International Engineering Research Journal

Experimental Investigation on Heat Transfer Augmentation in a Circular Tube under Forced Convection with Annular Differential Blockages/Inserts

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Abstract

Enhancement in heat transfer by generating turbulence in the fluid stream inside the heat exchanger tube is an innovative area of research for researchers. Hence, many techniques are been investigated and adopted for enhancement of heat transfer rate to reduce the size and the cost of the heat exchangers. In the present study the effect of differential solid ring inserts turbulators on heat transfer, friction factor of heat exchanger is evaluated through experimentation. The parameters used for the experimentation include thickness ratio, diameter ratio (d/D). The experiments are conducted in range of Reynolds number from 3000 to 6500.
Keywords: *Heat transfer, Friction factor, Solid ring inserts, Thermal Performance Factor.*

1. Introduction

Increasing energy demand caused high cost of energy as well as material, which has resulted in an increased effort to produce high performance heat exchanger equipment. The need to improve the thermal performance of heat exchangers, thereby effecting energy, materials and cost savings leads to development and use of techniques. Use of these heat enhancement techniques increases the heat transfer coefficient but at the same time there is increase in pressure drop also. Hence while using any of these methods it is necessary to conduct the heat transfer as well as pressure drop analysis. On the basis of the previous research [2-8] it is decided to use solid ring inserts as insert geometry for the present work. The thickness ratio is kept constant while the diameter ratio is varied by changing the inner diameter of the ring. The experiments are conducted for Reynolds number varying from 3000 to 6500. In the present work the effect of solid ring insert on heat transfer and friction factor is studied through experimental investigation.

Following are the assumptions made to avoid the losses while performing the experiment:

i. Test section is perfectly insulated, hence there is no heat loss from the test section.
ii. Heat flux is uniformly distributed throughout the test section.
iii. Heat transfer is taking place only through forced convection.

2. Research Methodology

An Experimental test setup is fabricated to study the heat transfer and friction factor behavior of water in a tube subjected to constant heat flux boundary condition. The fluid is allowed to flow through a tube. The flow circuit consist of a radiator, collecting tank, and a storage tank connected to a pump. The tube is heated uniformly by wrapping it with band type heaters, and the entire test section is to be subject to a constant heat flux boundary condition. Rock wool is used as insulation in order to minimize the loss of heat. The test section is provided with eight K-type thermocouples which are brazed to the surface and two are located at inlet and outlet temperature to measure respective temperature. Experiments are to be conducted with water with a view to test the accuracy of the results. The fluid from the tank flows through the test section with the help of a pump. The liquid gets heated in the test section and hot water is cooled by passing it through a radiator. The provision of the radiator helps to achieve the steady inlet fluid temperature. Two 3mm holes are drilled at both the ends of the test section to analyze the pressure difference. Digital manometer is used in order to measure the pressure difference. The Reynolds number of flow of the working fluid flowing is measured from the mass flow rate. The total test section is heated by giving constant heat flux provided by heater. All the heat transfer tests and friction factor tests are conducted in the flow Reynolds number. The data obtained is noted and used for calculation of heat transfer coefficient and friction factor.

Parts of the setup

i. Storage tank: 500 lit capacity
ii. Rotameter: 0 to 10 lpm
iii. Pump: 0.5 HP
iv. Heater: Band type, Capacity 1000W
v. Thermocouple: k type
vi. Digital Manometer
vii. Inserts: Aluminum and Nylon material
viii. Test Section:
Length: 500mm
Inner diameter: 25mm
Outer Diameter: 32mm
Type of the material: Copper

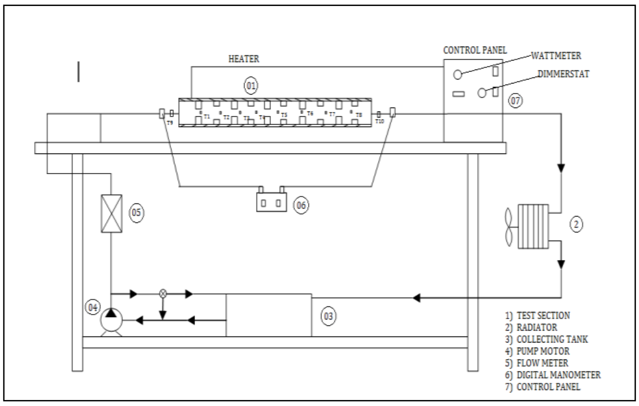

Fig. 1 General arrangement of the experimental setup

Working:

The circular ring inserts are made of aluminium with 7mm thickness. The inner diameter of pipe and the outer diameter of inserts is fixed at 25 mm while inner diameter of inserts were varied 23.72 mm, 22.36 mm, 20.92 mm, 19.36 mm and 17.67 mm for 20%, 30%, 40%, 50% flow blockage. Pitch of 50 mm is maintained between the inserts . The test pipe is made of mild steel with 25 mm inner diameter, length 500mm and thickness 3.5mm. Also differential blockages are created by placing two types of inserts alternately. Differential inserts with nylon material are also used. A 0.5 HP pump is used to force the fluid in the pipe. Band type heater of 1000W rating is used. The heater is enclosed with glass wool insulation to minimize convective heat loss. The heater was connected to 250 V, 4 A main. Ten K-type thermocouples are fixed at different locations, eight on the tube wall and the other two at the inlet and outlet to measure the temperature of the water. A rotameter of 10 lpm capacity was provided to set the water flow rate. A digital manometer is used to measure the pressure difference across the tube. A radiator was located in between test section and storage tank. Initially, water is pumped to the test section from the tank through rotameter. The flow rate is kept constant during experiment and then varied accordingly. Readings are noted for flow rate in range of 3 L/min to 6 L/min. Take readings for different heat input given to test section with uniform and differential inserts and without inserts.

3. Data Reduction and Validation

Q_h= V*I (energy supplied) ......(1)

Where Q_h is the heat input given by the heater

Heat added to water was calculated by,

$Q_{water} = m\, C_p\, (T_{out} - T_{in})$ ......(2)

Heat transfer coefficient was calculated from,

$$h = \frac{q}{T_{wm} - T_b} \qquad ......(3)$$

And heat flux was obtained from,

$$q = \frac{Q}{A} \qquad ......(4)$$

Where A= $\pi d_i L$

The bulk temperature is obtained from the average of water inlet and outlet temperatures,

$$T_b = \frac{T_{in} + T_{out}}{2} \qquad ......(5)$$

Where T_{in} is the inlet water temperature and T_{out} is the outlet water temperature

The standard correlations include Dittus-Boelter and Blasius for the fully developed turbulent flow in circular tube.

Nusselt number correlation: Dittus-Boelter correlation

$Nu = 0.023\, Re^{0.8} Pr^{0.3}$ ......(6)

Friction factor correlation:

Blasius correlation:

$f = 0.316\, Re^{0:25}$ ......(7)

Validation of Setup

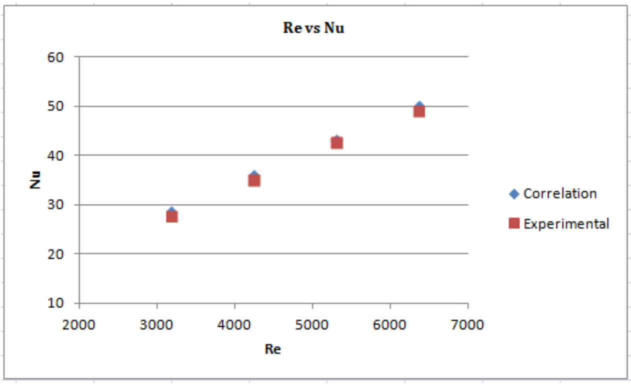

Fig. 2(a) Variation of Nusselt number with Reynolds number

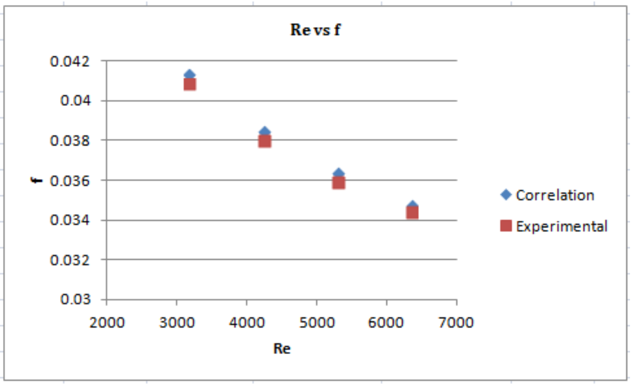

Fig. 2(b) Variation of friction factor with Reynolds number

4. Results and Discussions

On the basis of the experimentation done different results have been obtained for various sets of insert geometries. Variation of heat transfer and friction factor on the basis of various geometries and flow parameters is obtained through the experimental readings. These readings are used to plot the graphs showing the variation of heat transfer and friction factor with respect to different geometries and flow parameters.

4.1 Effect of flow blockages on heat transfer.

The main objective of the experiment is to enhance the heat transfer compared to plain tube heat exchangers. It is observed that the heat transfer is more for tube with inserts as compared the plain tube and it significantly increases with increases in the blockage percentage. Fig. 3(a) shows the comparison between Nusselt numbers for different geometries for particular Reynolds number. It is observed that the heat transfer increases with blockage and is highest for differential blockages/inserts. Also the heat transfer rate for tube fitted with differential metal inserts is high than for non metal inserts.

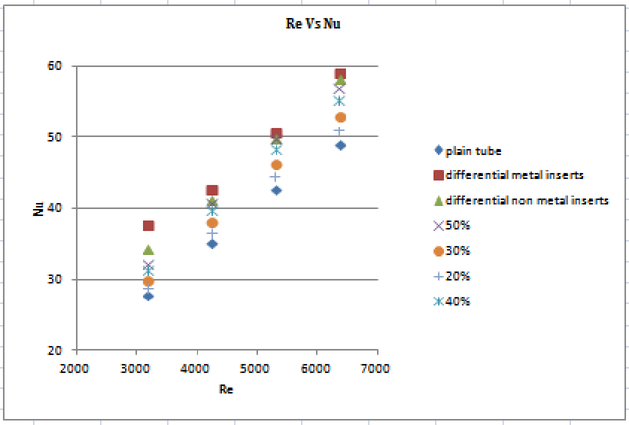

Fig. 3(a) Variation of Nusselt number with Reynolds number

4.2 Effect of flow blockage on friction factor

Effect of circular ring providing different blockages (20%, 30%, 40%, 50%, Differential metal and differential non-metal) is presented in fig. 3(b) the value of the friction factor increases with increase in the flow blockages and is highest for pipe with differential metal inserts.

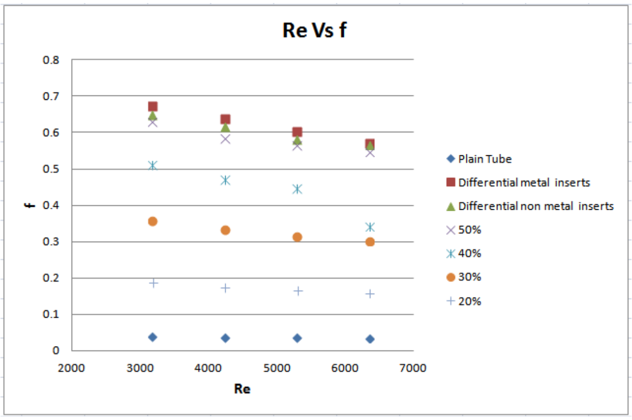

Fig. 3(b) Variation of friction factor with Reynolds number

4.3 Effect of flow blockage on thermal performance factor

It is an important for checking the utilization of the heat exchanger. It is the ratio of enhanced nusselt number to enhanced friction factor.

$$\eta = \frac{Nu/Nu_s}{f/f_s^{\ 1/3}} \qquad \text{......(8)}$$

Where Nu represents nusselt number of tube with insert and Nu_s represents Nusselt number for plain tube whereas f is friction factor for tube with inserts and f_s is friction factor for plain tube.

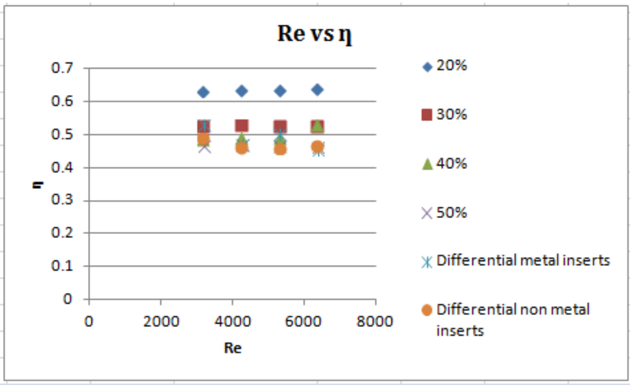

Fig. 3(c) Variation of Thermal performance factor with Reynolds number

5. Numerical Analysis

5.1 Computational Fluid Dynamics

Computational fluid dynamics is the use of the computer based simulation to analyze systems involving fluid flow, heat transfer and chemical reaction.

A numerical model is first constructed using a set of mathematical equations that describe the flow. These equations are then solved using a computer program in order to obtain the flow variables throughout the flow domain

5.2 Numerical investigation for plain tube

The numerical analysis of water flowing through circular tube at constant wall temperature, for estimation of heat transfer and friction factor characteristics. The results obtained are compared with the available correlations. The simulation is carried out by using ANSYS Fluent 16 software.

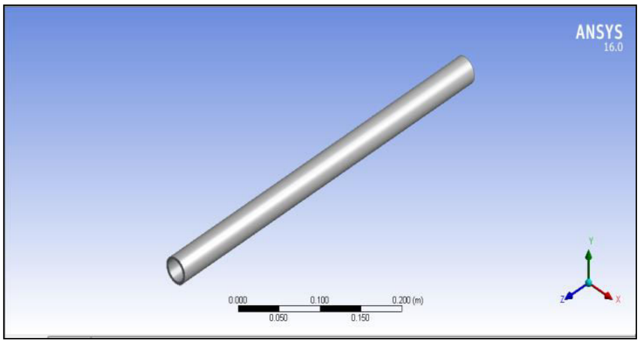

Fig. 4(a) Geometry of a plain tube

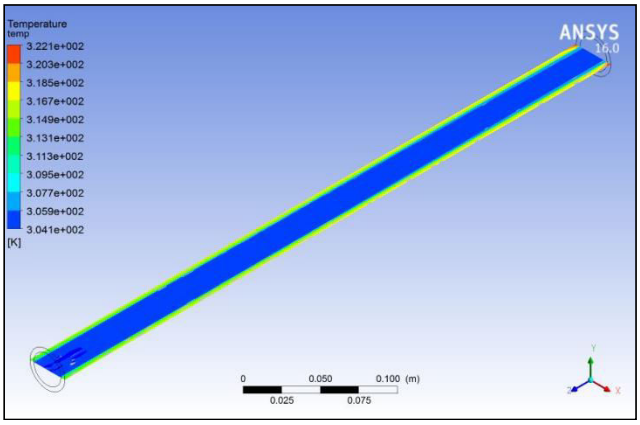

Fig. 4(b) Temperature variation for plain tube

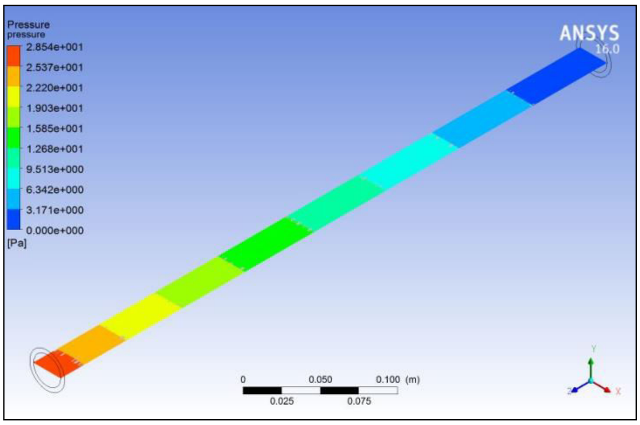

Fig. 4(c) Pressure variation for plain tube

5.3 Numerical Investigation of tube with uniform circular ring inserts

The numerical investigation of tube fitted with uniform circular ring inserts is carried out. The results are compared with the experimental results obtained

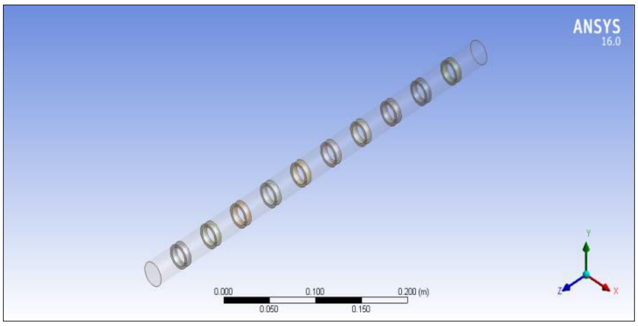

Fig. 5(a) Geometry of tube with uniform insert

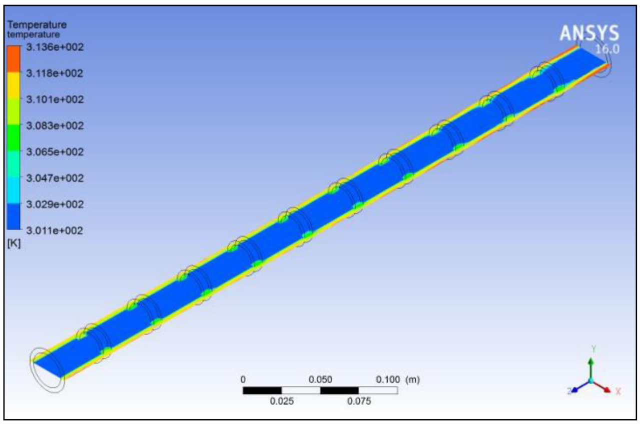

Fig. 5(b) Temperature Variation for uniform ring inserts

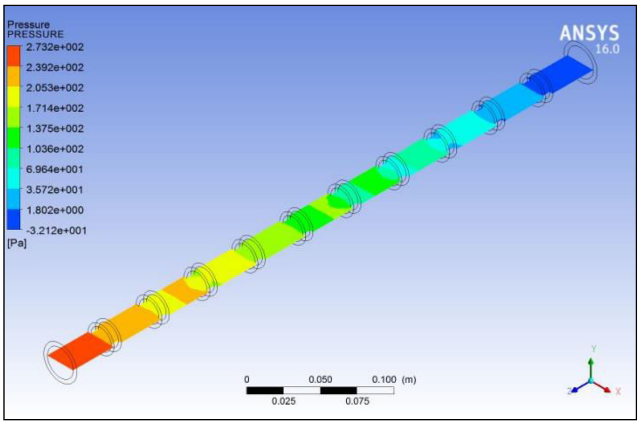

Fig. 5(c) Pressure Variation for Uniform ring inserts

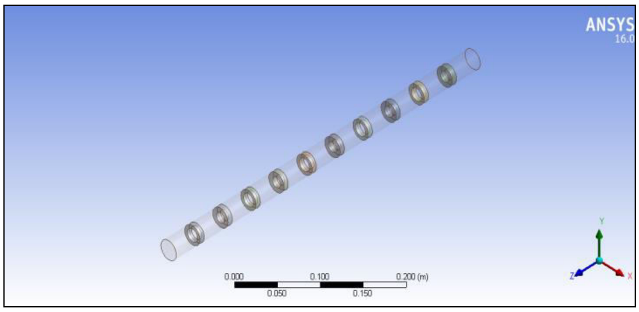

Fig. 6 Geometry of Differential inserts

5. Conclusion

Heat transfer enhancement in tube fitted with uniform metal inserts, differential metal inserts and differential non-metal inserts is studied in this experimentation. The effect of various combinations of circular ring inserts for flow blockages on heat transfer and friction factor is studied. The following are the conclusions obtained by using the uniform and differential inserts

1. Experimental Setup is validated by comparing the result obtained by correlation and experimental result.
2. Nusselt number is high for tube with inserts as compared to plain tube. It is greater for tube fitted with differential metal inserts as compared to tube with uniform inserts.
3. As the Reynolds number increases Nusselt number increases and friction factor decreases.
4. The heat transfer rate is high for tube with differential metal inserts as compared to differential non-metal inserts of the same geometry.
5. The heat transfer rate is high for differential combination of inserts as compared to tube fitted with uniform inserts.
6. The maximum heat transfer is obtained by the use of differential metal circular ring inserts.

Nomenclature

Re Reynolds number
Nu Nusselt number
Pr Prandtl number
f Friction factor
d_i Internal diameter of insert
L Length of the test section (m)

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