Enhancement of Heat Transfer With Conical Hole Filament Insert in a Flow through Circular Tube

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Abstract
In many engineering applications, the high-performance thermal systems need improvement, with various methods to improve heat transfer in the system. To date, many studies have been focused on passive heat-transfer enhancement methods and the fluid flow. In this research work, a new technique of heat transfer enhancement is proposed, which contains a filament having holes with conical geometry. The holes present on the filament inserts are convergent and divergent cross-section. The newly designed filament inserts are compared with filament inserts having straight hole at various pitch ratios. It has been clearly observed that the new passive technique proposed in this dissertation shows substantial increase in heat transfer rate over the plain tube and tube with filament inserts having straight holes.

Keywords
Heat Transfer Enhancement, Passive Technique, Filament Inserts

I. Introduction
Towards the goal of improved thermal management, heat transfer augmentation is a subject of vital importance in increasing the heat transfer rate and achieving higher efficiency. The interesting features of the insert is always to reduce the cost of heat transfer process and its promising potential in many heat transfer applications such as heat exchangers, nuclear reactors, solar heaters, gas turbines and combustion chambers have promoted abundant studies.

The study of enhanced heat transfer has gained serious momentum during recent years, however due to increased demands by industry for heat exchange equipment that is less expensive to build and operate than standard heat exchange devices. Savings in materials and energy use also provide strong motivation for the development of improved methods of enhancement. When designing cooling systems for automobiles and spacecraft, it is imperative that the heat exchangers are especially compact and lightweight. Enhancement devices are necessary for the high heat duty exchangers found in power plants (i.e. air-cooled condensers, nuclear fuel rods). These applications, as well as numerous others, have led to the development of various enhanced heat transfer surfaces. In general, enhanced heat transfer surfaces can be used for three purposes:

- To make heat exchangers more compact in order to reduce their overall volume, and possibly their cost,
- To reduce the pumping power required for a given heat transfer process, or
- To increase the overall heat transfer coefficient value of the heat exchanger.

A higher overall heat transfer coefficient value can be exploited in either of two ways:

- To obtain an increased heat exchange rate for fixed fluid inlet temperatures, or
- To reduce the mean temperature difference for the heat exchange, this increases the thermodynamic process efficiency which can result in a saving of operating costs.

A. Heat Transfer Enhancement Techniques
Enhancement techniques can be separated into two categories:

1. Passive Techniques
Passive methods require no direct application of external power. Instead, passive techniques employ special surface geometries or fluid additives which cause heat transfer enhancement. These techniques modify the heat transfer surface or incorporate an additional device into equipment. The existing flow mechanism is disturbed and the heat transfer performance is improved. But this is accompanied by an increase in the flow friction and pressure drop. The majority of commercially interesting enhancement techniques are passive ones. The passive techniques are normally classified into the following types:

- Treated surfaces
- Rough surfaces
- Extended surfaces
- Displaced surfaces
- Swirl-flow services
- Surface tension devices
- Additives for liquids
- Additives for gases

2. Active Techniques
Active augmentation techniques, which have also been studied extensively, require the addition of external power to bring about the desired flow modification. Active techniques have attracted little commercial interest because of the costs involved, and the problems that are associated with vibration or acoustic noise. These include the following types:

- Mechanical aids
- Surface vibrations
- Fluid vibrations
- Electrostatic fields
- Injection
- Suction

Usually two or more of the above techniques may be utilized simultaneously to produce an enhancement larger than that produced by only one technique.

II. Experimental Setup
In this experimental setup for forced convection heat transfer is explained. The experiment is carried out in an open-loop experimental facility. Calming region is provided after the blower exit of specified length. The test tube is provided with flange ends at both sides to assemble and disassemble the filament insert easily. The tube was heated by flexible electrical wire provided a uniform heat flux boundary condition. The outer surface of the test tube was well insulated with leak proof joints. Figure 1, shows the actual photograph of the experimental test setup.
The test section (test tube) is made of seamless steel tube with 1500 mm length, inner diameter is 36 mm and outer diameter is 42 mm. The test tube is provided with flange ends at both sides. This will facilitate to assemble and disassemble the filament insert conveniently.

The test tube was heated by continuously winding flexible electrical wire (heater of 500 Watts) which provides the uniform heat flux boundary condition. The electrical output power was controlled by a various transformer to obtain a constant heat flux along the entire length of test section and by keeping the current less than 3ampire. The outer surface of the tube was well insulated to minimize convective heat loss to surrounding and necessary precautions were taken to prevent the leakages (working fluid as well as electric current) from the system. The two thermocouples (copper- constantan), one at the inlet side and another at outlet side of the test section and the remaining six on the surface of test tube (approximately 165 mm apart) were placed to measure the temperature with the help of multi-channel temperature measurement unit. The filament insert assembly (all made up of aluminum) is sung fitted inside the test tube.

### III. Test Procedure
Initially the testing has been carried out without filament inserts, i.e. for plain tube only. The heater input voltage was set for different voltages. The blower was started and mass flow rate of air was adjusted suitably with the help of gate valve to have turbulent flow. Before taking the readings the steady state condition is maintained (approximately 2 hours are required to achieve steady state condition).

The temperature readings $T_o$ (Ambient temperature), $T_i$ (Air temperature at inlet side), $T_a$ (Air temperature at outlet side), and $T_a$ to $T_r$ (temperatures at different location in test section) were recorded for different heater voltage input along with the pressure drop. For every heater input (voltage input), such six sets of readings are taken at an interval of 10 minute each. The results for each case are tabulated next to observation table. Similar procedure has been followed for circular tube with different filament inserts.

### IV. Data Analysis
The calculation of each case and every velocity has been done using the equations as below:

Mean temperature ($T_m$) in (°C)

$$T_m = \frac{T_i + T_o}{2}$$  \hspace{1cm} (1)

When $T_i$ is the inlet air temperature in (°C) $T_o$ is the outlet air temperature in (°C)

Temperature different ($\Delta T$) in (°C)

$$\Delta T = T_o - T_i$$  \hspace{1cm} (2)

When $T_i$ is the inlet air temperature in (°C) $T_o$ is the outlet air temperature in (°C)

Average surface temperature ($T_{a.s.}$) in (°C)

$$T_{a.s.} = \frac{T_2 + T_3 + T_4 + T_5 + T_6 + T_7}{6}$$  \hspace{1cm} (3)

When $T_2, T_3, T_4, T_5, T_6$ and $T_7$ are surface temperature in (°C)

Volume flow rate ($\dot{V}$) in (m³/sec)

$$\dot{V} = \nu \times A$$  \hspace{1cm} (4)

When $\nu$ is the velocity of air in (m/sec) $A$ is the cross section area of tube in (m²)

Mass flow rate ($\dot{m}$) in (kg/sec)

$$\dot{m} = \dot{V} \times \rho$$  \hspace{1cm} (5)

When $\dot{V}$ is the volume flow rate of air in (m³/sec) $\rho$ is the density of air at mean temperature in (kg/m³)

Reynolds number ($Re$)

$$Re = \frac{\nu \times D}{\nu}$$  \hspace{1cm} (6)

When $\nu$ is the velocity of air in (m/sec) $D$ is the hydraulic diameter of tube in (m) $\nu$ is the kinematic viscosity of air at mean temperature (m²/sec)

Prandtl number ($Pr$) given at the mean temperature of air

$$Nu = 0.023 \times Re^{0.8} \times Pr^{0.4}$$  \hspace{1cm} (7)

When $Re$ is Reynolds number $Pr$ is Prandtl number

Heat transfer coefficient ($h$) in (W/m².k)

$$h = \frac{Nu \times k}{D}$$  \hspace{1cm} (8)

When $Nu$ is Nusslt number $k$ is the thermal conductivity of air at mean temperature in (W/m.k) $D$ is the hydraulic diameter of tube in (m)

Heat transfer rate ($Q$) in (Watts)

$$Q = h \times A \times \Delta T$$  \hspace{1cm} (9)

When $h$ heat transfer coefficient in (W/m².k) $A$ convection area in (m²) $\Delta T$ temperature different in (°C)

Pressure drop ($\Delta P$) in (Pascal), case of plain tube

$$\Delta P = \frac{F \times L \times \rho \times \nu^2}{2D}$$  \hspace{1cm} (10)

When $F$ is friction factor $L$ is the length of the tube in (m) $\rho$ is the density of air at mean temperature in (kg/m³) $\nu$ is the velocity of air in (m/sec) $D$ is the hydraulic diameter of tube in (m)

Pressure drop ($\Delta P$) in (Pascal), case of tube with filament inserts

$$\Delta P = \rho \times g \times \Delta h$$  \hspace{1cm} (11)

When $\rho$ is the density of water at ambient temperature (kg/m³)
is the earth gravity in (m/sec²)
Δh manometer reading in (m)

V. Results Analysis

From the data analysis for the different test conditions such as, plain tube, plain tube with filament insert having straight holes (2 pitch ratio and 4 pitch ratio), filament insert having convergent holes (2 pitch ratio and 4 pitch ratio) and filament insert having divergent holes (2 pitch ratio and 4 pitch ratio) results tables are prepared to recognize the arrangement of filament having the highest heat transfer rate with lowest pressure drop. The input data for the experimentation was, filament insert 2 pitch ratio and 4 pitch ratio, voltage – to supply the heat (100, 120, 140 and 160 volts), and air velocity – to adjust the mass flow rate of the working media (1, 2, 3, 4, 5, 6, and 7 m/sec). After conducting the experiments the data received is in the form of temperatures and manometric reading. By using the existingly available equations, the data is processed to find out volume flow rate, mass flow rate, Reynolds number, Prandtl number, Nusselt number, heat transfer coefficient, heat transfer rate, pressure drop and pump power. Above mentioned terms will help to make appropriate conclusions for the tests conducted.

VI. Conclusion

The plot mass flow rate versus pressure drop shows the higher pressure drop is with filament having convergent or divergent hole than filament with straight hole (approximately 10%). Also the pressure drop is maximum for pitch ratio 2 than pitch ratio 4, for filaments having straight, convergent and divergent hole. The pump power requirement (approximately 12%) is more for filament with convergent or divergent holes with that of straight hole. The plot mass flow rate versus heat transfer rate, the heat transfer enhancement is observed over the plain tube and filament insert with straight holes by using either filament insert with convergent holes or divergent holes. In case of filament insert with convergent holes or divergent holes, the heat transfer rate is increased nearly by 20% as compared to filament with straight holes and 40% with that of plain tube. The arrangement of filament having either convergent or divergent hole with pitch ratio 4 gives highest heat transfer rate and low pump power requirement as compared to other arrangements or plain tube.
References


Monis Abdulmanan Abdullah has received his master degree in Mechanical-Heat Power branch from Sinhgad College of Engineering, Pune University, Pune, Maharashtra (India). He plans to do his Ph.D. in the field of Heat Transfer Augmentation techniques.