makes it possiblefor water to flow easily through the inside and outside of the pipe. Thisleads to a mixing of water with different temperatures and velocities. Mixing increases the temperature gradient of the thermal boundarylayer and causes uniformity in fluid temperature. This enhances heattransfer.The tube fitted with small pipe inserts can achieve a high heat transfer with a lower increase in friction factor. A combination of insert A with 0.3%Tio_2/water nanofluid gave the best thermal performance factor among different combinations and it is 2.68.The results shows that the increase in particle volume concentration of nanofluid slightly enhances the heat transfer characteristics. Also the nusselt number increases with decreases in spacer distance.

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