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Experimental Investigation on Heat Transfer and Friction Factor Characteristics of MWCNT-Al_2O_3/DI Water Nanofluids in a Circular Tube with Inserts

K.Gurunath*, S.Anbu**, K. Velmurugan***, P.Arunkumar ****

*Aerospace Engineering, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur – 621 212, India.
**Mechanical Engineering, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur – 621 212, India.
***Mechanical Engineering, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur – 621 212, India.
****Mechanical Engineering, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur – 621 212, India.

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Abstract:

In this experimental investigation, convective heat transfer and friction factor characteristics of MWCNT-Al_2O_3/ DI water nanofluids flowing through a circular tube with and without spiraled rod inserts is carried out. The experiment is conducted under laminar flow. MWCNT-Al_2O_3 nanoparticles are used to prepare the nanofluids. The nanoparticles dispersed in DI water to form stable suspension of MWCNT-Al_2O_3/ DI water nanofluids with 0.1% volume concentration of nanoparticles. It is found that inclusion of nanoparticles to DI water augment Nusselt number. The Nusselt number are measured and found to increase by 29.9% at Re 2240 for plain tube with nanofluids of 0.1% volume concentration compared to DI water. Two spiraled rod inserts are used to enhance the Nusselt Number further which is made up of copper with two different pitches. The insert having lower pitch with nanofluids of 0.1% volume concentration gives maximum enhancement in Nusselt number which is 49.2% at Reynolds number 2240 compared to DI water.

Keywords **—MWCNT-Al_2O_3/DI Water nanofluids, Laminar flow, Heat transfer enhancement, Frictionfactor.**

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I. INTRODUCTION

Nanofluids are the conventional fluids having metals and non-metals of nanometer size suspended in them. It has been investigated and applied for the augmentation of heat transfer. Nanofluids have proven to be ofhaving massive potential in revolutionizing many industrial processes such as chemical process, heating and cooling process, transportation,power generation, and other micro-sized applications.The use of nanoparticles to augment the heat transfer was first done by Choi [1] in the year 1995 when the knownmicro particles did not evidence to be effective in enhancing heat transfer rate. Since then, a large number of researches have followed keeping choi's work as the base. 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 extreme increase in the heat transfer rate.

KyoSik Hwang et al.[2] investigated the flow and convective heat transfer characteristics of water-based Al_2O_3 nanofluids. According to their experimental results there was 8% rise in heat transfer coefficient at a concentration of 0.3 vol% compared to pure water.S. Zeinalia et al. [3]examinedthe convective heat transfer of Al_2O_3/water in a circular plain tube and found that heat transfer coefficient increased with the increase of concentration of nanoparticles. They also found out that the enhancement in heat transfer was much raisedin than conventional fluids.M. Saeediniaetal.[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 conducted with imposed wall temperature boundary conditions by SebasteinFerrouillatet al.[5]. Their results showed 10% to 60% rise in heat transfer coefficient compared to pure water. W. Duangthongsuk et al. [6] estimated that the enhancement of heat transfer and pressure drop behavior of TiO_2/Water nanofluids in a double-tube counter flow heat exchanger. Their result showed 6-11% rise in heat transfer rate than the base fluid.

Wei Yu et al. [7] examinedthe heat transfer properties of Al_2O_3 nanofluids using the mixture of ethylene glycol and water as base fluid and found 57% and 106% rise of heat transfer coefficient for 1.0 vol%and 2.0 vol% of nanofluids respectively. M.Chandrasekaret al.[8]studied the heat transfer and friction factor characteristics of Al_2O_3/Water nanofluids in a circular pipe under laminar flow.They used two wire coil inserts made of stainless steel with pitch ratios 2 and 3 in their study. According to their results 12.24% of increase in Nusselt number was found for 0.1% volume concentration of nanoparticles. When wire coil inserts were 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 carried out byGovarthanParthipakkaet 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 transferenhancementwas directly proportional to nanoparticles volume concentration and Reynolds number, and inversely proportionalto the twist ratio.In theirstudy, maximum heat transfer rate of 31.29% was obtained for 1.5% concentration of nanoparticles with helical inserts having twist ratio 2.93.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 smooth 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% higher when compared to plain water with same Reynolds number.

M.Saeediniaet al.[11] experimented on heat transfer and pressure drop of nanofluids in a horizontal coiled wire inserts under constant heat flux. They concluded that nanofluids had better heat transfer in tubes with wire coil insert than the smooth tube.They obtained a maximum heat transfer enhancement of upto 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.[12] carried out a comparative study on thermal performance of helical screw tape inserts in laminar flow. They used Al_2O_3/water and CuO/water nanofluids.They found that helical screw inserts with CuO/water showed better performance than with Al_2O_3/water nanofluids.C.J. Ho et al.[13] studied the laminar convective cooling performance of hybrid water-based suspensions of Al_2O_3 nanoparticles and MEPCM particles in a circular tube. Their result presented 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 cause of drastic increase in viscosity.S.Suresh et al.[14] experimented on the effect 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 hadelevated friction factor when compared to 0.1% Al_2O_3/water nanofluids.A comparison of thermal characteristics ofAl_2O_3/water and CuO/water nanofluids through a conventional circular duct fitted with helical screw tape inserts was carried out by S.Sureshet al.[15] and their experimental results showed 156.24,122.16 and 89.22% average enhancement in Nusselt number corresponding to twist ratios of 1.78,2.44 and 3 respectively. The experimental investigation also showed that CuO/water nanofluids gave better performance than Al_2O_3/water nanofluids with helical screw tape inserts.

H.R. Rayatzadeh et al.[16] experimented the effect 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.They found that with the increase in nanoparticles volume concentration heat transfer rate also increased except for 0.25% volume concentration.

In the present experimental work heat transfer and frictionfactor characteristics of MWCNT-Al_2O_3/DI water nanofluids in a plaincircular tube under laminar flow region is studied with spiraled rod inserts.

II. EXPERIMENTAL METHODS

A. *Preparation of MWCNT-Al_2O_3/DI water nanofluids*

Nanofluids of 0.1% volume concentrations are prepared by dispersing the required amount of MWCNT-Al_2O_3 particles in DI water. In order to get a homogeneous mixture, magnetic stirring is carried out for 30 minutes using a magnetic stirrer. Then, the nanofluid is sonicatedusing an ultrosonicator for 6 hrs duration to guarantee a stable suspension.

B. *Experimental set-up*

The schematic diagram of the experimental apparatus 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,
(vii) arrangements to measure pressure drop and temperature.

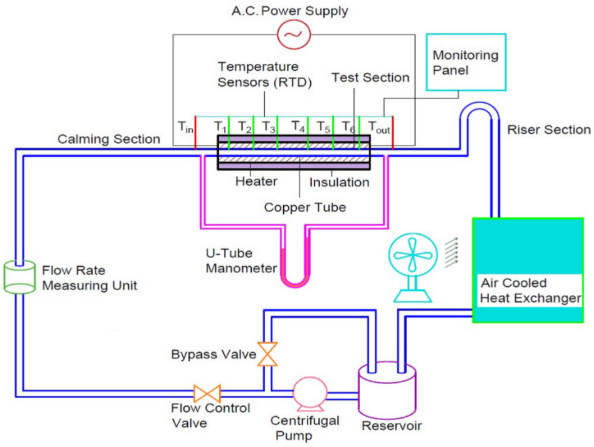

Fig.1.The schematic diagram of experimental setup

Thefluid is pumped from the reservoir using a centrifugal pump and the flow rate is controlled by a flow control valve and bypass valve. The flow rate of the fluid is measuredby a rotameter in the flow path. The fluid first enters the calming section whose length is just adequate to remove 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 heat exchanger (air cooled) and is finally collected in the reservoir. A straight copper smooth tube of length1000 mm, inner diameter (ID) 14 mm and outer diameter (OD) 16mm is used as the test section.

A Nichrome wire of resistance 120 Ω is used to deliver 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 including of glass wool, ceramic fiber and asbestos rope is provided over the heating coil to avoid radial heat losses.

C. 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.

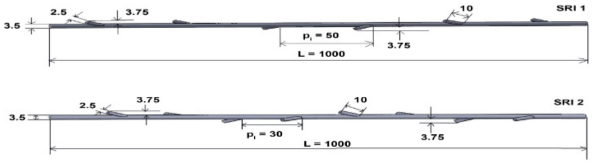

Fig.2.Geometrical configuration of spiraled rod inserts

III. DATA REDUCTION

A. Thermo-physical properties of nanofluids

The density of nanofluids was found by Pak and Cho's equation [17]

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

The specific heat of the nanofluids was found using Xuan and Roetzel's equation [18]

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

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 [19]

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

KD2 Pro thermal property analyser (Decagon Devices, Inc., USA) was used to measure the thermal conductivities of nanofluids, the effective thermal conductivity of the nanofluidsk_{nf} is found using Maxwell equation [20]

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

B. 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}) wasassessed 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 thereal 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,

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

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,

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

The average Nusselt number was calculated as below,

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

Thermal resistance was calculated as,

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

C. *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:

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

IV. RESULTS AND DISCUSSIONS

A. *Heat transfer study*

Fig. 3 depicts the Nusselt number variation with Reynolds number for smooth tube with and without spiraled rod inserts. The Nusselt number increases with Reynolds number in the case of DI water. An MWCNT-Al_2O_3/DI water nanofluid of 0.1% volume concentrations isexamined in this experimental work. Addition of nanoparticles has a positive effect on Nusselt number. The enhancement in Nusselt number for 0.1% volume concentrations of nanofluids is29.9% compared to DI water.

The augmentation 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, increased thermal conductivity, Brownian motion, migration and rearrangement of particles and large energy exchange due to chaotic motion of particles.

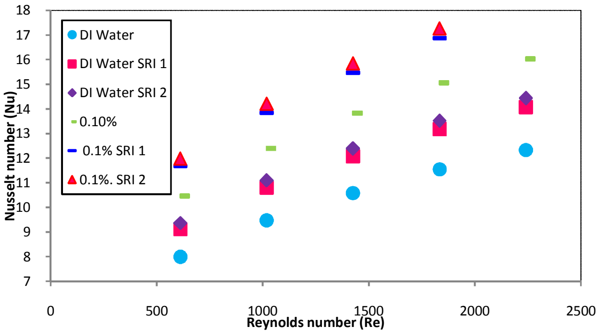

Fig.3. Variation of Nusselt Number with Reynolds number for plain tube

Insertion of spiraled rod in smooth tube enhances the Nusselt number further compared with DI water in smooth tube. Two inserts having pitches of 50 mm (SRI 1) and 30 mm (SRI 2) are used in this experimental study for the heat transfer enhancement. 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 attained is 45.92% for 0.1% volume concentrations with SRI 1 and 49.2% for SRI 2 compared to DI water in smooth tube.

The heat transfer augmentation due to the inserts is mainly because of; (1) Thepins 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.

B. Friction factor study

Friction factor variations with the Reynolds number are shown in Fig. 4 for smooth tube. Friction factor decreases with increasing Reynolds number in all the cases. Friction factor slightly increases with the inclusion of nanoparticles due to the increased shear force between the wall and the nanoparticles and also due to increased viscosity. The increase in friction factor for 0.1% volume concentration is 25.5% compared with DI water.

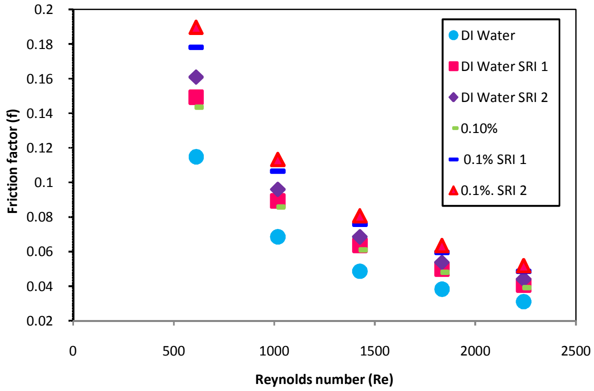

Fig.4. Variation of friction factor with Reynolds number for plain tube

Friction factor further increases in smooth tube fitted with spiraled rod inserts. The rise in friction factor in the case of plain tubes with DI water, 0.1% volume concentrations of nanofluids are 30.65, 55.7% for SRI 1 and 40.8, 65.8% for SRI 2 compared to DI water without inserts. Use of inserts increases the friction factor for both DI water and nanofluid. This is due to the geometry and larger contact surface. Also, the inserts decrease 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

Heattransfer and friction factor studies are carried out using MWCNT-Al_2O_3/DI water nanofluids in smooth tube with SRIs.The experimental results obtained are as follows:

a. Inclusion nanoparticles to the base fluid gives good enhancement in heat transfer rate.

b. Inserts in tubes has strong influence on heat transfer enhancement than the inclusion of nanoparticles to the base fluids.

c. For 0.1% volume concentration of nanofluids, the maximum enhancement in Nusselt number in plain tube with SRI 2 is 65.8%.

Future investigations may be carried out to find and optimize the geometries of different inserts in order to enhance the performance of heat exchangers.

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_i	pitch of the spiraled rod inserts (mm)
P	perimeter (m)
Pr	Prandtlnumber($c_p\mu/k$)
Q	electrical heat input(W)
R	thermal resistance($^{\circ}Cm^2/W$)
q″	heat flux(w/m^2)
Re	Reynolds number($\rho vD/\mu$)
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^{2}s)
Ø	Volume concentration(%)
Δp	pressure drop(N/m^2)

Subscripts

f	fluid
in	inlet
nf	nanofluid
out	outlet
s	solid phase
t	total
w	wall

Abbreviations

SRI	Spiraled rod insert
DI	Deionized

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