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Research Article

Heat Transfer Augmentation of Al_2O_3/DI Water Nanofluids with Spiraled Rod Inserts in a Circular Tube under Turbulent Flow

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ABSTRACT

Convective heat transfer and friction factor studies are carried out experimentally in a smooth tube with spiraled rod inserts (SRI). Turbulent flow (R_e = 4800 – 8900) and constant wall heat flux is maintained. The working fluids used are Deionized (DI) water and Al_2O_3/ DI water nanofluids. A 0.25% volume concentration of nanofluids is used in the study. The amalgamated effects of nanofluids, inserts in tubes on Nusselt number and friction factor are examined. The following are observed: (i) the suspending nanoparticles in DI water is the cause for the heat transfer augmentation. When compared to DI water in plain tube, the Nusselt number enhancement is 12.3% for 0.25% volume concentration of Al_2O_3 / DI water nanofluids. (ii) the heat transfer rate enhances by the use of inserts in tubes; further the Nusselt number is increased by 27.2% and 29.4% at Reynolds number 8853 with nanofluids of 0.25% volume concentration for the two spiraled rod inserts made up of copper with pitches 50 mm and 30 mm are used respectively; compared to DI water.

Keywords: Convective heat transfer, friction factor, heat transfer enhancement, Al_2O_3 / DI water, nanofluids, turbulent flow.

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

P density (kg/m^3)
M dynamic viscosity (kg/m^2s)
Ø volume concentration (%)
Δp pressure drop (N/m^2)

Subscripts

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

Abbreviations

SRI Spiraled Rod Inserts

1. Introduction:

The heat transfer enhancement has become a subject of substantial relevance due to its applications as cited; In making more compact, structured and efficient heat exchangers and air conditioners, for heat transfer in microelectronics, for efficient cooling of electronic devices, to let heatescape from electrical and mechanical devices of spaceships, automobiles and satellites, fuel cells, pharmaceutical process and hybrid powered engines. The methods to augment heat transfer rate include various active and passive methods. Spinning the surface and mingling fluids with mechanical fittings are some of the active methods wherein the heat transfer is ameliorated by providing supplementary energy to the system. On the other hand, providing additional energy to the system is not a requisite factor in the passive methods. Passive methods of augmentation of heat transfer rate necessitate creating a rugged surface, inserting inserts like spiraled rod inserts, twisted tape inserts or wire coil inserts.

Another passive method that encouraged many researchers was the way of introducing solid particles into liquids to enrich the thermal conductivity. The introduction of micro size particle laden fluid is considered to be an efficient method of heat transfer amelioration; as solids have more conductivity than liquids. But intercalating particle laden fluids has more scourge than being beneficial. Some serious issues were caused like severe logging into micro channels, setting down of particles at bottom of the pipe when the flow is slow. When the circulation speed is increased, an erosion of pipelines occurs. Another major problem is the significant amount of pressure drop due to an increase in viscosity. It was Choi [1] who initiated a new particle – laden fluid called nanofluids; he did so by suspending nanoparticles in the base fluid. A colloid made of the base fluids and solid particles of dimension less than 100 nm is known as nanofluid. Choi also proved that even when a traceable number of nanoparticles were introduced in the conventional fluids, the nanofluids exhibited an increase in the thermal conductivity at a considerable rate.

A great many researches have been done using nanofluids to boost up the heat transfer rate since then. The convective heat transfer of Al_2O_3/ water in a circular tube was examined by Heris et al. [2]. They perceived that with an increase of concentration of nanoparticles in nanofluids, the heat transfer coefficient had also increased. They also observed that the enhancement in heat transfer was a way higher than convectional fluids. Investigation on heat transfer and pressure drop for the turbulent flow of CuO/ water nanofluids in a circular tube for volume fraction less than 0.3% was conducted by Fotukian et al. [3] and have observed an increase of 25% heat transfer coefficient than in pure water. A comparison study on heat transfer and pressure drop in heat exchangers i.e., vertical helically coiled heat exchanger and horizontal helically coiled heat exchangers; with CuO/water based nanofluid was conducted by Kannadasan et al. [4]. They observed that there was no traceable difference among the horizontal and vertical fittings in enhancement of heat transfer; but has resulted in a significant increase in Nusselt number for greater concentration nanofluids at turbulent flow. Researches on the convective performance of CuO/ water nanofluids in an electronic heat sink were made by Selvakumar et al. [5].The study explained that for the 0.2% volume fraction nanoparticles associated to DI water; there was a topmost rise of 29.36% of convective heat transfer coefficient.

Rather than using single nanofluids, the chances of making use of hybrid nanofluids were also experimented for the amelioration of heat transfer rate. An experiment held by Suresh et al. [6] on the sway of the Al_2O_3-Cu/ water hybrid nanofluids in heat transmit and gained a maximum intensification of 13.56% in Nusselt number to that of water. A slightly upraised friction factor was observed in 0.1% Al_2O_3-Cu/ water hybrid nanofluids to those of 0.1 Al_2O_3/ water nanofluids. Through helical screw tape inserts in transition flow inside a circular duct, the thermal attributes of Al_2O_3/ water and CuO/water nanofluids were subjected to study by Suresh et al. [7]and their outcomes proved 156.24%, 122.16% and 89.22% of net amelioration in the Nusselt number agreeing to twist ratio of 1.78, 2.44 and 3 respectively. Their examination also concluded that a better performance was given by the CuO/water nanofluids than the Al_2O_3/ water nanofluids with the helical screw tape inserts. Experiments on the laminar flow using Al_2O_3/ water and CuO/water nanofluids were held by Suresh et al. [8] and their results proved the helical coil inserts with CuO/water had exhibited a better performance then than helical coil inserts with Al_2O_3/ water nanofluids.

Nasiriet al. [9] performed studies about the heat transfer of nanofluids through an annular duct. It was confirmed that there was an amelioration of heat transfer with the two nanofluids namely the Al_2O_3/ water nanofluids and TiO_2 /water nanofluids. Experimental study on heat transfer performance and pressure drop for TiO_2/ water nanofluids under a turbulent flow was conducted by Duangthongsuk et al. [10]. It was observed that the heat transfer coefficient of nanofluids was nearly 26% higher than the pure water at 1.0 volume % yet, it was 14%lower than pure water at 2.0 volume % for the similar conditions. Sajidi et al. [11] had investigated the turbulent heat transfer and pressure drop of TiO_2 /water nanofluids in a circular tube and their examination had shown an increase in the heat transfer coefficient even with small introduction of nanoparticles in the base fluid. The team also observed a notable increase in the pressure drop of nanofluids than the base fluid. A Research on the study of hydraulic and heat transfer study of SiO_2 /

water nanofluids with imposed wall temperature boundary conditions in horizontal tubes was held by Ferrouillat et al. [12]. Their outcome showed 10% to 60% increase in heat transfer coefficient when compared to pure water. Yiamsawasd et al. [13] conducted studies by measuring the thermal conductivity of titania and alumina nanofluids and as a sequel found that with respect to the base fluids, the thermal conductivity increased with increase in concentration and temperature. They also arranged a relation for forecasting thermal conductivity of Al_2O_3 and TiO_2.

Saeedinia et al. [14] conducted studies under constant heat flux on pressure drop and heat transfer of nanofluids in a horizontal coiled wire insert and have concluded that in the tubes with wire coil insert, the nanofluids had greater heat transfer than the plain tube. Under turbulent flow with spiraled rod insertions, experimental studies on friction factor and heat transfer behaviours of Al_2O_3/ water nanofluids were carried out by Sureshet al. [15]. As a result, they came to a conclusion that there was an increase in the Nusselt number of about 10-48% for spiraled rod inserts when compared to the Nusselt number of the plain tube. They also noticed that there was an elevation of 2-8%of the isothermal pressure drop for spiraled rod inserts than the plain tube. A completely advanced study on mixed convection utilizing nanofluids in horizontal and inclined tubes was heldby Akbari et al. [16] and the results prove that the heat transfer coefficient at 4.0 volume % Al_2O_3 exhibited an increase of 15%. They also configured that the increase in the inclination of tube led to an increased skin friction coefficient and also the heat transfer coefficient attained a high rate at 45% of the tube inclination.

Anbu et al. [17] investigated experimentally the convective heat transfer characteristics of Al_2O_3/ DI water nanofluids flowing through smooth tube with a constant heat flux under laminar flow conditions. They used spiraled rod inserts in their study. They observed increase in Nusselt number by using nanofluids and inserts. Gurunath et al.[18] investigated experimentally heat transfer behaviours of MWCNT – Al_2O_3/ DI water in a plain tube with inserts under laminar flow. Their results showed that there is a considerable improvement in heat transfer. Arunkumar et al. [19] studied experimentally convective heat transfer performance of CuO/DI water nanofluids under laminar flow inside a tube with spiraled rod inserts. They observed a notable increase in heat transfer performance.

The current experimental study deals with the heat transfer amelioration in a circular tube with spiraled rod inserts by using Al_2O_3/ water nanofluids. The effects and impacts of nanoparticles and spiraled rod inserts (SRI) in a circular tube on the friction factor and heat transfer are subjected to discussions in the upcoming sections.

2. Experiments

2.1 The preparation of Al_2O_3/ water nanofluids

By dispersion the required quantity of Al_2O_3 particles in DI water; the preparation of nanofluids of 0.25 volume concentrations is done. A magnetic stirring is done so as to obtain a homogenous mixture and is continued for 30 minutes with the help of a REMI magnetic stirrer. To secure stable suspension, using a LARK ultrasonicator, the nanofluid is sonicated for the next 6 hours.

2.2 Convective experimental set up

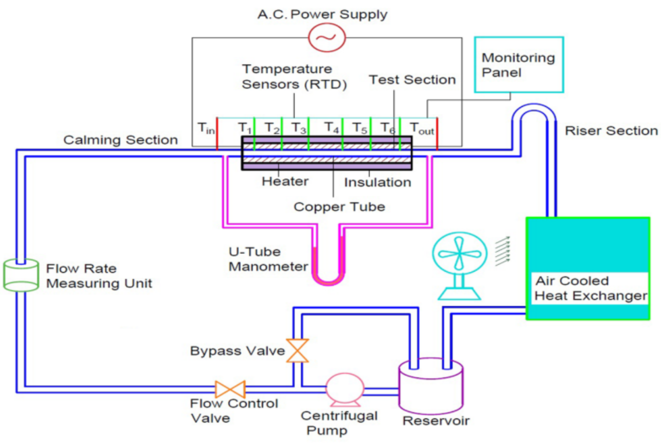


Fig.1.The schematic diagram of experimental setup

Fig.1 depicted the schematic diagram of the experimental set up. The following are the major components of the apparatus. (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. The fluid from the reservoir is pumped by using a centrifugal pump and a flow control valve and bypass valve control the flow rate. First, the fluid enters the calming section where the length is just enough to terminate the entrance effects, so that the flow is fully developed when it enters the test section. Then, the fluid flows through the riser section and then comes to the air-cooled heat exchanger and following to this, it is collected in the reservoir. The test section is a straight copper smooth tube of length 1000 mm, inner diameter (ID) 14 mm and outer diameter (OD) 16 mm.

In order to produce uniform heating in test section, a nichrome wire that has a resistance of 12Ω is used. With an accuracy of 0.1^{o} C, the Resistance Temperature Detectors (RTD PT 100) are used to measure the temperatures at the inlet, outlet and wall temperatures. The pressure drop across the test is measured by a U-tube manometer. For the purpose of avoiding radial heat losses, a thick insulation consisting of glass wool, asbestos rope and ceramic fiber is provided over the heating coil.

2.3 Technical details of Spiraled rod inserts

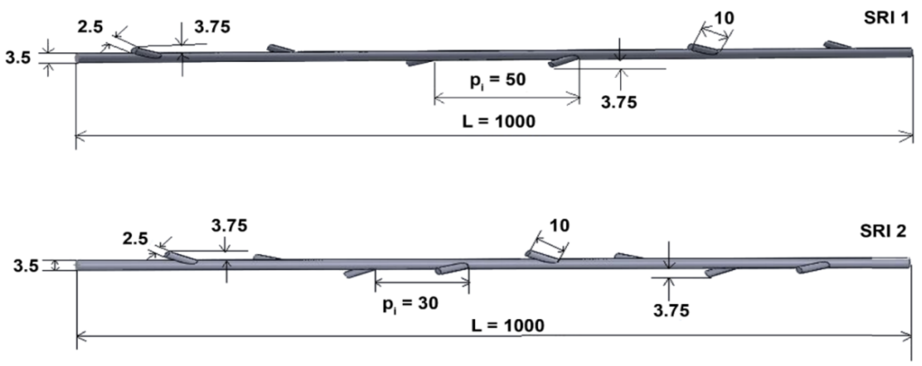


Fig.2.Geomentrical configuration of spiraled rod inserts

Fig.2 shows the spiraled rod inserts fabricated using 3.5 mm diameter copper rod to which pin like projections of length 10mm and diameter 2.5mm are attached at an angle of 22º to the copper rod with pitch of 50 mm (SRI 1) and 30 mm (SRI 2) respectively. An angle of 90º is maintained between two adjacent pins throughout the length of the rod.

3. Data Reduction

3.1 Thermo-physical properties of nanofluids

The density of Al_2O_3nanofluids is found using Pak and Cho's equation [20]

$\rho_{nf}= \Phi_{\rho s}+ (1 - \Phi)\ \rho$ (1)

By using Xuan and Roetzel's equation [21], the specific heat of nanofluids is found.

$(\rho C_p)_{nf}=(1 - \Phi)(\rho C_p) + \Phi(\rho C_p)\ s$ (2)

So as to obtain the viscosity of the nanofluids, Brookfield cone and plate viscometer (LVDV – 1 PRIME C/P) from Brookfield engineering laboratories in USA is used. With the help of the viscosity correlation put forward by Einstein [22], the viscosity of nanofluids could be calculated.

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

Measures of thermal conductivities of nanofluids are carried out with the use of KD2 Pro thermal analyser (Decagon Devices, Inc. USA). The effective thermal conductivity of nanofluids k_{nf} is found by Maxwell equation [23]

$k_{nf}/ k = k_s + 2k + 2\ \Phi\ (k_s - k)/ k_s + 2k - \Phi(k_s - k\ )$ (4)

3.2 Heat transfer calculations

The total heat transfer is measured using the following equation

$Q_{total} = V\ I$ (5)

An approximate value of 3.5% of the total heat supplied is found to be the loss of heat through insulation; from the measurement of wall temperature and ambient temperature.

Therefore,

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

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

Hence,

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

Heat flux,

$q" = Q / (\pi DL)$ (9)

The local wall temperature and heat flux is considered in order to calculate the local heat transfer coefficient using the formula as given below.

$h_x= q" / (T_{wx} - T_{fx})$ (10)

The local fluid temperature (T_{fx}) is calculated from the following energy balance equation

$T_{fx} = T_{in} + (q"\ Px)/ (\rho CpvA)$ (11)

The calculated local Nusselt number Nu_x,

$Nu_x = (h_x\ D)/ k$ (12)

The average heat transfer coefficient,

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

The determination of the average Nusselt number is done using,

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

The resistance is determined using

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

3.3 Pressure drop calculations

The friction factor from the pressure drop (Δp) measured across the test section under isothermal condition is calculated by using the following relation.

$$f = \Delta p / (½)\ \rho v2\ (L/D) \quad (16)$$

4. Results and Discussions

4.1 Heat transfer studies

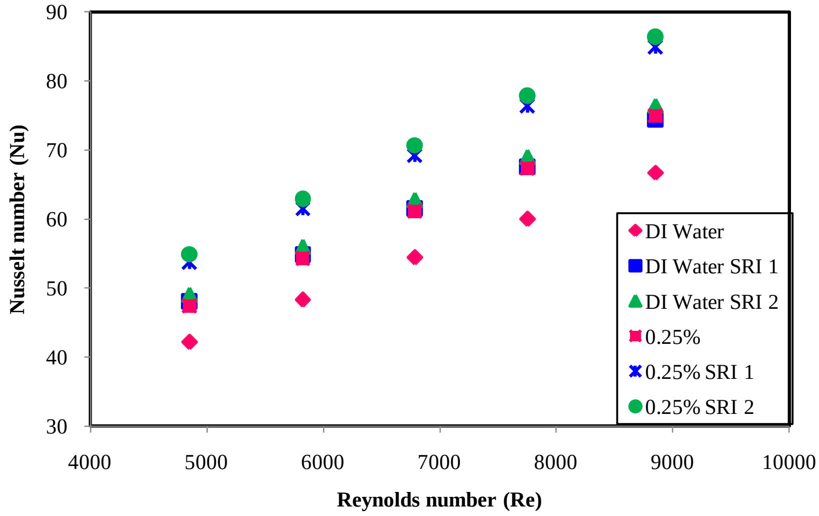


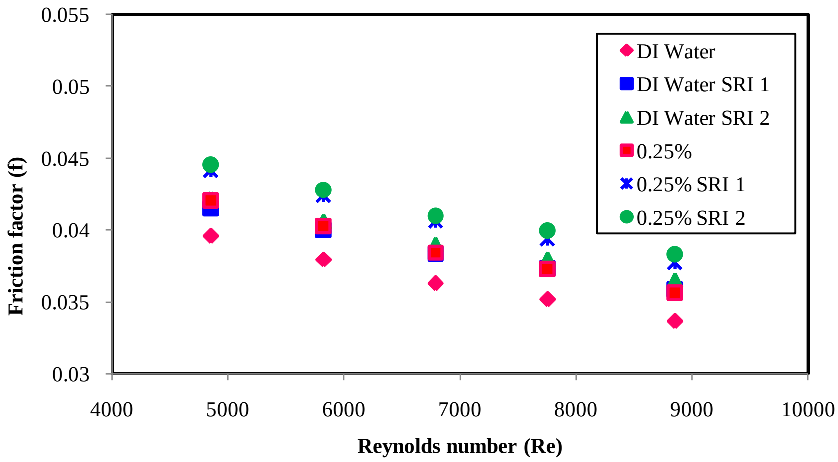
Fig.3. Variation of Nusselt number with Reynolds number of DI water and Nanofluids with and without inserts

The variation of Nusselt number with Reynolds number with and without spiraled rod inserts for a plain tube is depicted in fig. 3. In case of DI water, it is definite that the Nusselt number is increasing with the Reynolds number. The nanofluid that is taken into concern and is examined in the Al_2O_3/DI water nanofluids of 0.25% volume concentrations. A constructive influence is observed on the Nusselt number by the introduction of nanoparticles. An amelioration of 12.3% is observed in the Nusselt number for the volume concentration of 0.25% of nanofluids when compared to the Deionized (DI) water.

The following are the grounds on which the heat transfer augmentation is caused; due to the suspended nanoparticles, there is an increase in the thermal conductivity, Brownian motion, the cut down in the thickness of the boundary layer.

Further amelioration of heat transfer is possible by the use of spiraled rod inserts. The spiraled rod inserts stimulate turbulence and secondary flows. A noticeable reduction takes place in the hydraulic diameter. Two spiraled rod inserts of different pitch namely SRI 1 of 50mm and the other SRI 2 of 30 mm are used in this experimental investigation. Both the spiraled rod inserts exhibit an enhancement in the Nusselt number.An intensification in the Nusselt number is observed by decreasing the pitch of the inserts. An improvement of 11.5% for SRI 1 and 14.6% for SRI 2 is noticed. The heat transfer is further enhanced by the utilization of nanofluids along with the inserts. For volume concentration of 0.25%, 27.2% enhancement in Nusselt number is observed in SRI 1 and an improvement of 29.4% in the Nusselt number is found in SRI 2.

4.2 Friction factor studies



. Fig.4. Variation of friction factor with Reynolds number of DI water and Nanofluids with and without inserts

Measurements of the pressure drop of Al_2O_3/DI water nanofluids are done experimentally to guarantee the benefit of nanofluids in industrial applications. The effect of Reynolds number on the friction factor for smooth tube is depicted in fig. 4. The friction factor drops down on increase in the Reynolds number in all the cases; which is caused due to the reduction in laminar sublayer thickness. An imperceptible increment in the friction factor and a moderate forfeit in pumping power is observed in the base fluid by the introduction of nanoparticles. When compared to DI water, there is an increase of 5.8% for volume concentrations of 0.25%.

The usage of inserts in the plain tubes leads to further increase in friction factor. When compared to DI water without inserts, the hype in friction factor for plain tube with DI water, for volume concentrations of 0.25% is 6.56, 12.05% for SRI 1 and 8.49, 13.08% for SRI 2. The pitch of the insert is a factor that influences the friction factor. Due to the geometry and greater contact surface; an increase in pitch lead to the reduction of friction factor. The free flow area is decreased by the usage of inserts and also initiates turbulence, which lead to a higher friction between the inner tube wall and the surface of the core rod.

5. Conclusions

1. By the dispersion of a certain amount of the Al_2O_3nanoparticles in DI water, Al_2O_3 / DI water nanofluids with volume concentration of 0.25% is prepared.
2. The heat transfer is enhanced by the addition of nanoparticles to the base fluids.
3. The maximum possible enhancement in the Nusselt number for volume concentration of 0.25% in plain tube with SRI 2 is 29.4%
4. The pressure drop penalty by the use of nanofluids in the plain tube is less; hence it can be used in heat transfer applications. .

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