1. INTRODUCTION

1.1 INTRODUCTION

Energy and materials saving considerations, as well as economic incentives, have led to efforts to produce more efficient heat exchange equipment. Common thermo hydraulic 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.

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. Attempts to increase "normal" heat transfer coefficients have been recorded for more than a century, and there is a large store of information. A survey [Bergles et al. (1991)] cites 4345 technical publications, excluding patents and manufacturers' literature. The recent growth of activity in this area is clearly evident from the yearly distribution of the publications presented in Figure 1.
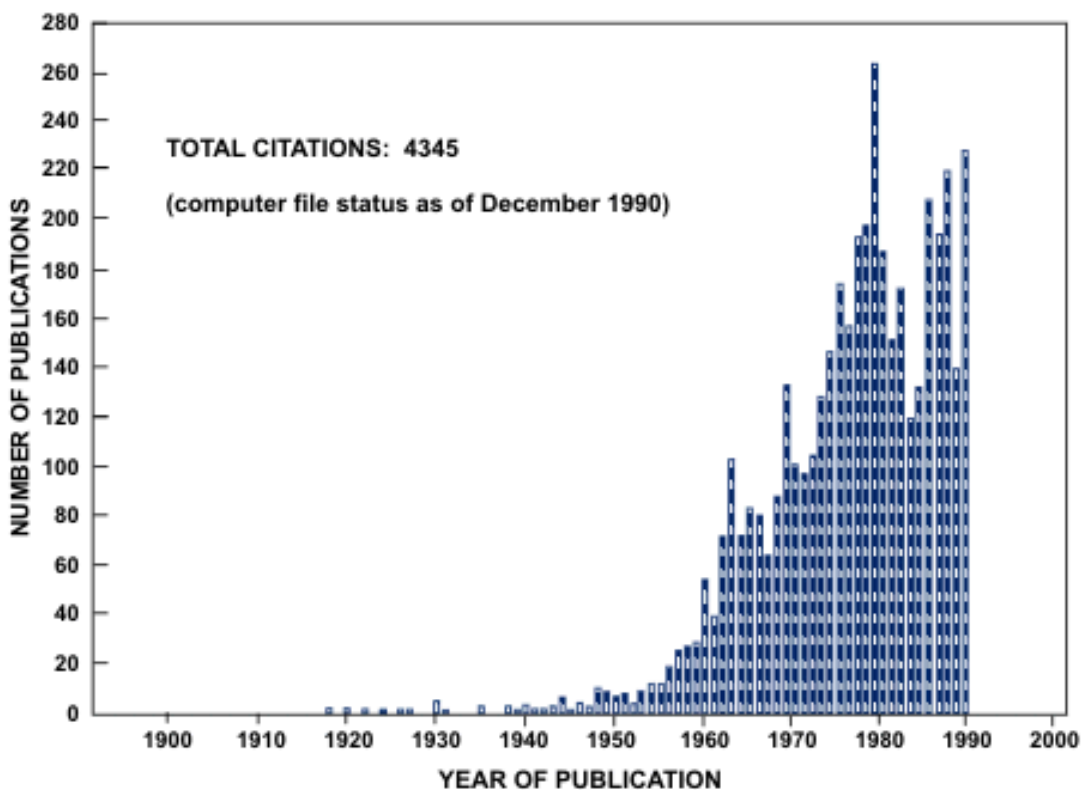

Figure 1.1.1 Statistical Data

Heat transfer enhancement is the process of increasing the effectiveness of heat exchangers. This can be achieved when the heat transfer power of a given device is increased or when the pressure losses generated by the device are reduced. A variety of techniques can be applied to this effect, including generating strong secondary flows or increasing boundary layer turbulence.

Heat transfer augmentation techniques (passive, active or a combination of passive and active 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 augment 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).In the past decade, several studies on the passive techniques of heat transfer augmentation have been reported. The present study is review on progress with the passive augmentation techniques in the recent past and will be useful to designers implementing passive augmentation techniques in heat exchange. Twisted tapes, wire coils, ribs, fins, dimples, etc., are the most commonly used passive heat transfer augmentation tools. The study, emphasis is given to works dealing with twisted tapes and streamlined body because, according to recent studies, these are known to be economic heat transfer augmentation tools. The former insert is found to be suitable in a laminar flow regime and the latter is suitable for turbulent flow. The thermo hydraulic behavior of an insert mainly depends on the flow conditions (laminar or turbulent) apart from the insert configurations. The present review is organized in five different sections: twisted tape in laminar flow; twisted tape in turbulent flow; wire coil in laminar flow; wire coil in turbulent flow; other inserts such as ribs, fins, dimples, etc.

1.2 CLASSIFICATION OF AUGMENTATION TECHNIQUES

Generally, heat transfer augmentation techniques are classified in three broad categories:

- Active method
- passive method
- compound method

The active and passive methods are described with examples in the following subsections. A compound method is a hybrid method in which both active and passive methods are used in combination. The compound method involves complex design and hence has limited applications.

1.2.1 Active Method

This method involves some external power input for the enhancement of heat transfer and has not shown much potential owing to complexity in design. Furthermore, external power is not easy to provide in several applications. Some examples of active methods are induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, etc.

Examples of active enhancement methods are:

- Mechanical aids
- Surface vibrations
- Fluid vibration
- Electrostatic fields (DC or AC)

1.2.2 *Passive Method*

This method does not need any external power input and the additional power needed to enhance the heat transfer is taken from the available power in the system, which ultimately leads to a fluid pressure drop. The heat exchanger industry has been striving for improved thermal contact(enhanced heat transfer coefficient) and reduced pumping power in order to improve the thermo hydraulic efficiency of heat exchangers. A good heat exchanger design should have an efficient thermodynamic performance, i.e. minimum generation of entropy or minimum destruction of available work (energy) in a system incorporating a heat exchanger.

It is almost impossible to stop energy loss completely, but it can be minimized through an efficient design.

Examples of passive enhancing methods are:

 - Treated surfaces,
 - Rough surfaces,
 - Extended surfaces,
 - Displaced enhancement devices,
 - Swirl flow devices,
 - Coiled tubes,
 - Surface tension devices,
 - Additives for fluids, and many others.

1.2.3 *Compound Method*

A compound augmentation technique is the one where more than one of the above mentioned techniques is used in combination with the purpose of further improving the thermo-hydraulic performance of a heat exchanger. This method, involves more complex design and hence has limited applications.

1.3 OBJECTIVES

The main objective of this investigation is to study the performance of multiple twisted tape inserts and streamlined body in tubular heat exchanger. The proposed work includes the determination of:

➢ Overall heat transfer coefficient of air with/without twisted tape and streamlined body inserts.

➢ The effect of twisted tape and streamlined body inserts on the overall heat transfer coefficient.

➢ The effect of twisted tape and streamlined body inserts on frictional pressure loss.

➢ Effect of Reynolds number on Thermal performance factor.

➢ Effect of Nusselt number and Reynolds number on the heat transfer coefficient.

➢ Deciding the feasibility of twisted tape and streamlined body inserts with and without nano fluid for enhancing the heat transfer rate.

1.4 NEED FOR HEAT TRANSFER AUGMENTATION

➢ To make the equipment compact

➢ To achieve high heat transfer rate using minimum pumping power

➢ Minimize the cost of energy and material

➢ A need for miniaturization of a heat exchanger in specific applications

➢ Increase efficiency of process & system

➢ Design optimization of heat exchanger

➢ Transfer required amount of heat with high efficiency

➢ Reduce the volume and weight

➢ For given temperature difference improve heat transfer

➢ Effective utilization of energy and minimum operating cost

1.5 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.
7. Enhancing effective thermal conductivity of the fluid under static conditions.
8. Enhancing effective thermal conductivity of the fluid under dynamic conditions.
9. Delaying the boundary layer development.
10. Thermal dispersion.
11. Increasing the order of the fluid molecules.
12. Redistribution of the flow.
13. Modification of radioactive property of the convective medium.
14. Increasing the difference between the surface and fluid temperatures.
15. Increasing fluid flow rate passively.
16. Increasing the thermal conductivity of the solid phase using special nanotechnology fabrications.
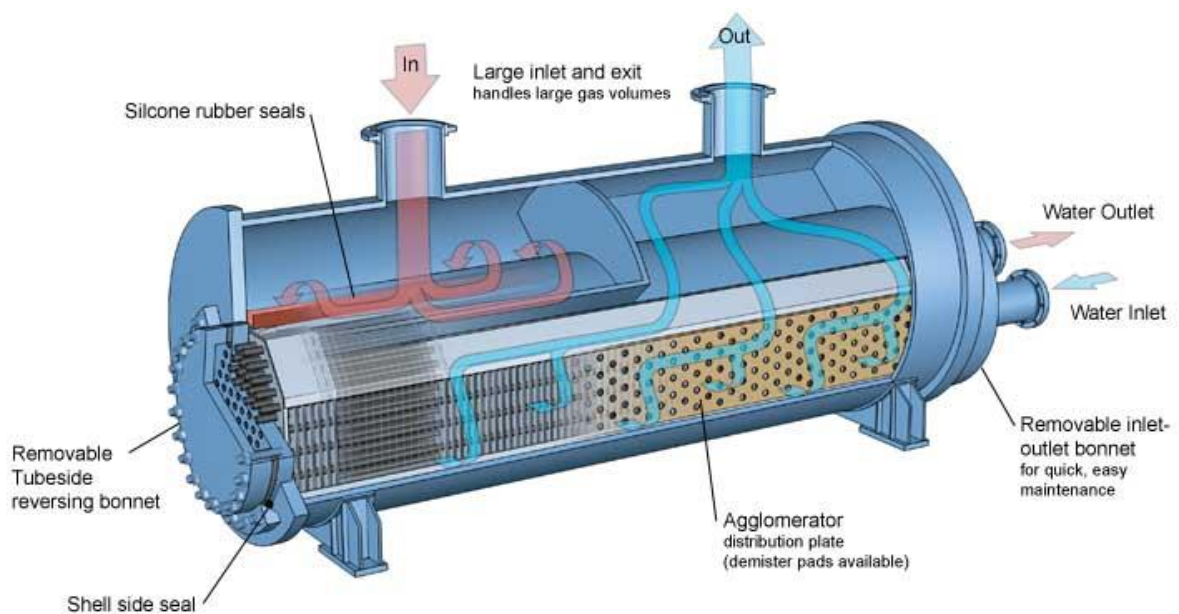
1.6 HEAT TRANSFER ENHANCERS

From the concise summary about mechanisms of enhancing heat transfer described in last section, it can be concluded that these mechanisms cannot be achieved without the presence of the enhancing elements. These elements will be called as "heat transfer enhancers". In this report, the following heat transfer enhancers will be explained:

1. Extended surfaces (Fins);
2. Porous media;
3. Large particles suspensions
4. Nano fluids
5. Phase change devices
6. Flexible seals
7. Flexible complex seals
8. Vortex generators
9. Protrusions
10. Ultra high thermal conductivity composite materials.

1.7 HEAT EXCHANGER

A heat exchanger is a device which is constructed to facilitate the heat transfer between one medium to another medium efficiently. The word "Exchanger" really applied to all types of equipment in which heat is exchanged but it is often used specially to the equipment in which heat is exchanged between two process streams that are at different temperature and are separated by a solid wall and where the two process fluid do not mix with each other. Heat exchanger is an important and expensive equipment that is used in almost all field of process such as food and dairy processes, waste heat recovery processes, air conditioning and refrigeration systems and also plants of oil, petrochemical, sugar, chemical reactors, pharmaceutical, power generation, etc.

Figure 1.7.1 Shell & Tube Heat Exchanger

Energy recovery is the prime requirement of today to optimize the energy consumption in industry. To achieve maximum utilization of thermal energy, several heat transfer enhancement techniques have been used in many thermal engineering applications such as nuclear reactor, chemical reactor, chemical process, automotive cooling, refrigeration, and heat exchanger, etc. Heat transfer enhancement techniques are powerful tools to increase heat transfer rate and thermal performance as well as to reduce the size of heat transfer system in installing and operating costs. Heat transfer enhancement in thermal systems can be carried out either by active or passive methods.

1.8 CLASSIFICATION OF HEAT EXCHANGER

1.8.1 According To Nature Of Transfer Process

- ➢ Direct Contact Type
- ➢ Indirect Contact Type
  - i. Regenerators
  - ii. Recuperators

1.8.2 According To Relative Direction Of Fluid Motion

- ➢ Parallel Flow Or Unidirectional Flow
- ➢ Counter Flow
- ➢ Cross Flow

1.8.3 According To Design And Constructional Features

- ➢ Concentric Tube
- ➢ Shell & Tube
- ➢ Multi Plate Shell & Tube
- ➢ Compact Heat Exchanger

1.8.4 According To Physical State Of Fluid

- ➢ Condensers
- ➢ Evaporators

1.9 LITERATURE REVIEW

Kreith F. et al. [1], they discussed about different techniques used to enhance the heat transfer. In that three method i.e. passive technique, active technique and compound technique for single phase forced are discussed in detail. In case of passive technique the turbulence promoters are inserted in a tube, the promoter produces a sizable elevation in the Nusselt no. Or heat transfer coefficient at constant Reynolds no. Or velocity. Also the correlations are recommended for tubes with transverse or helical repeated ribs with turbulent flow. Under active techniques, mechanically aided heat transfer in the form of surface scraping can increase forced convection heat transfer. Compound techniques are not practical but some of examples of Compound techniques are rough tube wall with twisted-tape inserts, rough cylinder with acoustic vibrations, internally finned tube with twisted-tape inserts, finned tubes in fluidized beds, externally finned tubes subjected to vibrations, rib-roughened passage being rotated.

Suhas V. Patilet et al. [2],this paper is a review of research work in last decade on heat transfer enhancement in a circular tube and square duct. In this paper emphasis is given to works dealing with twisted tape, screw tape inserts because according to the recent studies, these are known to be economic tool in the field of heat transfer enhancement.

Dr. Anirudh Gupta et al.[3],In this journal the Passive heat transfer techniques improved by the different researchers are discussed, which shows many researchers are taking interest to enhance heat transfer rate with passive methods. Dimple, protrude and rough surfaces etc passive methods are used in heat exchangers, air heaters and heat sinks to enhance heat transfer. Also heat transfer enhancement techniques are discussed in detail which includes passive, active and compound technique.

A Dewan et al. [4], has reviewed Techniques for heat transfer augmentation such as passive, active or a combination of passive and active methods which are relevant to several engineering applications. Heat transfer enhancement in a tube flow by inserts such as twisted tapes, wire coils, ribs and dimples is mainly due to flow blockage, partitioning of the flow and secondary flow. Also they summarized of important investigations of twisted tape in laminar flow in tabular format and summary of important investigations of twisted tape in turbulent flow in tabular form.

Sandeep S. Kore et al. [5], the experimental investigation has been carried out to study heat transfer and friction coefficient by dimpled surface. Using data from experiment heat transfer, friction factor and thermal performance characteristics of duct are discussed with respect to Nusselt no., Reynolds no. And their effects it is observed that Nusselt number increases with Reynolds number for dimpled surface as well as for smooth channel, but rate of increase is more for the dimpled surface as compared to smooth surface.

Arthur E. Burgles et al [6],focuses on characterization of twisted-tape-induced helical swirl flows for enhancement of forced convective heat transfer. A frequent usage is to retrofit existing heat exchangers in order to upgrade their heat load capacity. When twisted tapes are incorporated in the design of a new exchanger, then, for a specified heat duty and process application, significant size reduction can be achieved relative to that in a plain tubular exchanger. Structure and Scaling of Single-Phase Swirl Flow in that twisted tape induced swirl flow pattern & computational characteristics of swirl in circular tubes with twisted tape inserts with variation of Reynolds no. are studied. Heat transfer coefficient and friction factor correlations for both laminar and turbulent regimes are presented.

Joseph Cernecky et al.[7],the paper deals with visualization of temperature fields in the vicinity of profiled heat transfer surfaces and a subsequent analysis of local values of Nusselt numbers by forced air convection in an experimental channel. The effect of heat transfer area roughness on heat transfer enhancement by forced convection experiments were carried out at Re 462 up to 2338 at the distances between heat transfer surfaces of 0.025m and 0.035 m. Holographic Interferometer was used to Visualization of Temperature Fields.

Amruta A. Herle et al.[8]. Whenever inserts are used for the heat transfer enhancement, along with the increase in the heat transfer rate, the pressure drop also increases. This increase in pressure drop increases the pumping cost. Therefore any augmentation device should optimize between the benefits due to the increased heat transfer coefficient and the higher cost involved because of the increased frictional losses. Experimental work on heat transfer augmentation using annular blockages. Inserts when placed in the path of the flow of the fluid, create a high degree of turbulence resulting in an increase in the heat transfer rate and the pressure drop. The work includes the determination of friction factor and heat transfer coefficient for various annular blockages and annular blockages having different diameter. The results of annular blockages having different diameter have been compared with the values for the plain tube.

2. INSTRUMENTATION

2.1 CENTRIFUGAL BLOWERS

Figure 2.1.1 Centrifugal Blower

Centrifugal Blower Centrifugal blowers use high speed impellers or blades to impart velocity to air or other gases. They can be single or multi-stage units. Like fans, centrifugal blowers offer a number of blade orientations, including backward curved, forward curved, and radial. Blowers can be multi- or variable speed units. They are usually driven by electric motors, often through a belt and sheave arrangement, but some centrifugal blowers are directly coupled to drive motors. Fan speed can be changed to vary flow rates by resizing sheaves, using variable speed drives, etc., but dampers are even more common as a means of adjusting flow. Fan affinity laws dictate that a percent reduction in speed will produce a like reduction in flow.

Power	:	0.56 HP
Speed	:	2800 RPM
Voltage	:	230 Volts
Current	:	2 Amp
Phase	:	Single Phase
Energy	:	375 Watts

2.2 HEATER (Nichrome Coil Heater)

Nichrome (NiCr, nickel-chrome, chrome-nickel, etc.) generally refers to any alloy of nickel, chromium, and often iron and/or other elements or substances. Nichrome alloys are typically used in resistance wire.

A common alloy is 80% nickel and 20% chromium, by mass, but there are many others to accommodate various applications. It is silvery-grey in colour, is corrosion-resistant, and has a high melting point of about 1,400 °C (2,550 °F). Due to its resistance to oxidation and stability at high temperatures, it is widely used in electric heating elements, such as in appliances and tools. Typically, nichrome is wound in coils to a certain electrical resistance, and current is passed through it to produce heat.

Nichrome is used in a very wide variety of devices where electric heating is required. Almost any conductive wire can be used for heating, but most metals will be rapidly oxidized when heated in air. When heated to red hot temperatures, nichrome wire develops an outer layer of chromium oxide,[1] thermodynamically stable in air, mostly impervious to oxygen, and protects the heating element from further oxidation. Nichrome is used in the explosives and fireworks industry as a bridge wire in electric ignition systems, such as electric matches and model rocket igniters..

Figure 2.2.1 Nichrome Coil Heater

2.2.1 *Specification*

Voltage	:	230 Volts
Current	:	2 Amp
Phase	:	Single Phase
Energy	:	500 Watts

2.3 CONTROL UNIT

Figure 2.3.1 Control Unit

2.3.1 Volt Meter

A voltmeter is an instrument used for measuring electrical potential difference between two points in an electric circuit. Analog voltmeters move a pointer across a scale in proportion to the voltage of the circuit; digital voltmeters give a numerical display of voltage by use of an analog to digital converter.

a) Digital Volt Meter

A digital voltmeter (DVM) measures an unknown input voltage by converting the voltage to a digital value and then displays the voltage in numeric form. DVMs are usually designed around a special type of analog-to-digital converter called an integrating converter.

DVM measurement accuracy is affected by many factors, including temperature, input impedance, and DVM power supply voltage variations. Less expensive DVMs often have input resistance on the order of 10 MΩ. Precision DVMs can have input resistances of 1 GΩ or higher for the lower voltage ranges (e.g. less than 20 V). To ensure that a DVM's accuracy is within the manufacturer's specified tolerances, it must be periodically calibrated against a voltage standard such as the Weston cell.

2.3.2 *Ammeter*

       An ammeter (from Ampere Meter) is a measuring instrument used to measure the current in a circuit. Electric currents are measured in amperes (A), hence the name. Instruments used to measure smaller currents, in the milliampere or microampere range, are designated as milliammeters or microammeters.

Types

- ➤ Moving Coil
- ➤ Moving Magnet
- ➤ electrodynamics
- ➤ Moving iron
- ➤ hot wire
- ➤ digital

a) *Digital Ammeter*

In much the same way as the analogue ammeter formed the basis for a wide variety of derived meters, including voltmeters, the basic mechanism for a digital meter is a digital voltmeter mechanism, and other types of meter are built around this. Digital ammeter designs use a shunt resistor to produce a calibrated voltage proportional to the current flowing. This voltage is then measured by a digital voltmeter, through use of an analog to digital converter (ADC); the digital display is calibrated to display the current through the shunt. Such instruments are often calibrated to indicate the RMS value for a sine wave only, but many designs will indicate true RMS within limitations of the wave crest factor.

Figure 2.3.2 Digital Volt Meter & Ammeter

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2.3.3 Dimmer Stat/Autotransformer

An autotransformer (sometimes called auto step down transformer is an electrical transformer with only one winding. The "auto" (Greek for "self") prefix refers to the single coil acting alone and not to any kind of automatic mechanism. In an autotransformer, portions of the same winding act as both the primary and secondary sides of the transformer. In contrast, an ordinary transformer has separate primary and secondary windings which are not electrically connected.

The winding has at least three taps where electrical connections are made. Since part of the winding does "double duty", autotransformers have the advantages of often being smaller, lighter, and cheaper than typical dual-winding transformers, but the disadvantage of not providing electrical isolation between primary and secondary circuits. Other advantages of autotransformers include lower leakage reactance, lower losses, lower excitation current, and increased VA rating for a given size and mass.

Autotransformers are often used to step up or step down voltages in the 110-115-120 V range and voltages in the 220-230-240 V range - for example, providing 110 V or 120 V (with taps) from 230 V input, allowing equipment designed for 100 or 120 V to be used with a 230 V supply.

Figure 2.3.3 Auto Transformer

2.3.4 *Thermocouple*

A thermocouple is an electrical device consisting of two dissimilar conductors forming electrical junctions at differing temperatures. A thermocouple produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature. Thermocouples are a widely used type of temperature sensor.

Commercial thermocouples are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self powered and require no external form of excitation. The main limitation with thermocouples is accuracy; system errors of less than one degree Celsius (°C) can be difficult to achieve.

Thermocouples are widely used in science and industry; applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. Thermocouples are also used in homes, offices and businesses as the temperature sensors in thermostats, and also as flame sensors in safety devices for gas-powered major appliances.

Figure 2.3.4 Thermocouple

2.3.5 *Test Section*

Specifications

Length of test section	: 500mm
Inner diameter of test section	:25mm
Outer diameter of test section	:32mm
Thickness of test section	:7mm

Figure 2.3.5 Test Section

2.4 FABRICATION OF INSERTS

2.4.1 *Fabrication Of Twisted Strip*

Aluminum strip of 24mm and length 500 mm (which is 1 mm less than the diameter of test section for clearance fit) is cut from the aluminum sheet having thickness of 1mm. The nomenclature of twisted strip depends on No. Of turns and pitch length. The main reason behind common use of twisted strip in heat transfer augmentation is ease in manufacturing . The manufacturing of twisted strip is done on 4 jaw lathe machine.

The steps to be carried out in manufacturing are as follows :

1) Cut the Aluminum Strip of required width and length.
2) Hold the strip between the 4 jaws and the center support of lathe machine from both side.
3) Rotate the chuck in clockwise direction and count the No. Of turns and measure the pitch length.
4) Hold the chuck for some time for plastic deformation.

Figure 2.4.1 Twisted Strip

2.4.2 Fabrication Of Streamlined Body

Aluminum strip of 24mm and length 150 mm (which is 1 mm less than the diameter of test section for clearance fit) is cut from the aluminum sheet having thickness of 1mm. The half length of the strip is kept fixed on the bench wise and the half length is bend over at an angle after that the ends are riveted. the surface of the surface of streamlined is then finished by performing buffing operation to reduce friction due to irregular surface finish.

Figure 2.4.2 Streamlined Body

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3. EXPERIMENTATION

3.1 EXPERIMENTAL SET-UP

An experimental set-up has been designed and fabricated to study the effect of annular blockages on heat transfer and fluid flow characteristics in circular pipe. A schematic diagram of the experimental set-up is shown in Figure.

Figure 3.1.1 Experimental Setup

The test apparatus is an open air flow loop that consists of a centrifugal blower (1), flow control valve (2), orifice meter along with water manometer to measure mass flow rate of air (3), test section 0.5m length, 25mm diameter, L1=0.1m (4), Annular blockages (material aluminum) having thickness 3mm, outer diameter 25mm & inner diameter with 20%,30%,40% & 40% reduction in outer diameter.(5), Band heater nicrome wire with GI gladding encloses the test section to a length 0.5m to cause electric heating (6), pressure sensor digital(7),

Digital Temp. Indicator (8), 10 thermocouples T2, T3, T4, T5, T6, T7, T8, T9 (0 to 200ºC) calibrated are embedded on the walls of the test tube and T1 and T10 are placed in air stream (10),one at the entrance and the other at the exit of test section to measure the temperature of flowing air. The types of thermocouples used are copper constant. The control panel consists of dimmer state 2 amps& 0 to 200 volts (10), ammeter digital 0 to 2 amps (11), volt meter digital 0 to 200 volt (12), Temp. Indicator digital, and Selector switch.
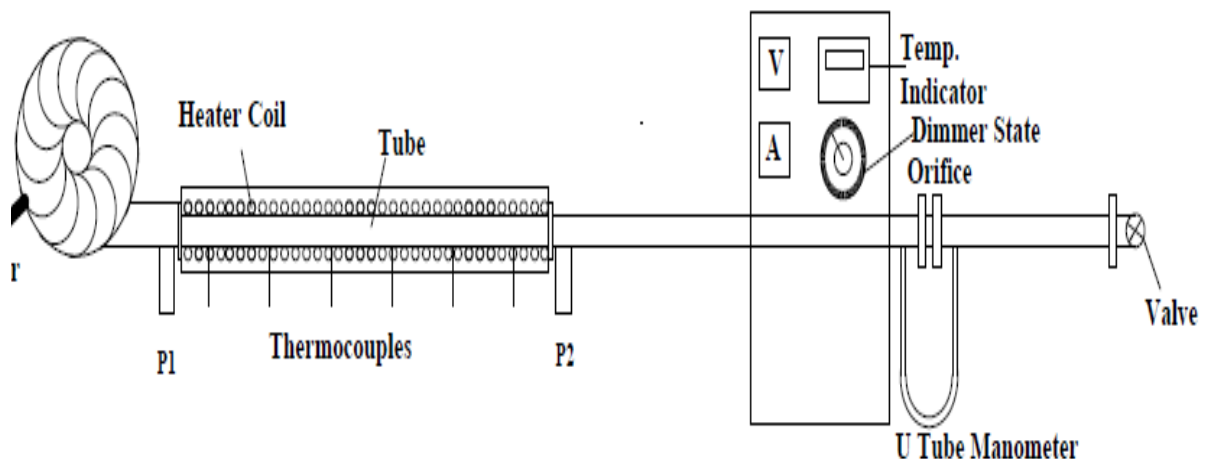
Figure 3.1.2 General Layout

Difference in the levels of manometer fluid represents the variations in the flow rate of air. The velocity of air flowing in the tube is measured with the help of an orifice meter and the water manometer is fitted on the board. The pipe consists of a valve which controls the rate of air flow through it. The diameter of orifice is 12.5mm and coefficient of discharge was found as 0.65.

3.2 EXPERIMENTAL PROCEDURE

1. The test section is assembled in test bracket and checked for air leakage.
2. The blower was switched on to let a predetermined rate of airflow through the pipe.
3. Initially the experiment was carried out for plain tube. The experiment were carried out for different insert such as twisted strip and streamlined body.
4. A constant heat flux is applied to the test section.
5. The changes in temperature are determined with the help of thermocouples placed on it.
6. Four values of flow rates were used for each set at same or fixed uniform heat flux.
7. At each value of flow rate and the corresponding heat flux, system was allowed to attain a steady state before the temperature data were recorded.
8. The pressure drops were measured when steady state is reached.

4. DATA REDUCTION

1) Average Temperature Of Tube Wall :

$$T_s = \frac{T2 + T3 + T4 + T5 + T6 + T7 + T8 + T9}{8}$$

2) Bulk Temperature Of Air :

$$T_b = \frac{T1 + T10}{2}$$

Properties Of Air Were Taken From The Air Table Corresponding To Above Bulk Temperature Of Air :

- Density of Air (ρ_a)
- Specific Heat Of Air (C_p)
- Kinematic Viscosity Of Air (v)
- Prandtl Number (P_r)
- Thermal Conductivity (k)

3) Areas:

a) Convective Heat Transfer Area (A):

$$A = \pi D_i L$$

b) Area Of Orifice (A_o):

$$A_o = \frac{\pi}{4} d_o{}^2$$

c) Test section inner tube area(A_i)

$$A_i = \frac{\pi}{4} d_i{}^2$$

4) Equivalent Height Of Air Column:

$$h_a = \frac{\rho_w \times h_w}{\rho_a}$$

5) Mass Flow Rate Of Air:

$$\dot{m} = C_d\, a_o \times \frac{\rho_a \times \sqrt{2gh_a}}{\sqrt{1-\beta^4}}$$

Where

- C_d=Coefficient Of Discharge Of Orifice
- a_o=Cross Sectional Area Of Orifice
- β=d/D,Diameter Of Pipe/Diameter Of Orifice
- g=Acceleration Due To Gravity
- h_a=Height Of Air Column

6) Discharge Of Air Through Test Section:

$$q = \frac{m}{\rho_a}$$

7) Convective Heat Transfer To Air:

$$Q = m \times C_p \times (T_{10} - T_1)$$

Where

- T_{10}=Fluid Temperature At The Exit Of The Duct (°C)
- T_1=Fluid Temperature At The Inlet Of The Duct (°C)
- m=Mass Flow Rate Of Air
- C_p=Specific Heat Of Air
- Q = Convective Heat Transfer To Air

8) Convective Heat Transfer Coefficient

$$h = \frac{Q}{A \times (T_s - T_b)}$$

Where

- T_s=Average Temperature Of The Test Surface
- T_b=Bulk Temperature Of Air In The Duct

➢ A = Projected Surface Area Of Test Surface

➢ h = Convective Heat Transfer Coefficient

9) Velocity Of Air:

$$U = \frac{q}{A_i}$$

10) Reynolds Number:

$$R_e = \frac{U \times D_i}{\upsilon}$$

11) Experimental Nusselt Number Is Calculated By:

$$N_u = \frac{h \times D_i}{k}$$

12) Nusselt Number By Dittus - Boelter Equation Is Given By:

$$N_u = 0.023 \times Re^{0.8} \times P_r^{0.4}$$

13) Friction Factor:

$$f_{exp} = \frac{\Delta p \times D_i}{2\rho_a \times L \times V_{air}^2}$$

14) Theoretical Friction Factor For Plain Tube By Swami And Jain Equation:

$$\frac{1}{\sqrt{f_{the}}} = 1.14 - 2\log\left(\frac{\epsilon_s}{D} + \frac{21.25}{Re^{0.9}}\right)$$

Where

➢ ϵ_s = Effective Surface Roughness Of Pipe

15) Overall Enhancement Ratio:

$$\eta = \frac{\frac{Nu_i}{Nu}}{\left(\frac{f_{exp}}{f_{the}}\right)^{\frac{1}{3}}}$$

5. OBSERVATION & RESULT

5.1 FOR PLAIN TUBE

5.1.1 Observations Table

Input in Watts	Mano-meter Reading	Temperature (Degree centigrade)									
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
60	4	33.1	40.8	51.3	60.5	63.3	62.5	63.7	58.5	48.2	39.4
60	6	33.5	40.4	49.6	57.5	60.1	58.9	60.2	55.2	46.3	39.1
60	8	33	40.6	49.5	57.3	59.6	58.2	59.6	54.2	45.9	38
90	4	34.1	50.2	73.2	93.2	98.7	97.6	99.5	88.6	88.4	52.2
90	6	33.1	46.9	65.8	81.7	86.7	84.4	86.5	76.7	58.3	45.1
90	8	33.5	46.8	65.5	81	85.2	83	84.1	72	55.7	44.8
120	4	34.6	66.4	112.6	131.3	141.1	141.4	143.5	124	87.6	67.3
120	6	33.2	60.8	88.9	109.8	119.1	115.3	118.5	101.3	83.5	54.6
120	8	33	57.7	88.2	109	117.3	114	115.1	100.4	71.3	52.9

Table 5.1.1 Steady State Temperatures For Plain Tube For Different Reynolds Number And Different Heater Inputs

5.1.2 Result Table

Input In Watts	Manometer readings	Re	T_b	T_s	Nu_{act}	Nu_{th}	h_{actual}	h_{th}	Power Consumption	Friction Factor
60	4	6602.928	36.25	56.1	19.03695	23.01454	20.05924	24.25042	0.27439	0.036704
60	6	8085.867	36.3	53.525	23.87792	27.06414	25.1637	28.52149	0.277094	0.035901
60	8	9367.237	35.5	53.1125	24.16077	30.44752	25.40457	32.01496	0.281955	0.035398
90	4	6424.114	43.15	86.175	24.48251	22.49169	26.29725	24.15886	0.327988	0.036824
90	6	7995.619	39.1	73.375	25.40045	26.81146	26.97873	28.47742	0.339879	0.035942
90	8	9230.719	39.15	71.6625	29.10985	30.07628	30.92292	31.94955	0.348297	0.035445
120	4	6232.576	50.95	118.4875	27.2621	21.92854	29.90037	24.05066	0.418216	0.036959
120	6	7844.832	43.9	99.65	27.2703	26.38688	29.35222	28.40136	0.434363	0.036012
120	8	9092.217	42.95	96.625	30.54033	29.69756	32.78602	31.88128	0.45	0.035494

Table 5.1.2 Results Of Heat Transfer For Plain

5.2 FOR TWISTED STRIP

5.2.1 Observation Table

Input in Watts	Mano-meter Reading	Temperature (Degree centigrade)									
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
60	4	30	56.6	60.8	63.4	66.2	60.2	59.9	47.6	39.1	43.8
60	6	30	50.2	52.8	55	57.1	55.4	53.9	47.2	40.7	41
60	8	30	45	45.3	50.1	50.2	51.2	51.4	47	42.4	39.2
90	4	30	76.6	86.9	91.3	92	88.5	76	60.2	39.4	52.8
90	6	30	65.3	73.4	78	82	83.2	72	64	53	49.5
90	8	30	50	61.6	72	76.5	78	77.2	68.4	56	46.3
120	4	30	111	127.7	133.7	136.2	123	105	80.2	46.5	65
120	6	30	88.4	103.2	107.6	119.8	112	104	89	70	59
120	8	30	67	79.6	106	104.8	107.2	104	90.8	68.6	54

Table 5.2.1 Steady State Temperatures For Twisted Strip For Different Reynolds Number And Different Heater Inputs

5.2.2 Result Table

Input in Watts	Mano-meter Readings	Re	T_b	T_s	Nu_{act}	Nu_{th}	h_{actual}	h_{th}	Power Consumption	F_{act}	F_{th}	Over all Enhancement
60	4	6586	36.9	56.7	41.63	22.96	43.94	24.24	0.279	0.0367	0.4142	0.8036
60	6	8112	35.5	51.5	50.55	27.13	53.15	28.53	0.280	0.0358	0.4215	0.8243
60	8	9401	34.6	47.8	59.44	30.54	62.34	32.03	0.282	0.0353	0.4992	0.8055
90	4	6468	41.4	76.3	38.24	22.62	40.87	24.18	0.333	0.0367	0.4142	0.7498
90	6	7975	39.7	71.3	44.62	26.75	47.48	28.46	0.342	0.0359	0.4215	0.7385
90	8	9267	38.1	67.4	46.77	30.17	49.55	31.96	0.368	0.0354	0.4992	0.6418
120	4	6315	47.5	107.9	33.09	22.17	35.96	24.09	0.437	0.0368	0.4142	0.6627
120	6	7826	44.5	99.2	37.53	26.33	40.46	28.39	0.441	0.0360	0.4215	0.6314
120	8	9126	42	91	40.51	29.79	43.37	31.89	0.444	0.0354	0.4992	0.5633

Table 5.2.2 Results Of Heat Transfer For Twisted Strip

5.3 FOR STREAMLINED BODY

5.3.1 Observation Table

Input in Watts	Mano-meter Reading	Temperature (Degree centigrade)									
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
60	4	30	55.1	58.4	59	58.3	62.2	48.1	38.8	35.7	41.9
60	6	30	45.8	51	54.2	53.1	57.5	46.7	45.1	43	40.2
60	8	30	43	48.7	51.3	52	52.4	46.1	43	36	39
90	4	30	75.2	81	84.5	85.3	86.6	72	64.2	40.6	52
90	6	30	72	75.8	78.2	79	81.9	68	60	39.5	48.9
90	8	30	68	71	73	73.6	75.4	64	56.2	38.5	46
120	4	30	113	125.1	129.6	132	118.8	108	59.3	45.4	64
120	6	30	84.3	98.5	106	115	111.1	96	85.3	67	58
120	8	30	78	103.5	104	109	102	96	77.7	40.9	53.4

Table 5.3.1 Steady State Temperatures For Streamlined Body For Different Reynolds Number And Different Heater Inputs

5.3.2 Result Table

Input in Watts	Mano-meter Readings	Re	T_b	T_s	Nu_{act}	Nu_{th}	h_{actual}	h_{th}	Power Consumption	F_{act}	F_{th}	Over all Enhancement
60	4	6611	35.9	51.9	44.67	23.03	47.02	24.25	0.278	0.0366	0.3328	0.9297
60	6	8125	35.1	49.5	52.11	27.17	54.73	28.54	0.279	0.0358	0.3698	0.8813
60	8	9405	34.5	46.5	63.78	30.55	66.87	32.03	0.284	0.0353	0.4326	0.9062
90	4	6479	41	73.6	39.55	22.65	42.23	24.18	0.331	0.0367	0.3394	0.8324
90	6	7984	39.4	69.3	45.86	26.78	48.76	28.47	0.341	0.0359	0.2218	0.9336
90	8	9273	38	64.9	49.95	30.19	52.89	31.96	0.361	0.0354	0.4326	0.7185
120	4	6328	47	103.9	34.20	22.20	37.12	24.10	0.432	0.0368	0.3394	0.7350
120	6	7841	44	95.4	38.68	26.37	41.64	28.39	0.436	0.0360	0.3698	0.6747
120	8	9137	41.7	88.8	41.07	29.82	43.94	31.90	0.461	0.0354	0.4326	0.5984

Table 5.3.2 Results Of Heat Transfer For Streamlined Body

5.4 SAMPLE CALCULATION

For Streamlined Body

Input= 60W

Manometer Difference=8

1) Average Temperature Of Tube Wall :

$$T_s = \frac{T2 + T3 + T4 + T5 + T6 + T7 + T8 + T9}{8}$$

$$T_s = \frac{43 + 48.7 + 51.3 + 52 + 52.4 + 46.1 + 43 + 36}{8} = 46.56 \; Centigrade$$

2) Bulk Temperature Of Air :

$$T_b = \frac{T1 + T10}{2} = \frac{30 + 39}{2} = 34.5 \; Centrigrade$$

3) Areas:

a) Convective Heat Transfer Area (A):

$$A = \pi D_i L = \pi * 0.025 * 0.5 = 0.03927 \; m^2$$

b) Area Of Orifice (A_o):

$$A_o = \frac{\pi}{4} d_i{}^2 = \frac{\pi}{4} * 0.0125^2 = 0.000123 \; m^2$$

c) Test section inner tube area(A_i)

$$A_i = \frac{\pi}{4} d_i{}^2 = \frac{\pi}{4} * 0.025^2 = 0.000491 \; m^2$$

4) Equivalent Height Of Air Column:

$$h_a = \frac{\rho_w \times h_w}{\rho_a} = \frac{1000 * 0.08}{1.1469} = 69.753 \; m$$

5) Mass Flow Rate Of Air:

$$\dot{m} = C_d \times A_o \times \frac{\rho_a \times \sqrt{2gh_a}}{\sqrt{1 - \beta^4}}$$

$$\dot{m} = 0.65 * 0.000123 * 1.1469 * \frac{\sqrt{2 * 9.81 * 69.753}}{\sqrt{1 - \left(\frac{1}{2}\right)^4}} = 0.003469 \frac{kg}{sec}$$

6) Discharge Of Air Through Test Section:

$$q = \frac{\dot{m}}{\rho_a} \quad \frac{0.00396}{1.1469} = 0.00308 \frac{m^3}{sec}$$

7) Convective Heat Transfer To Air:

$$Q = \dot{m} \times C_p \times (T_{10} - T_1) = 0.003496 * 1007 * (39 - 30) = 31.6827 \ W$$

8) Convective Heat Transfer Coefficient

$$h = \frac{Q}{A \times (T_s - T_b)} = \frac{31.6827}{0.039275 * (46.56 - 34.5)} = 66.875 \frac{w}{m^2 k}$$

9) Velocity Of Air:

$$U = \frac{q}{A_i} = \frac{0.003469}{0.000491} = 6.203 \frac{m}{sec}$$

10) Reynolds Number:

$$R_e = \frac{U \times D_i}{v} = \frac{6.208 * 0.025}{1.65 * 10^{-5}} = 9405.38$$

11) Experimental Nusselt Number Is Calculated By:

$$N_u = \frac{h \times D_i}{k} = \frac{66.875 * 0.025}{0.026213} = 63.7812$$

12) Nusselt Number By Dittus - Boelter Equation Is Given By:

$$N_u = 0.023 \times Re^{0.8} \times P_r^{0.4} = 0.023 * 9405.385^{0.8} * 0.7269^{0.4} = 30.5512$$

13) Friction Factor:

$$f_{exp} = \frac{\Delta p \times D_i}{2\rho_a \times L \times V_{air}{}^2} = \frac{191.295 * 0.025}{2 * 1.1469 * 0.5 * 6.2086^2} = 0.43269$$

14) Theoretical Friction Factor For Plain Tube By Swami And Jain Equation:

$$\frac{1}{\sqrt{f_{the}}} = 1.14 - 2\log\left(\frac{\epsilon_s}{D} + \frac{21.25}{Re^{0.9}}\right)$$

$$\frac{1}{\sqrt{f_{the}}} = 1.4 - 2\log\left(\frac{0.15}{25} + \frac{21.25}{9405.385^{0.8}}\right)$$

$$f_{the} = 0.03538$$

Where

➤ ϵ_s=Effective Surface Roughness Of Pipe

15) Overall Enhancement Ratio:

$$\eta = \frac{\dfrac{Nu_i}{Nu}}{\left(\dfrac{f_{exp}}{f_{the}}\right)^{\frac{1}{3}}}$$

$$\eta = \frac{2.0876}{2.3036}$$

$$\eta = 0.9062$$

6. GRAPHICAL REPRESENTATION OF RESULT

6.1 DIFFERENT INSERTS V/S HEAT TRANSFER CO-EFFICIENT
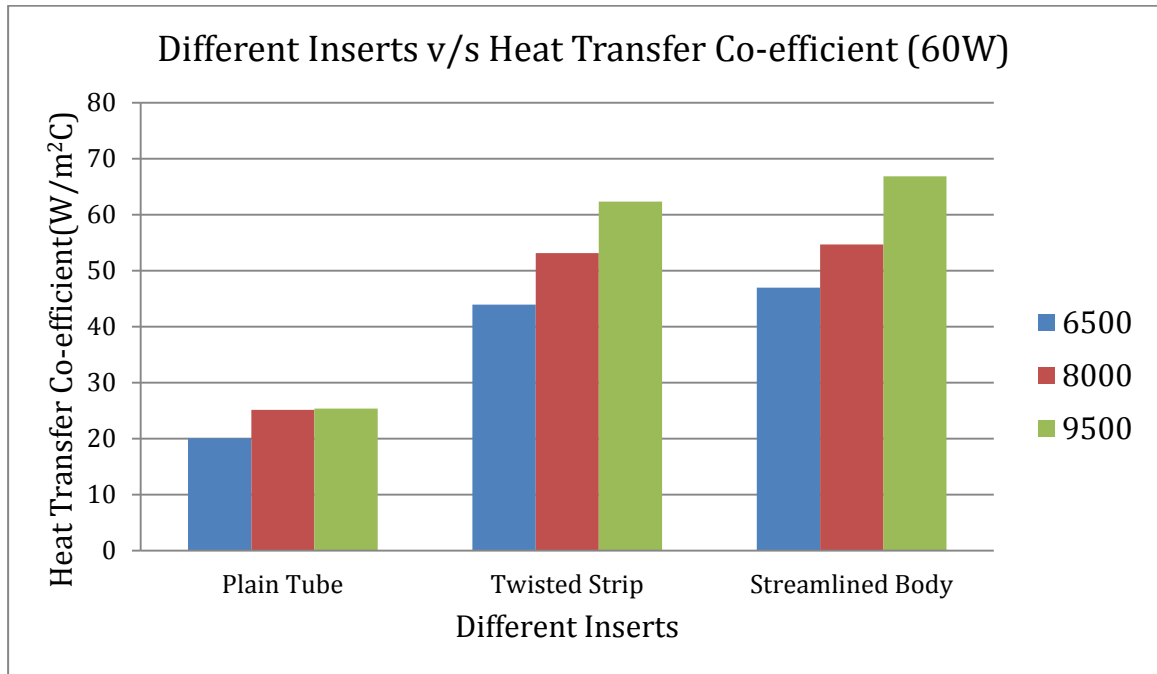
Graph 6.1.1 Different Inserts V/S Heat Transfer Co-Efficient (60W)
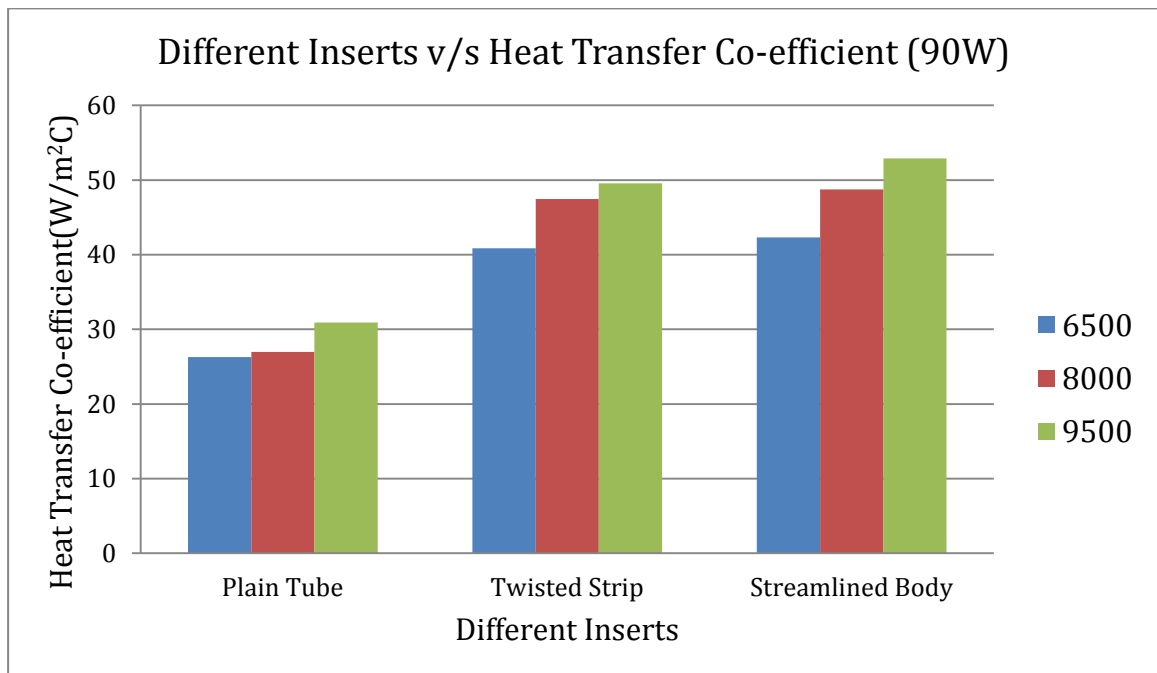
Graph 6.1.2 Different Inserts V/S Heat Transfer Co-Efficient (90W)
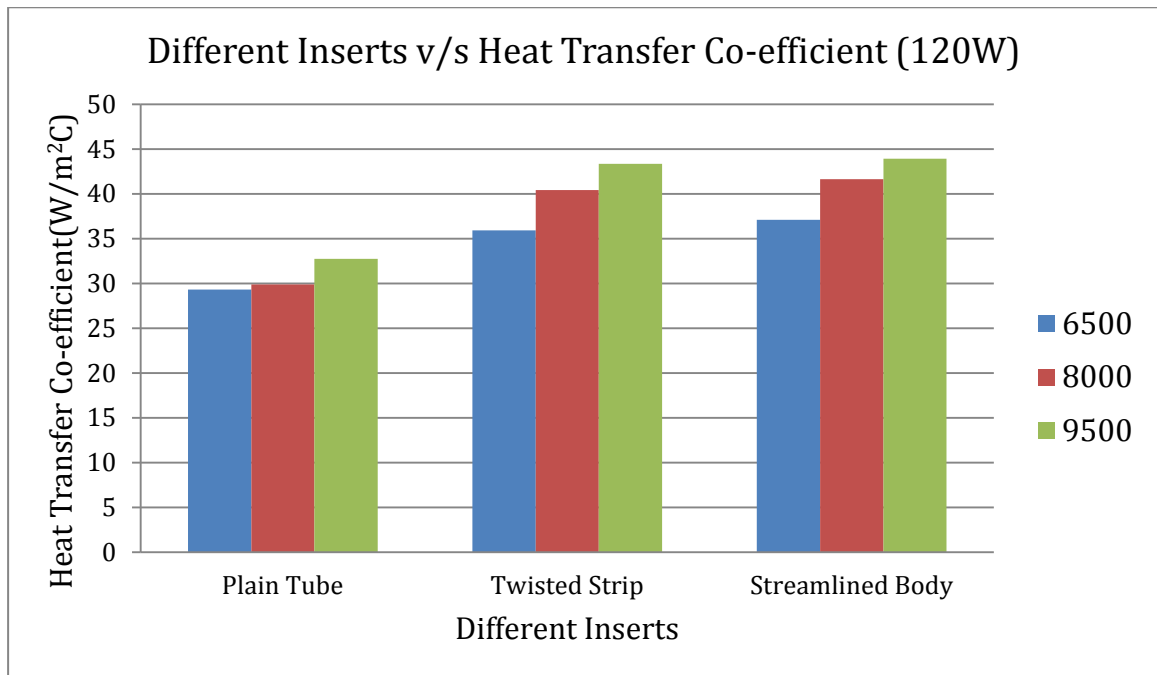
Graph 6.1.3 Different Inserts V/S Heat Transfer Co-Efficient (120W)

Heat transfer co efficient values for different inserts are compared at different Reynolds numbers. Figure no 6.1.1, 6.1.2 & 6.1.3 shows the comparison of heat transfer co efficient values for different inserts at different Reynolds number values. It is observed that the value of heat transfer co efficient for twisted strip is higher when compared with the values of plain tube And values of heat transfer co efficient for streamlined body is higher when compared with the values of plain tube and twisted strip. The streamlined body gives the maximum values of heat transfer as compared with the other inserts.

6.2 REYNOLDS NUMBER V/S NUSSELT NUMBER (COMPARISON)
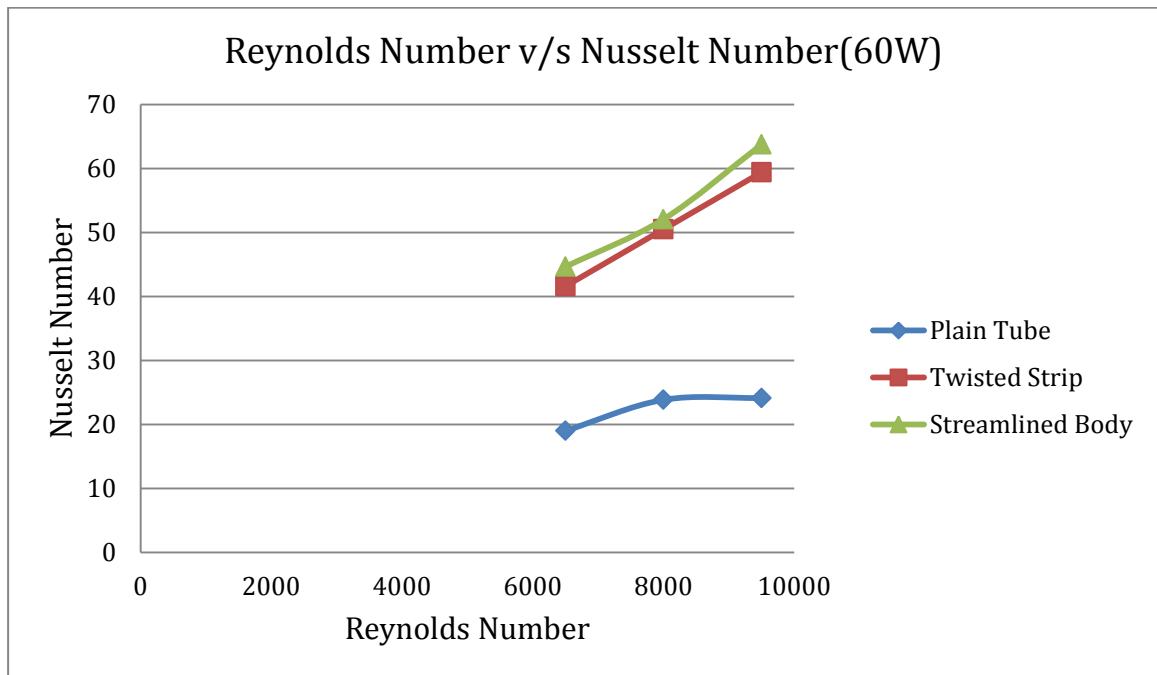
Graph 6.2.1 Reynolds Number V/S Nusselt Number(60W)
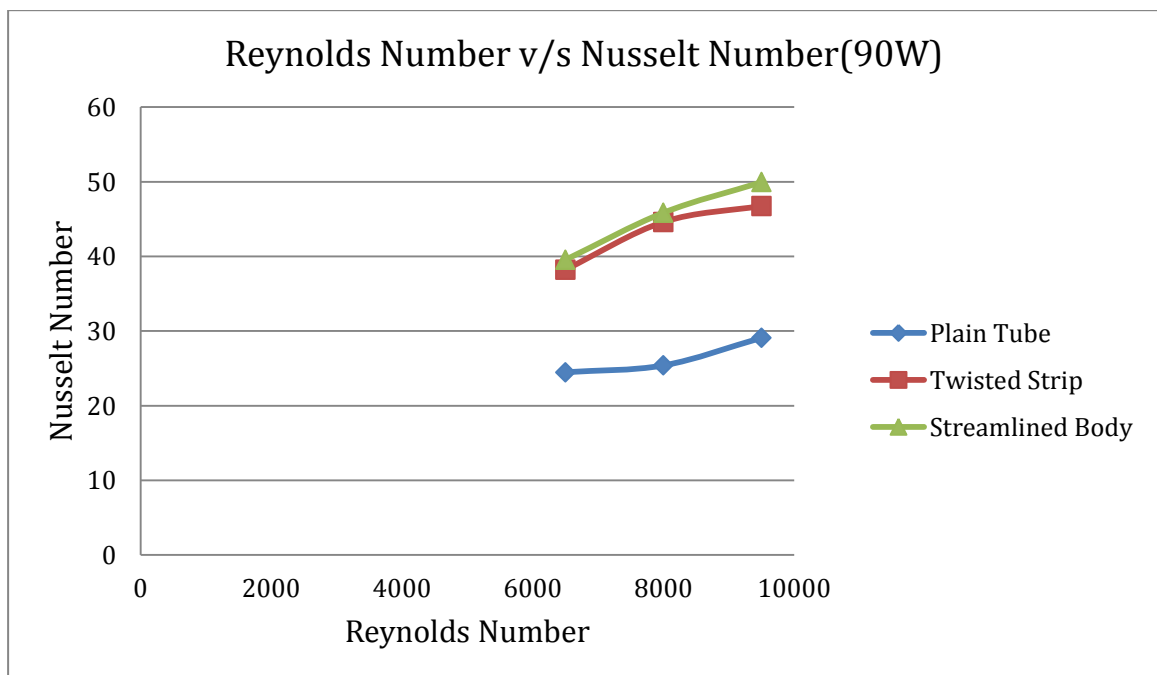
Graph 6.2.2 Reynolds Number V/S Nusselt Number(90W)
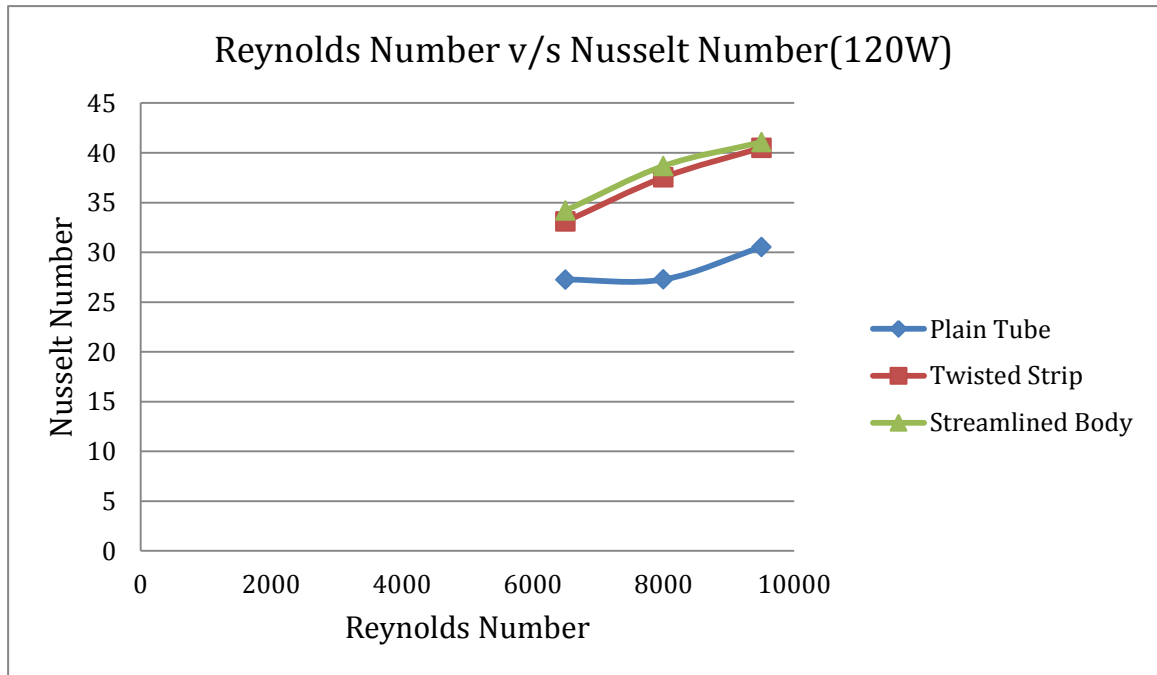
Graph 6.2.3 Reynolds Number V/S Nusselt Number(120W)

Experimentally determined values for plain tube, twisted strip and streamlined body are compared. Figure 6.2.1, 6.2.2 & 6.2.3 shows the nusselt number obtained for different inserts at different heat input values. It is observed that the value of nusselt number for twisted strip is higher when compared with the values of plain tube and values of nusselt number for streamlined body is higher when compared with the values of plain tube and twisted strip. The twisted gives the maximum values of nusselt number as compared with the other inserts. However the values of nusselt number are equal with the values of twisted strip at some points.

6.3 REYNOLDS NUMBER V/S NUSSELT NUMBER(PLAIN TUBE)
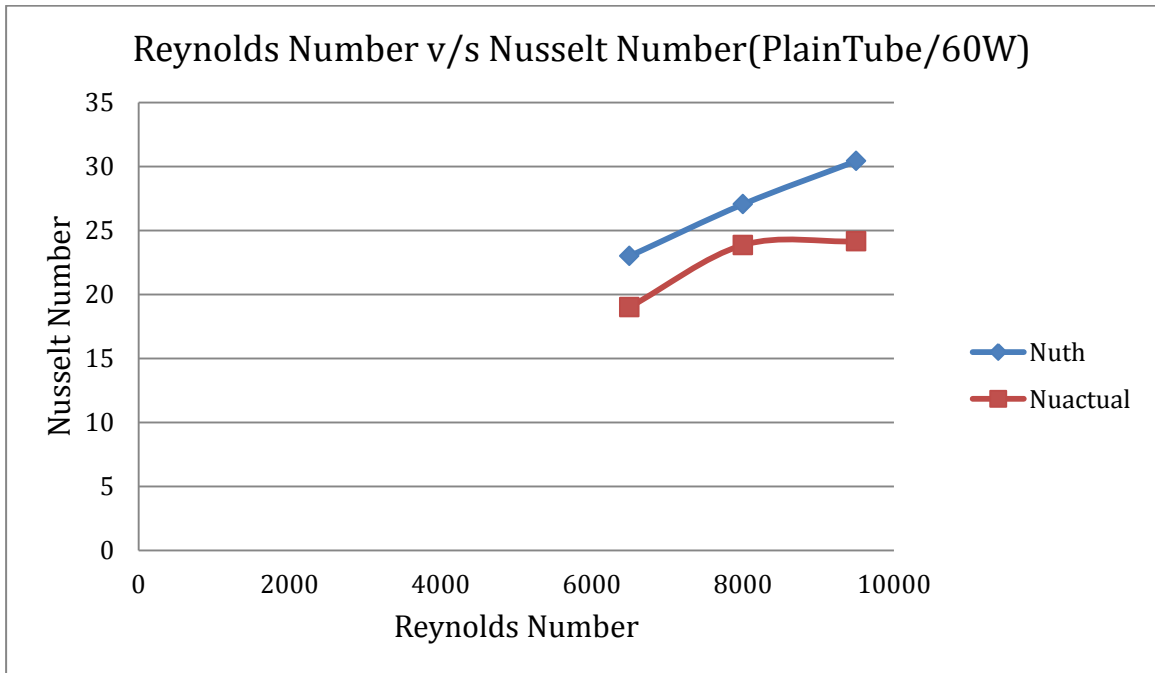
Graph 6.3.1 Reynolds Number V/S Nusselt Number(Plain Tube/60W)
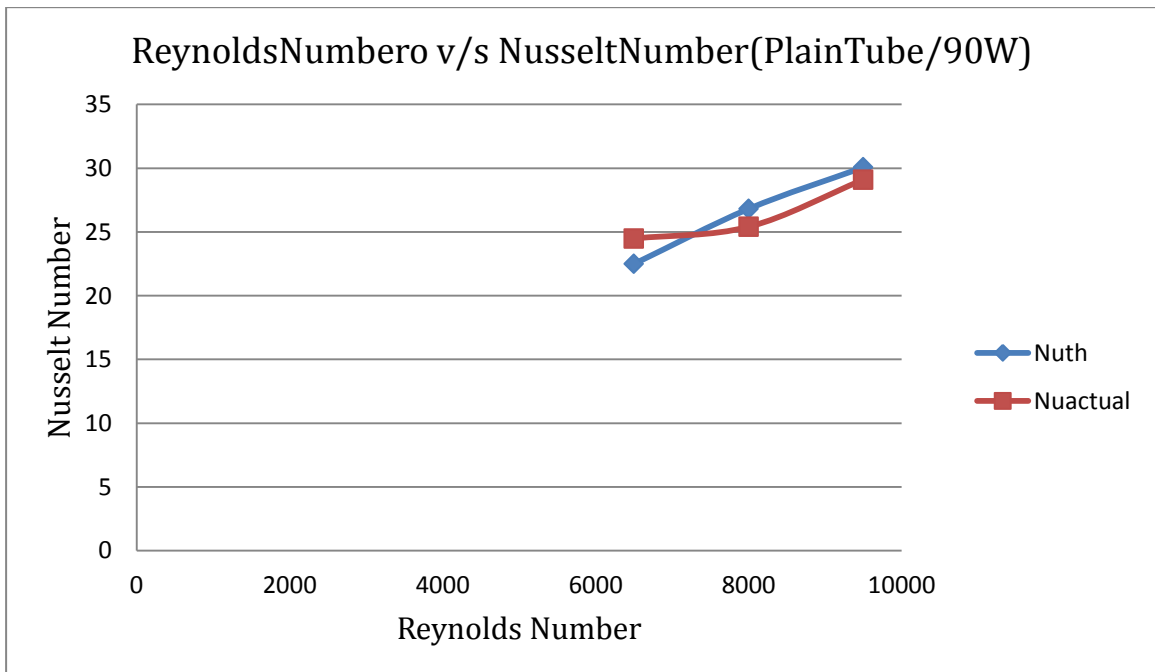
**Graph 6.3.2 Reynolds Number V/S Nusselt Number(Plain Tube/90W)**
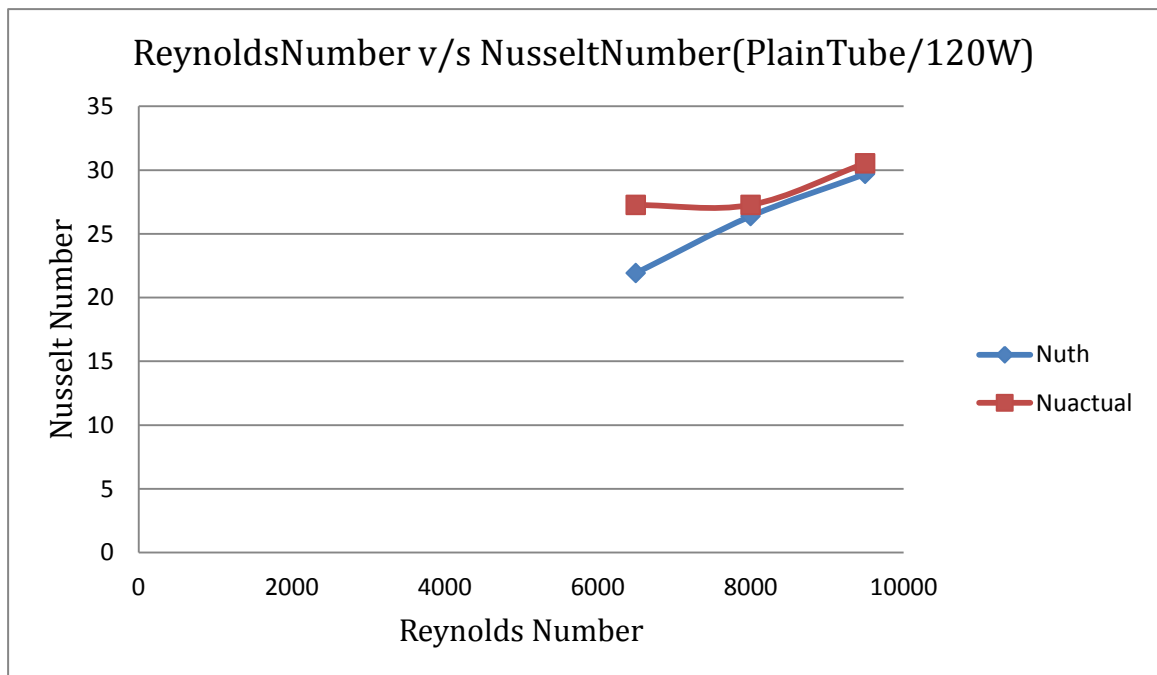
Graph 6.3.3 Reynolds Number V/S Nusselt Number(Plain Tube/120W)

The above graph shows the comparison between experimentally obtained values of nusselt number and values obtained using dittus bolter correlation for different heat input for plain tube. The figure 6.3.1, 6.3.2 & 6.3.3 shows the comparison between the theoretically obtained nusselt number and experimentally obtained nusselt number for plain tube. It is observed that experimental results are in good agreement with aforementioned studies. The experimental values of nusselt number are less at some points and higher at some points.

6.4 REYNOLDS NUMBER V/S NUSSELT NUMBER(TWISTED STRIP)
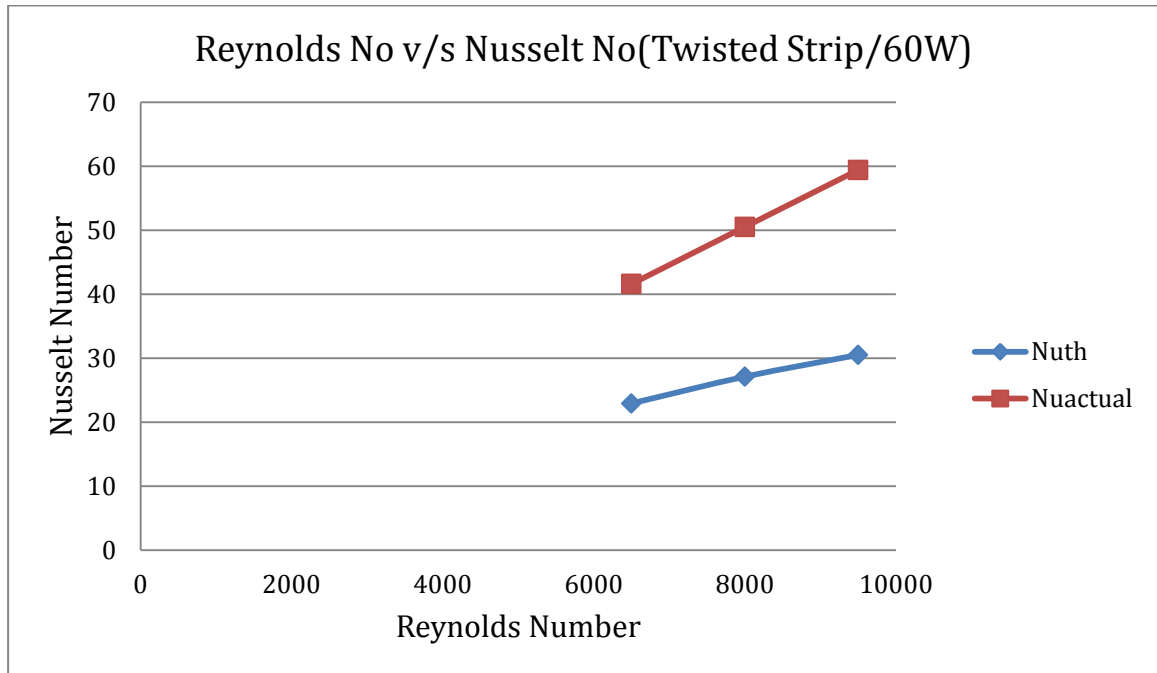
Graph 6.4.1 Reynolds No V/S Nusselt No(Twisted Strip/60W)
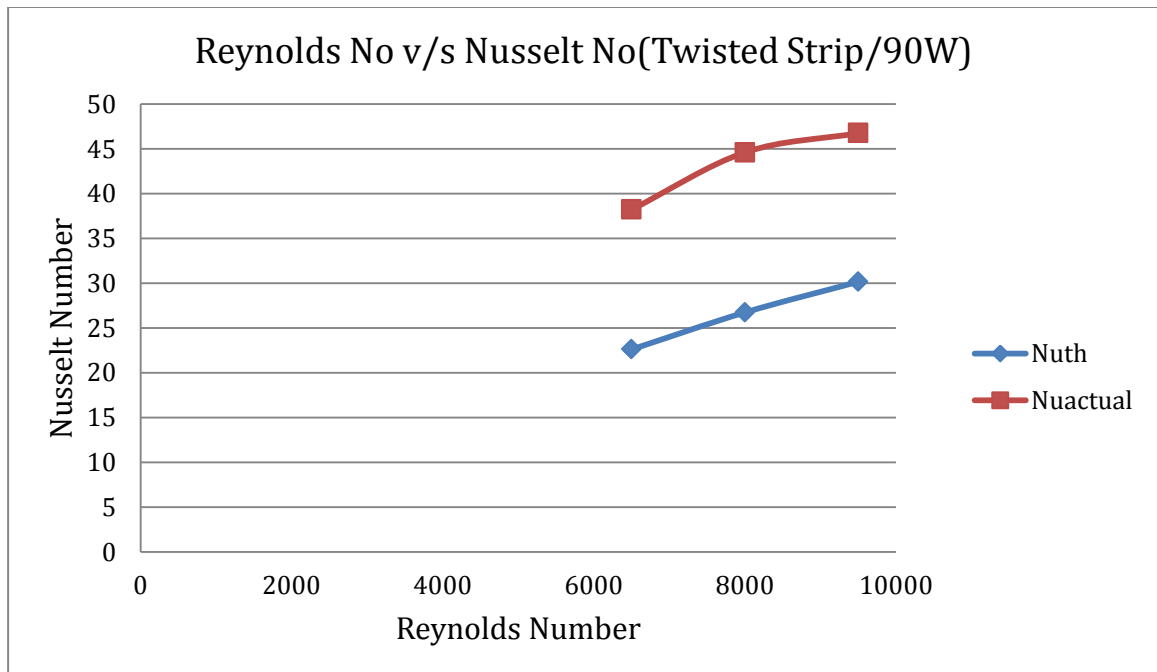
Graph 6.4.2 Reynolds No V/S Nusselt No(Twisted Strip/90W)
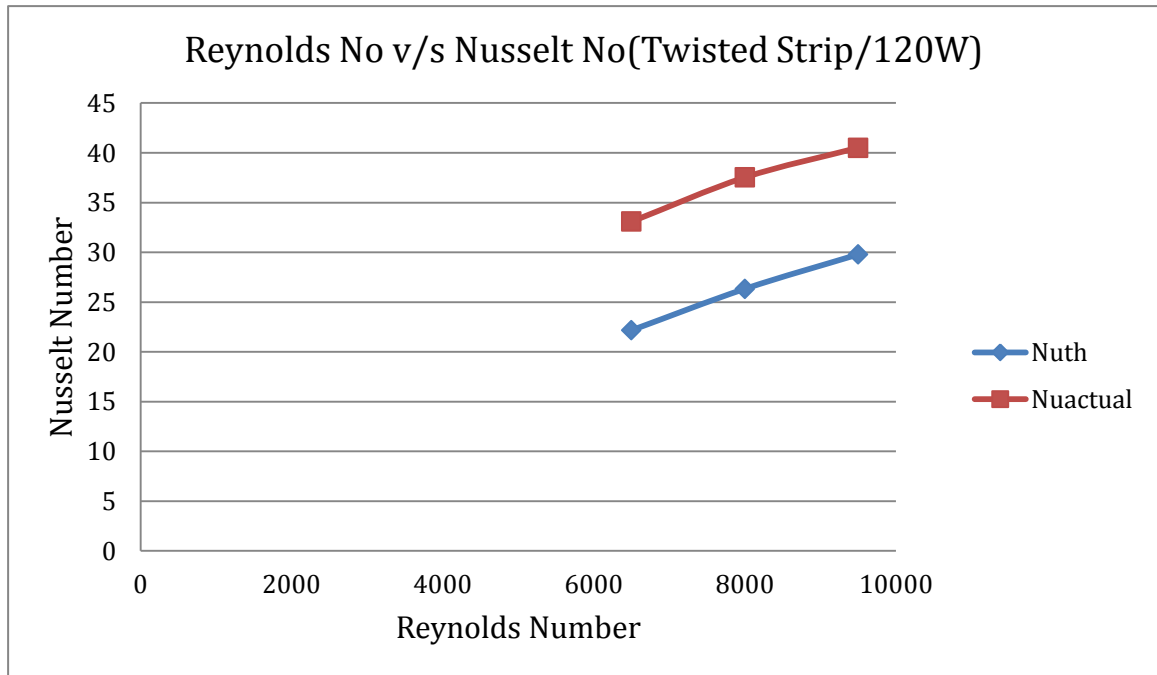
Graph 6.4.3 Reynolds No V/S Nusselt No(Twisted Strip/120W)

The above graph shows the comparison between experimentally obtained values of nusselt number and values obtained using dittus bolter correlation for different heat input for twisted strip. The figure 6.4.1, 6.4.2 & 6.4.3 shows the comparison between the theoretically obtained nusselt number and experimentally obtained nusselt number for twisted strip. It is observed that experimental results are in good agreement with aforementioned studies. The experimental values of nusselt number are higher than the values of theoretical nusselt number.

6.5 REYNOLDS NUMBER V/S NUSSELT NUMBER(STREAMLINED)
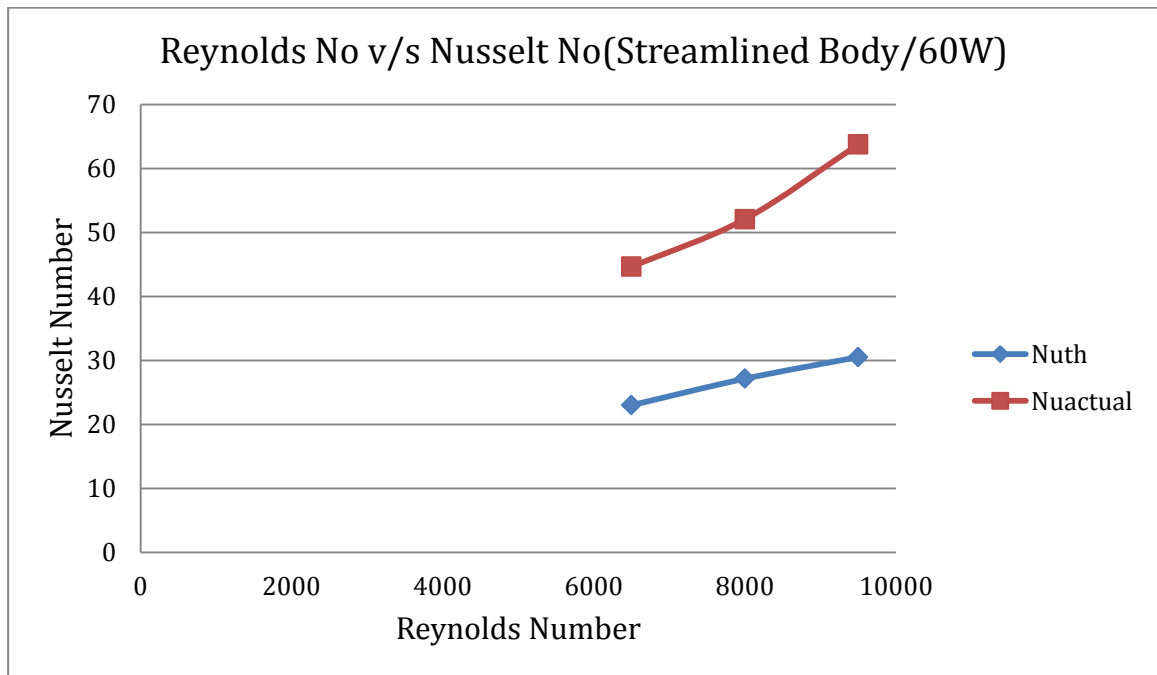
Graph 6.5.1 Reynolds No V/S Nusselt No(Streamlined Body/60W)
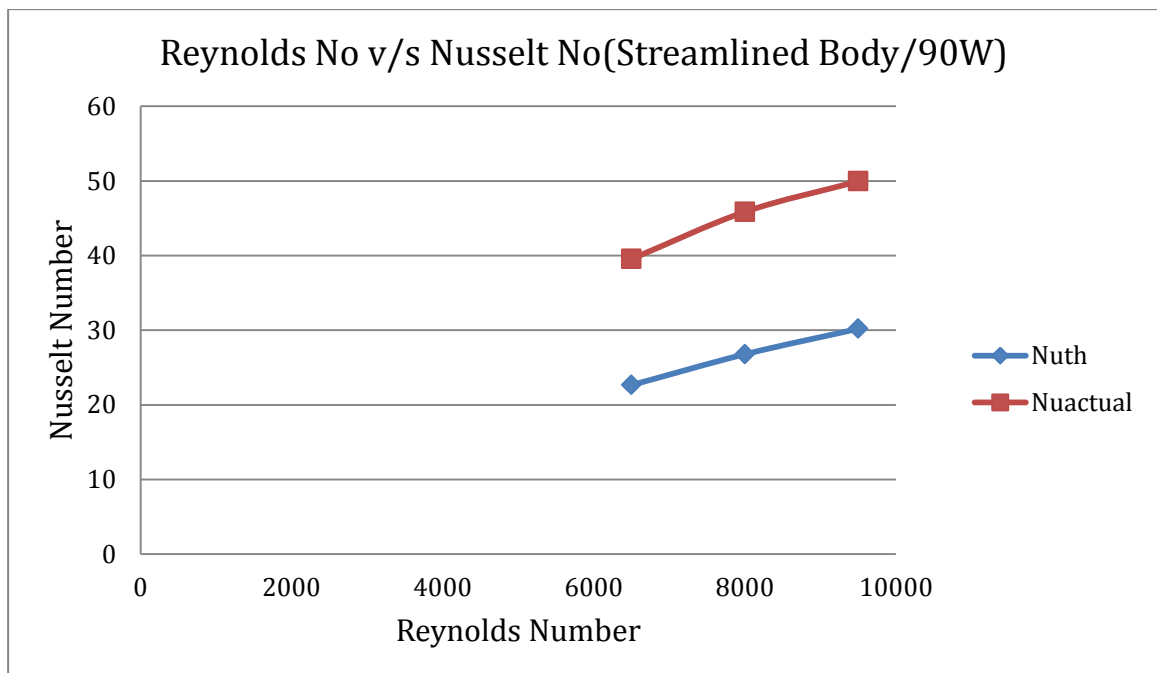
Graph 6.5.2 Reynolds No V/S Nusselt No(Streamlined Body/90W)
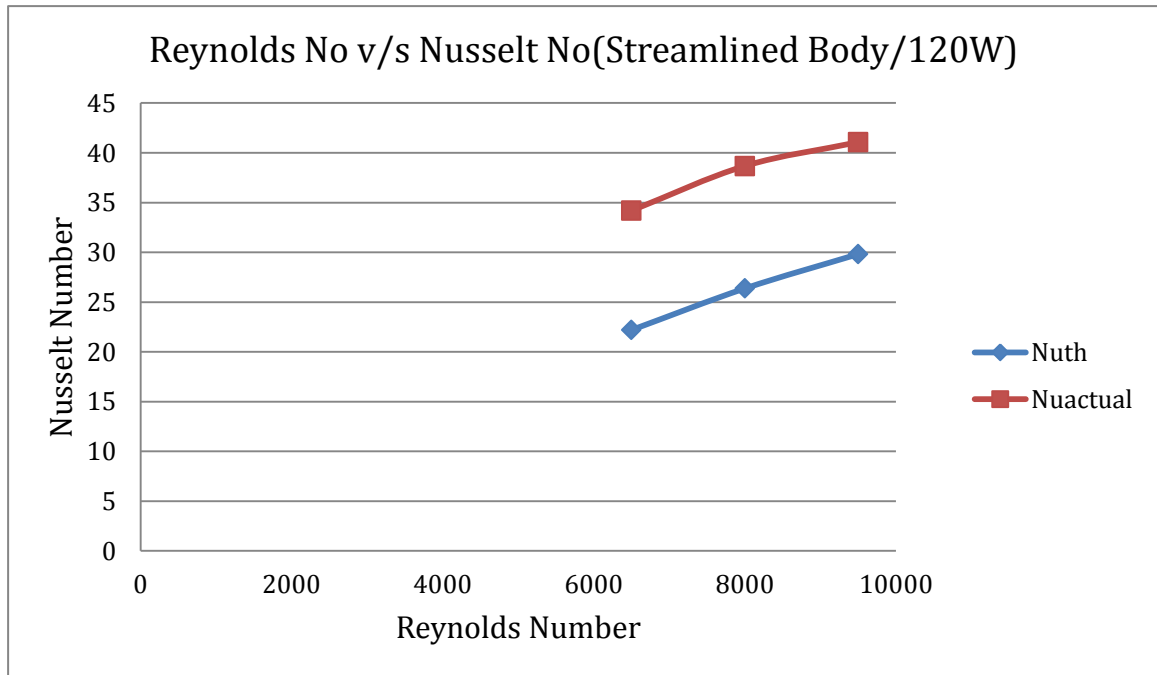
Graph 6.5.3 Reynolds No V/S Nusselt No(Streamlined Body/120W)

The above graph shows the comparison between experimentally obtained values of nusselt number and values obtained using dittus bolter correlation for different heat input. The figure 6.5.1, 6.5.2 & 6.5.3 shows the comparison between the theoretically obtained nusselt number and experimentally obtained nusselt number. It is observed that experimental results are in good agreement with aforementioned studies. The experimental values of nusselt number are higher than the values of theoretical nusselt number.

6.6 REYNOLDS NO V/S OVER ALL ENHANCEMENT RATIO
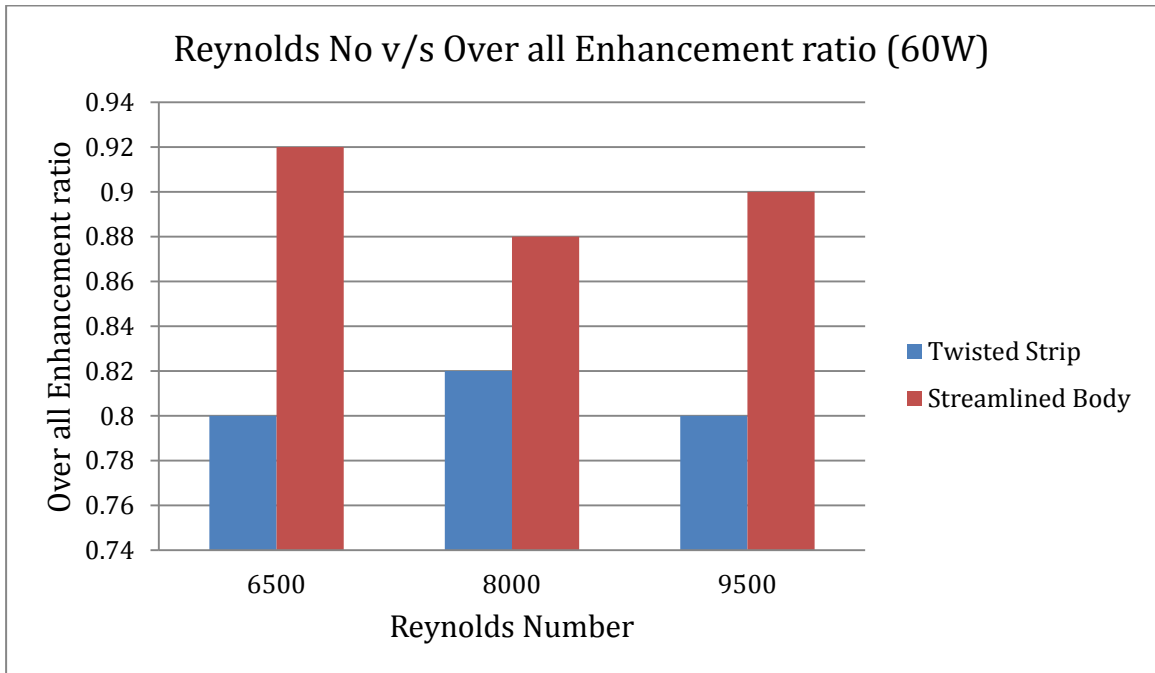
Graph 6.6.1 Reynolds No V/S Over All Enhancement Ratio (60W)
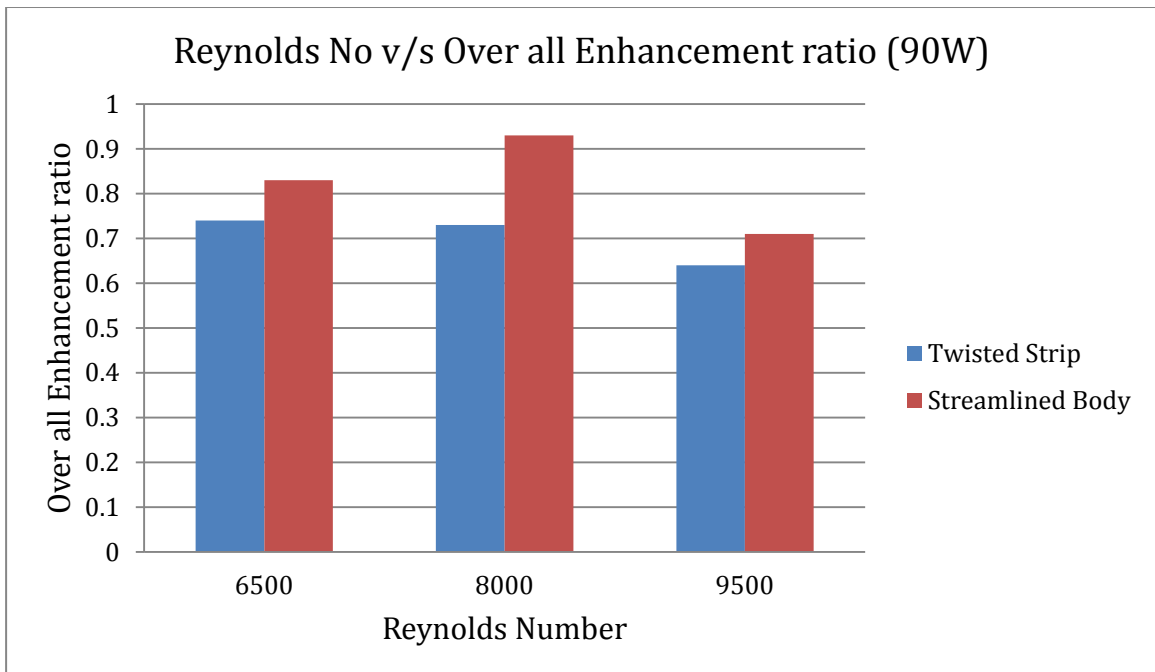
Graph 6.6.2 Reynolds No V/S Over All Enhancement Ratio (90W)
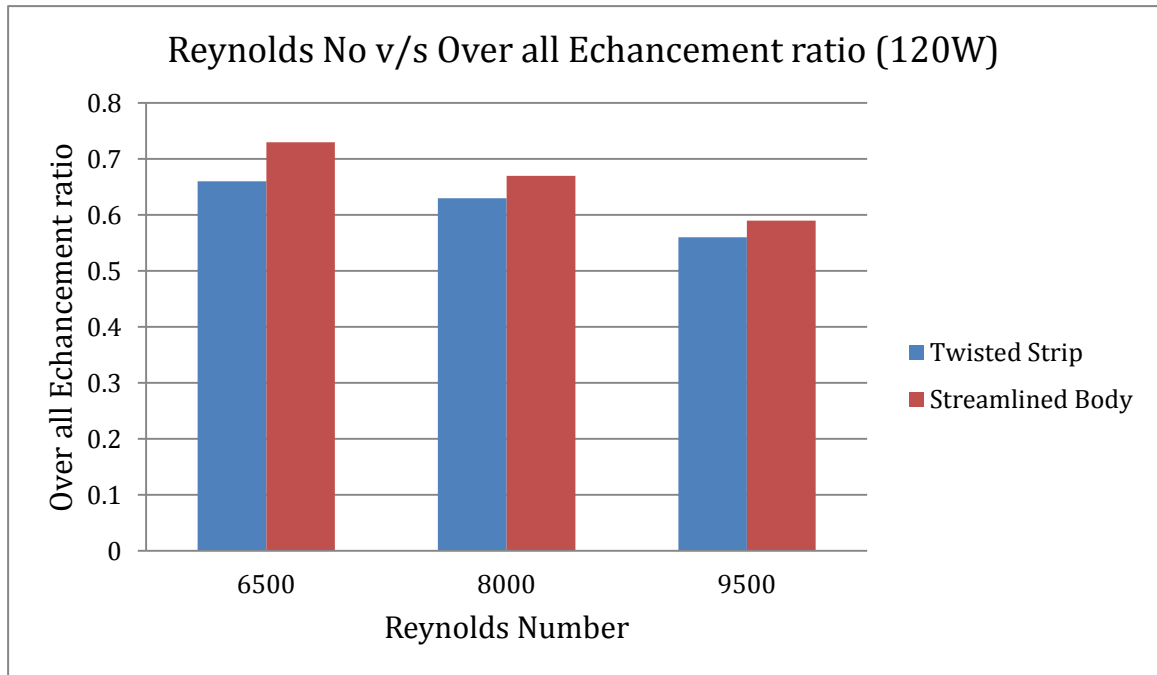
Graph 6.6.3 Reynolds No V/S Over All Enhancement Ratio (120W)

Overall enhancement ratio is defined as the ratio of heat transfer enhancement ratio to the friction factor. Overall efficiency of different inserts are compared at different values of Reynolds number. The figure 6.6.1, 6.6.2 & 6.6.3 shows the comparison of overall efficiency of twisted strip with the overall efficiency of streamlined body at different heat inputs. It is observed that the overall efficiency of streamlined body is higher than that of overall efficiency of twisted strip.

6.7 REYNOLDS NO V/S POWER CONSUMPTION
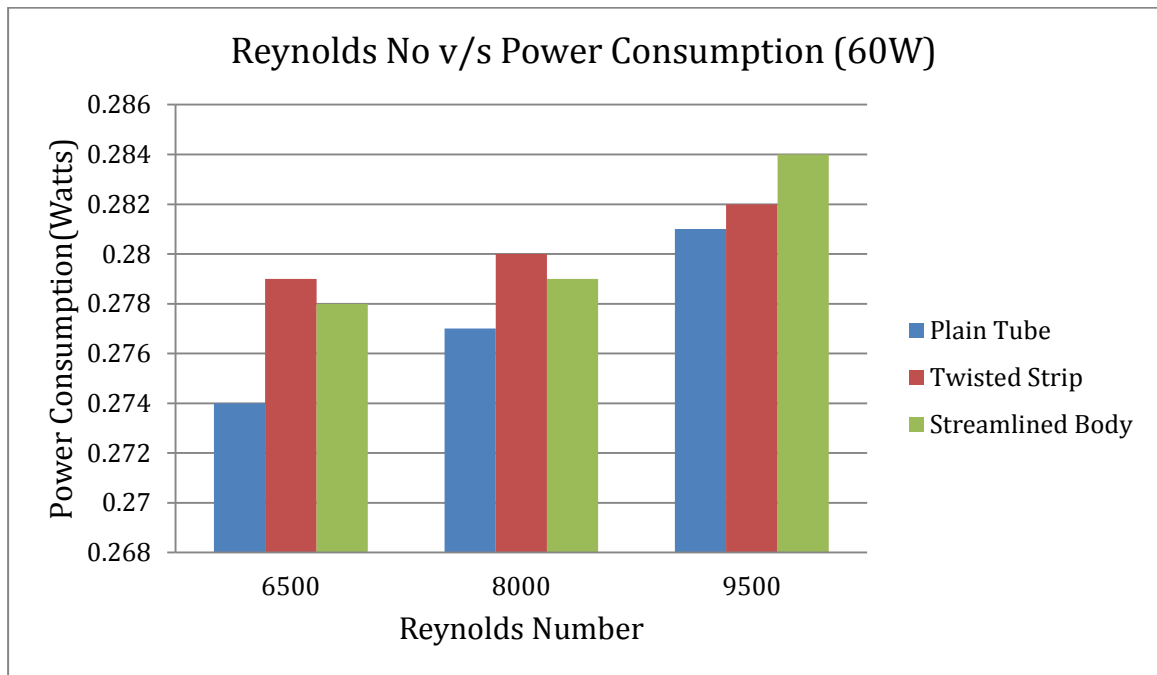
Graph 6.7.1 Reynolds No V/S Power Consumption (60W)
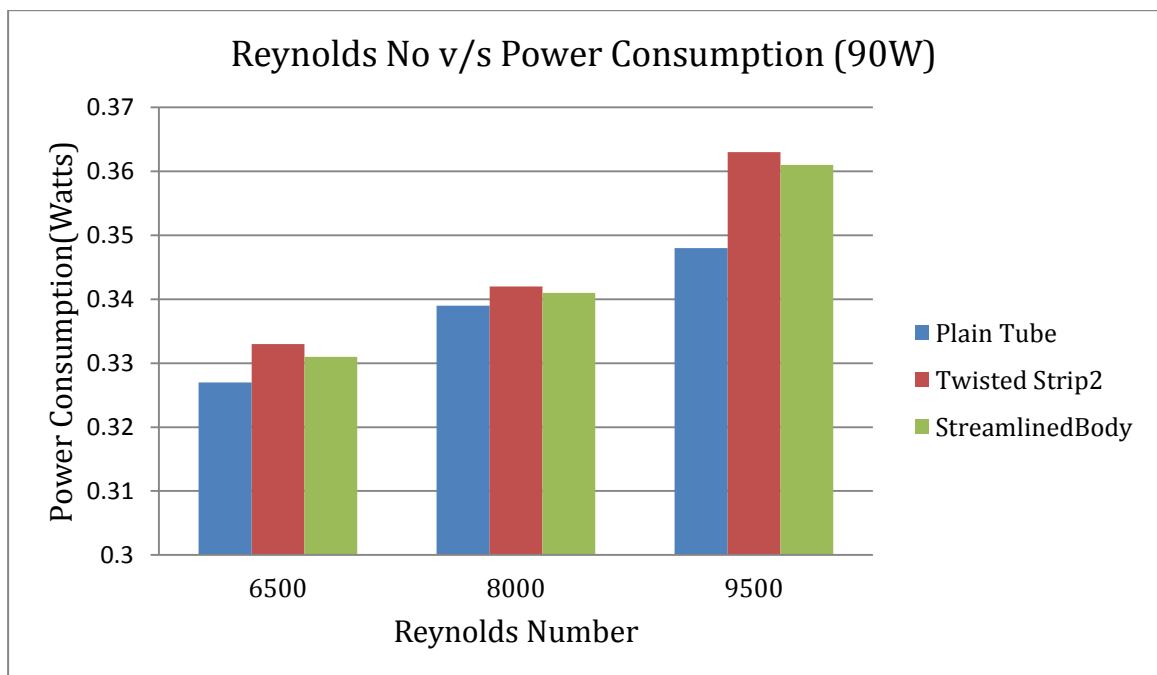
**graph 6.7.2 Reynolds No v/s Power Consumption (90W)**
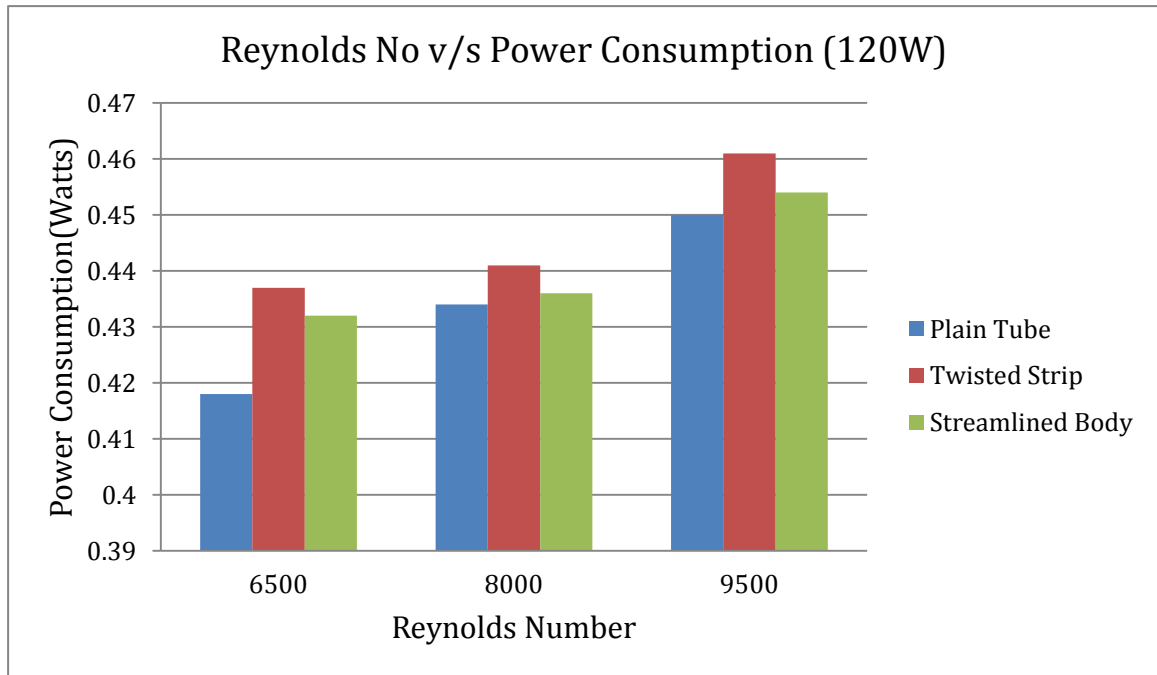
Graph 6.7.3 Reynolds No V/S Power Consumption (120W)

Power consumption of different inserts and plain tube are compared at different values of Reynolds number. The figure 6.7.1, 6.7.2 & 6.7.3 shows the comparison of the power consumption of plain tube with the power consumption of twisted strip & streamlined body at different heat inputs. It is observed that the power consumption of plain tube is minimum for a particular heat input & Reynolds number followed by that of streamlined body & twisted strip.
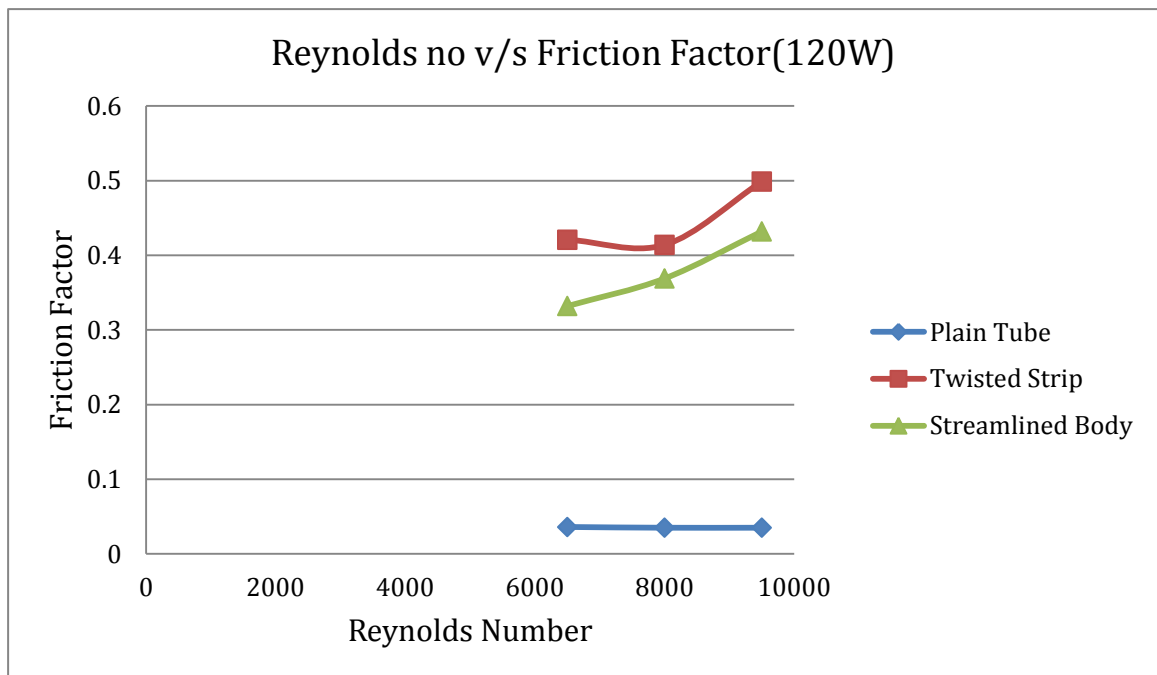
6.8 REYNOLDS NO V/S FRICTION FACTOR
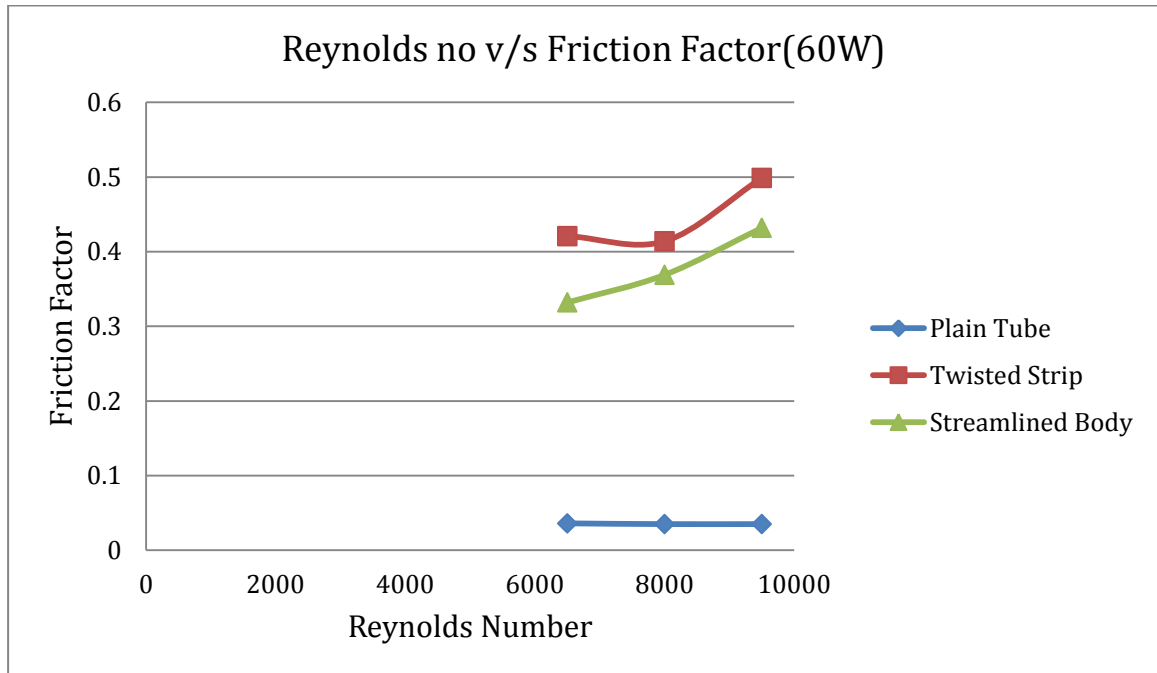
**Graph 6.8.1 Reynolds No V/S Friction Factor(60W)**
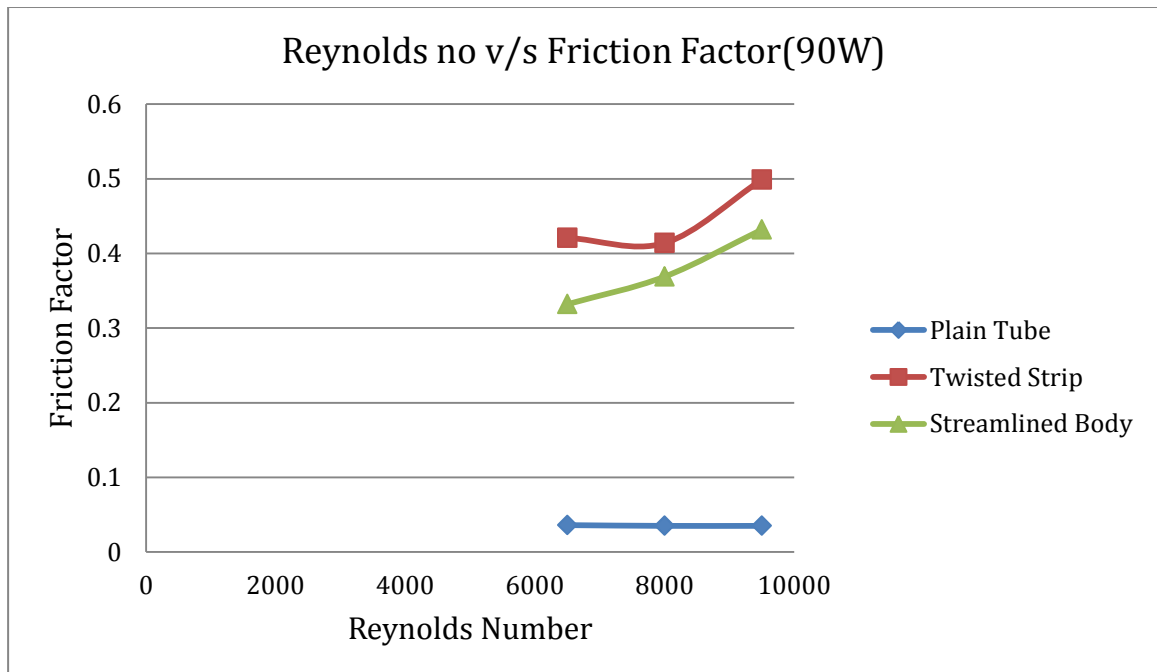
**Graph 6.8.2 Reynolds No V/S Friction Factor(90W)**

Graph 6.8.3 Reynolds No V/S Friction Factor(120W)

Friction factor is a measure of pressure loss in a system to the kinetic energy of the fluid. Friction factor of different inserts and plain tube are compared at different values of Reynolds number. The figure 6.8.1, 6.8.2 & 6.8.3 shows the comparison of the friction factor of plain tube with the friction factor of twisted strip & streamlined body at different heat inputs. It is observed that the friction factor of plain tube is minimum and friction factor of streamlined body is less than that of twisted strip for a particular heat input & reynolds number.
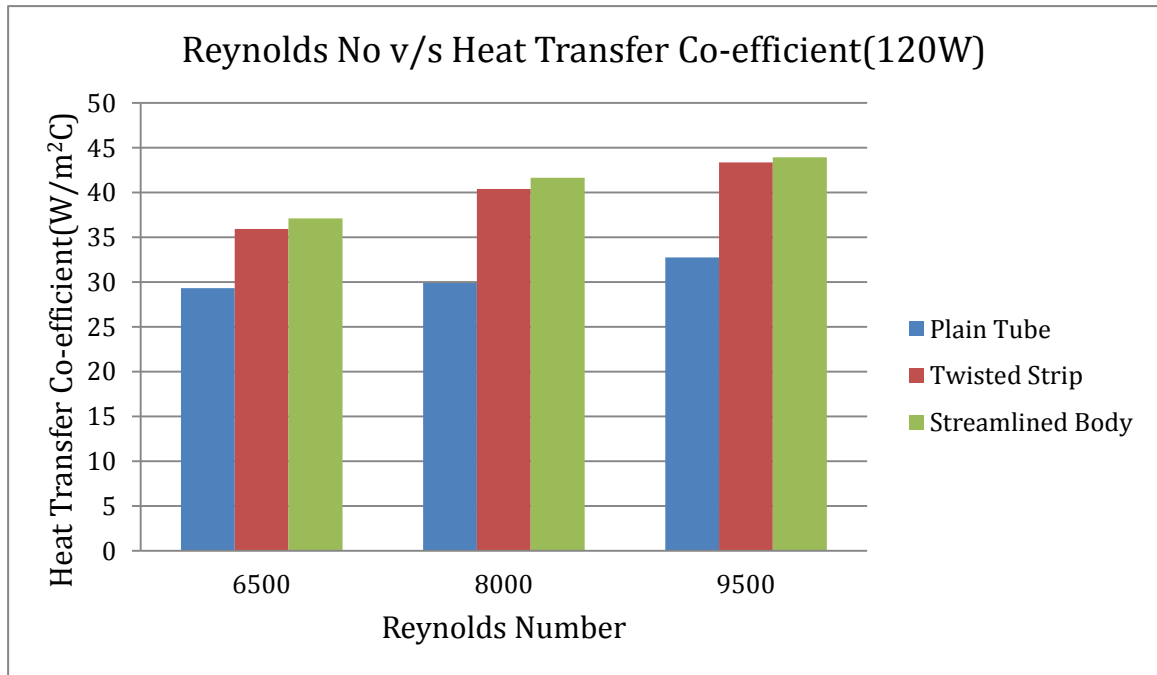
6.9 REYNOLDS NO V/S HEAT TRANSFER CO-EFFICIENT
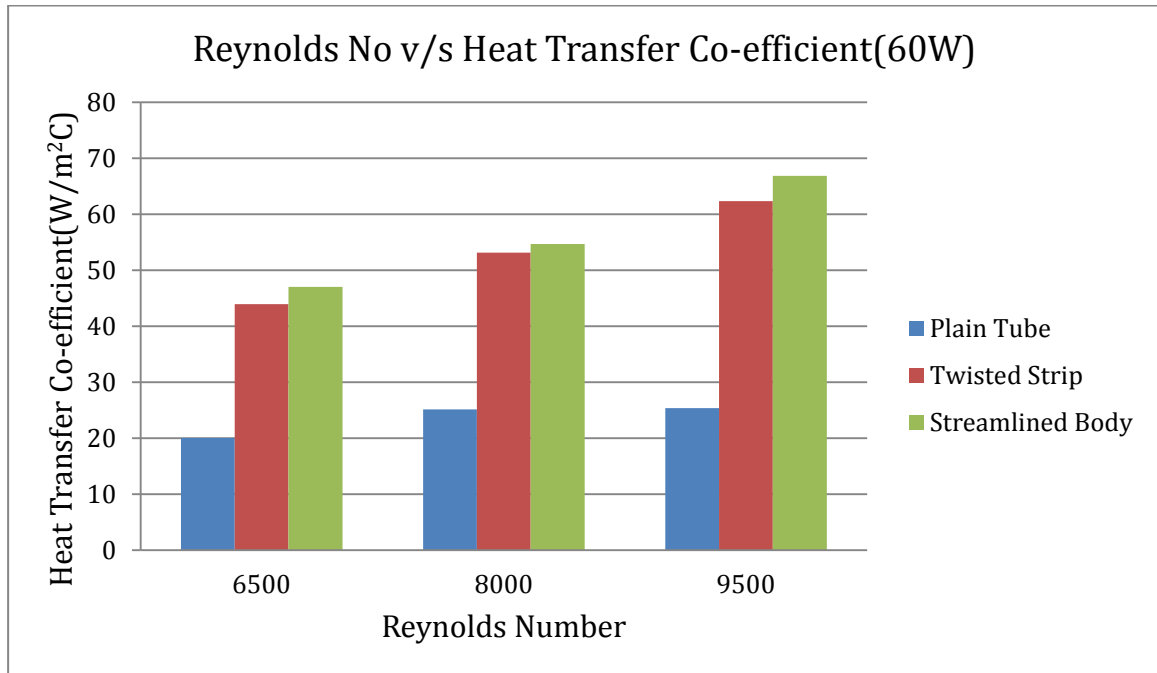
Graph 6.9.1 Reynolds No V/S Heat Transfer Co-Efficient(60W)
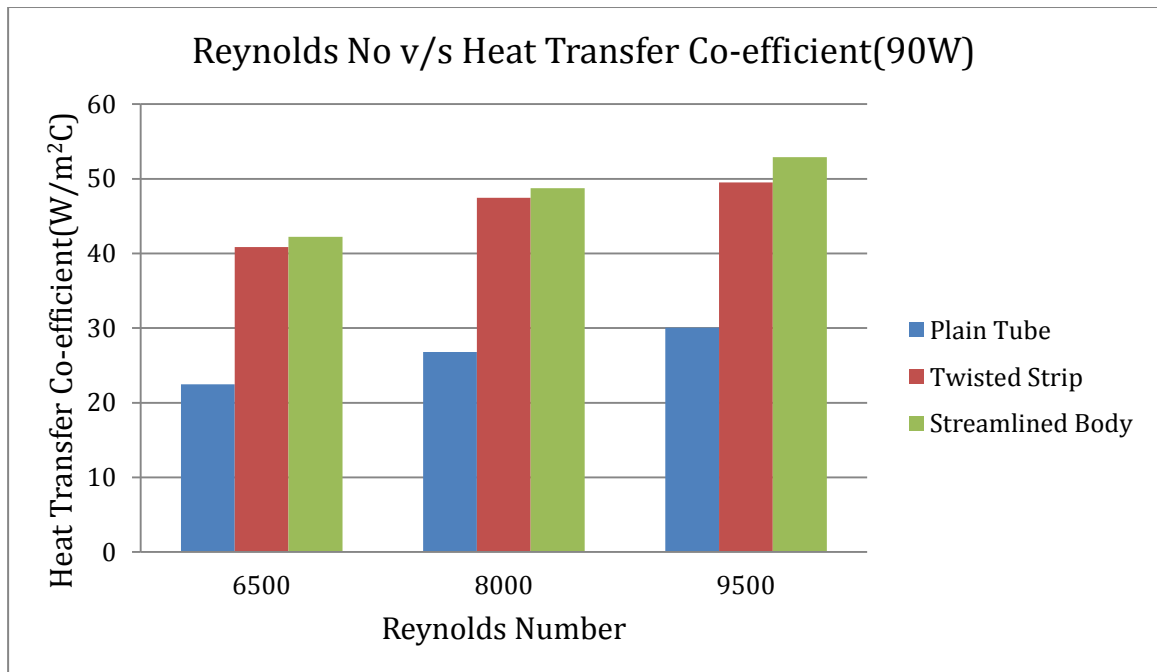
Graph 6.9.2 Reynolds No V/S Heat Transfer Co-Efficient(90W)

Reynolds No v/s Heat Transfer Co-efficient(120W)

Graph 6.9.3 Reynolds No V/S Heat Transfer Co-Efficient(120W)

Heat transfer co-efficient values for different inserts are compared at different Reynolds numbers. Figure no 6.1.1, 6.1.2 & 6.1.3 shows the comparison of heat transfer co efficient values for different inserts at different Reynolds number values. It is observed that the value of heat transfer co-efficient for twisted strip is higher when compared with the values of plain tube And values of heat transfer co-efficient for streamlined body is higher when compared with the values of plain tube and twisted strip. The streamlined body gives the maximum values of heat transfer as compared with the other inserts.

7. CONCLUSION

An experimental study of the flow of air in a circular channel with annular blockages subjected to uniform heat flux boundary condition has been performed.

The effect of different inserts on Reynolds number, heat transfer co-efficient and friction factor has been studied. Experimental results measured with twisted strip and streamlined body in test surface, are given for Reynolds number from 6500 to 9500.

Following conclusions have been drawn.

- ➢ With increase in Reynolds number, nusselt number also increases.
- ➢ For twisted strip it was observed that the heat transfer enhancement can be achieved up to 1.8 to 2 times that that for plain tube.
- ➢ For streamlined body it was observed that the heat transfer enhancement can be achieved up to 2 to 2.3 times that that for plain tube.
- ➢ Over all enhancement ratio for streamlined body is higher than twisted strip.
- ➢ The pressure drop increases with different inserts, but the pressure drop for streamlined body is less as compared with the twisted strip.

8. REFERENCES

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2. **Dr. Anirudh Gupta, Mayank Uniyal** "Review of Heat Transfer Augmentation through Different Passive Intensifier Methods"IOSR Journal of Mechanical and Civil Engineering (IOSRJMCE) ISSN: 2278-1684 Volume 1, Issue 4 (July-Aug 2012), PP 14-21.

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