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Heat Transfer Augmentation by Rotating Insert

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Abstract- **Enhancement of heat transfer using various techniques has received strong attention over the years. Many techniques have been developed for enhancing heat transfer rate in heat exchanger like active methods and passive methods. Any techniques for enhancing the heat transfer should be optimized between higher heat transfer coefficient and lower pumping cost. This paper reviews the work undertaken by researchers on the passive techniques such as ribs, conical ring inserts, twisted tapes etc. to enhance the thermal performance in heat exchangers. This paper shows that a tube employed with passive techniques has better heat transfer rate than that of plain tube with minimum pumping power requirement. Heat transfer can also be enhanced by using rotating inserts in a round tube. These rotating insert acts as a swirl generator. The use of the swirl generator is expected to create the tangential velocity or swirling flow to prolong residence time of the flow and to enhance the tangential and radial fluctuation, therefore leading to increase in heat transfer inside the test tube. The higher heat transfer occurs with lowest pitch ratio than that of other pitch ratios. For the lowest pitch ratio stronger swirl flow will create. So turbulence intensity will be higher for lowest pitch ratio. This stronger swirl flow results in higher pressure drop because of more blockage of fluid. So a tube with lowest pitch ratio has higher friction factor than other pitch ratios.**

Index Terms- Heat Transfer Rate, Heat Exchanger, Rotating Insert, Twisted Tapes, Heat Transfer Coefficient.

I. INTRODUCTION

Heat transfer intensify techniques (passive, active or a combination of passive and active methods or compound methods) are commonly used in areas such as process industries, heating and cooling in evaporators, thermal power plants, air-conditioning equipment, refrigerators, radiators for space vehicles, automobiles, etc. Passive techniques, where inserts are used in the flow passage to intensify the heat transfer rate, are advantageous compared with active techniques, because the insert manufacturing process is simple and these techniques can be easily employed in an existing heat exchanger. In design of compact heat exchangers, passive techniques of heat transfer augmentation can play an important role if a proper passive insert configuration can be selected According to the heat exchanger working condition (both flow and heat transfer conditions). Many researchers have used different passive methods to improve heat transfer. Passive heat transfer methods are not only applicable in heat exchanger but also in solar air heater and cooling of electronic components (heat sink).

Heat exchangers have its application in industrial and engineering field. The design procedure of heat exchangers includes exact analysis of heat transfer rate, efficiency and pressure drop. Whenever inserts technologies are employed for the heat transfer augmentation, along with the improvement in the heat transfer rate, the pressure drop also increases which increases the pumping cost. Therefore any augmentation device or methods utilized into the heat exchanger should be optimized between the benefits of heat transfer coefficient and the higher pumping cost owing to the increased friction losses. To use passive techniques economically we define Thermal Performance Factor which is the ratio of heat transfer enhancement ratio to friction factor ratio. In general, heat transfer augmentation methods are classified into three broad categories:

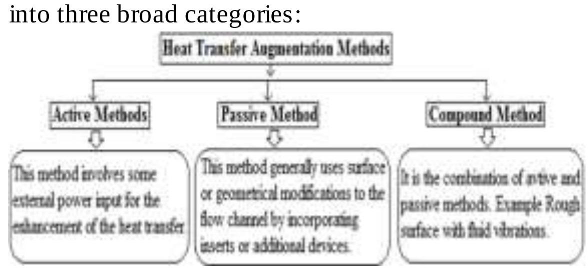

Fig 1. Heat transfer augmentation Methods

1.1 PASSIVE TECHNIQUES

- These techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. They promote higher heat transfer coefficients by disturbing or altering the existing flow behavior (except for extended surfaces) which also leads to increase in the pressure drop. In case of extended surfaces, effective heat transfer area on the side of the extended surface is increased. Passive techniques hold the advantage over the active techniques as they do not require any direct input of external power. These techniques do not require any direct input of external power; rather they use it from the system itself which ultimately leads to an increase in fluid pressure drop.

- Rough surfaces: These are the surface modifications that promote turbulence in the flow field in the wall region, primarily in single phase flows, without increase in heat transfer surface area.
- Extended surfaces: They provide effective heat transfer enlargement. The newer developments have led to modified finned surfaces that also tend to improve the heat transfer coefficients by disturbing the flow field in addition to increasing the surface area.
- Displaced enhancement devices: These are the inserts that are used primarily in confined forced convection, and they improve energy transport indirectly at the heat exchange surface by displacing the fluid from the heated or cooled surface of the duct with bulk fluid from the core flow.
- Swirl flow devices: They produce and superimpose swirl flow or secondary recirculation on the axial flow in a channel. These include helical strip or cored screw type tube inserts, twisted tapes. They can be used for single phase and two-phase flows..

1.2 ACTIVE TECHNIQUES

These techniques are more complex from the use and design point of view as the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer. It finds limited application because of the need of external power in many practical applications. In comparison to the passive techniques, these techniques have not shown much potential as it is difficult to provide external power input in many cases.

In these cases, external power is used to facilitate the desired flow modification and the concomitant improvement in the rate of heat transfer. Augmentation of heat transfer by this method can be achieved by:

- Mechanical Aids: Such instruments stir the fluid by mechanical means or by rotating the surface. These include rotating tube heat exchangers and scrapped surface heat and mass exchangers.
- Surface vibration: They have been applied in single phase flows to obtain higher heat transfer coefficients.
- Fluid vibration: These are primarily used in single phase flows and are considered to be perhaps the most practical type of vibration enhancement technique.
- Electrostatic fields: It can be in the form of electric or magnetic fields or a combination of the two from dc or ac sources, which can be applied in heat exchange systems involving dielectric fluids. Depending on the application, it can also produce greater bulk mixing and induce forced convection or electromagnetic pumping to enhance heat transfer

1.3 MECHANISMS OF AUGMENTATION OF HEAT TRANSFER

To the best knowledge of the authors, the mechanisms of heat transfer enhancement can be at least one of the following.

1. Use of a secondary heat transfer surface.
2. Disruption of the unenhanced fluid velocity.
3. Disruption of the laminar sub layer in the turbulent boundary layer.
4. Introducing secondary flows.
5. Promoting boundary-layer separation.
6. Promoting flow attachment/reattachment.

II OBJECTIVE

Heat transfer can also be enhanced by using rotating inserts in a round tube. These rotating insert acts as a swirl generator. The use of the swirl generator is expected to create the tangential velocity or swirling flow to prolong residence time of the flow and to enhance the tangential and radial fluctuation, therefore leading to increase in heat transfer inside the test tube. The objectives of this work are to:

1. Compare the heat transfer rate (Nu) with respect to plane tube.
2. Compare the friction losses or pressure drop with respect to plane tube.
3. Find out the enhancement efficiency.

III EXPERIMENTAL SETUP (DETAIL OF TECHNOLOGY)

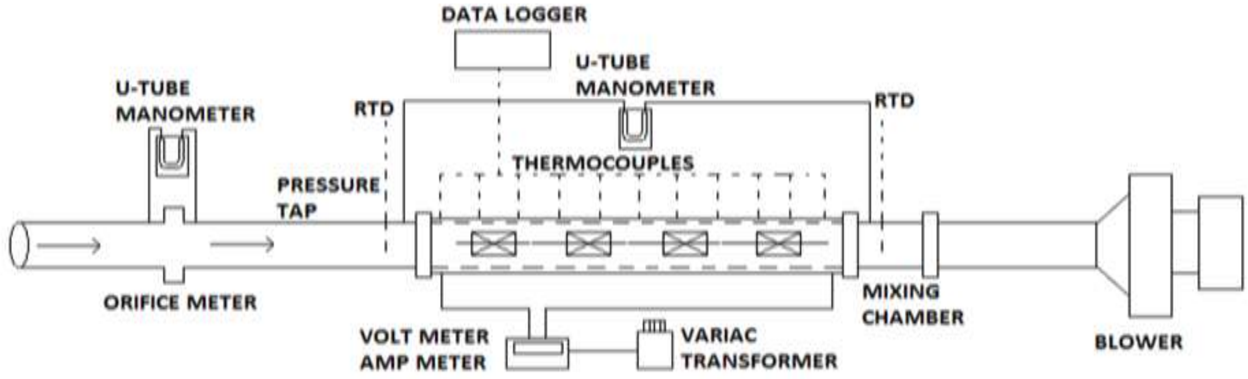

Fig 2 Experimental Setup Block Diagram

Fig 3 Experimental Setup

3.1 INSTRUMENTATION

- Heater:

The test tube will be heated by a flexible electrical wire continuously wounding around the tube to provide a uniform heat flux. The electrical output power is controlled by a Variac Transformer to obtain a constant heat flux along the entire length of the test section and keeping the current constant.

- Inclined U tube Manometer:

An inclined U tube manometer is used for following purposes:

1- For the measurement of pressure drop across the orifice plate. So Discharge can be calculated.

2- For the measurement of pressure drop across the test section. So friction factor can be calculated.

- Micro Voltmeter:

Micro Voltmeter is an electronic device used to measure low DC voltage. It is used for measuring voltage produced in thermocouple generated due to See back effect.

3.2 DATA REDUCTIONS

1. Mean bulk air temperature (Tb):

It is the average temperature of air at inlet and exit of the test section.

$T_b = (T_i + T_o)/2$

Here, T_i = Inlet temperature of air

T_o = Outlet temperature of air

2. Mean Temperature of tube wall (Tw):

This is the average of all the wall temperatures, measured by attaching the thermocouples on the wall at equal distance.

$$T_w = (T1 + T2 + T3 + T4 + ... + Tn)/n$$

Here n= No. Of thermocouples

3. Mass flow rate (m):

Mass flow rate can be find out by using Orifice meter Mass flow rate can be find out by using Orifice meter.

$m = C_d \; X \; A_o \; X \; [2p\,(\Delta P)/(1 - \beta 4)]0.5$

where,

$\beta = d2/d1$

Cd = coefficient of discharge of orifice meter i.e. 0.62

A_o = Area of orifice plate, m2

P = density of air in kg/m3

4. Velocity of air:

$$V = m/\rho A1$$

5. Reynold Number:

$$Re = \rho VD/\mu$$

Here D= Hydraulic mean Diameter.

μ = Dynamic Viscosity of air.

6. Sensible heat gained by air (Qa):

$Q_a = mC_{pa}(T_o - T_i) = VI$

Here C_{pa} = Sp. Heat of air at constant Pressure

7. Convective heat transfer from the test section (Q_{conv}):

$Q_{conv} = hA(T_w - T_b)$

Here h = Convective heat transfer Coefficient (W/m^2K)

A= Tube surface area (m^2)

8. Convective heat transfer coefficient (h):

Convective heat transfer coefficient can be calculated as

$Q_a = Q_{conv}$

So $mC_{pa}(T_o - T_i) = hA(T_w - T_b)$

$h = mC_{pa}(T_o - T_i)/A(T_w - T_b)$

9. Nusselt Number:

$Nu = hD/K$

Here K = Thermal Conductivity of air

10. Friction Factor (f):

$$f = \frac{\Delta P}{\left(\frac{L}{D}\right)\left(\frac{\rho V^2}{2}\right)}$$

11. Thermal Performance factor (TPF) :

$$TPF = \frac{\left(\frac{Nu}{Nu_0}\right)}{\left(\frac{f}{f_0}\right)^{\frac{1}{3}}}$$

Here Nu, f, Nu_0 and f_0 are the Nusselt numbers and friction factors for a tube configuration with and without inserts respectively.

IV EXPERIMENTAL RESULTS AND VALIDATION

The Nusselt number and friction factor determined from plain tube are compared with Dittus Boelter correlations and Blasius correlations.

4.1 Heat transfer:

The Nusselt number obtained from plane tube will be validated by Dittus Boelter correlations. This correlation is valid for Reynolds number more than 10000 and in our experiment Reynolds number is also more than 10000. This correlation can be expressed as:

$Nu = 0.023\ Re^{0.8}\ Pr^n$

For Heating n =0.4

For cooling n = 0.3

Our experiment is carried out in heating mode so we will take n = 0.4 and finally correlation for our experiment will be

$Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$

Re	'h' obtained by Dittus Boelter correlations	'h' obtained by experiment
19034.4	14.48	13.4664
31083.21	21.43	19.92
37536.3	24.93	23.43
40128.25	26.299	24.13
49959.27	31.3385	29.173

Table 1 Confirmatory Test of Plain Tube for 'h'

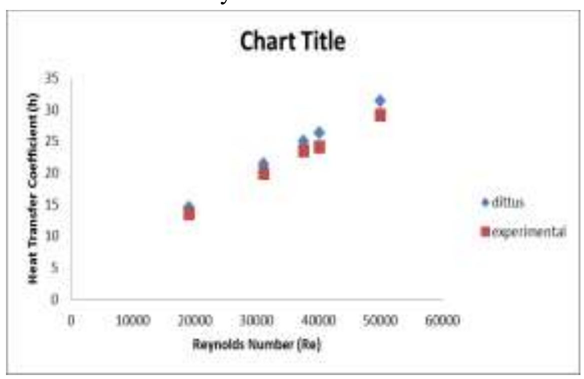

Fig 4 Confirmatory Test of Plain Tube for 'h'

4.2 Friction Factor:

The friction factor obtained from plane tube will be validated by Blasius correlations. This correlation can be expressed as

$f = 0.316\ Re^{-0.25}$

Re	'f' obtained by correlations	'f' obtained by experiment
19034.4	0.026903	0.023674
31083.21	0.023799	0.021349
37536.3	0.022703	0.020495
40128.25	0.022326	0.019214
49959.27	0.021136	0.018181

Table 2 Confirmatory Test of Plain Tube for 'f'

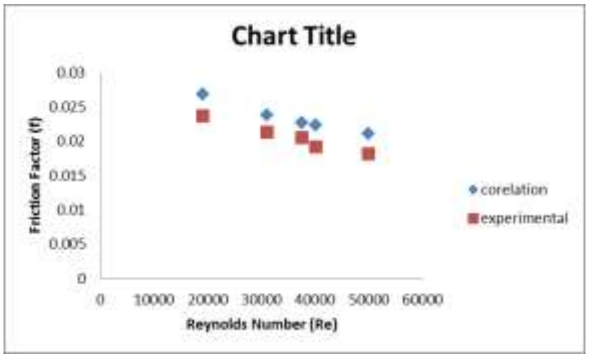

Fig 5 Confirmatory Test of Plain Tube for 'f'

4.3 CALIBRATION OF THERMOCUPLES:

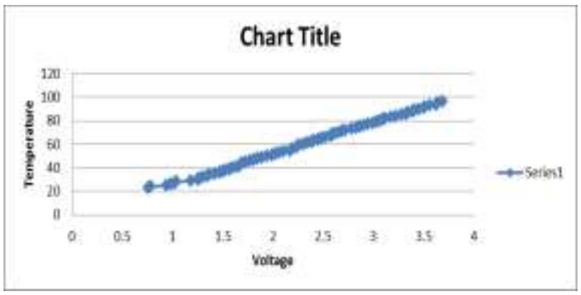

Fig 6

Equation will be T = 26.38V-0.998

V RESULTS AND DISCUSSION

Figure shows the effect of pitch ratio. A tube equipped with rotating inserts has three pitch ratios i.e. 4,5 and 6. Pitch ratio is defined as the ratio of distance between two rotating inserts to the diameter of the rotating inserts. The higher heat transfer occurs with lowest pitch ratio than that of other pitch ratios. For the lowest pitch ratio stronger swirl flow will create. So turbulence intensity will be higher for lowest pitch ratio. This stronger swirl flow results in higher pressure drop because of more blockage of fluid. So a tube with lowest pitch ratio has higher friction factor than other pitch ratios.

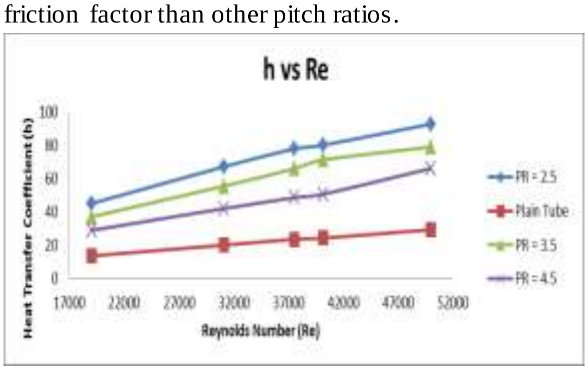

Fig 7 Results h vs Re

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