IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

EXPERIMENTAL HEAT TRANSFER OF MWCNT-Al_2O_3/DI WATER NANOFLUIDS IN A CIRCULAR TUBE UNDER TURBULENT FLOW WITH INSERTS

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Abstract:The performance of nanofluids in convective heat transfer in a circular tube with inserts is investigated experimentally.The experiment is conducted in a turbulent flow with a constant wall heat flux.Deionized (DI) water and MWCNT-Al_2O_3/DI water nanofluids are used as working fluids. The investigation discovered that suspending nanoparticles in DI water causes heat transfer enhancement. Compared to DI water in the plain tube, the Nusselt number augmentation for 0.25 % volume concentration of MWCNT-Al_2O_3/ DI water nanofluids is 30.1%. The use of copper spiraled rod inserts (SRIs) with pitches of 50 mm, and 30 mm improved the Nusselt number by 44.9 % and 47.1 %, respectively, at Reynolds number 8853 with nanofluids of 0.25 % volume concentration compared to DI water.

Keywords: MWCNT-Al_2O_3/DI Water Nanofluids, Turbulent flow, Heat transfer enhancement, Friction factor

1. INTRODUCTION

Fluids with poor thermal characteristics are a major obstacle to developing efficient heat exchangers. The enhancement of heat transfer has received a lot of attention. The use of nanofluids to enhance heat transfer has gotten a lot of interest in recent years. Choi [1] developed nanofluids, particle-laden fluids produced by suspending nanoparticles in a base fluid.Nanofluids are colloids made up of conventional fluids and solid particles with sizes less than 100 nanometers. He also revealed that nanofluids significantly increased thermal conductivity even when just a small amount of nanoparticles were added to the base fluids compared to conventional fluids. Heris et al. [2] studied convective heat transfer of Al_2O_3/water in a circular tube and discovered that the heat transfer coefficient increased as the concentration of nanoparticles in nanofluids increased.

Fotukian et al. [3] investigated pressure drop and heat transfer for the turbulent flow of CuO/water nanofluids in a circular tube with a volume fraction smaller than 0.3%. They reported a 25% increase in heat transfer coefficient over pure water. Suresh et al. [4] investigated the thermal characteristics of Al_2O_3/water and CuO/water nanofluids in transition flow inside a circular duct using helical screw tape inserts. They found that the average Nusselt number increased by 156.24 %, 122.16 %, and 89.22 %, respectively, with twist ratios of 1.78, 2.44 and 3. According to their research, CuO/water nanofluids performed better than Al_2O_3/water nanofluids with helical screw tape inserts. Suresh et al. [5] repeated the experiment in laminar flow with Al_2O_3/water and CuO/water nanofluids and discovered that helical coil inserts with CuO/water outperformed Al_2O_3/water nanofluids. Duangthongsuk et al. [6] investigated heat transfer performance and pressure drop for TiO_2/water nanofluids in a turbulent flow regime. They discovered that the heat transfer coefficient of nanofluids was 26 % greater than pure water at 1.0vol.% but 14 % less at 2.0 % for the same conditions.

Sajidi et al. [7] investigated the turbulent heat transfer and pressure drop of TiO_2/water nanofluids in a circular tube, finding that even minor additions of nanoparticles in the base fluid enhanced the heat transfer coefficient. They also observed that nanofluids had a slightly higher pressure drop than base fluid. Ferrouillat et al. [8] conducted a hydraulic and heat transfer study of SiO_2/water nanofluids in horizontal tubes with imposed wall temperature boundary conditions. Their results indicated a 10% to 60% increase in heat transfer coefficient compared to pure water. Saeedinia et al. [9] studied the pressure drop and heat transfer of nanofluids in a horizontal coiled wire insert under constant heat flux. They found that nanofluids had higher heat transfer in wire coil insert tubes than in plain tubes. For 0.3 vol.% nanofluids flow inside the wire coil inserted tube with the largest diameter, they discovered an extraordinary heat transfer augmentation of up to 40.2 % greater than pure oil flow in plain tube. Suresh et al. [10] investigated the heat transfer and friction factor characteristics of Al_2O_3 / water nanofluids in turbulent flow with spiraled rod insertions. They discovered that the Nusselt number for spiraled rod inserts was about 10-48% higher than the plain tube Nusselt number and that the isothermal pressure drop for spiraled rod inserts was 2-8 % higher than the plain tube isothermal pressure drop.

Anbu et al. [11] studied the convective heat transfer properties of Al_2O_3/ DI water nanofluids passing through a smooth tube with a constant heat flux under laminar flow conditions. In their research, spiraled rod inserts were employed. The use of nanofluids and inserts increased in Nusselt number. Gurunath et al. [12] investigated the heat transfer behavior of MWCNT-Al_2O_3/ DI water in a plain tube with inserts under laminar flow in one experiment. Their findings revealed that heat transfer has significantly improved. Arunkumar et al. [13] explored the convective heat transfer performance of CuO/DI water nanofluids in a tube with spiraled rod inserts under laminar flow. They saw a significant improvement in heat transfer performance. The current experiment employs MWCNT-Al_2O_3/ DI water nanofluids to improve heat transfer in a circular tube with spiraled rod inserts. The combined impact of nanoparticles and spiraled rod inserts in a circular tube on heat transfer and pressure drop is discussed in the next sections.

2. EXPERIMENTS

2.1 Preparation of MWCNT-Al_2O_3/water nanofluids

Nanofluids with 0.25 % volume concentrations are produced by dispersing the requisite amount of MWCNT-Al_2O_3 particles in DI water. Magnetic stirring for 30 minutes using a REMI magnetic stirrer produces a homogeneous mixture. The nanofluid is sonicated for 6 hours using a LARK ultrasonicator to obtain a stable suspension.

2.2 Convective experimental setup

Fig.1 shows a schematic representation of the experimental setup. The apparatus' main components are (i) calming section, (ii) test section, (iii) riser section, (iv) air-cooled heat exchanger, (v) fluid storage tank, (vi) centrifugal pump, and (vii) pressure drop and temperature measurement devices. The fluid is pumped from the reservoir by a centrifugal pump, and the flow rate is regulated by a flow control valve and a bypass valve. The fluid flow rate is measured using a rotameter in the flow route. The fluid initially passes through a calming section, which is long enough to remove the entry effects, allowing the flow to develop before fully entering the test section. After passing through the riser portion, the fluid enters the air-cooled heat exchanger before being collected in the reservoir. The test section is a 1000 mm long straight copper smooth tube with an inner diameter (ID) of 14 mm and an outer diameter (OD) of 16 mm.

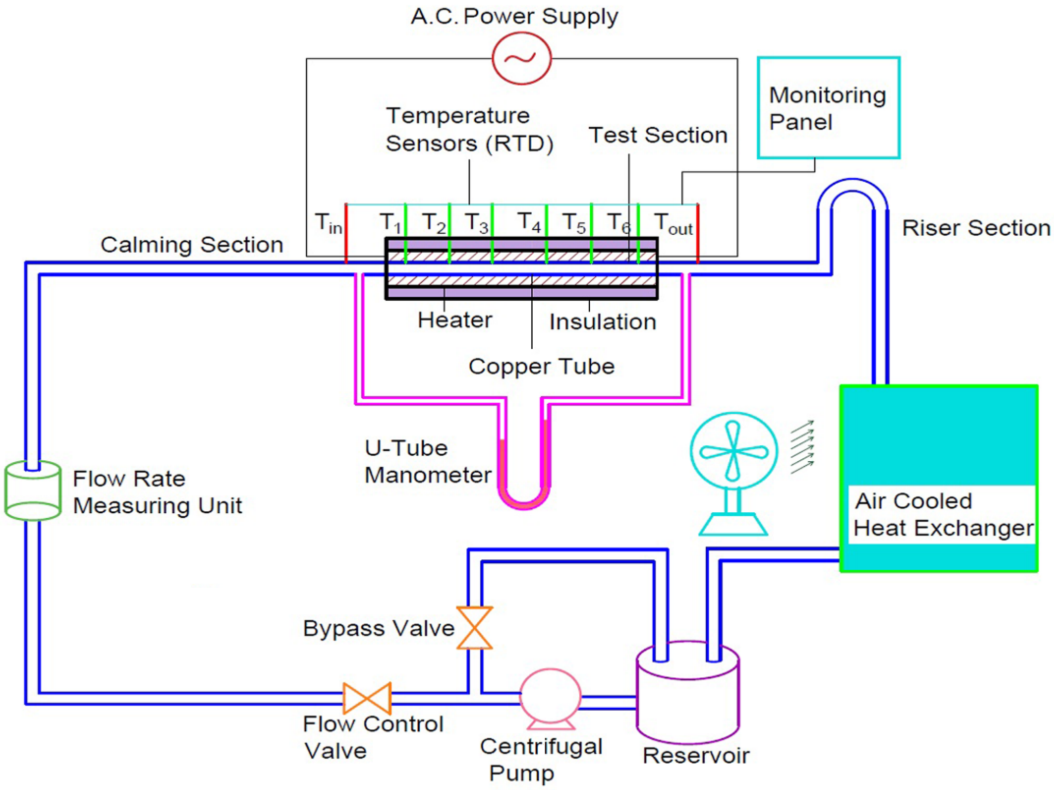

Fig.1.The schematic diagram of experimental setup

The test section is uniformly heated using a Nichrome wire with a resistance of 120. To change the heat flux, an autotransformer is employed. Resistance Temperature Detectors (RTD PT 100) with 0.1°C accuracy are used to measure the inlet, outflow, and wall temperatures at six separate places. The pressure drop over the test segment is measured using a U–tube manometer. A thick insulation made of glass wool, ceramic fiber, and asbestos rope is placed above the heating coil to prevent radial heat losses.

2.3 Technical details of Spiraled rod inserts

Fig.2 exhibits spiraled rod inserts made from 3.5 mm copper rod with a pitch of 50 mm (SRI 1) and 30 mm (SRI 2) with pin-like projections of length 10 mm and diameter 2.5 mm affixed at an angle of 22^{o} to the copper rod. Throughout the length of the rod, a 90^{o} angle is maintained between two neighboring pins.

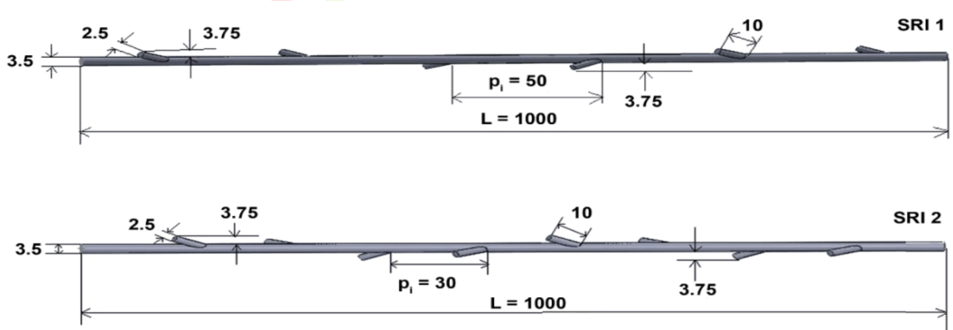

Fig.2.Geomentrical configuration of spiraled rod inserts

3 DATA REDUCTION

3.1 Thermo-physical properties of nanofluids

Pak and Cho's equation is used to calculate the density of nanofluids [14]

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

Using Xuan and Roetzel's equation, the specific heat of the nanofluids is calculated [15]

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

Brookfield cone and plate viscometer (LVDV-I PRIME C/P) from Brookfield engineering laboratories,USA,is used to determine nanofluids' viscosity. The viscosity of the nanofluidscould be calculated using the viscosity correlation suggested by Einstein [16]

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

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 by Maxwell equation [17]

$$K_{nf}/k=k_s+2k+2\emptyset\ (k_s-k)/k_s+2k-\emptyset(k_s-k) \quad (4)$$

3.2 Heat transfer calculations

The following equation is used to measure total heat transfer,

$$Q_{total} = VI \quad (5)$$

The loss of heat through the insulation (Q_{loss}) is approximately 3.5% of the total heat supplied from measuring wall temperature and ambient temperature.

Therefore, the total heat supplied by the heater,

$$Q_1 = Q_{total} - Q_{loss} \quad (6)$$

$$Q_2 = m\ Cp\ (T_{f,out} - T_{f,in}) \quad (7)$$

$$Q = (Q_1 + Q_2)/2 \quad (8)$$

Heat flux,

$$q'' = Q/(\pi DL) \quad (9)$$

The average heat transfer coefficient,

$$h = q''/(T_w-T_f) \quad (13)$$

The average Nusselt number is determined using,

$$Nu= (hD)/k \quad (14)$$

Thermal resistance is determined using,

$$R= (T_w-T_{f,in})/q'' \quad (15)$$

3.3 Friction factor calculations

The following relation is used to calculate the friction factor from the pressure drop (Δp) measured across the test section under isothermal conditions.

$$f = \Delta p/(1/2)\ \rho v^2(L/D) \quad (16)$$

4. RESULTS AND DISCUSSION

4.1Heat transfer studies

Fig.3 shows the relationship between Nusselt number and Reynolds number for plain tubes with and without spiraled rod inserts. According to the graph, the Nusselt for nanofluids is higher than DI water. This research is aimed at MWCNT-Al_2O_3/DI water nanofluids with 0.25 % volume concentrations. The addition of nanoparticles increases the Nusselt number. When 0.25 %volume concentrations of nanofluids is compared to DI water, the Nusselt number increases by 30.1 %.
Enhanced thermal conductivity due to suspended nanoparticles, Brownian motion, a decrease in boundary layer thickness, and a delay in establishing the boundary layer are the causes of the increased heat transfer.

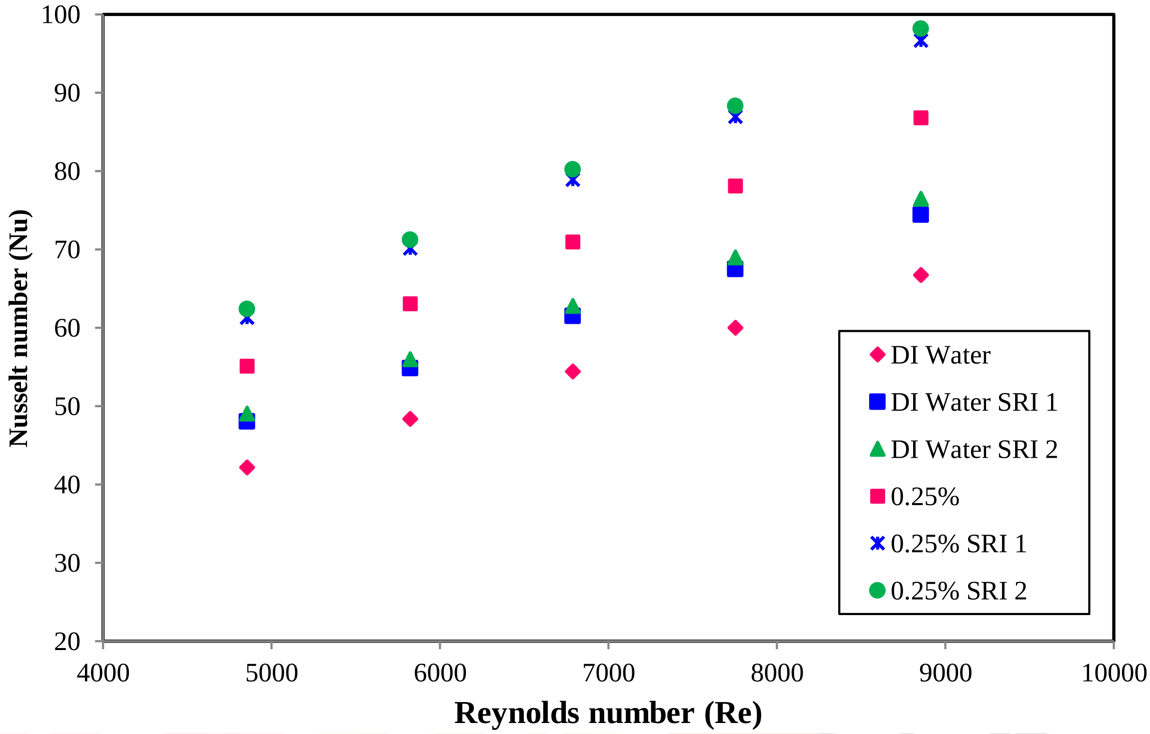

Fig.3. Variation of Nusselt number with Reynolds number (MWCNT-$Al_2 0_3$ / DI water)

The inclusion of spiraled rod inserts, which produce turbulence, secondary flows, and a decrease in hydraulic diameter, improves heat transfer. Two inserts with differing pitches of 50 mm (SRI 1) and 30 mm (SRI2)) are employed in this study. For both inserts, there is an increase in the Nusselt number. The Nusselt number is improved by decreasing the pitch of inserts by 11.5 and 14.6 % for SRI1 and SRI 2, respectively. The use of nanofluids with inserts improves heat transfer even further. For SRI 1 and SRI 2, the Nusselt number enhancement found at 0.25 % volume concentration is 44.9 and 47.1 %, respectively.

4.2Friction factor studies

The effect of the Reynolds number on the friction factor for a smooth tube is shown in Fig.4. The friction factor decreases as the Reynolds number increases in all instances, owing to the decrease in laminar sublayer thickness. The addition of nanoparticles to the base fluid causes a minor increase in friction factor and a substantial loss of pumping power. When comparing 0.25 % volume concentrations to DI water, the friction factor increases by 33.6 %.

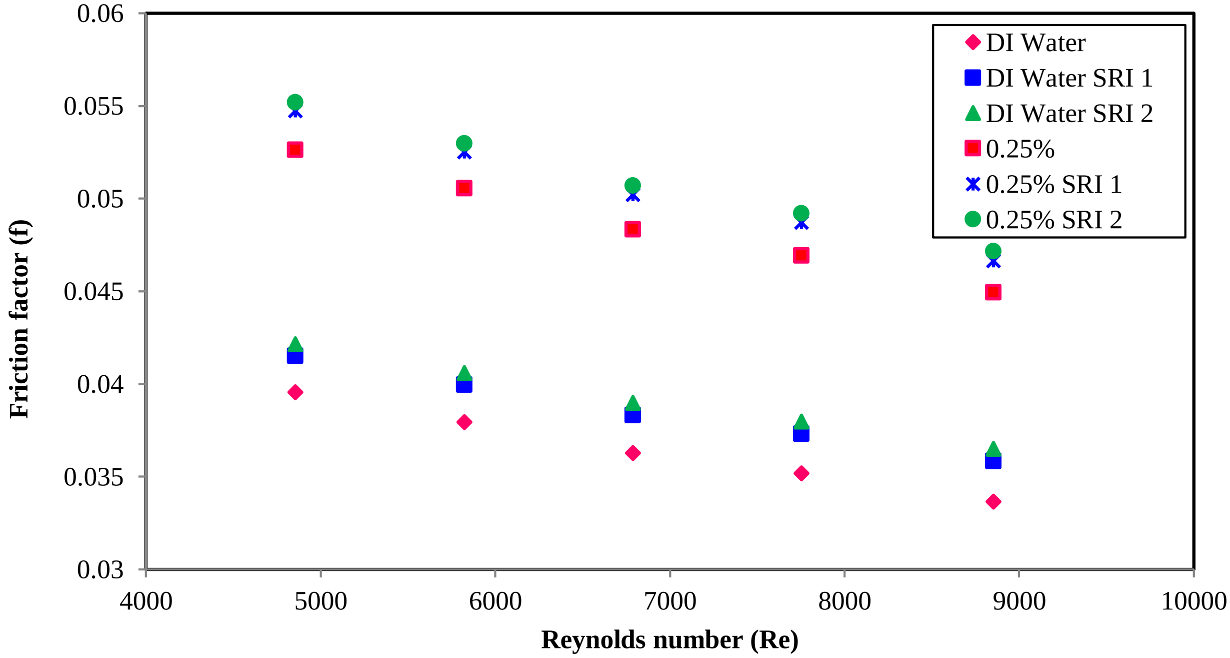

Fig.4. Variation of friction factor with Reynolds number (MWCNT-Al_20_3 / DI water)

When inserts are utilized in plain tubes, the friction factor is further raised. Compared to DI water without inserts, the increase in friction factor for plain tube with 0.25 % volume concentrations of nanofluids is 6.56, 38.6 % for SRI 1 and 8.49, 40.2 %for SRI 2. The insert pitch influences the friction factor; increasing pitch causes the friction factor to decrease, owing to the geometry and bigger contact area. Inserts reduce the free flow area and cause turbulence, resulting in increased friction between the core rod's surface and the tube's inner wall.

5. CONCLUSIONS

The current experimental research' findings are presented here.

1. Adding nanoparticles to the base fluid improves heat transfer rate
2. The maximum increase in Nusselt number in a plain tube with SRI 2 is 47.1 % at 0.25 % volume concentration.
3. Using nanofluids in plain tubes has a lower pressure drop penalty, making it suitable for heat transfer applications.

Nomenclature

A cross sectional area (m^2)
Cp specific heat (J/kgK)
D test section diameter (mm)
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 SRI (mm)
P perimeter (m)
Pr Prandtl number ($c_p\mu/k$)
Q electrical heat input (W)
R thermal resistance ($^0Cm^2/W$)
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^2s)
ø Volume concentration (%)
Δp pressure drop(N/m^2)

Subscripts

f fluid
in inlet
nf nanofluids
out outlet
pt plain tube
s solid phase

t total
w wall

Abbreviations
SRI Spiraled rod inserts

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