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Effect of Al_2O_3/DI water Nanofluids and Inserts in Heat Transfer

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ABSTRACT

In this experimental work, fully established laminar flow convective heat transfer and friction factor characteristics of Al_2O_3/DI water nanofluids flowing through a uniformly heated horizontal circular tube with and without spiraled rod inserts (SRI) is presented. In DI water, the Al_2O_3 nanoparticles are dispersed to form stable suspension of Al_2O_3/DI water nanofluids with 0.1% volume concentration of nanoparticles. It is found that inclusion of nanoparticles to DI water ameliorates Nusselt number. The Nusselt number in the fully developed region are measured and found to be increased by 9.9% at Re 2240 for plain tube with nanofluids of 0.1% volume concentration compared to DI water. Two spiraled rod inserts made up of copper with pitches 50 mm and 30 mm are used which increased the Nusselt number by 24.8% and 27.9% respectively at Reynolds number 2240 with nanofluids of 0.1% volume concentration compared to DI water. The measured friction factor with the used nanofluids is 3% higher than the DI water, which is negligible one, so there is no penalty in the pumping power.

KEYWORDS:Al_2O_3*/DI Waternanofluids, Laminarflow, Heat transfer enhancement, friction factor.*

INTRODUCTION

Nanofluids are the conventional fluids having metals and non-metals of nanometer size suspended in them. It has been researched and used for heat transfer augmentation for over a decade now. Nanofluids have proven to be of having immense potential in revolutionizing many industrial processes such as transportation, chemical process, heating and cooling process, power generation and other micro-sized applications. The use of nanoparticles to enhance heat transfer was first done by Choi[1] in the year 1995 when the known micro particles did not prove to be effective in enhancing heat transfer rate. Since then, a multitude of research has followed keeping choi's work as the base. Al_2O_3, CuO, TiO_2 and SiO_2 are some of the nanoparticles, which are dispersed in base fluids such as water, ethylene glycol and oil to form nanofluids to enhance heat transfer. Researchers have also used hybrid nanoparticles to enhance heat transfer rate along with various inserts such as twisted tape inserts, spiraled rod inserts, wirecoil inserts and numerous other inserts and have found drastic increase in the heat transfer rate.

KyoSik Hwang et al.[2] studied the flow and convective heat transfer characteristics of water-based Al_2O_3 nanofluids in fully developed laminar flow regime. According to their result there was 8% increase in heat transfer coefficient at a concentration of 0.3 vol% compared to pure water. S. Zeinaliaet al.[3] inspected the convective heat transfer of Al_2O_3/water in a circular tube and found that heat transfer coefficient increased with the increase of concentration of nanoparticles in nanofluids. They also found out that the amelioration in heat transfer was much elevated in than conventional fluids. M. Saeediniaet al.[4] studied the thermal and rheological characteristics of CuO-Base oil nanofluids flow inside a circular tube and found that there was an increase in heat transfer coefficient of nanofluids to that of pure oil flow and they found a maximum enhancement of 12.7% in heat transfer coefficient for 2wt% nanofluids. In horizontal tubes using SiO_2/water nanofluids, hydraulic and heat transfer studies were done with imposed wall temperature boundary conditions by SebasteinFerrouillatet al.[5]. Their results showed 10% to 60% increase in heat transfer coefficient compared to pure water. W. Duangthongsuket al.[6] calculated that the augmentation of heat transfer and pressure drop characteristics of TiO_2/Water nanofluids in a double-tube counter flow heat exchanger and the result showed 6-11% increase in heat transfer rate than the base fluid. It was also noted that heat transfer coefficient was directly proportional to the mass flow rate of hot water and nanofluids but inversely proportional to nanofluids temperature.

Wei Yu et al.[7] investigated the heat transfer properties of Al_2O_3 nanofluids using the mixture of ethylene glycol and water as base fluid and found 57% and 106% increase of heat transfer coefficient for 1.0 vol% and 2.0 vol% of nanofluids respectively. M. Chandrasekar et al.[8] studied the heat transfer and friction factor characteristics of Al_2O_3/Water nanofluids in a circular pipe under laminar flow with wire coil inserts and found that 0.1% volume concentration of nanoparticles and there was 12.24% of increase in Nusselt number at Reynolds number 2275 compared to water. When two wire coil inserts made of stainless steel with pitch ratios 2 and 3 was used, the Nusselt number was found to increase by 15.91% and 21.53% respectively at Reynolds number 2275 with nanofluids compared to water. Heat transfer behavior of nanofluids in a uniformly heated circular tube fitted with helical inserts in laminar flow was studied by GovarthanParthipakkaet al.[9].They used helical coil inserts with twist ratios2.93,3.91 and 4.89 with Al_2O_3 nanoparticles in water of 0.1, 1.0 and 1.5% concentrations respectively. It was found that the heat transfer amelioration was directly proportional to Reynolds number and nanoparticles volume concentration and inversely proportional to twist ratio. In the experiment maximum heat transfer rate of 31.29% was found for 1.5% concentration of nanoparticles with helical inserts having twist ratio 2.93 at Reynolds number2039. L. Syam. Sundar et al.[10] studied the effect of full-length twisted tape inserts on heat transfer and friction factor enhancement with Fe_3O_4 magnetic nanoparticles inside a plain tube and they found that for 0.6% volume concentration of nanofluids with twisted tape insert of twist ratio H/D=5 heat transfer rate augmentation was 51.88% more when compared to plain water with same Reynolds number. S. Suresh et al.[11] studied heat transfer and friction factor characteristics of CuO/water nanofluids in a helically dimpled tube and their result showed that for 0.1, 0.2 and 0.3% volume concentration the Nusselt number was 19,27 and 39% respectively which were higher than the plain tube and water.

M. Saeediniaet al.[12] experimented on heat transfer and pressure drop of nanofluids in a horizontal coiled wire inserts under constant heat flux and came to the conclusion that nanofluids had better heat transfer in tubes with wire coil insert than the plain tube. They found a maximum heat transfer enhancement of up to 40.2% above the values for pure oil flow in plain tube for 0.3 vol% nanofluids flow inside the wire coil inserted tube with highest wire diameter. S. Suresh et al.[13] did a comparative study on thermal performance of helical screw tape inserts in laminar flow using Al_2O_3/water and CuO/water nanofluids and found that helical screw inserts with CuO/water showed better performance than with Al_2O_3/water nano fluids. C. J. Ho et al.[14] studied the laminar convective cooling performance of hybrid water-based suspensions of Al_2O_3 nanoparticles and MEPCM particles in a circular tube and their result showed that the hybrid-based suspension showed considerable increase in heat transfer rate when compared to pure PCM suspension, nanofluids or water. However, they found that this enhanced heat transfer technique could not be manipulated due to high-pressure drop caused by the hybrid suspension compared to the nanofluids or water due to drastic increase in viscosity. S. Suresh et al.[15] experimented on the influence of Al_2O_3-Cu/water hybrid nanofluids in heat transfer and found a maximum enhancement of 13.56% in

Nusselt number at a Reynolds number of 1730 when compared to Nusselt number of water. They also found that 0.1% Al_2O_3-Cu/water hybrid nanofluids had elevated friction factor when compared to 0.1% Al_2O_3/water nano fluids. A comparison of thermal characteristics of Al_2O_3/water and CuO/water nanofluids through a conventional circular duct fitted with helical screw tape inserts was done by S. Suresh et al.[16] and their result showed 156.24,122.16 and 89.22% average improvement in Nusselt number corresponding to twist ratios of 1.78,2.44 and 3 respectively. The investigation also showed that CuO/water nanofluids gave better performance than Al_2O_3/water nanofluids with helical screw tape inserts.

H.R. Rayatzadehet al.[17] experimented on the influence of constant sonication on laminar connective heat transfer inside the tube using TiO_2/ water nanofluids for 0.1,0.15 and 0.25% volume concentration of nanofluids and found that with the increase in nanoparticles volume concentration heat transfer rate also increased except for 0.25% volume concentration. The Nusselt number of nanofluids at 0.25 vol% was around the similar as base fluid for the same given conditions. Ulzie Rea et al.[18] experimented on heat transfer and pressure drop of Alumina/water and Zirconia/water nanofluids and their result showed that for Alumina/water nanofluids at 6 vol% heat transfer coefficients in the entry region and fully established region was found to increase by 17and 27% respectively and for 1.32 vol% of Zirconia/water nanofluids it was 2 and 3% respectively.

In the present work heat transfer and friction factor characteristics of Al_2O_3/DI water nano fluids in a plain tube under laminar flow condition is studied with spiraled rod inserts.

II. EXPERIMENTAL METHODS

Preparation of Al_2O_3/DI water nanofluids

Nanofluids of 0.1% volume concentration is prepared by dispersing the required quantity of Al_2O_3 particles in DI water. In order to obtain a homogeneous mixture, magnetic stirring is done for 30 minutes using a REMI magnetic stirrer. Then, the nanofluid is sonicated using a LARK ultrosonicator for 6 hr duration to ensure stable suspension.

Experimental set-up

The schematic diagram of the experimental setup is shown in Fig. 1. The major components of the apparatus are (i) calming section, (ii) test section, (iii) riser section, (iv) air cooled heat exchanger, (v) fluid storage tank, (vi) centrifugal pump and (vii) arrangements to measure pressure drop and temperature. A centrifugal pump is used to pump the fluid from the reservoir and the flow rate is controlled by a flow control valve and bypass valve. A rotameter in the flow path measures the flow rate of the fluid. The fluid first enters the calming section whose length is just sufficient to eliminate the entrance effects, so that the flow is fully developed when it enters the test section. Fluid then flows through the riser section and then enters the air-cooled heat exchanger and is finally collected in the reservoir. A straight copper smooth tube of length 1000 mm, inner diameter (ID) 14 mm and outer diameter (OD) 16 mm is used as the test section.

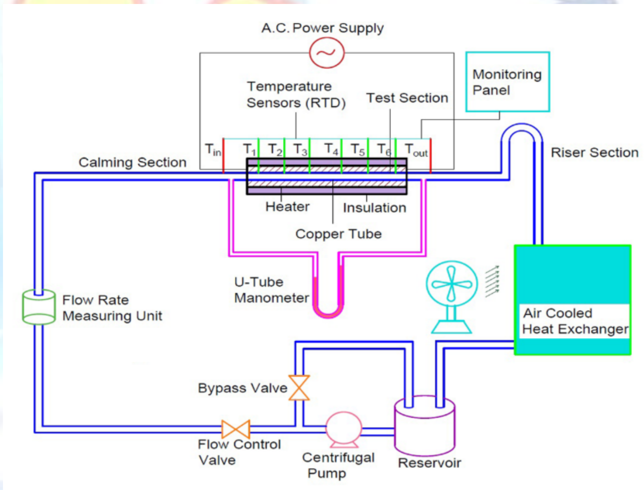

Fig.1.The schematic diagram of experimental setup

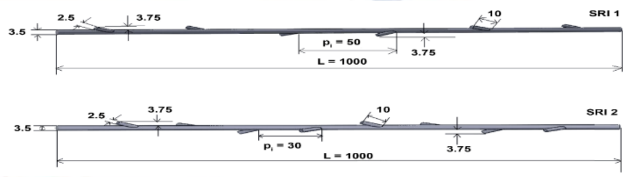

Fig.2.Geometrical configuration of spiraled rod inserts

A Nichrome wire of resistance 120 Ω is used to provide uniform heating of the test section. An autotransformer is used to vary the heat flux. The inlet, outlet and wall temperatures at six different locations are measured using Resistance

Temperature Detectors (RTD PT 100) having 0.1°C accuracy. A U–tube manometer is used to measure the pressure drop across the test section. A thick insulation comprising of glass wool, ceramic fiber and asbestos rope is provided over the heating coil to avoid radial heat losses.

Technical details of Spiraled rod inserts

Fig.2 shows the spiraled rod inserts fabricated using 3.5 mm copper rod to which pin like projections of length 10 mm and 2.5 mm diameter were attached at an angle of 22° to the copper rod at a distance of 50 mm and 30 mm perpendicular to each other for the entire length of copper tube for insert 1 and 2 respectively.

III. DATA REDUCTION

Thermo-physical properties of nanofluids

The most used regression correlations in the literature for the calculation of thermo physical properties of nanofluids for a volume concentration of $\emptyset$ at the average bulk mean temperature of the nanofluids were as follows,

The density of Al_2O_3 nanofluids was found by Pak and Cho's equation[19]

$$\rho_{nf} = \emptyset\rho_s + (1-\emptyset)\,\rho \qquad (1)$$

The specific heat of the nanofluids was found using Xuan and Roetzel'sequation[20]

$$(\rho C_p)_{nf} = (1-\emptyset)(\rho C_p) + \emptyset(\rho C_p)_s \qquad (2)$$

Brookfield cone and plate viscometer (LVDV-I PRIME C/P) from Brookfield engineering laboratories, USA was used to find out the viscosity of nanofluids. The viscosity of the nanofluids could be calculated using the viscosity correlation proposed by Einstein[21]

$$\mu_{nf} = (1+2.5\emptyset) \qquad (3)$$

KD2 Pro thermal property analyser (Decagon Devices, Inc., USA) was used to measure the thermal conductivities of nanofluids, the effective thermal conductivity of the nanofluids k_{nf} is found using Maxwell equation[22]

$$\frac{k_{nf}}{k} = k_s + 2k + \frac{2\emptyset(k_s-k)}{k_s} + 2k - \emptyset(k_s-k) \qquad (4)$$

Heat transfer calculation

The Nusselt number, friction factor, and thermal performance factors at diverse of Reynolds numbers in laminar flow regime were calculated from the experimental data.Following equation was used to measure total heat transfer,

$$Q_t = VI \qquad (5)$$

The loss of heat through the insulation (Q_{loss}) was assessed to be 3.5% of the total heat supplied from the measurements of wall temperature and ambient temperature.Therefore, the total heat supplied by the heater,

$$Q_1 = Q_t - Q_{loss} \qquad (6)$$

The heat absorbed by the fluid was calculated by the following equation,

$$Q_2 = mc_p(T_{f,out} - T_{f,in}) \qquad (7)$$

Heat balance of the real heat input (Q_1) and the heat carried by the fluid (Q_2) was under 3.1% for the entire experiment. The average heat transfer rate of the heat delivered by electrical winding and heat absorbed by the fluid was taken for the calculation of convective heat transfer coefficient.Therefore,

$$Q = \frac{(Q_1+Q_2)}{2} \qquad (8)$$

Heat flux was calculated as,

$$q'' = \frac{Q}{(\pi DL)} \qquad (9)$$

From the equation given below the local heat transfer coefficient was calculated using local wall temperature, local fluid temperature and heat flux

$$h_x = \frac{q''}{(T_{wx} - T_{fx})} \qquad (10)$$

The local fluid temperature was calculated from the energy balance equation given below,

$$T_{fx} = T_{in} + \frac{(q'' P_x)}{(\rho c_p vA)} \qquad (11)$$

The local Nusselt number Nu_x was calculated as,

$$Nu_x = \frac{(h_x D)}{k} \qquad (12)$$

The average heat transfer coefficient is calculated using average wall temperature, mean fluid temperature and heat flux from the equation given below,

$$h = \frac{q''}{(T_w - T_f)} \quad (13)$$

The average Nusselt number was calculated as below,

$$Nu = \frac{(hD)}{k} \quad (14$$

Thermal resistance was calculated as,

$$R = \frac{(T_w - T_f)}{q''} \quad (15)$$

Pressure drop calculations

The pressure drop(Δp) measured across the test section using U-tube manometer under isothermal condition was used to determine the friction factor (f) using the following equation:

$$f = \frac{\Delta p}{\frac{1}{2}\rho v^2\left(\frac{L}{D}\right)} \quad (16)$$

IV. RESULTS AND DISCUSSIONS

Heat transfer study

Nusselt number variation with Reynolds number for plain tube with and without spiraled rod inserts are depicted in Fig. 3. With the increase in Reynolds number the Nusselt number is increases in the case of DI water. An Al_2O_3/DI water nanofluid with the volume concentration of 0.1% is studied in this work. Nusselt number obtain the positive impact with the enhancement for 0.1% volume concentrations of nanofluids is 9.9 % compared to DI water on addition of nanoparticles.

The enhancement in Nusselt number due to the addition of nanoparticles are mainly attributed to the decrease of boundary layer thickness and delayed growth of boundary layer, improved thermal conductivity, Brownian motion, migration and rearrangement of particles and large energy exchange due to chaotic motion of particles.

The spiraled rod inserts when added in plain tube enhances the Nusselt number further compared with DI water in plain tube. Two inserts having pitches of 50 mm (SRI 1) and 30 mm (SRI 2) are used in this study. The Nusselt number is found to increase in both cases compared to DI water in plain tube. The Nusselt number also increases with decrease in pitch of inserts. The enhancement in Nusselt number is 14 and 17% for SRI 1 and SRI 2 respectively. It can be perceived from the Fig. 3 that the use of spiraled rod inserts with nanofluids enhances the Nusselt number further compared to plain tube. The enhancement in Nusselt number obtained is 24.8 for 0.1% volume concentrations with SRI 1 and 27.9% for SRI 2 compared to DI water in plain tube.

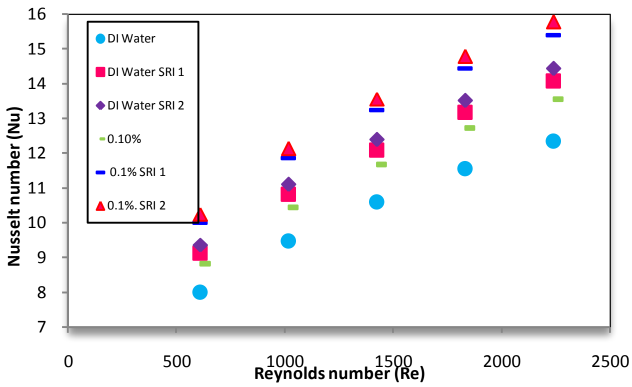

Fig.3. Variation of Nusselt Number with Reynolds number for plain tube

The heat transfer augmentation due to the inserts is mainly because of the following reasons:

(1) The pins attached on the rod act as turbulent promoters.

(2) Development of secondary flows.

(3) Reduction in hydraulic diameter.

(4) Enhanced energy exchange in the fluids due to irregular and random movement of the particles.

(5) Excellent fluid mixing and an efficient redevelopment of the thermal and hydrodynamic boundary layers due higher turbulence intensity close to the tube wall.

Friction factor drop study

In spite of nanofluids increases the heat transfer performance, it is also important to measure the pressure drop in order to use them in industrial applications. Hence, in a plain tube at different flow rates the pressure drops of nanofluid are experimentally measured and the friction factor is calculated.The variations of Friction factor with the Reynolds number for plain tube are shown in Fig. 4. Increase in Reynolds number resulted the decrease in friction factor. The addition of nanoparticles causes the increase in shear force between the wall and the nanoparticles and also cause increase in viscosity which leads to the slight increase in friction factor.

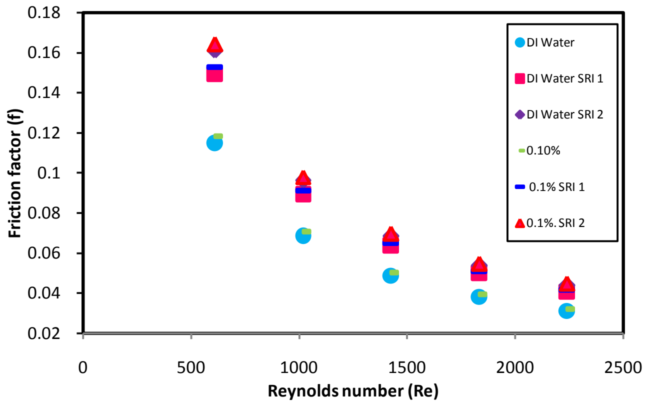

Fig.4. Variation of friction factor with Reynolds number for plain tube

But this increase in friction factor is not significant compared with DI water and hence the pressure drop penalty is negligible. The increase in friction factor for 0.1% volume concentration is 3.1% compared with DI water.

Plain tube fitted with spiraled rod inserts increases the friction factor further. The increase in friction factor in the case of plain tubes with DI water, 0.1% volume concentrations of nanofluids are 30.65, 33.11% for SRI 1 and 40.8, 43.12% for SRI 2 compared to DI water without inserts. The pitch of spiraled rod inserts plays a vital role in the friction factor, increasing pitch reduces the friction factor. This is due to the geometry and larger contact surface. Also, the inserts diminish the free flow area and induces turbulence in the flow. This leads to increased friction between the surface of the core rod and the inner wall of the tube.

V. CONCLUSIONS

The development of nanofluids with enhanced thermal properties is vital for enhanced heat transfer applications. Inserts in tubes enhances the heat transfer further. Hence, heat transfer and friction factor studies are carried out using Al_2O_3/DI water nanofluids in plain tube with SRIs.The results obtained are as follows:

a. The heat transfer rate is improved on adding nanoparticles to the base fluid.

b. Rather addition of nanoparticles to the base fluids using inserts in tubes has strong influence on heat transfer enhancement.

c. For 0.1% volume concentration, the maximum enhancement in Nusselt number in plain tube with SRI 2 is 27.9%.

d. The Pressure drop penalty by using nanofluids in plain tube is less; hence it can be used for the heat transfer applications.

Nomenclature

A cross sectional area (m^2)
$C_p$specific heat (J/kgK)
D test section diameter (m)
f friction factor
h heat transfer coefficient (W/m^2K)
I current (A)
L length of the test section (mm)
m mass flow rate (kg/s)
Nu Nusselt number (hD/k)
p pitch of the spiraled rod inserts (mm)
P perimeter (m)
PrPrandtlnumber ($c_p\mu$/k)
Q electrical heat input (W)
R thermal resistance (°Cm^2/W)
q″ heat flux (w/m^2)
Re Reynolds number (ρvD/μ)
T Temperature (K)
v fluid velocity (m/s)
V voltage (V)
x axial distance from tube entrance (mm)

Greek symbol

ρ density (kg/m^3)
μ dynamic viscosity (kg/m^2s)
Ø Volume concentration(%)
Δp pressure drop (N/m^2)

Subscripts

amb ambient
exp experimental
f fluid
in inlet
nf nanofluid
out outlet
pt plain tube
s solid phase
t total
w wall

Abbreviations

SRI Spiraledrod insert
DI Deionized

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