EXPERIMENTAL STUDIES ON HEAT TRANSFER AUGMENATATION USING GALVANISED IRON WIRE INSERT WITH AND WITHOUT BAFFLES

A thesis submitted in partial fulfilment of the requirements for the degree of

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Under the Guidance of

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By

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CERTIFICATE

This is to certify that the thesis entitled, **"EXPERIMENTAL STUDIES ON HEAT TRANSFER AUGMENTATION USING GALVANISED IRON WIRE INSERT WITH AND WITHOUT BAFFLES"** submitted by **Tulika Rastogi (110CH0476)** in partial fulfilment of the requirement for the award of Bachelor of Technology Degree in Chemical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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Date:

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ABSTRACT

The present project work on "**Experimental Studies on Heat Transfer Augmentation Using Galvanised Iron Wire Insert With and Without Baffles**" was undertaken with a view to increase the effective thermal performance of heat exchangers. Every commercial, industrial and domestic application, where conversion or utilization of energy is involved, requires a heat exchange process. In the present project work, the effect of addition of GI wire insert with and without baffles, in the flow path of liquid was investigated. This project deals with the using four Twisted Galvanised Iron (GI) wires with and without baffles, as passive augmentation device. By introduction of these inserts in the flow path of liquid in the inner tube of the heat exchanger the effect of turbulence on Nusselt number was observed. It was compared with the values for smooth tube. The effect of baffles made of tin was also taken into account and a comparative study was made on the basis of varying baffle space. All the results and readings were compared with the standard data from the smooth tube. The Nusselt number was found to increase with decreasing baffle space. The 4 wire insert with baffle space 6cm was found to be the most efficient among all the configurations used.

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NOMENCLATURE

A_i	Heat transfer area, m^2
A_{xa}	Cross- section area of tube with twisted tape, m^2
A_{xo}	Cross-section area of tube, m^2
C_p	Specific heat of fluid, J/Kg.K
d_i	ID of inside tube, m
d_o	OD of inside tube, m
f	Fanning friction factor, Dimensionless
f_a	Friction factor for the tube with inserts, Dimensionless
f_o	Theoretical friction factor for smooth tube, Dimensionless
g	acceleration due to gravity, m/s^2
Gz	Graetz Number, Dimensionless
h	Heat transfer coefficient, $W/m^2 °C$
h_a	Heat Transfer Coefficient for tube with inserts, $W/m^2 °C$
h_o	Heat Transfer Coefficient for equivalent smooth tube, $W/m^2 °C$
L	heat exchanger length, m
LMTD	Log mean temperature difference, °C
m	Mass flow rate, kg/sec
Nu	Nusselt Number, Dimensionless
Nu_a	Nusselt number for tube with inserts
Nu_o	Nusselt number for smooth tube
$Nu_i(exp)$	Experimental Nusselt number
$Nu_i(theo)$	Theoretical Nusselt number
Pr	Prandtl number, dimensionless
Q	Heat transfer rate, W
Re	Reynolds Number, Dimensionless
R_1	Performance evaluation criteria based on constant flow rate, Dimensionless

R_3	Performance evaluation criteria based on constant pumping power, Dimensionless
U_i	Overall heat transfer coefficient based on inside surface area, W/m^2°C
v	flow velocity, m/s^2

Greek letters

Δh	Height difference in manometer, m
ΔP	Pressure difference across heat exchanger, N/m^2
μ	Viscosity of the fluid, N s/m^2
μ_b	Viscosity of fluid at bulk temperature, N s/m^2
μ_w	Viscosity of fluid at wall temperature, N s/m^2
ρ	Density of the fluid, kg/m^3
β	Baffle spacing in cm.

Chapter 1

INTRODUCTION

Heat exchangers are used in different procedures spanning from conversion, consumption & recovery of thermal energy in various industrial, industrial & domestic applications. Some general examples include steam generation & concentration in power & cogeneration plants; sensible heating & cooling in thermal processing of chemical, pharmaceutical & agricultural products; fluid heating in manufacturing & waste heat recovery etc. Increase in Heat exchanger's performance can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to a heat exchange process.

The need to increase the thermal performance of heat exchangers, thereby effecting energy, material & cost savings have led to advancement & use of many techniques as ―*Heat transfer Augmentation*‖. These methods are also known as ―*Heat transfer Enhancement*‖ or ―*Intensification*‖. Augmentation techniques increase convective heat transfer by decreasing the thermal resistance of a equipment.

Use of Heat transfer enhancement methods lead to increase in heat transfer coefficient but at the risk of increase in pressure drop. So, while designing a heat exchanger using any of these techniques, analysis of heat transfer rate & pressure drop has to be done.

The objective of this project is to find a suitable insert that will give the desired heat transfer enhancement. And thus develop empirical equations for all configurations of Nu vs Re.

Chapter 2

LITERATURE REVIEW

2.1 CLASIFICATION OF ENHANCEMENT TECHNIQUES: [1, 2]

Heat transfer enhancement or augmentation techniques refer to the improvement of thermohydraulic performance of heat exchangers. Existing enhancement techniques can be broadly classified into three different categories:

1. Passive Techniques
2. Active Techniques
3. Compound Techniques

1. PASSIVE TECHNIQUES: These techniques usually use surface or geometrical modifications to the flow channel by using inserts/additional devices. They encourage higher heat transfer coefficients by altering the existing flow behaviour (except for extended surfaces) which also leads to increase in the pressure drop. In case of extended surfaces, effective heat transfer area, which is on the side of the extended surface, is increased.

Passive techniques hold the benefit over the active techniques as they do not require any external power. Heat transfer augmentation by these techniques can be obtained by using:

- **Treated Surfaces**: This technique uses pits, cavities or scratches like alteration in the surfaces of the heat transfer area which can be continuous or discontinuous. They are mainly used for boiling and condensing duties.
- **Rough surfaces**: These surface modifications create disturbance in the viscous sub-layer region. These techniques are applicable in single phase turbulent flows.
- **Extended surfaces**: Plain fins are one of the earliest types of extended surfaces used in many heat exchangers. Finned surfaces have become very popular owing to their ability to disturb the flow field apart from increasing heat transfer area.
- **Displaced enhancement devices**: These inserts are used in confined forced convection. They improve heat transfer 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 swirl flow or secondary circulation on the axial flow in a channel. Helical twisted tape, twisted ducts & various forms of altered (tangential to axial direction) are swirl flow devices. They can be used for both single phase and two-phase flows.

- **Coiled tubes**: In these devices secondary flows or vortices are generated due to curvature of the coils which encourage higher heat transfer coefficient in single phase flows and in most regions of boiling. This leads to relatively compact heat exchangers.
- **Surface tension devices:** These devices direct and improve the flow of liquid to boiling surfaces and from condensing surfaces. Examples are wicking or grooved surfaces.
- **Additives for liquids**: This technique incorporates addition of solid particles, soluble trace additives and gas bubbles added to the liquids to Decrease the drag resistance in case of single phase flows. In case of boiling systems, trace additives are added to Decrease the surface tension of the liquids.

2. ACTIVE TECHNIQUES: The method requires external power input for desired flow modification and enhancement in the rate of heat transfer. It finds limited application because of the need of external power in many practical applications. Various active techniques are as follows:

- **Mechanical Aids**: Examples of the mechanical aids are rotating tube exchangers and scrapped surface heat and mass exchangers. These devices stir the fluid by mechanical means or by rotating the surface.
- **Surface vibration**: They have been used primarily in single phase flows. A low or high frequency is applied to facilitate the surface vibrations which results in higher convective heat transfer coefficients.
- **Fluid vibration**: Instead of applying vibrations to the surface, pulsations are created in the fluid itself. This kind of vibration enhancement technique is employed for single phase flows.
- **Electrostatic fields**: Electrostatic field like electric or magnetic fields or a combination of the two from DC or AC sources is applied in heat exchanger systems which induces greater bulk mixing, force convection or electromagnetic pumping to enhance heat transfer. This technique is applicable in heat transfer process involving dielectric fluids.
- **Injection**: In this technique, same or other fluid is injected into the main bulk fluid through a porous heat transfer interface or upstream of the heat transfer section. This technique is used for single phase heat transfer process.
- **Suction**: This technique is used for both two phase heat transfer and single phase heat transfer process. Two phase nucleate boiling involves the vapour removal through a porous heated surface whereas in single phase flows fluid is withdrawn through the porous heated surface.

- **Jet impingement:** This technique is applicable for both two phase and single phase heat transfer processes. In this method, fluid is heated or cooled perpendicularly or obliquely to the heat transfer surface.

3. COMPOUND TECHNIQUES: 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.

2.2 PERFORMANCE EVALUATION CRITERIA: [1]

In most practical applications of enhancement techniques, the following performance objectives, along with a set of operating constraints and conditions, are usually considered for optimizing the use of a heat exchanger:

1. Increase the heat duty of an existing heat exchanger without altering the pumping power (pressure drop) or flow rate.
2. Decrease the approach temperature difference between the two heat-exchanging fluid jets for a specific heat load and size of exchanger.
3. Decrease the size or heat transfer surface area requirements for a specified heat duty and pressure drop or pumping power.
4. Decrease the process stream's pumping power requirements for a given heat load and exchanger surface area.

It may be noted that objective 1 accounts for increase in heat transfer rate, objective 2 and 4 yield savings in operating (or energy) costs, and objective 3 leads to material savings and Decreased capital costs.

Different Criteria used for evaluating the performance of a single phase flow are:

- Fixed Geometry (FG) Criteria: The area of flow cross-section (N and d_i) and tube length L are kept constant. This criterion is typically applicable for retrofitting the smooth tubes of an existing exchanger with enhanced tubes, thereby maintaining the same basic geometry and size (N, d_i, L). The objectives then could be to increase the heat load Q for the same approach temperature ΔT_i and mass flow rate *m* or pumping power P; or decrease ΔT_i or P for fixed Q and m or P; or Decrease P for fixed Q.
- Fixed Number (FN) Criteria - The flow cross sectional area (N and d_i) is kept constant, and the heat exchanger length is allowed to vary. Here the objectives are to seek a reduction in either the heat transfer area (A → L) or the pumping power P for a fixed heat load.
- Variable Geometry (VN) Criteria - The flow frontal area (N and L) is kept constant, but their diameter can change. A heat exchanger is often sized to meet a specified heat duty Q for

a fixed process fluid flow rate *m*. Because the tube side velocity Decreases in such cases so as to accommodate the higher friction losses in the enhanced surface tubes, it becomes necessary to increase the flow area to maintain constant *m*. This is usually accomplished by using a greater number of parallel flow circuits.

Table 1: Performance Evaluation Criteria [1]

Case	**Geometry**	**M**	**P**	**Q**	**ΔT_i**	**Objective**
FG-1a	N, L, Di	X			X	Q↑
FG-1b	N, L, Di	X		X		ΔTi↓
FG-2a	N, L, Di		X		X	Q↑
FG-1b	N, L, Di		X	X		Δ Ti↓
FG-3	N, L, Di			X	X	P↓
FN-1	N, Di		X	X	X	L↓
FN-2	N, Di	X		X	X	L↓
FN-3	N, Di	X		X	X	P↓
VG-1	---	X	X	X	X	(NL) ↓
VG-2a	N, L	X	X		X	Q↑
VG-2b	N, L	X	X	X		Δ Ti↓
VG-3	N, L	X		X	X	P↓

Bergles et al [3] suggested a set of eight (R1-R8) number of performance evaluation criteria as shown in Table 2.

Table 2: Performance Evaluation Criteria of Bergles et al [3]

	Criterion number							
	R1	R2.	R3	R4	R5	R6	R7	R8
Basic Geometry	×	×	×	×				
Flow Rate	×						×	×
Pressure Drop		×				×		×
Pumping Power			×					
Heat Duty				×	×	×	×	×
Increase Heat Transfer	×	×	×					
Decrease pumping power				×				
Decrease ExchangeSize					×	×	×	×

Chapter 3

PRESENT EXPERIMENTAL WORK

3.1 SPECIFICATIONS OF HEAT EXCHANGER USED

The experimental study is done in a double pipe heat exchanger having the specifications as listed below:-

Specifications of Heat Exchanger:
Inner pipe ID = 22mm
Inner pipe OD=25mm
Outer pipe ID =53mm
Outer pipe OD =61mm
Material of construction of inner tube= Copper
Heat transfer length= 2.43m
Pressure tapping to pressure tapping length = 2.825m

Water at room temperature was allowed to flow through the inner pipe while hot water (set point 60°C) flowed through the annulus side in the counter current direction.

3.2 EXPERIMENTAL SETUP

Figure 1 shows the schematic diagram of the experimental setup. It is a double pipe heat exchanger consisting of a calming section, test section, rotameters, overhead water tank for supplying cold water & a constant temperature bath (500 litre capacity) for supplying hot water with in-built heater, pump & the control system. The test section is a smooth copper tube with dimensions of 3000mm length, Inner tube-22mm ID, and 25mm OD; Outer GI pipe-53mm ID, and 61 mm OD. The outer pipe is well insulated using 15mm diameter asbestos rope to Decrease heat losses to the atmosphere. Two calibrated rotameters, with the flow ranges 300 to 1250 LPH, are used to measure the flow of cold water. The water, at room temperature is drawn from an overhead tank using gravity flow. Similarly a rotameter of same capacity is provided to control the flow rate of hot water from the inlet hot water tank. Hot water flow rate is kept constant at 1000 LPH. Two pressure tapings- One just before the test section and the other just after the test section are attached to the U-tube manometer for pressure drop measurement. Carbon tetrachloride is used as the manometric fluid. Bromine crystals were dissolved in it to impart pink colour to it for easy identification. Four RTDs measure the inlet & outlet temperature of hot water & cold water (T_1 –T_4) through a multipoint digital temperature indicator. Figure 2 shows photograph of the setup.

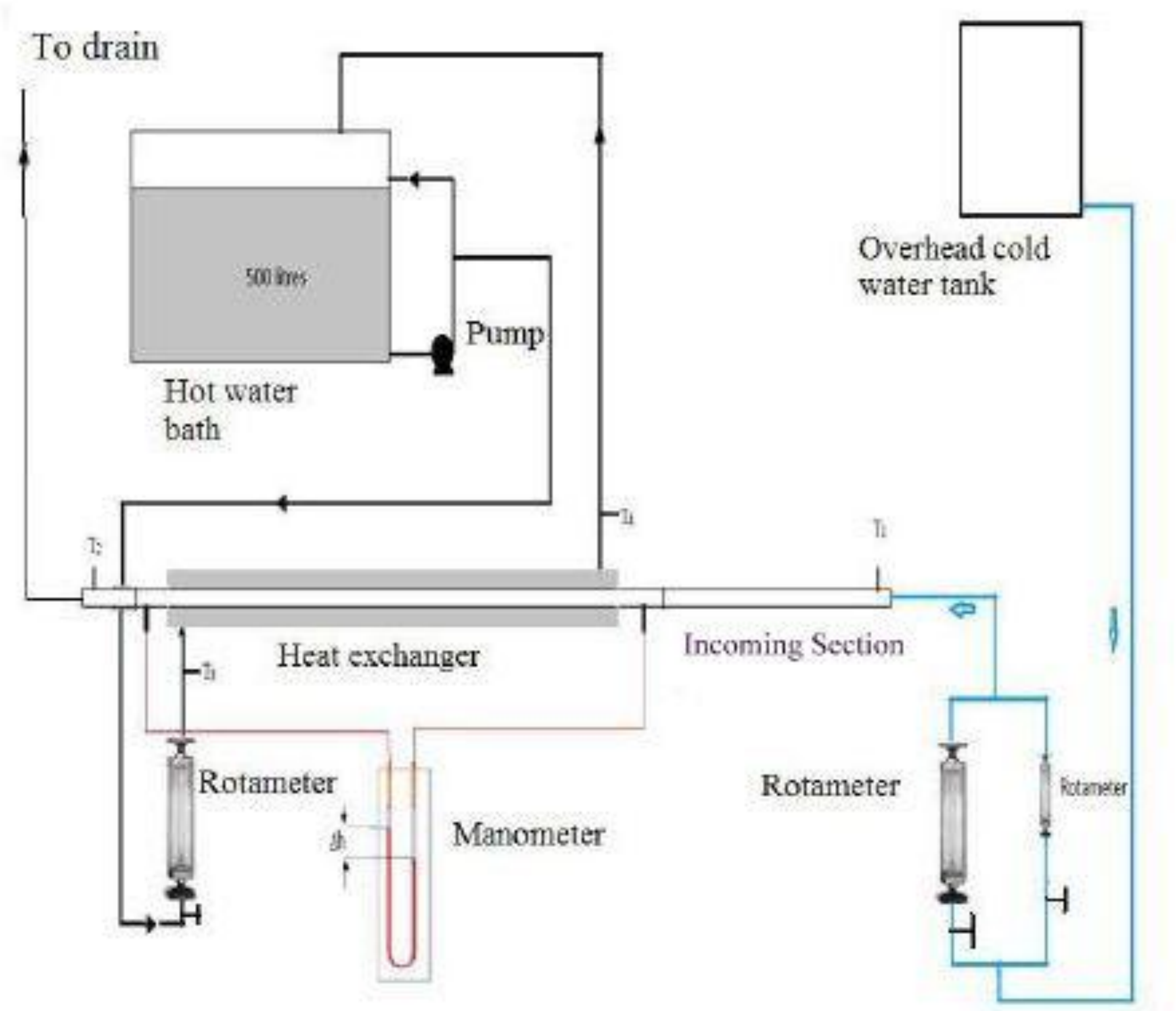

Figure 1: Schematic Diagram of the Heat Exchanger

Figure 2: Photograph of the Heat Exchanger

3.3 TYPE OF INSERT USED

For experiments insert made from Galvanised iron (GI) wire of diameter 1.2 mm were used. Figure 3 shows the GI wire used to make the inserts.

Figure 3: Galvanised Iron wire used to make the insert.

Four GI wires of 3m length each were twisted together to form an insert. At equal intervals 18mm long GI wires were tied perpendicular to the insert to support it. Figure 4 shows the 4 wire insert along with 18mm perpendicular wires to support it.

Figure 4: 4 wire insert without baffles

Baffles of diameter 14mm were made of tin sheet. They were attached at distances of 6cm, 12cm, 24cm for experimental studies.

Figure 5 shows the baffles attached to the insert.

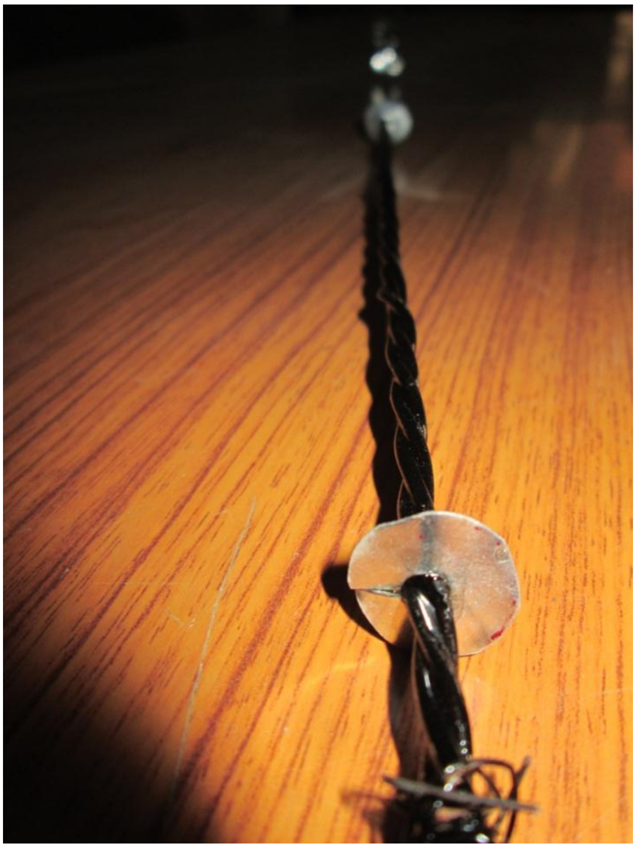

Figure 5: Circular baffles attached to the insert.

Figure 6 shows the 4 wire insert with baffle spacing 24cm.

Figure 6: The 4 wire insert with baffle spacing 24cm

Figure 7 shows the 4 wire insert with baffle spacing 12cm.

Figure 7: 4 wire insert with baffle spacing 12cm.

Figure 8 shows the 4 wire insert with baffle spacing 6 cm.

Figure 8: 4 wire insert with baffle spacing 6cm.

3.4 FABRICATION OF INSERT

Four galvanised wire strip of length 300cm, diameter 1.2 mm were taken. One end of the wires were tied to a pole, each separated by an equal distance of 15cm. The other end of the four wires was attached to a 4-Way Lug Wrench. Figure 9 shows the 4-Way Lug Wrench to which the wires were attached.

Figure 9: 4-Way Lug Wrench

The desired twist was obtained manually until the backpressure was negated completely. One end was kept fixed on the pole while the other end was given a slow rotatory motion by rotating the lug wrench. During the whole procedure the wire was kept under tension by applying a mild back pressure on the set up to avoid its distortion. Six 18 mm long GI wire were tied at a distance of 50cm to support the setup when inserted inside the inner tube of the double pipe heat exchanger. They helped to keep the insert in the middle of the pipe. Figure 10 shows the GI wire tied to support the insert.

Figure 10: Support used for the insert

Thus an insert of total length of 3.0m, which is sufficient enough for the double pipe heat exchanger, was fabricated and used for the experiment.

3.5 FABRICATION OF BAFFLES

Tin sheet of thickness 1mm was used to make baffles. Circular baffles of diameter 14mm were cut and a 6mm hole was drilled in the centre of the baffle. For the ease of attachment the circular baffles were cut open from one side. They were then attached to the twisted wire insert at distances of 6cm, 12cm and 24cm. Figure 11 shows the baffles that were used for the experiment.

Figure 11: Baffles used in the experiment.

3.6 EXPERIMENTAL PROCEDURE:

1. All the rotameters & RTD are calibrated first.

i. For rotameter calibration, water is collected in a bucket. Weight of water collected & time of collection is noted to calculate mass flow rate of water.

ii. A minimum of 3 readings are taken for each flow rate & average flow rate is used for calculations. The readings are given in A.1.1

iii. For RTD calibration, all the RTDs are dipped in a constant water bath & readings shown by each RTD are noted. Temperature shown by one of the RTD (T1) was taken as reference & corrections were made to other RTDs values (i.e. T2-T4) accordingly.

2. Standardization of the set-up:

Before starting the experimental study on friction & heat transfer in heat exchanger using inserts, standardization of the experimental setup is done by obtaining the friction factor &

heat transfer results for the smooth tube & comparing them with the standard equations available.

3. For Nusselt number calculation:

a) Then, heater is put on to heat the water to 60°C in a constant temperature water tank of capacity 500 litres. The tank is provided with a centrifugal pump & a bypass valve for recirculation of hot water to the tank & to the experimental setup.

b) Hot water at about 60°C is allowed to pass through the annulus side of heat exchanger at 1000LPH ($\mathbf{m}_h$=0.2715 Kg/sec).

c) Cold water is now allowed to pass through the tube side of heat exchanger in counter current direction at a desired flow rate.

d) The water inlet and outlet temperatures for both hot water & cold water (T1-T4) are recorded only after temperature of both the fluids attains a constant value.

e) The procedure was repeated for different cold water flow rates ranging from 0.0331-0.3492 Kg/sec.

4. Preparation of Wilson chart:

$$\frac{1}{U} = \frac{1}{hi} + \frac{di}{do*ho} + \frac{xw*di}{kw*dl} + R_d + R_{do}$$

where R_d is the dirt resistance

All the resistances, except the first term on the RHS of equation are constant for this set of experiments.

For Re>10000, Seider Tate equation for smooth tube is of the form: $h_i = A \times Re^{0.8}$

$$\frac{1}{U} = \frac{1}{A \times Re\text{^}0.8} + K$$

5. After confirmation of validity of experimental values of Nusselt number in smooth tube with standard equations, heat transfer studies with inserts was conducted. The heat transfer observations & results for all the cases are presented in Tables A.2.1 – A.2.5 and Figures 15-19 respectively.

3.7 STANDARD EQUATIONS TO BE USED:

For heat transfer calculations following equations are used.

1. Laminar Flow:
   For Re<2100
   Nu= f(Gz)

Where $Gz = \frac{Re*Pr*di}{L}$

a. For Gz< 100, Hausen Equation is used.

$$Nu = 3.66 + \frac{0.085Gz}{1+0.045Gz^{0.67}}(\mu b/\mu w)^{0.14}$$

b. For Gz>100, Seider Tate equation is used.

$$Nu = 1.86Gz^{(1/3)}(\mu b/\mu w)^{0.14}$$

2. Transition Zone:

For 2100<Re<10000, Hausen equation is used

$$Nu = 0.116\left(Re^{(2/3)} - 125\right) * Pr^{1/3} * \left[1 + (D/L)^{(2/3)}\right] * (\mu b/\mu w)^{0.14}$$

3. Turbulent Zone:

For Re>10000, Seider-Tate equation is used.

$$Nu = 0.023 * Pr^{(1/3)} * Re^{0.8} * (\mu b/\mu w)^{0.14}$$

Viscosity correction Factor $(\mu b/\mu w)^{0.14}$ is assumed to be equal to 1 for all calculations as this value for water in present case will be very close to 1 & the data for wall temperatures is not measured.

3.8 PRECAUTIONS:

1. Rotameters should be calibrated properly to measure exact flow rate of water for a given rotameter reading.
2. RTDs should be calibrated properly. This is done by measuring temperature of normal water by all RTDs at the same time & then taking one of them as reference.
3. Temperature readings should be taken only when the inlet & outlet temperature of both the liquids reach a constant value.

Chapter 4

SAMPLE CALCULATIONS

4.1 ROTAMETER CALIBRATION

For 700 lph (Table No. A.1.1)

Observation No.1

Weight of water collected= 12.25 kg

Time= 65sec

m_1=0.1900 kg/sec

Observation No.2

Weight of water collected= 12.65kg

Time= 66sec

m_2= 0.1917 kg/sec

Observation No.3

Weight of water collected= 11.5 kg

Time= 61sec

m_3= 0.1885 kg/sec

$m = \frac{(m1+m2+m3)}{3} = \frac{(0.1900+0.1917+0.1885)}{3}$ = 0.1901kg/sec

4.2 HEAT TRANSFER CALULATION:

For 4 wire insert with ß=24cm (Table No.A.2.3)

m_c= 0.1901 kg/sec (600Kph) & **m_h**=0.2778 kg/sec

Temperature correction has already been taken into account while noting data in appendix.

T1 = 38.2 ^{0}C

T2 =41.7 ^{0}C

T3 =52.8 ^{0}C

T4 =50.8 ^{0}C

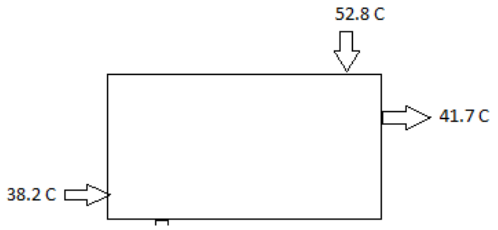

Figure 12: Line diagram of heat exchanger.

$\Delta T_1 = 50.7\text{-}38.2 = 12.5^0$C

$\Delta T_2 = 52.8\text{-}41.7 = 11.1^0$C

LMTD = $\frac{\Delta T1 - \Delta T2}{ln\frac{\Delta T1}{\Delta T2}} = \frac{12.5 - 11.1}{ln\frac{12.5}{11.1}}$ $=11.83^0$C

$Q_1 = m_c \times C_{pc} \times (T_2 - T_1) = 0.1901 \times 4187 \times (41.7\text{-}38.2) = 2785\ 82$ W

$Q_2 = m_h \times C_{ph} \times (T_3 - T_4) = 0.1901 \times 4187 \times (52.8 - 41.7) = 2835.03$ W

Heat Balance Error = $\frac{(2785.82 - 2835.03)}{2835.03} \times 100 = -1.74\%$

$Q_{avg} = \frac{Q1+Q2}{2} = 2810.43$W

Heat transfer area = $\pi \times di \times L = \pi \times 0.022 \times 2.43 = 0.168$m^2

$U_i = \frac{Qavg}{A \times LMTD} = \frac{2810.43}{0.1956 \times 11.83} = 1101.34$ W/m^{20}C

Re = $\frac{4 \times m}{\pi \times di \times \mu} = \frac{4 \times 0.1901}{\pi \times 0.022 \times 0.00078} = 14105$

h_a can be calculated by using the equation

$$\frac{1}{Ui} = \frac{1}{ha} + K$$

K is found form Wilson chart as intercept on y axis. $(1/Ui)\ vs\ (1/Re$^$0.8)$

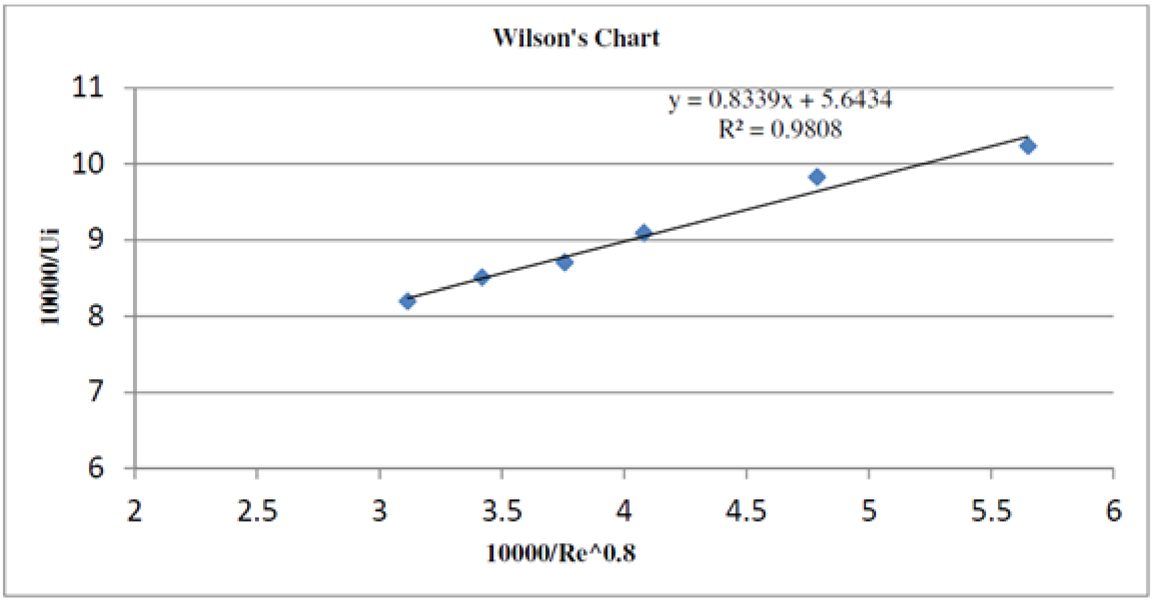

Figure 13: Wilson chart for smooth tube.

$$\frac{1}{ha} = \frac{1}{Ui} - 5.6434 \times 10^{-4}$$

h_a = 2960.1 W/m^2 ^{0}C

$Nu_a = (h * di)/k = \frac{2960.1*0.022}{0.6322} = 103.00$

Theoretical calculation for smooth tube

$Nu = 0.023 \times Re^{0.8} \times Pr^{1/3}$

$\frac{ho \times di}{k} = 0.023 \times Re^{0.8} \times Pr^{1/3}$

$h_o = \frac{0.023 \times k}{di} \times Re^{0.8} \times Pr^{1/3}$

For Prandlt number calculation Figure 14 is used

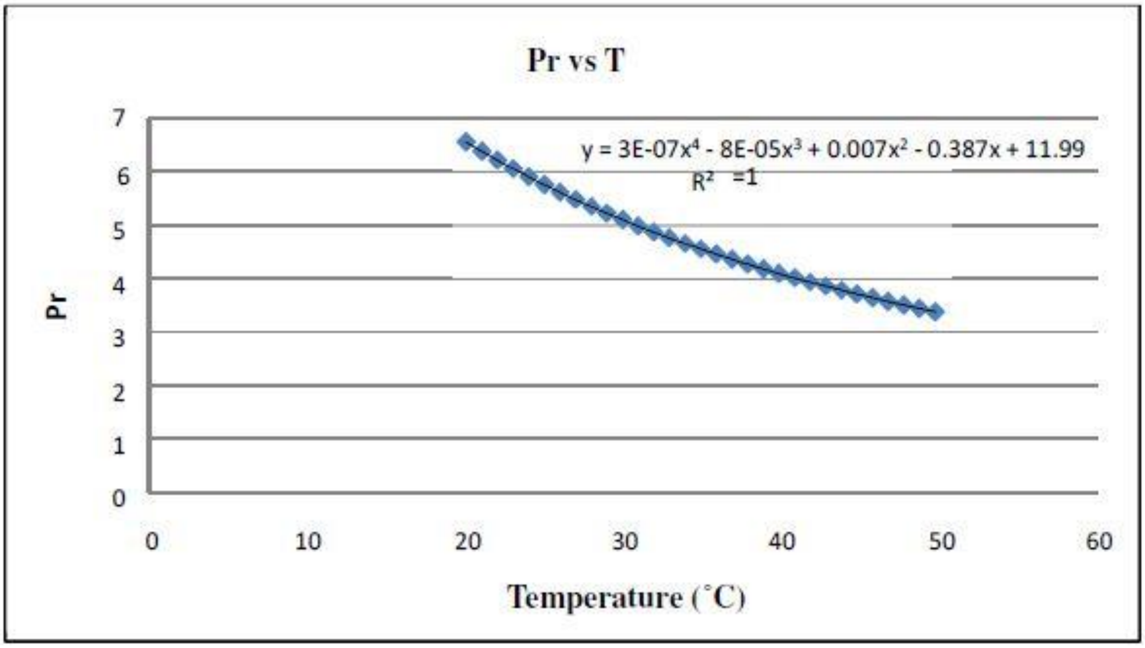

Figure 14: Pr vs Temperature relation

$Pr = 3 \times 10^{-7}T^4 - 8 \times 10^{-5}T^3 + 0.0072 \times T^2 - 0.03873 \times T + 11.995$

$Tavg = \frac{T1+T2}{2} = 39.95℃$

Pr(at T= T_{avg}) = 4.34

h_o (for smooth tube) = $\frac{0.023 \times 0.6322}{0.022} \times 14105^{0.8} \times 4.34^{1/3}$

h_o = 2179.61 w/m^{20}C

Performance evaluation criteria = $\frac{ha}{ho}$ = 1.36

$Nu_o = (h * di)/k = \frac{2179.61 \times 0.022}{0.6322} = 75.85$

Chapter 5

RESULTS AND DISCUSSION

5.1 HEAT TRANSFER RESULTS FOR INSERT WITHOUT BAFFLES

Table A.2.1-A.2.5 gives the heat transfer results for smooth tube, 4 wire insert without any baffle and with baffles(=24cm, 12cm, 6cm) along with the performance evaluation criteria for each of the readings. As shown in Figure 15 and Table 9, the difference between the experimental values and the values calculated using the empirical equations is within ±5%. So the experimental setup can be considered to produce reliable heat transfer results.

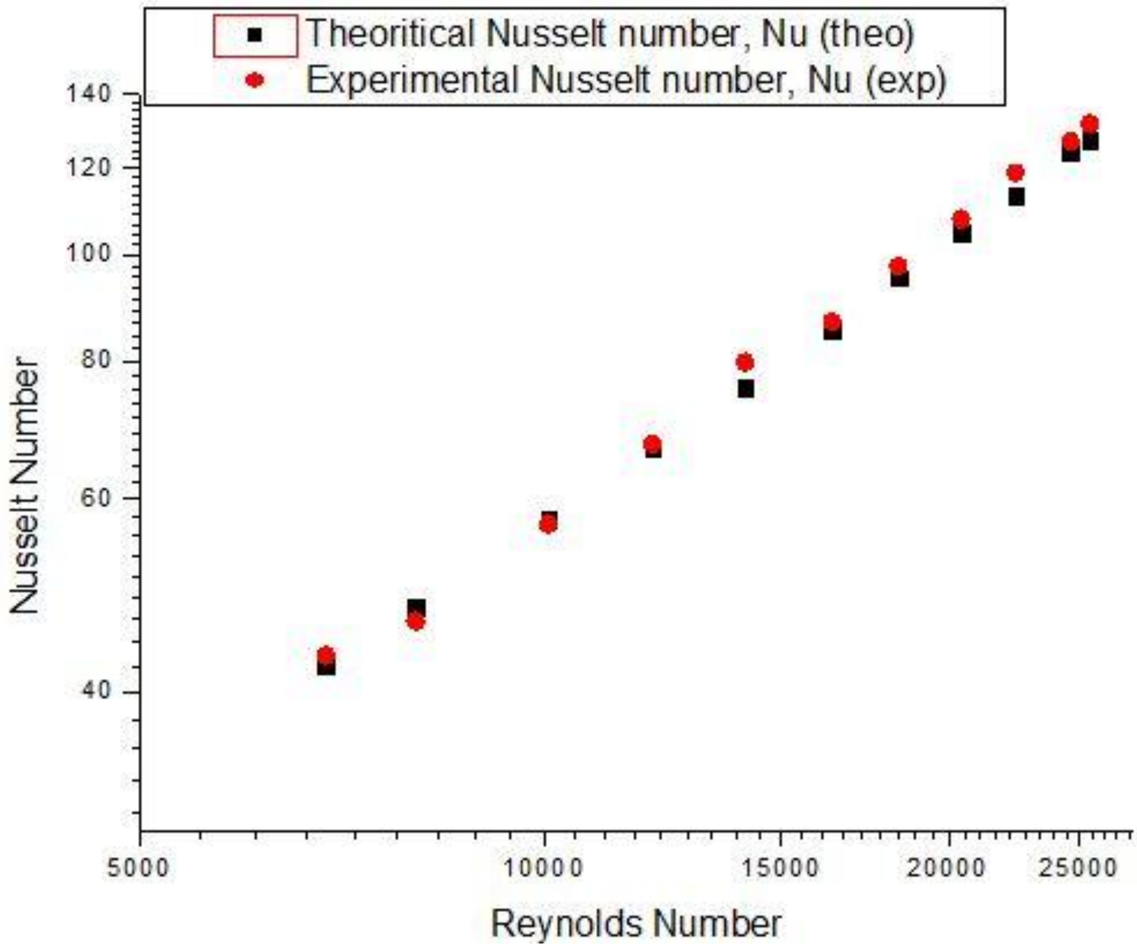

Figure 15: Nusselt number comparison for smooth tube.

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5.2 HEAT TRANSFER RESULTS FOR INSERT WITH BAFFLES

Figures below show the comparision of heat transfer results for smooth tube, 4 wire insert without any baffle and with baffles at 24cm, 12cm and 6cm. Figure 16 shows the variation of Nusselt number for smooth tube and 4 wire insert without baffles, against varying Reynolds number.

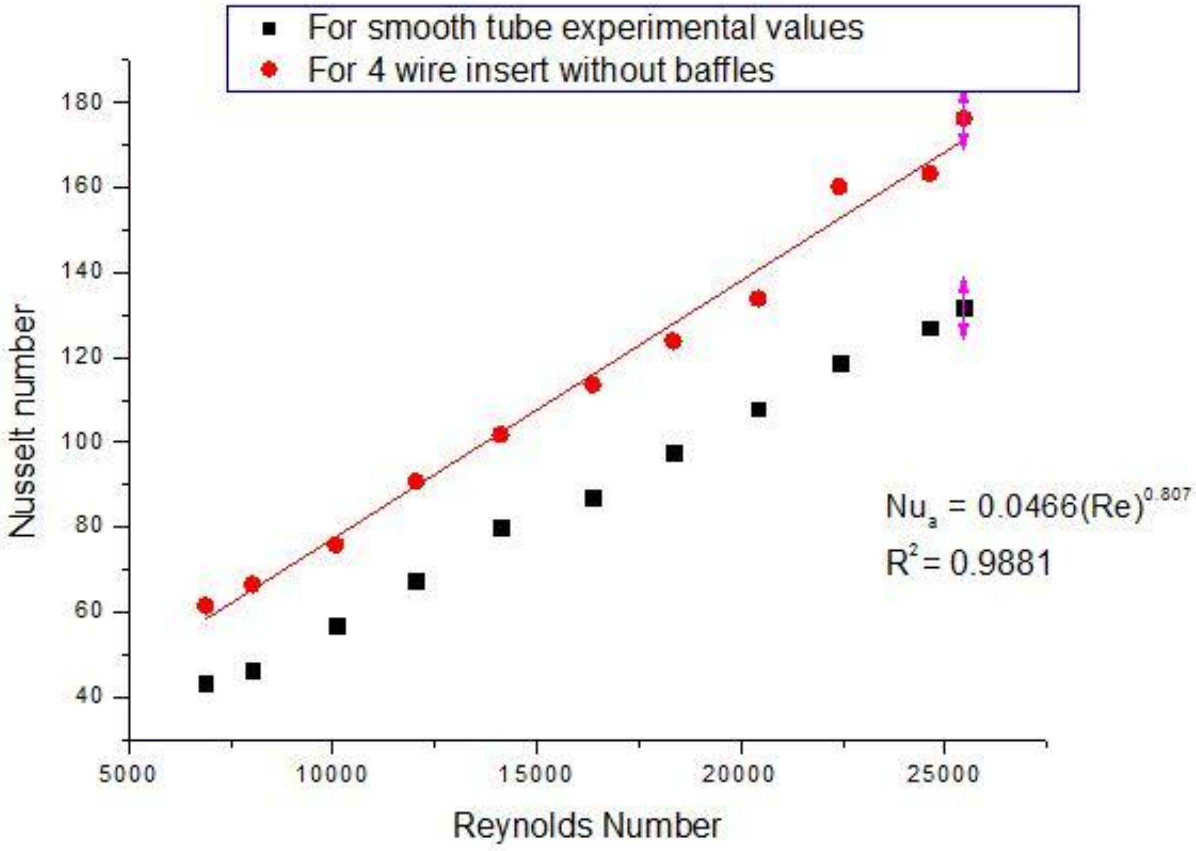

Figure 16: Comparison of Nusselt number for smooth tube and 4 wire insert without baffles.

As seen from figure 16, the 4 wire insert without baffles can be represented by equation $Nu = 0.0466\ (Re)^{0.807}$. From Table 10 it can also be observed that the Nusselt number for 4 wire insert without baffles is 28-45% higher than that for equivalent smooth tube.

Figure 17 shows the variation of Nusselt number values for smooth tube and 4 wire insert with baffles at 24cm. Equation $Nu = 0.0689(Re)^{0.7718}$ can be used to represent 4 wire insert with baffles at 24cm. From Figure 17 and Table 11 it can also be observed that the Nusselt number for the insert is 33-55% higher than that for equivalent smooth tube.

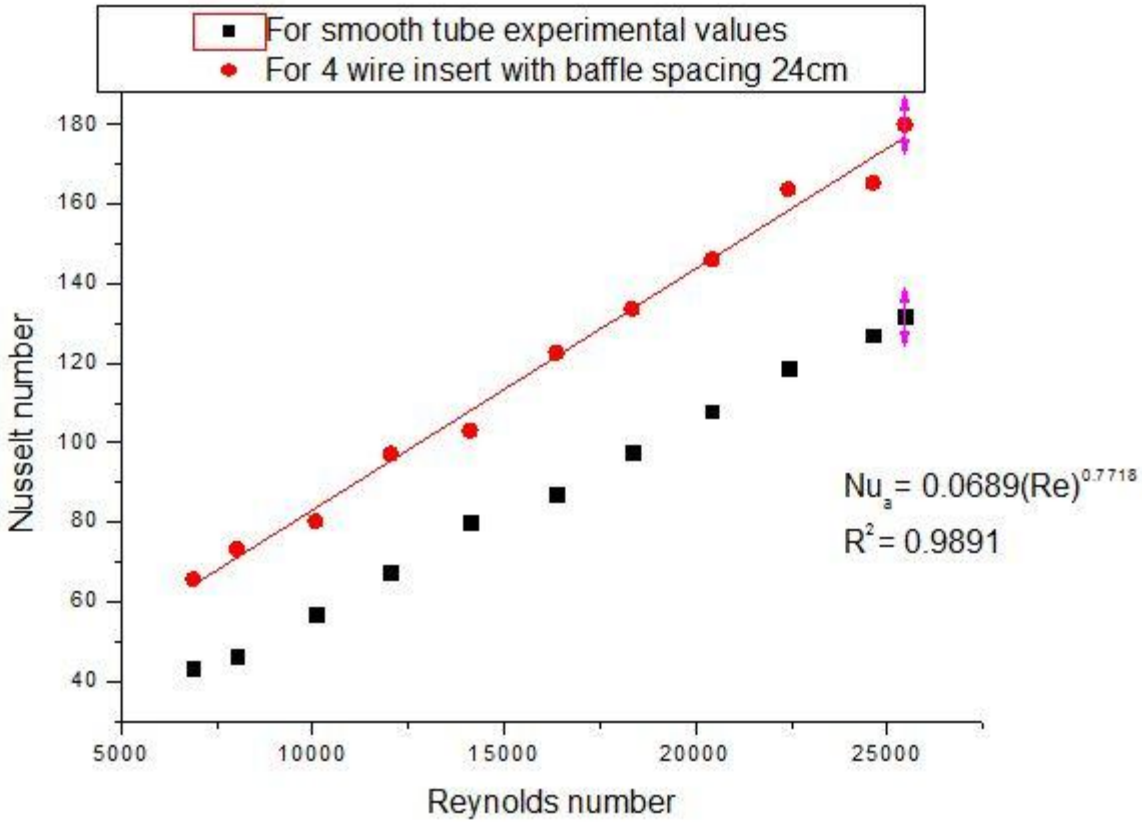

Figure 17: Comparison of Nusselt number values for smooth tube and 4 wire insert with baffles at 24cm.

Figure 18 shows the variation of Nusselt number values for smooth tube and 4 wire insert with baffles at 12cm.

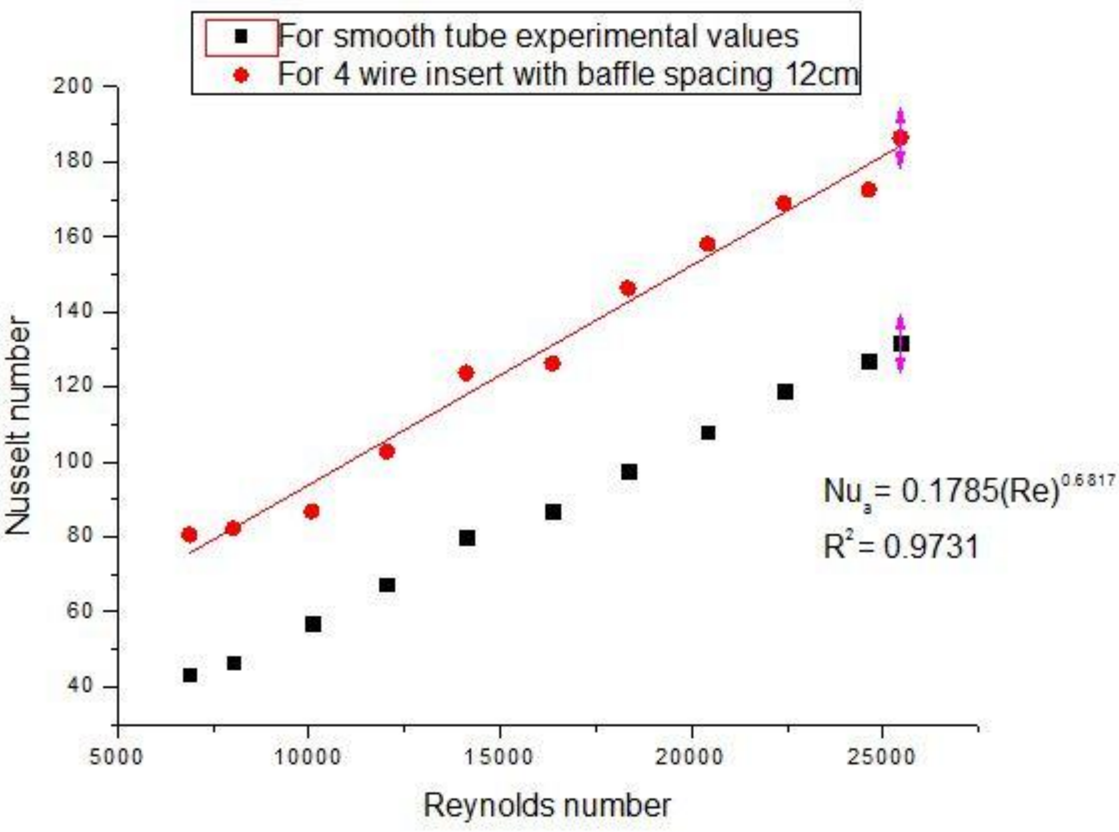

Figure 18: Comparison of Nusselt number values for smooth tube and 4 wire insert with baffles at 12cm

From Figure 18 and Table 12 it can be seen that the Nusselt number for 4 wire insert with baffle spacing 12cm is 39-90% higher than that of equivalent smooth tube. It can be represented by the equation $Nu = 0.1785(Re)^{0.6817}$

Figure 19 shows the variation of Nusselt number values for smooth tube and 4 wire insert with baffles at 6cm.

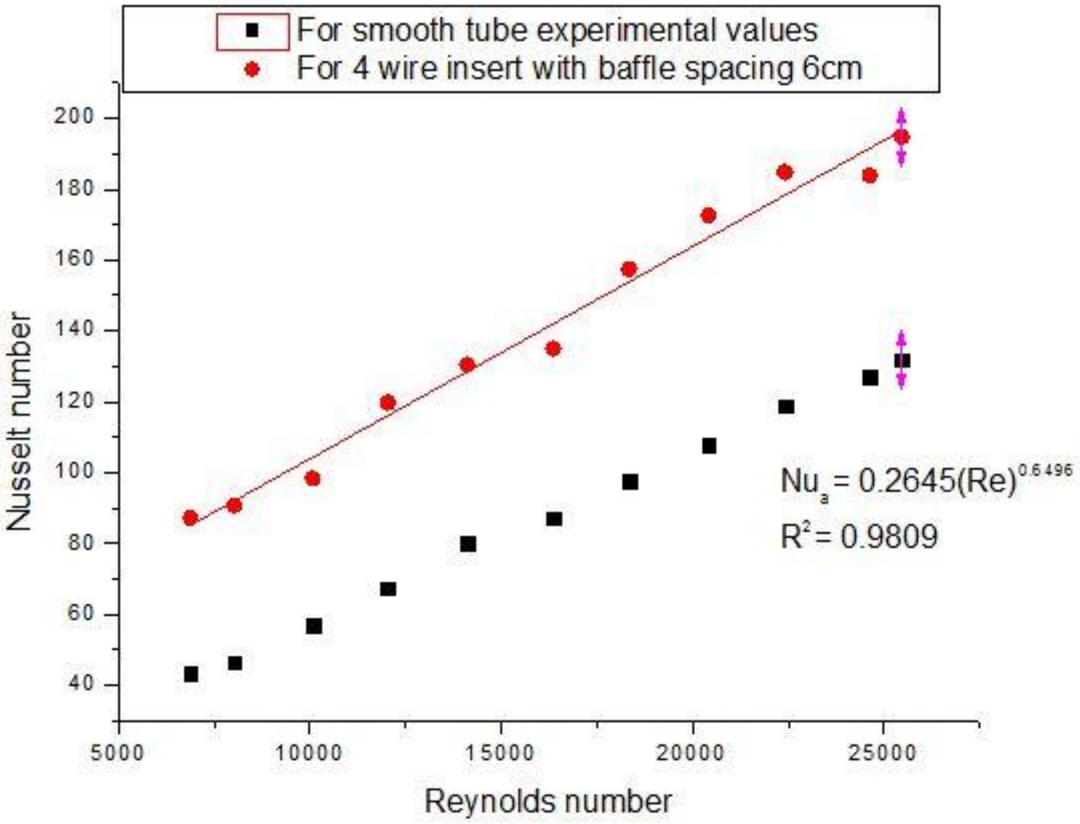

Figure 19: Comparison of Nusselt number values for smooth tube and 4 wire insert with baffles at 6cm.

From figure 19 and table 13 it can be seen that the Nusselt number for 4 wire insert with baffle spacing 6cm is 48-100% higher than that of equivalent smooth tube. It can be represented by the equation $Nu = 0.2645(Re)^{0.6495}$

Figure 20 shows the variation of Nusselt number values for smooth tube and 4 wire insert with and without baffles.

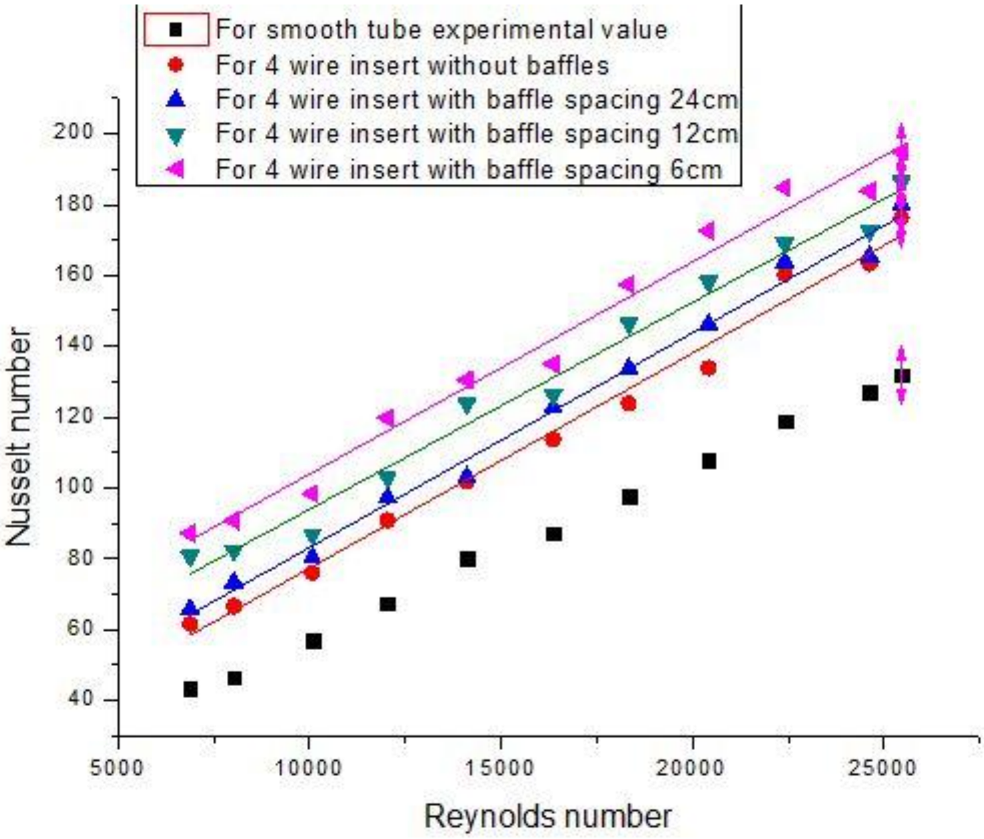

Figure 20: Comparison of Nusselt number for all configurations

As can be seen from the graph; as baffle spacing ß decreases a higher degree of turbulence is created in the tube & hence the Nusselt number increases as the baffle spacing decreases.

In Figure 21, performance evaluation criteria R_1 is plotted against Reynolds number for smooth tube, 4 wire insert without any baffle and the 4 wire insert with baffles at 24cm, 12cm and 6cm, where R_1 is defined as the increase in the heat transfer rate for fixed geometry and flow rate. From table 6, the overall range of R_1 has been found to be 1.28-2.05, increasing in the order of decreasing baffle spacing, the minimum being for the insert without baffles and the maximum being for insert with baffle space 6cm. With this we can conclude that this is the best arrangement out of all arrangements tested for this experiment.

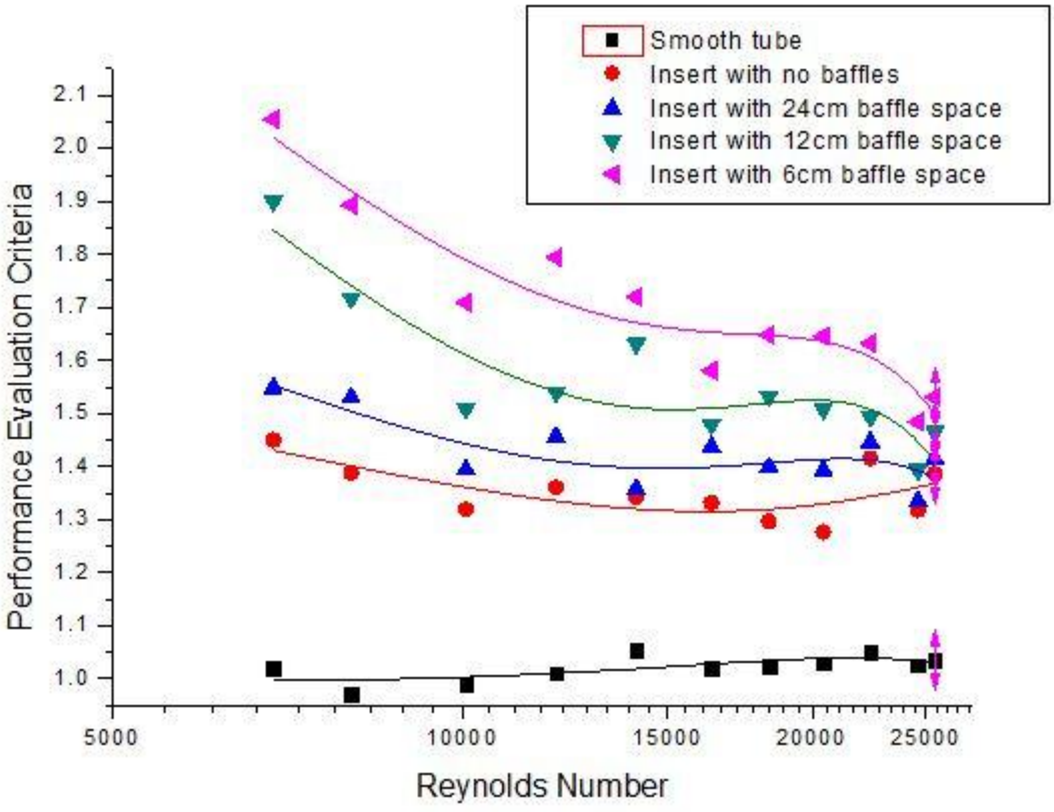

Figure 21: Comparison of Performance Evaluation Criteria for all the inserts.

Figure 21 has been obtained by fitting a polynomial of degree 3 to the data points obtained from all configurations.

EMPIRICAL RELATIONS DEVELOPED

From Figure 15-19 , the equations developed to represent the inserts have been summarized in the table below.

Table 3: Summary of equations developed for all configurations of the insert.

S.no	**Configuration**	**Equation Developed**
1.	Tube with 4 wire insert without baffles	$Nu = 0.0466\ (Re)^{0.807}$
2.	Tube with 4 wire insert with baffles at 24cm	$Nu = 0.0689(Re)^{0.7718}$
3.	Tube with 4 wire insert with baffles at 12cm	$Nu = 0.1785(Re)^{0.6817}$
4.	Tube with 4 wire insert with baffles at 6cm	$Nu = 0.2645(Re)^{0.6495}$

In the above equations the effect of $(\mathrm{Pr})^{(1/3)}$ is included with the average value of Prandlt number being 4.34.

Chapter 6

CONCLUSION

The range of Nusselt number and performance evaluation criteria is given in the table below.

Table 4: Summary of the results.

S.no	**Insert**	**Nusselt number**	**Performance Evaluation Criteria**
1	4 wire insert with no baffles	61-176	1.28 - 1.45
2	4 wire insert with baffles at 24cm	65-180	1.33 - 1.55
3	4 wire insert with baffles at 12 cm	80-187	1.39 - 1.90
4	4 wire insert with baffles at 6 cm	87-195	1.48 - 2.05

On the basis of performance evaluation criteria, it can be said that the 4 wire insert with baffle space 6cm is the best among all the configurations used as it gives the highest value of performance evaluation criteria value

It can also be observed that with decrease in baffle spacing ß, the Nusselt number increases. It varies in the range of 61-195, the minimum being for insert without any baffles and maximum being for insert with baffle space 6cm. But this improvement comes with an increase in values of pressure drop as well. Hence it would not be reliable to judge an insert's compatibility on the basis of Nusselt number value alone.

SCOPE FOR FUTURE WORK

Further modification can be done taking this study as the basis. Some of the possible areas of research may be:

1. Design of baffles can be changed to observe the effect they have on heat transfer coefficient of the tube and thus its Nusselt number.
2. The distance between baffles can further be Decreased as reducing the baffle distance gives good results
3. Different material for fabrication of baffles can be used.
4. Different number of wires can be used to alter the thickness of the main insert and hence changes in the Nusselt number can be noted.

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APPENDIX

A.1: CALIBRATION RESULTS

A.1.1: ROTAMETER CALIBRATION

Table 5: Rotameter Calibration

		Observation 1			Observation 2			Observation 3			
Rotameter reading LPH	Mass flow rate Kg/sec	Wt kg	Time sec	m Kg/sec	Wt kg	Time sec	m Kg/sec	Wt kg	Time sec	m Kg/sec	Average m Kg/sec
350	0.0972	12.6	150	0.1284	11.2	138	0.081159	11.96	153	0.07817	0.0927
400	0.1111	12.4	125	0.0992	12.4	132	0.093939	11.16	121	0.092231	0.1081
500	0.1381	11.2	105	0.106667	12	111	0.108108	11.14	103	0.108155	0.1357
600	0.16667	12.45	92	0.135326	13.7	99	0.138384	12.3	92	0.133696	0.1622
700	0.1945	13.3	82	0.162195	11.8	72	0.163889	12.6	78	0.161538	0.1901
800	0.2223	12.25	66	0.185606	12.55	65	0.193077	11.6	62	0.187097	0.2205
900	0.2501	13.3	62	0.214516	11.65	52	0.224038	11.55	51	0.226471	0.2471
1000	0.2778	12.75	53	0.240566	12.05	48	0.251042	12.9	45	0.286667	0.2752
1100	0.3056	13.6	51	0.266667	11.7	42	0.278571	12.3	41	0.3	0.302
1200	0.3334	12.25	42	0.291667	12.4	40	0.31	12.1	43	0.281395	0.3319
1250	0.3473	12.5	39	0.320513	13.2	39	0.338462	12.7	40	0.3175	0.3431

A.1.2: RTD CALIBRATION

Table 6: Rtd Calibration

S.NO	Temperature Readings							
	T1	Corrected T1	T2	Corrected T2	T3	Corrected T3	T4	Corrected T4
1	34.0	34.0	34.3	34.0	34.1	34.0	33.9	34.0
correction			-0.3		-0.1		+0.1	

A.2: HEAT TRANSFER RESULTS

A.2.1: STANDARDISATION OF SMOOTH TUBE (Nu_o vs Re)

Table 7: Standardisation Of Smooth Tube (Nu_o Vs Re)

S.no	m	T_1	T_2	T_3	T_4	LMTD	U_i	Re	Nu_i (exp)	Nu_i (theo)	%diff	$R_1=\frac{Nui\ (exp)}{Nu\ i(theo)}$
1	0.093	36.1	40.8	52.7	50.9	13.29	564.98	6878	43.26	42.41	-1.9994	1.0999
2	0.108	36	40.9	53	51.3	13.64	651.81	8021	46.47	47.91	3.0002	0.9699
3	0.136	36.1	40.6	52.3	50.3	12.91	851.39	10069	56.95	57.53	1.0004	0.9899
4	0.162	36.2	39.9	52.6	50.7	14.05	805.61	12035	67.40	66.73	-1.0001	1.01
5	0.19	36.1	39.3	52.9	50.8	14.14	887.92	14105	79.95	75.84	-5.412	1.0541
6	0.221	36.2	39.3	52.7	50.5	13.85	1051.5	16361	87.06	85.36	-2	1.0199
7	0.247	34	37.2	52.4	49.8	15.5	1152.4	18335	97.76	95.53	-2.339	1.0233
8	0.275	33.5	36.3	52.5	49.8	16.25	1160.7	20419	107.91	104.87	-2.8973	1.0289
9	0.302	33.5	35.8	52.9	49.9	16.75	1190.8	22408	118.90	113.24	-5	1.05
10	0.332	32.9	35	52.9	49.7	17.34	1264.2	24626	127.04	123.90	-2.5296	1.0252
11	0.343	31.7	34.6	53	49.8	18.25	1419.3	25457	131.73	127.24	-3.5304	1.0353

A.2.2: Nu VS Re FOR 4 WIRE INSERT WITH NO BAFFLES

Table 8: Nu Vs Re For 4 Wire Insert With No Baffles

S.no	m	T1	T2	T3	T4	LMTD	Ui	Re	Nu_a	Nu_o	$R1=\frac{Nu\ a}{Nu\ o}$
1	0.0927	35.4	41.3	53.8	51.7	14.32	645.34	6878	61.50	43.26	1.45
2	0.1081	36	40.5	53.2	51.1	13.87	640.99	8021	66.49	46.47	1.3877
3	0.1357	36.8	40	53.6	51.4	14.09	648.08	10069	75.89	56.95	1.3191
4	0.1622	35.6	39.9	53	50.9	14.17	912.9	12035	90.81	67.40	1.3608
5	0.1901	35.8	39.3	52.6	51.1	14.28	829.44	14105	101.80	79.95	1.3422
6	0.2205	36	39.2	53.3	50.7	14.4	1106.72	16361	113.65	87.069	1.3314
7	0.2471	35.9	38.9	52.1	49.8	13.55	1204.41	18335	123.84	97.764	1.2964
8	0.2752	36.1	38.9	52.1	49.8	13.45	1300.09	20419	133.85	107.91	1.2763
9	0.302	36.4	39.1	52.5	50.2	13.6	1383.57	22408	160.28	118.90	1.4154
10	0.3319	36.9	40.1	52	49.8	12.39	1802.57	24626	163.29	127.04	1.3179
11	0.3431	36.5	38.9	52.6	50.8	13.99	1283.56	25457	176.36	131.74	1.386

A.2.3: Nu VS Re FOR 4 WIRE INSERT WITH ß= 24CM

Table 9: Nu Vs Re For 4 Wire Insert With ß= 24cm

S.no	m	T1	T2	T3	T4	LMTD	Ui	Re	Nu_a	Nu_o	R1=$\frac{Nu\ a}{Nu\ o}$
1	0.0927	39	44.4	53.5	51.7	10.8	770.11	6878	65.66	43.26	1.5481
2	0.1081	39	43.9	53.1	51.4	10.72	829.35	8021	73.30	46.47	1.5299
3	0.1357	37.9	42.2	52.5	50.5	11.41	933.68	10069	80.20	56.95	1.3941
4	0.1622	38.1	42.3	52.7	50.7	11.46	1093.5	12035	97.18	67.40	1.4562
5	0.1901	38.2	41.7	52.8	50.8	11.83	1101.3	14105	103.00	79.95	1.3581
6	0.2205	38.1	41.1	52.6	50.3	11.85	1228.9	16361	122.65	87.069	1.4368
7	0.2471	38.3	40.3	52.9	50.6	11.95	1365.7	18335	133.63	97.764	1.3988
8	0.2752	38.5	41.1	52.5	51.2	12.04	1110.8	20419	146.11	107.91	1.3932
9	0.302	38.6	41	52.2	49.7	11.15	1653.8	22408	163.75	118.90	1.446
10	0.3319	38.7	41.3	53	50.5	11.75	1810.4	24626	165.39	127.04	1.3348
11	0.3431	38.5	41.1	52.4	50.2	11.5	1784.6	25457	179.99	131.74	1.4145

A.2.4: Nu VS Re FOR 4 WIRE INSERT WITH ß= 12CM

Table 10: Nu Vs Re For 4 Wire Insert With ß= 12cm

S.no	m	T_1	T_2	T_3	T_4	LMTD	U_i	Re	Nu_a	Nu_o	R1=$\frac{Nu\ a}{Nu\ o}$
1	0.0927	35	41.7	52.6	46.6	11.25	904.05	6878	80.58	43.26	1.8999
2	0.1081	35.6	40.9	53.1	48.4	12.5	1077.7	8021	82.27	46.47	1.7171
3	0.1357	36.4	40.4	53	49.6	12.9	1150.5	10069	86.82	56.95	1.509
4	0.1622	35.2	40.3	53.9	49.4	13.9	1396	12035	102.76	67.40	1.5398
5	0.1901	35.4	39.7	52.7	49	13.3	1424.9	14105	123.70	79.95	1.631
6	0.2205	35.6	39.6	52.3	48.9	13	1564.1	16361	126.23	87.069	1.4788
7	0.2471	35.7	39.1	52.8	50	14	1617.2	18335	146.35	97.764	1.5321
8	0.2752	35.9	39.1	53.1	50.5	14.3	1694.7	20419	158.12	107.91	1.5077
9	0.302	36.2	39.3	52.9	50.4	13.9	1776.1	22408	169.07	118.90	1.493
10	0.3319	36.7	40.3	53	50	13	1902.7	24626	172.60	127.04	1.393
11	0.3431	36.3	38.7	53.1	51.8	15.2	2100.6	25457	186.46	131.74	1.4654

A.2.5: Nu VS Re FOR 4 WIRE INSERT WITH ß= 6CM

Table 11: Nu Vs Re For 4 Wire Insert With ß= 6cm

S.no	m	T_1	T_2	T_3	T_4	LMTD	U_i	Re	Nu_a	Nu_o	R1=$\frac{Nu\ a}{Nu\ o}$
1	0.0927	38.5	44.9	52	46.4	7.5	1848.3	6878	87.15	43.26	2.05482
2	0.1081	38.5	44.3	52.7	47.7	8.8	1653.2	8021	90.70	46.47	1.89291
3	0.1357	37.4	42.7	52.3	47.8	9.495	1658	10069	98.32	56.95	1.70902
4	0.1622	37.6	42.8	53	48.6	10.6	1831.4	12035	119.73	67.40	1.79413
5	0.1901	37.7	42.2	53.6	49.9	11.8	1646.9	14105	130.42	79.95	1.71957
6	0.2205	37.6	41.6	53.4	50.2	12.2	1622.1	16361	134.95	87.069	1.581
7	0.2471	37.7	40.8	52.7	50.4	12.3	1352.3	18335	157.42	97.764	1.6479
8	0.2752	38	40.6	52.5	50.7	12.3	1227.2	20419	172.58	107.91	1.64564
9	0.302	38.1	41.5	52.9	50.3	11.8	1914.4	22408	184.83	118.90	1.63221
10	0.3319	38.2	41.8	53	50.2	11.6	2282.9	24626	183.86	127.04	1.48388
11	0.3431	38	41.6	53.1	50.3	11.9	2300.3	25457	194.82	131.74	1.53105