Experimental investigation of heat transfer coefficient and flow parameters in circular tube by using porous medium

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Abstract: In most engineering application and contain heat transfer through circular tube. There are many methods to enhance heat transfer through circular tubes. Among all the technology the heat transfer with porous structure arrangement within the flow area shows adequate enhancement. This paper gives heat transfer coefficient and flow parameter calculated in a circular tube with porous medium placed inside the circular tube. The porous medium is prepared using the G I material having different hole diameters. The effect of porosity, heat transfer coefficient, pressure drop, Reynolds number, friction factor are calculated. The calculated result compared with circular tube without porous medium.

Keywords: Porous medium, Heat transfer coefficient, Reynolds number, Circular tube, Friction factor.

1. Introduction
In the current years there is rising demand of energy for the industries, national use, protection missile, financial development of the nation, and power production. There are apparatus’s which are concerning heat putting and heat removing. Such as nuclear waste repositories, solar power collector, electronic devices, heat exchanger, chemical catalytic reactor, thermal power plant, drying agriculture products and storage, cooling applications. All these application need heat transferrable process. Owing to this reason we have to design such a system which is additional effective heat transferrable improvement with minimum frictional loss.

Most of all the engineering heat transferrable applications contain cylindrical section to transfer heat. Thus circular pipe is main problematic in convective heat transference. They are many method suggested to advance the convective heat modification in the tubular sector. Such as placing the fines on the surfaces of the cylinder, warped tape inside the cylinder, tapes, rips inside the cylinder and porous medium inside the cylindrical section.

Among all above mention technique cylindrical tube with porous medium is one of the promising techniques is used because of its great surface to volume ratio. Additional face exchange provides the superior heat transference at lesser interval of period.

By way of the flow proceeds in the circular duct, these porous medium materials create the obstruction to the fluid flow. Due to this laminar viscous layer breaks into viscous sub layers and more turbulence is created due to boundary layer thinning i.e. more turbulence is created at the boundary than the core flow in duct. This helps us to attain greater heat transferrable rates.
1.1 Porous medium: Porous medium is one type of medium which allow flowing the fluid through it. Porous medium contains pores or voids. The porous material is combination of matrix or frame like structure and pores which are permit flow through it. Combination of matrix and pore create a porous medium. The pore is permitting the fluid movement through it. Different type of porous medium are rocks, soil, biological tissue, bones, wood material and human created materials like cement, ceramics are porous medium.

1.2 Circular tube/channel: In this work circular duct is used for studying the air flow characteristics inside the duct. Because it is found that the circular channels have greater heat transferred and friction influence performance than ducts of square, semi-circular. Circular channels provide the greatest convective heat transferred performance. Therefore in the present experiments circular duct is chosen to study the fluid flow specifics inside the circular channel.

![Figure 1. Circular tube](image)

**Table 1: Test section specification**

| Material used            | SS material 0.2mm thick |
|--------------------------|------------------------|
| Size of the circular tube| D=25mm, L=300mm        |
| Length of the test section| L_s=230mm              |

2. Literature Review

Literature survey done in this chapter is to study the several techniques existing for the heat transference augmentation i.e. active, passive, and compound methods. In this work we are concentrating on the passive techniques which need a special geometry. Also this literature reviewed will help us to learn the things from the past works. This will definitely help us in deriving more accurate results as expected.

2.1 Details of the effort approved available by various researchers:

**Hyung Jin Sung et al [1]** studied the fluid movement and heat transfer characteristics of forces convective in duct are moderately placed by permeable moderate. The flow geometry prototype convective cooling process is printed in circuit board of system with porous medium insert. The channel is considered as adiabatic. They conclude that if porosity rises, the flow rate between the porous medium and duct wall is rises. A fall of Darcy number for a particular value of porous medium also course’s rise to the stream rate, if the stream rate in porous layer is fall.

**T.S.zhao and Y.J.song et al [2]** studied the forced convection in a soaked permeable moderate placed to the heating system with a absorbent barrier vertical to the flow way is examined methodically. Aimed at the situation of periphery film stream overhead a plane platter inserted in a permeable moderate suggests that heat transfer can be significantly enhanced when the flow way is matching to the practical temperature gradient. The experimentations did in a permeable assembly containing of
cut-glass drops heated by a finned surface must present the investigative explanation in moral arrangement with the investigational statistics at low Peclet numbers.

D.A. Nield and A.V. Kuznetsov et al [3] studied the completely generated laminar movement in forced convective in a matching plate duct employed by a Nano fluid or through a permeable moderate soaked through a Nano fluid, subject to constant.

G.M. Chen, et al [4] studied uniform heat system. Area interaction examination is achieved with importance on the connection angle among the velocity route and heat rise route with the presence of heat sink. The properties of heat transference through the partition heat transference constant must resulting after the improved connection angle which signifies the interaction among the velocity vector and improved heat rise route by the heat removed.

Seyyed Mohammad Hosseini Hashemi, et al [5] studied the Forced convective heat transfer in a permeable annular micro duct is investigated analytically for hydro dynamically then warm air completely developed movement of a dilute gas. They worked and drive the second low of thermodynamic to generate entropy annulus.

Chen Yang, et al [6] studied the Heat transference improvement impost be present for forced convective in a cylinder through a permeable moderate essential and a cylinder with a barrier enclosed with a permeable moderate film, hence to study efficiency of permeable moderate material insert inside a cylinder. To find local thermal and non-thermal symmetry investigations be approved aimed at dual cases of incomplete permeable moderate filed, to study the performance of local thermal symmetry statement.

3. EXPERIMENTAL SET UP AND METHODOLOGY

3.1: Experimental Arrangement: Circular duct of size 25mm diameter, 300mm length then two pressure taps are provided for the measurement of the pressure across the test section. U-tube manometer is used for the measurement differential pressure head across the venturimeter and gate valve used to regulate and control the compressed air flow rate. Porous medium is placed inside the circular tube.

![Diagram of experimental setup](image)

**Figure 2**

1. Compressor  
2. value  
3. Air flow control value  
4. Venturimeter  
5. U-tube meter  
6. Micro-manometer  
7. Test section  
8. Milli-voltmeter  
9. Ammeter  
10. Voltmeter  
11. transformer  
12. dimerstast  
13. CT  
14. Switch board  
15. Switch board
3.2 Methodology: A schematic arrangement of the experimental set up used in the measurement of pressure distribution and temperature is shown in Fig 3.1. Air from a compressor passes in the test section through a venturimeter, where the volume flow rate is measured. The Reynolds number based on the duct diameter was varied from 4225 to 11664. Compressor delivers the air; air enters into the test section through the valve which controls the flow of air through the test section. Using venturimeter and simple U-tube manometer the flow rate of air is maintained to required value, when air flows through the test section there is friction between air and surfaces of the circular duct. Due to this pressure drop takes place. This pressure drop across the test section is measured by using Micro-Differential manometer. Same process is followed to obtain the friction factor for different configurations of the porous medium which are placed in the circular duct. The measurement of pressure drop was done at the atmospheric temperature condition (i.e. tests without heating) and the friction factor was finding in terms of pressure drop across the test section of circular tube and the mass velocity of air.

3.3 Geometry and Computational Details: Circular shaped 90 degree angled porous medium are placed into mainstream flow direction on the circular duct to study the flow characteristics. The circular duct are denoted as p, d, L, D and ɛ are given below

- Pitch (p): it is the distance between the two identical porous medium on the spaceman.
- Diameter (d): it is the diameter of the porous medium used.
- Porosity (ɛ): it is the porosity of porous medium used.
- Diameter (D): it is the diameter of the circular duct.
- Length of the circular duct (L): it is the length of the test section.

In this project we are using GI material with voids is porous medium. GI material has thickness 0.2mm, having the voids 1.63mm, 2.03mm the two materials shown below

![Figure 3 GI porous medium used](image)

**Table 2** Types of porous medium

| Porous medium | Diameter of porous medium d(mm) | Length of pitch p (mm) | ɛ% | porous Angle with main stream flow |
|---------------|-------------------------------|------------------------|----|-----------------------------------|
| 1             | 24.5                          | 3                      | 6.73 | 90                                |
| 2             | 24.5                          | 5                      | 6.73 | 90                                |
| 3             | 24.5                          | 3                      | 8.28 | 90                                |
| 4             | 24.5                          | 5                      | 8.28 | 90                                |

4. Data reduction:

4.1 Flow rate through venture–meter

\[
Q_m = C_d \frac{A_1 \times A_2}{\sqrt{(A_1^2 - A_2^2)}} \sqrt{2gh_a}
\]
4.2 Mass flow rate:

\[ m = \rho \, \dot{Q}_{\text{in}} \]

4.3 The Reynolds number based on the channel hydraulic diameter

\[ R_e = \rho_a u \frac{D}{\mu} \]

4.4 The friction factor analysis across the test section in terms of pressure drop and the mass velocity of air

\[ f = \frac{\Delta P}{L} \left( \frac{\rho_a u^2}{2} \right) \]

4.5 Smooth duct friction factor is estimated by using the correlation as proposedby

\[ FFS = (0.1582 \times Re^{-0.2}) \]

4.6 Convective heat transfer from test section which can be expressed below:

\[ Q_{\text{air}} = Q_{\text{convection}} \]

\[ Q_{\text{air}} = mc_{p,\text{air}} (T_o - T_i) \]

Where

5. Results and Discussions

5.1 Results of smooth tube: The Fig shows that the change of friction factor with Reynolds number for the smooth circular tube. FFs are the smooth tube friction factor obtained from experiment. These values are compared with the theoretical friction factor obtained from the Blasius equation for the smooth channels i.e. FFs=0.1582*Re^{-2} for the validation of the experimental results. From this graph the experimental results for friction factor in smooth circular tube reasonably agree well within ±5% values estimated from correlation proposed by Blasius

![Graph showing experimental results](image)

5.2 Results of Temperature distribution: Experiments were conducted for averaged span wise axial distribution of Nusselt number for smooth channel (Nus) and porous medium roughened channel (Nuc) for different Reynolds numbers in the range of 4225–11664. Experimental outcomes are plotted in terms of variation of Nusselt number with X/D.
In the above fig showed the how the Nusselt number increase in smooth channel as the Reynolds number increases. That means that at high $Re=10915$ the heat transfer rate is more and at $Re=4161$ the heat transfer rate is minimum.

5.3 Variation Nusselt number V/S X/D porosity=6.73%

Figure 6: Graph showing the variation of Nusselt number for 6.73% porosity

5.4 variation Nusselt number V/S X/D for porosity= 8.28%
From the all above figures if we compare the smooth channel and channel with porous medium placed the Nusselt number is high in the circular channel with porous medium. If increasing the pitch (p=5cm) the Nusselt number increases shown in fig 5.2 and decreasing the pitch (p=3cm) Nusselt number decreases shown in fig 5.3. Also if Reynolds number increases the Nusselt number also increases and decreases at the low Reynolds number. At Re=4225 Nu=4425.606 and at Re=11697 Nu=34053.51 shown in the fig 5.4. Also as the porosity increases i.e. $\varepsilon=8.28\%$ Nusselt number increase and reducing the porosity $\varepsilon=6.73\%$ Nusselt number decreases.

**References**

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**Figure 7** Graph showing the variation of nusselt number