Experimental Analysis of Heat Transfer Enhancement through Pipe using Baffles

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Abstract: Energy saving plays a important role in industrial development as well as reducing environmental effect. The necessity of energy saving is increasing because of the current energy prices. Reducing energy cost can be achieved by producing more resourceful devices. Heat exchangers are the most important apparatuses in the refrigeration, automotives, chemical and process industries.So there is a need for the cost effective, more efficient and compact heat exchanger in the industrial market.In passive heat transfer enhancement strategy the use of inserts in channel is commonly used. Considering the rise in energy demand, effective heat transfer enhancement techniques have become important task . The present paper is a detail study of experimentation carried out and and calculations based on that experimentation.According to recent studies inserts are known to be economic heat transfer augmentation tools.

***Index Term* - Baffle, heat transfer enhancement, Inserts, Augmentation.**

1. INTRODUCTION

Energy and materials saving considerations, as well as economic incentives, have led to efforts to produce more efficient heat exchange equipment. Common thermohydraulic goals are to reduce the size of a heat exchanger required for a specified heat duty, to upgrade the capacity of an existing heat exchanger, to reduce the approach temperature difference for the process streams, or to reduce the pumping power [4]. 'The study of improved heat transfer performance is referred to as heat transfer augmentation, enhancement, or intensification. In general, this means an increase in heat transfer coefficient. Heat exchangers have several industrial and engineering applications. Techniques for heat transfer augmentation are relevant to several engineering applications. In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment [2]. Furthermore, as a heat exchanger becomes older, the resistance to heat transfer increases owing to fouling or scaling. These problems are more common for heat exchangers used in marine applications and in chemical industries. In some specific applications, such as heat exchangers dealing with fluids of low thermal conductivity (gases and oils) and desalination plants, there is a need to increase the heat transfer rate. The heat transfer rate can be improved by introducing a disturbance in the fluid flow (breaking the viscous and thermal boundary layers), but in the process pumping power may increase significantly and ultimately the pumping cost becomes high [9]. Therefore, to achieve a desired heat transfer rate in an existing heat exchanger at an economic pumping power, several techniques have been proposed in recent years.

Heat transfer enhancement techniques are broadly classified into three major groups [11]:

a) Active method: In this method some external power input for the enhancement of heat transfer is required few examples of active method include induced pulsation by cams and reciprocating plunger, use of magnetic field to disturb the seeded light particle in a flowing stream, etc.

b) Passive method: In passive heat transfer method no external power input is needed. Few example of this method are rough surfaces, inserts, etc.

c) Compound method: The combination of above two mentioned methods is the compound method.

1.1 Passive heat transfer techniques

In conventional cooling method that are based on forced convection one way to enhance heat transfer is by increasing the effective surface area and residence time of the heat transfer fluid. Passive heat transfer method uses surface or the geometrical modification to the flow channel by incorporating inserts or additional devices. Due to this geometrical modification most of the turbulence enhancement and boundary layer break down are localized near the heat transfer surface and consequently heat transfer coefficient in the existing system is increased. The following methods are generally used [2].

1.1.1 Ribs

Placing ribs periodically on the heat transfer surface increases the turbulence and since these ribs are small they do not disturb the core flow hence a high heat transfer performing surface could be achieved without incurring the penalties of frication and pressure drop [5].

1.1.2 Extended surfaces

Use of heat sink such as fins increases the surface area in contact with the coolant. These extended dissipation area are widely recognized to improve the heat transfer. Various examples are plain fin, wavy fin, louvered fin, offset-strip fin, etc [3].

1.1.3 Twisted tapes and wire coils

Twisted tapes are metallic strips twisted in some ratio known as twist ratio, inserted in the flow.

Wire coil inserts are made by tightly wrapping a coil of spring wire on a rod. When the coil spring is pulled up the wires forms a helical roughness [3].

1.1.4 Surface modification

This section includes such surface which has fin scales or coating which may be continuous or discontinuous. It also includes rough surfaces which promotes turbulence in the flow field[13] .

1.1.5 Impingement cooling

It involves high velocity jet to cool directly the surface of inserts. It also involves the direction of heating or cooling fluid perpendicularly or obliquely to the heat transfer surface [15].

1.1.6 Additives

These include addition of solid particles, liquid droplets, gas bubbles, etc which are introduced in single phase flow. Additive for gas is introduced as a dilute phase (gas-solid suspension) or as dense phase (fluidized bed).

Liquid additives usually depress the surface tension of liquids for boiling system [11].

1.1.7 Baffles

Inserting baffles into the heat transfer devices promote mixing of coolants. These baffles can significantly disturb the bulk flow [11].

Use of baffles[11]

The main roles of a baffle in a heat exchanger are,

- To prevent the effect of vibration which is increased with both fluid velocity and the length of exchangers.
- To increase the heat transfer area.
- To promote mixing in static mixture in a chemical reactor, baffles are often attached to interior walls to promote mixing and thus increase heat transfer and chemical reaction rates.
- To increase the stiffness of the system.

2. LITERATURE REVIEW

After reviewing lots of research work, it may be concluded that heat transfer rate is more in case of inserts as compared to without inserts. And in some cases it is double of that of without inserts. This increment is depends on the type of the inserts, orientation of the inserts and specification of the inserts.

It may be concluded that as the Reynolds number increases heat transfer rate is increases and hence heat transfer coefficient is also increase. But with the increase in Reynolds number, there is also an increase in friction factor. It may be also concluded that, if the baffles are used as an inserts then heat transfer enhancement is increases as the baffle height increases.

Step To Be Followed:

- Finalization of the geometry of the flow channel.
- Calculation for the critical mass flow rate.
- Finalization of the geometry of the baffles.
- Determination of the actual mass flow rate for the experimentation.
- Calculation for the theoretical mass flow and heat transfer rate.
- Finalizations of all component required for the experimentation.
- Calculation for heat transfer rate, efficiency of the system and effectiveness of the system.

3. PROBLEM FORMULATION

Successful execution of the experimentation is possible only when the initial reading selection is proper. For the selection of proper mass flow rate, one have to find out the critical mass flow rate, from which mass flow rate selection for the project is easier.

Calculation for critical mass flow rate:

Critical Reynolds number = 2300 (for turbulent flow)

$\therefore$ Re $=\frac{4m}{\mu\pi d}$

$\therefore$ $2300=\frac{4m}{\mu\pi d}$

$\therefore m = 2300\times \mu\pi d/4$

P = 985 kg/m^3

υ = 0.478 × 10^{-6} m^2/s

$\therefore 2300 = \frac{4m}{\rho \times \upsilon \times \pi \times d}$

$\therefore 2300 = \frac{4m}{985 \times 0.478 \times 10-6 \times \pi \times 0.04}$

$\therefore m = 0.003\ kg/s$

After reviewing all the literature following assumptions have been made for the formulation of the experimental set up.

- Steady state heat transfer;
- Fully developed turbulent flow;
- Uniform mass flow rate;
- Uniform mass of cooling medium.

Let,

Length of the rod=1 meter

Diameter of the rod=40 mm

Thickness of the rod=1 mm

Inlet temperature of water= 76^0 C

Outlet temperature of water without baffles=75.1^0C

Outlet temperature of water with baffles=65.9^0C

Mass flow rate of water=0.076 kg/s

Consider a simple cross flow arrangement for a copper rod of length 1 meter, thickness 1 mm and diameter 40 mm. Hot water is flowing through the rod with a mass flow rate of 0.076 kg/sec at a temperature of 76^0 C and leaves the rod at a temperature of 75.1^0C.Surface Temperatures are 64.5,63.1,62.7. Then baffles are inserted in the same rod and hot water flows through the rod at the same mass flow rate and initial temperature. After insertion of baffles water outlet temperature is reduces to 65.9^0C and the surface temperatures are 58.9, 56.2, 53.9 . Find the heat transfer rate with baffles and without baffles.

Area of rod=0.126m^2

Calculations for heat transfer rate without baffles:

Bulk mean temperature=75.55^0C

Reynolds Number,

Re=4m/μπd

$= \frac{4 \times 0.076}{0.000378 \times 3.14 \times 0.04}$

=6399

As Re>2300, therefor flow is turbulent.

Prandtl Number,

$Pr = \frac{\mu Cp}{K}$

= 378×10^{-6}×4.186/(0.6643)

= 2.381

As the flow is turbulent, By using Dittus-Boelter Equation,

Nu = 0.023×$Re^{0.8}$×$Pr^{0.4}$

= 571

But, Nu = $h \times d \div K$

$\therefore h = Nu \times K \div d$

$\therefore h = 571 \times 0.6643 \div 0.04$

$\therefore h = 9.499\ W/m^2K$

Heat Transfer rate,

Q=$hA\Delta T$

$\therefore Q = 9.499 \times 0.126 \times (T_b - T_\infty)$

T_b=348.55K, T_∞=336.43K

$\therefore Q = 14.50$ W

This is the theoretical value of the heat transfer rate in case of without any inserts.

Calculations for heat transfer rate when baffles are used as an inserts:

Bulk mean temperature=70.95^0C (343.9K)

Reynolds Number,

Re = 4m/μπd

$= \frac{4\times0.076}{0.000404\times3.14\times0.04}$

= 5988

As Re>2300, therefor flow is turbulent.

Prandtl Number,

$Pr = \frac{\mu Cp}{K}$

$= 404\times10^{-6}\times4.186/(0.66)$

= 2.55

As the flow is turbulent, By using Dittus-Boelter Equation,

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

=558.16

But, Nu = $h \times d \div K$

$\therefore h = Nu \times K \div d$

$\therefore h = 558.16 \times 0.66 \div 0.04$

$\therefore h = 9.209 W/m^2K$

Heat Transfer rate,

$Q = hA\Delta T$

$\therefore Q = 9.209 \times 0.126 \times (T_b - T_\infty)$

Where, T_b=343.95K, T_∞=329K

$\therefore Q = 17.34W$

This is the theoretical value of the heat transfer rate when baffles are used as an inserts

4. BAFFLES

4.1 Baffle Geometry

Large number of baffle geometries has been proposed for the use in heat exchanger channel and more are still being developed

Common attributes of baffles are

i. Shape: Most of the baffles found in literature are square, rectangular, triangular, helical or wedge shaped in the present work rectangular baffles have been studied.

ii. Height: Small height baffles are preferred to minimize the pressure drop.

iii. Spacing: It is the distance between two consecutive baffles.

iv. Perforations: Perforations are the slots or holes in the baffles which causes less resistance against the stream and improve heat transfer and pressure drop over the channel.

v. Porosity: Porous medium can be defined as a material consisting of a solid matrix with an interconnected void. Due to its structural stiffness and light weight, it can be used for thermal management in aerospace applications. [10]

4.2 Baffle Orientation

Baffle orientation plays a crucial role to enhance the heat transfer within the channel without incurring the penalties of friction and pressure drop that are severe enough to negate the benefits of heat transfer augmentation. Baffles should be oriented in such a way that it will produce the proper turbulence in the flow so that heat transfer rate will increase but at the same time care should taken so that there will not be the more increment in the friction factor.

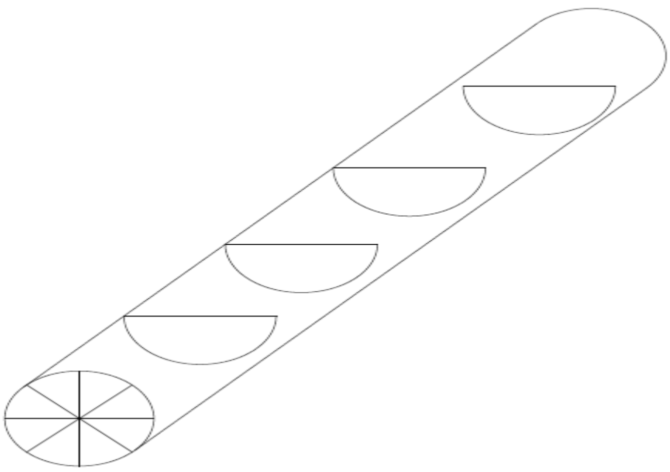


Fig.4.1 Schematic of half circle baffled tube

The above figure shows the schematic of the half circle baffled tube, in which baffles are oriented at the angle of 90^0. Baffles are semicircular in shape and attach to the bottom of the copper [6].

5. EXPERIMENTAL SETUP

Experimental set up required for the experimentation is consists of following elements:

- copper rod
- Water circulating tube
- Heater
- Manometer
- thermocouples
- water tank,
- pump
- valves and
- piping element.

Schematic of the experimental set up is given below-

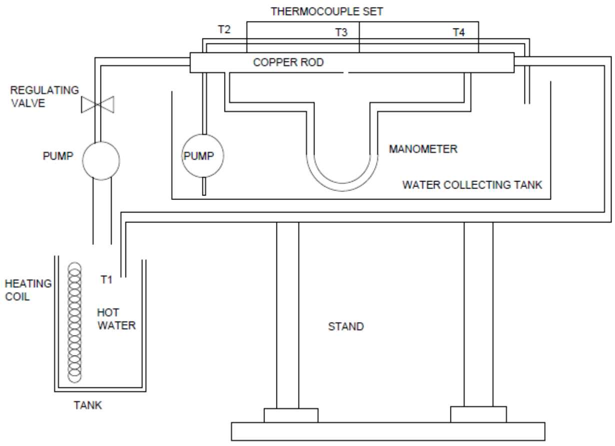


Fig.5.1 Schematic of Experimental set up

Specification of the each element included in the schematic of the experimental set up is given below:

Copper rod:

- Length of the rod =1 meter
- Diameter of the rod=40 cm
- Thickness of rod=1 mm

Thermocouple:

- No of thermocouples used=6
- Position of Thermocouples:
  One thermocouple is used to measure the inlet temperature of the hot water entering into the copper rod.
  Three thermocouples are placed on outer surface of copper rod at equidistance position.
  One thermocouple is used to measure the outlet temperature of the hot water coming out from the copper rod.
- Water regulating valve:
  Water regulating valve is placed at inlet position of copper rod to regulate the flow of hot water.
- Heater:
  Electric emmersion water heater
  Capacity-1500 W(230 volt,AC,50 Hz)
  Position of the heater: Heating coil is placed in the water tank to heat the water.
- Water Tank:
  Length of the tank = 1 meter
  Height of the tank = 20 cm

6. METHODOLOGY

The arrangement of set up is simply a cross flow heat exchanger. In which hot water is flowing through the copper rod and cold water is circulated through the pipe fitted on the upward side of the copper rod, this pipe is having holes at equidistance position of 2 mm.

Initially water is heated in a water tank up to the temperature of 50 to 55^{o}C. This hot water is circulated through the copper rod by using water pump. Before sending the water through the pump, temperature of the hot water was noted. While passing the water through the copper rod it transfers it's heat to the rod, due to which temperature of rod increases. This increase in temperature of the rod was measured at three equidistance position on the copper rod. Outlet temperature of water coming out from the rod was also measured.

Two valves are fitted at inlet and outlet position of copper rod.

Photo. 6.1 Experimental set up

Readings are taken by considering two cases:

1) Without baffles
2) With baffles

Mass flow rate of water is regulated by using the valves fitted at the inlet and outlet position of copper rod. Mass flow rate is measured manually by measuring the time required to collect the one liter of water. This mass flow rate is changed by changing the flow rate by using the valves.

Three mass flow rates are used for comparision. Readings are taken without baffles using the three mass flow rates. Then baffles with different orientations are inserted. While taking the readings in case of baffles, readings are taken by taking the angles of baffles such as 30^{0},60^{0} and 90^{0}.

Readings are taken by taking the mass flow rates such as 0.05 kg/sec, 0.06 kg/sec,0.07kg/sec.

Readings are teken in twelve sets such as by keeping the mass flow rate constant and changing the angles. Initially readings are taken for mass flow rate of 0.05 kg/sec and angle 30^{0},then for the same mass flow rate, readings are taken by changing the angles such as 60^{0} and 90$^{0.}$.Same set of readings are obtained by changing the mass flow rate.

7. EXPERIMENTATION AND EVALUATION

After completion of the experimental procedure the following readings have been taken. In Which T_i is the inlet temperature of the hot water, T_o is the outlet temperature of the hot water, Ts_1, Ts_2 and Ts_3 are the surface temperature of the copper rod and T_w is the temperature of the cold water. All the temperatures are in ^{0}C. For each case readings are taken for ten to fifteen times. Initially readings have taken without baffles for different mass flow rate such as 0.071,0.06 and 0.05 kg/s. Then readings have taken using baffles for different mass flow rates and by changing the orientation of baffles for each mass flow rate. After completion of performance a calculations have been done using following analytical treatment.

Analytical Treatment:

Bulk mean temperature,

$T_b = \frac{T_i+T_o}{2}$

Reynolds Number,

$Re = \frac{4m}{\mu\pi d}$

If Re>2300,Then flow is turbulent.

Prandtl Number,

$Pr = \frac{\mu Cp}{K}$

If the flow is turbulent, then by using Dittus-Boelter Equation,

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

But, $Nu= \frac{h\times d}{K}$

$\therefore h = \frac{Nu \times K}{d}$

Heat Transfer rate,

$Q = hA\Delta T$

$Where\ \Delta T = (T_b - T_\infty)$

$T_\infty = \frac{(T_{S_1} + T_{S_2} + T_{S_3})}{3} =$

This is the actual amount of heat transfer,

$\therefore Q_{act} =$

$\therefore$ Efficiency $= \frac{Q_{act}}{Q_{th}}$

Effectiveness of the system

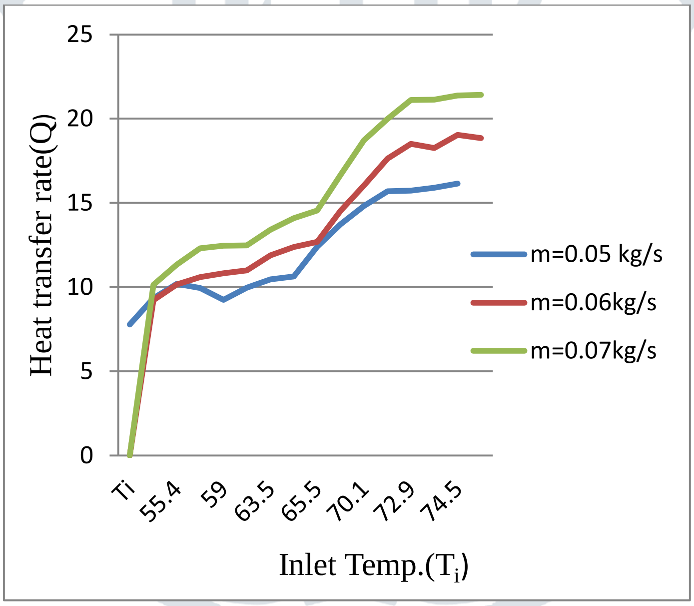
$$\epsilon = \frac{Q_{act}}{Q_{max}} = \frac{T_i - T_o}{T_i - T_w}$$

8 RESULTS AND DISCUSSION

After completion of the experimentation all the readings are note down and calculations regarding all the readings have been completed and comparative graphs related to the calculation are plotted in the following pages.

8.1 Q Vs T_i when baffles are oriented at an angle30^0

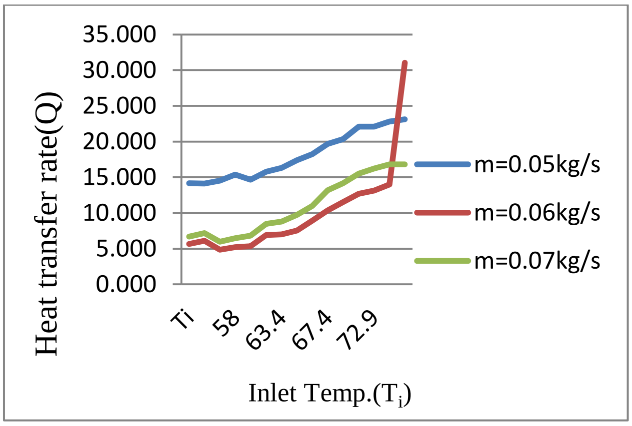
The following graph shows the variation of heat transfer rate with respect to the inlet temperature of the hot water when mass flow rate is varying from 0.05 kg/s to 0.07 kg/sec and baffles are oriented at an angle of 30^0.



Graph 8.1 Q Vs T_i for different mass flow rate when baffles are oriented at 30^o

8.2 Q Vs T_i when baffles are oriented at an angle 60^0

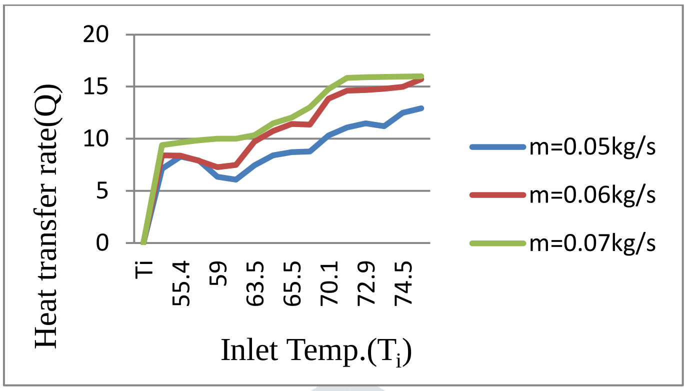
The following graph shows the variation of heat transfer rate with respect to the inlet temperature of the hot water when mass flow rate is varying from 0.05 kg/s to 0.07 kg/sec and baffles are oriented at an angle of 60^0.



Graph 8.2 Q Vs T_i at different mass flow rates when baffles oriented at 60^0

8.3 Q Vs T_i When baffles are oriented at 90^0

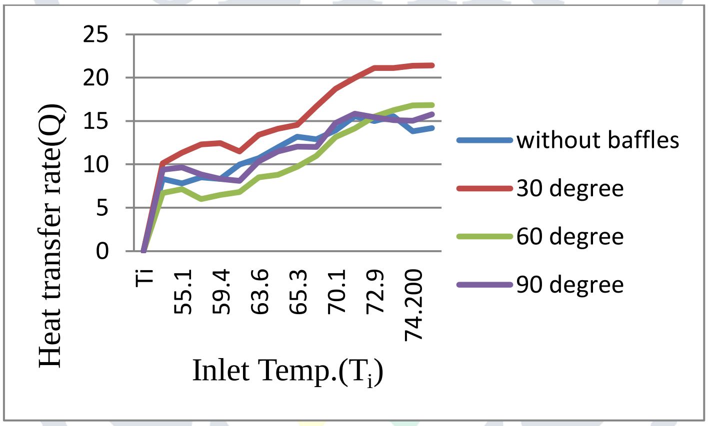
The following graph shows the variation of heat transfer rate with respect to the inlet temperature of the hot water when mass flow rate is varying from 0.05 kg/s to 0.07 kg/s and baffles are oriented at an angle of 90^0.



Graph 8.3 Q Vs T_i at different mass flow rate when baffles are oriented at angle 90^0

8.4 Q Vs T_i When mass flow rate of water is 0.07 kg/s

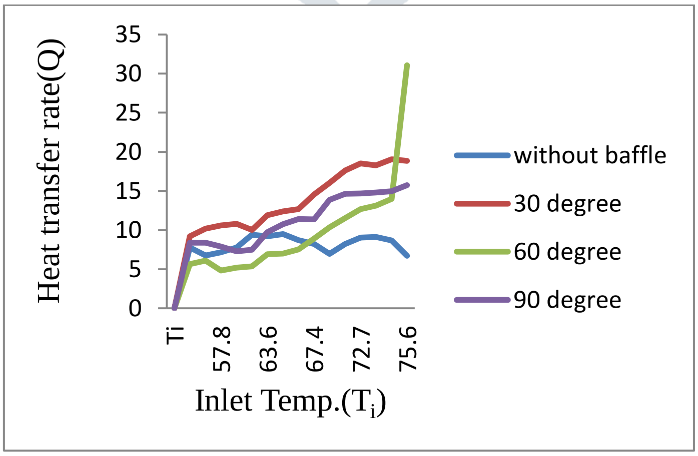
The following graph shows the variation of heat transfer rate with respect to the inlet temperature of the hot water when mass flow rate of hot water is 0.07 kg/s and angle of baffle is varying in between 30^0 to 90^0.



Graph 8.4 Q Vs T_i at different angles when mass flow rate is 0.07 kg/s

8.5 Q Vs T_i When mass flow rate is 0.06kg/s for different angles

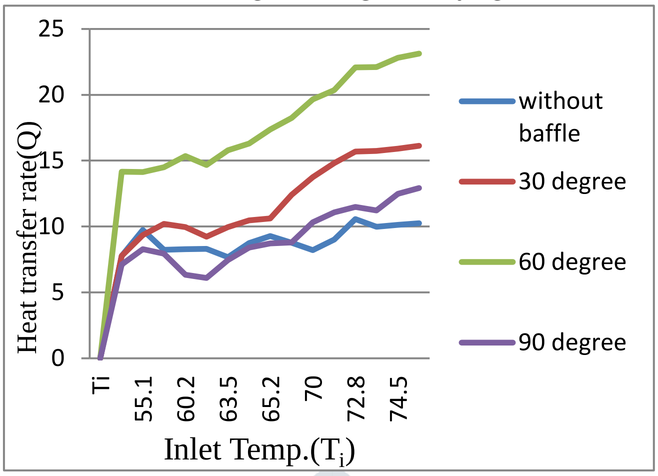
The following graph shows the variation of heat transfer rate with respect to the inlet temperature of the hot water when mass flow rate of hot water is 0.06 kg/s and angle of baffle is varying in between 30^0 to 90^0.



Graph 8.5 Q Vs T_i at different angles when mass flow rate is 0.06 kg/s

8.6 Q Vs T_i When mass flow rate is 0.05 kg/s for different angles

The following graph shows the variation of heat transfer rate with respect to the inlet temperature of the hot water when mass flow rate of hot water is 0.05 kg/s and angle is varying in between 30^0 to 90



Graph 8.6 Q Vs T_i at different angles when mass flow rate is 0.05 kg/sec

9 CONCLUSIONS AND FUTURE SCOPE

9.1 Conclusions:

Experimental investigations have been conducted on the circular copper tube and after the successful execution of the experimentation one may conclude that when inlet conditions are same, heat transfer rate is more when water flows through the tube with a mass flow rate of 0.05 kg/sec and baffles are placed at an angle of 60^0.As compared to the other cases efficiency is also maximum when baffle angle is 60^0 and mass flow rate is 0.05 kg/sec. As compared to the other cases effectiveness of the system is also greater in the case where water is flowing with mass flow rate 0.05 kg/s and baffles orientation is 60^0.

As the Reynolds's number increases, higher heat transfer rates are observed regardless of the position of the baffles.

From these results it can be also concluded that system is more effective in case of inserts as compaired to the case of without inserts.

9.2 Future Scope:

- In this project baffles are used as a inserts to increase the heat transfer coefficient, in future there is a scope to use the other different types of inserts such as conical rings, twisted tape, perforated baffles, baffles with notches etc., in the same trajectory.
- In present project water is used as a working medium, in future one can use air as well as a nano fluid as a working medium.
- In this project position of baffle is attached to the bottom of the tube instead of this there is a scope to change the position of the baffles, such as baffle can also be attaches on the top of the tube as well as in the alternate position.
- In this project a circular trajectory is used for the experimentation, one can use the rectangular section also to increase the heat transfer rate.

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