EXPERIMENTAL STUDIES ON HEAT TRANSFER ASPECTS USING CIRCULAR [MS] RODS 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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CERTIFICATE

This is to certify that the thesis entitled, **"EXPERIMENTAL STUDIES ON HEAT TRANSFER ASPECTS USING CIRCULAR [MS] RODS INSERT WITH AND WITHOUT BAFFLES IN TUBES"** submitted by **Rajan Kumar Kujur (111CH0072)** bonafide project work and is worthy 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 him 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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ABSTRACT

To study the heat transfer aspect of heat exchanger on a project named "Experimental studies on heat transfer aspect using circular [MS] rods insert with and without baffles" was endeavor. Heat exchange process which is daily used in industries in which energy takes one form to other. This project deals with the introduction of Circular [MS] rods as inserts as passive augmentation device, in the flow path of inner tube side of liquid flow. The impact of turbulence on heat Transfer was compared with the values for smooth tube. The impact of baffles was also taken into account and again a comparative study was made on the basis of varying the baffle spacing. All the outcomes and readings were contrasted and the standard information from the smooth tube. Two Circular Rods (d_i = 8 mm, 10 mm) were used for the experimental purpose. In the beginning the experiment was conducted without any insert to get the value for plane heat exchanger and thereafter the experiment was repeated with circular rods (d_i = 8mm, 10 mm) without any baffles and with baffles with varying baffle spacing (β=7.5cm, 15cm, 30cm).The Nusselt number was found to increase with decreasing baffle spaces The insert with baffle space 7.5 cm was found to be the most efficient among all the configuration used.

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NOMENCLATURE

A_i	Heat transfer area, m^2
Cp	Specific heat of fluid, J/Kg.K
d_i	ID of inside tube, m
Do	OD of inside tube, m
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

Greek letters

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

B	Baffle spacing in cm.

CHAPTER 1

INTRODUCTION

The usage of heat exchangers in different ways in conversion of energies in industries for the consumption and recovery of energy. Steam generation, power efficiency, in power generating plants, sensible heating, to cool the products in chemical, agricultural, pharmaceutical process plants etc. are common examples. Increasing the heat exchanger's efficiency leads to designing it in an economical way to increase the generation of power, to reduce the cost of materials used in the process. The purpose of increasing the heat exchanger's thermal efficiency in economical way made to find and implement many new techniques such as Heat transfer Enhancement techniques increases the heat transfer in convection method by decreasing the thermal resistance of an equipment. Usage of Heat transfer enhancement methods led to increment of heat transfer coefficient by increasing the pressure drop. The heat exchanger designed by using these techniques. The Aim of this project is to find a suitable insert that will give the desired heat transfer enhancement. For experimental work, Circular rods of diameter 8 mm and 10 mm are used. Effect of circular rods with baffles of varying baffle spacing (β= 7.5cm, 15cm, 30cm) have been studied.

CHAPTER 2

LITERATURE REVIEW

2.1 ENHANCEMENT TECHNIQUES CLASIFICATION: [1, 2]

The process of the heat transfer progress (augmentation) is categorized into mainly three classes:

- Passive Techniques
- Active Techniques

The above two techniques differ in a way i.e. the external energy is been used by active techniques to bring the effect whereas passive techniques do not use the external power.

- Compound Techniques

Sixteen various improvement (augmentation) techniques of heat transfer were kept forward by Bergles et al, are shown in the table given below

PASSIVE TECHNIQUES: These techniques mostly use the changes in geometry of flow channel by using along with the insertions. They prone the heat transfer coefficients to increase by adjusting the flow currents in channel *(*with the exception of extended surfaces) which is also a cause to increase the pressure drop. If there should be an occurrence of extended surfaces, successful heat transfer zone as an afterthought of the extended surface is expanded. Passive methods hold the preference over the active strategies as they don't oblige any immediate info of outer force. Heat transfer augmentation by these procedures might be attained by utilizing:

a. **Treated Surfaces**: These processes include the smooth finishing of surface by coating it which is either continuous all over the surface or might not be. They are mainly used for phenomenon like condensation and vaporization by boiling it; it is coated in such a way that its thickness of roughness doesn’t affect the single phase heat transfer.

b. **Rough Surfaces**: Adjustment of the surfaces reveals about the turbulence in flow channel which is necessary in the single stage flows and does not involve in credit of expanding the heat transfer surface zone. The geometrical measurements might have a very large change from grain thickness to finite number.

c. **Extended Surfaces**: The extended surfaces are generally finny and are solely used in many heat exchangers to increase the field of heat transfer mainly on surfaces which are thermally resistant.

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d**. Displaced Enhancement Devices**: These are the insertions basically used in limited forced convection. The fluid from the duct surface is been displaced by the core flow fluid by inserting the insertions into the field of the flow channel which enhances the transfer of energy which is not a main objective at the heated surface.

e. **Swirl Flow Devices**: Rotating flow is also been caused by inserting these devices which consists of tube inserts. Some of the different types are Inlet Vortex Generators, Twisted Tape Inserts, Stationary Propellers and Axial-Core Inserts with a screw type winding. They work out not only in the single phase but also in the double phase flow.

f. ***Coiled Tubes*****:** The curved surface of the coils develops the secondary flow which raises higher single phase heat coefficients and also in the methods of boiling. All of these leads to formation of complex heat exchanger.

g. **Additives for liquids**: In this technique addition of solid particles, soluble additives in small quantity and gas bubbles added to liquid phase decreases the resistance in case of single flow. For boiling case additives in traces are been added to decrease the surface tension of liquids.

2. ACTIVE TECHNIQUES: These techniques requires the external power for modifications in the flow and enhancing the rate of heat transfer. Due to commercial value of the external power they are used limitedly where ever needed. The different active techniques are given as:

a.Mechanical Aids: They stir the fluid by mechanical means or by the surface rotation. Ex: rotating tube exchangers, scrapped surface exchangers of heat and mass energy.

b.Surface vibration: They are basically used in single phase flows. A low or high frequency vibrations have been applied to surface which increases the convective heat transfer coefficients.

c.Fluid vibration: Pulses are been created rather causing the vibrations to the surface in the fluid itself. This pulsation enhances the single phase flows rather than vibration technique.

d.Electrostatic fields: It involves the AC or DC sources for the production of electric and magnetic fields as they induces the mixing of the bulk, convection of force or electromagnetic pumping to improve the heat transfer. This method is used in heat transfer process using the dielectric fluids.

e.Injection: In this method same or the other fluid is kept in the bulk flow through porous heat transfer interface or in the upstream section of the heat transfer. This method is used in single phase heat transfer process.

f. Suction: This method is used in two phase heat transfer as well as in single phase heat transfer process. Vapor is removed through porous heated surface in two phase flow and is withdrawn through porous heated surface in single phase flow.

g. Jet impingement: This method is used in single phase as well as two phase heat transfer process. The heat transfer surface is kept at an angle of 90 for the fluid been heated or cooled.

3. COMPOUND TECHNIQUES: In compound augmentation technique combination of any technique with the other for the enhancement of thermo-hydraulic performance in a heat exchanger…

2.2 PERFORMANCE EVALUATION CRITERIA: [1]

The objectives taken into the consideration along with variables and conditional situations to be followed during the usage and dealing with heat exchanger with enhancement techniques:

1. Without changing the pumping power i.e pressure drop thermal energy of heat exchanger has to be increased.
2. The temperature difference between
3. The heat transfer surface area is decreased for a specified heat duty and pressure drop or pumping power.
4. By decreasing the process stream's pumping power requirements for a given heat load and surface area of exchanger.

It is observed that objective 1 refers to increase in heat transfer rate, objective 2 and

4 help in saving the energy as well as operating cost and objective 3 refers to material savings and decrease in investment in equipment.
The different ways of criteria used for evaluation of the performance of a single phase flow are:

a.Fixed Geometry (FG) Criteria: The area of flow cross-section (N and di) and tube length L are assigned a constant value. This criteria is mainly applied for retrofitting the smooth tubes of an existing exchanger with enhanced tubes, with the maintenance of same basic geometry and size (N, di, L). The criteria helps in increasing the heat load Q for same temperature ΔT_i , mass flow rate "m" or pumping power P; or by decreasing ΔT_i or P for constant Q and "m" or P; or by decreasing P for fixed Q.

b.Fixed Number (FN) Criteria - The flow cross sectional area (N and di) is made constant, and the heat exchanger length is varied. The main objectives is to reduce either the heat transfer area (A □□L) or the pumping power P for an assigned heat load.

c.Variable Geometry (VN) Criteria - The flow frontal area (N and L) is assigned a constant value, but diameter can be varied. A heat exchanger is designed to bear a specified heat duty Q for a process having known fluid flow rate *m*. As the tube side velocity decreases in those conditions to attain the higher friction losses in the surface tubes which are enhanced, it is compulsory flow area to increase and to attain constant "m". This job is generally done by using many parallel flow circuits.

Table 2.1: Performance Evaluation Criteria [1]

Case	**Geometry**	**M**	**P**	**Q**	**Ti**	**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		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		Ti↓
VG-3	N, L	X		X	X	P↓

Table 2.2: 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 Exchange Size					×	×	×	×

CHAPTER 3

PRESENT EXPERIMENTAL WORK

3.1 SPECIFICATIONS OF HEAT EXCHANGER USED

The experiment done using a double pipe heat exchanger acquiring specified measurements and materials as given 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

Water at room temperature is made to flow through the inner pipe whereas hot water having temperature of 60°C from the annular side in the opposite direction.

3.2 EXPERIMENTAL SETUP

Figure 3.1 shows the schematic diagram of the experimental setup. It is a double pipe heat exchanger accompanying a calming section, test section, rotameters, overhead water tank to supply cool water and a constant temperature bath of 500 liter volume for supplying hot water having a heater in it, pump and the control system. The test section made of smooth copper tube having dimensions of length-3000mm, Inner tube of 22mm ID and 25mm OD; Outer GI pipe of 53mm ID and 61 mm OD. The outer pipe is thermally insulated by 15mm diameter asbestos rope so as to decrease loss of heat to the atmosphere. The water at room temperature from an overhead tank is taken out with the gravity flow. In the same way a rotameter with the same capacity is made to tackle the hot water flow rate from the inlet hot water tank. Hot water flow rate is assigned to be 1000 LPH. All the four RTDs are made to take down the inlet and outlet temperature of both hot water and cold water (T1 –T4) from multipoint digital temperature indicator. Figure 3.2 shows photograph of the setup

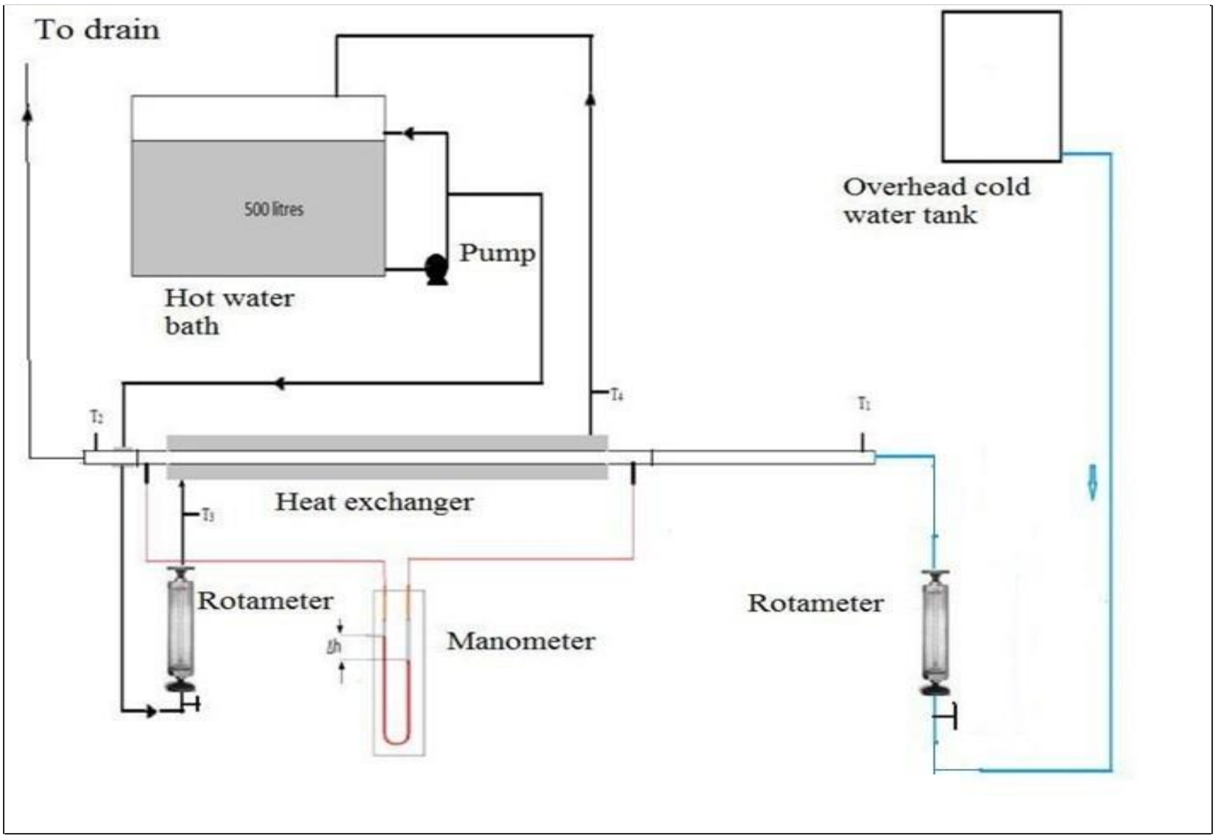

Figure 3.1: Schematic Diagram of the Heat Exchanger

Figure 3.2: Heat exchanger setup

3.3 TYPES OF INSERTS USE

For experimental purpose eight type of inserts made from Circular [MS] rods of Dia. 8mm and 10mm were used.

1. Circular [MS] rod (without any baffle) of diameter 10mm.
2. Circular [MS] rod of diameter 8mm with baffle spacing 7.5cm.
3. Circular [MS] rod of diameter 8mm with baffle spacing 15cm.
4. Circular [MS] rod of diameter 8mm with baffle spacing 30cm.
5. Circular [MS] rod (without any baffle) of diameter 10mm.
6. Circular [MS] rod of diameter 10mm with baffle spacing 7.5cm.
7. Circular [MS] rod diameter 10mm with baffle spacing 15cm.
8. Circular [MS] rod of diameter 10mm with baffle spacing 30cm.

3.4 FABRICATION OF CIRCULAR [MS] RODS AS INSERTS

Circular [MS] rods of 8mm dia and 10 mm dia and length 2.94 meter were taken and four holes were drilled with equal spacing and with the help of nut and bolt the rods were supported inside the pipe. After leaving 5cm from both ends the rest 2.84 meter length was marked in 9 parts for 30 cm baffle spacing, 19 parts for 15cm baffle spacing and similarly 38 parts for 7.5 cm baffle spacing. We used chalk for marking purpose and there after the marked space were twisted around with 1mm thickness GI wire that too in two rounds that worked as baffles.

Fig 3.3: Circular [MS] rod used without baffle of diameter 10mm

3.5 FABRICATION OF BAFFLES ON CIRCULAR [MS] RODS

On Circular [MS] rods after leaving 5cm from both ends the rest 2.84 meter length was marked in 9 parts for 30 cm baffle spacing, 19 parts for 15cm baffle spacing and similarly 38 parts for 7.5 cm baffle spacing. We used chalk for marking purpose and there after the marked space were twisted around with 1mm thickness GI wire that too in two rounds that worked as baffles.

Fig 3.4:10mm Circular [MS] rods with baffle spacing 7.5

Fig 3.5: 10mm Circular [MS] rods with baffle spacing 15cm

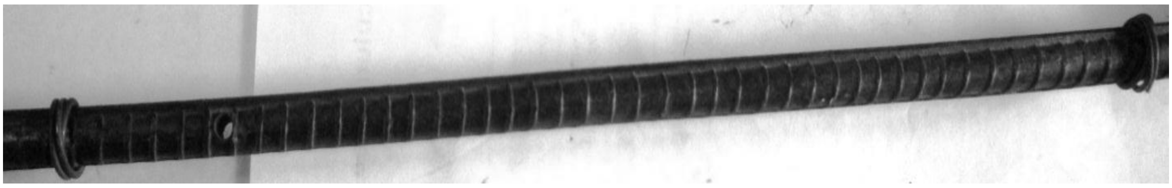

Fig 3.6: 10mm Circular [MS] rods with baffle spacing 30cm

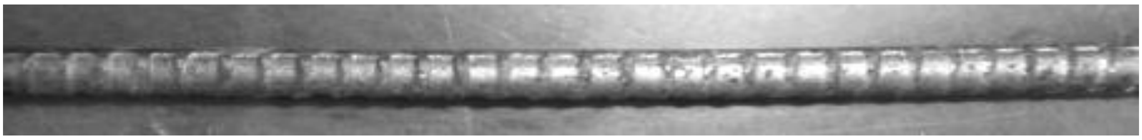

Fig 3.7: 8mm Circular [MS] rods without baffle

Fig 3.8: Circular [MS] rods of diameter 8mm with baffle spacing 7.5 cm

Fig 3.9: Circular [MS] rod of diameter 8 mm with baffle spacing 15 cm

Fig 3.10: Circular [MS] rod of diameter 8mm with baffle spacing 30 cm

3.6 EXPERIMENTAL PROCEDURES

1. Rotameters & RTD are measured first.

- For measuring the rotameter, water is collected in a bucket is weighed and time of filling was noted to calculate the mass flow rate of water.
- For each flow rate and average flow rate of readings were noted for purpose of calculations. The readings are given in A.1.1
- All the RTD's are dipped in water bath and each RTD reading were noted. Temperature given by one of the RTD (T1) was taken as reference and others RTD temperatures were corrected from T2-T4.

2. Standardization of the set-up:

Standardization of the set up was done by calculating the heat transfer results of smooth tube were compared with the standard equations. This was done before the experimental study on heat transfer in heat exchanger.

3. For Nusselt number calculation:

a) The water was made to heat to 60°C in a constant temperature in a water tank of capacity of holding 500 liters. The centrifugal pump was provided to tank and a bypass valve to circulate hot water to the tank and to the experimental apparatus.

b) Hot water at a temperature 60°C is made to pass through the annulus of heat exchanger at 1000LPH (**m**h=0.2778 Kg/sec).

c) Now cold water is also made to pass through the tube of heat exchanger in counter current direction at a constant flow rate.

d) The water inlet and outlet temperatures for both hot water and cold water (T1-T4) were noted only after the temperature of both the fluids attains same temperature.

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

4. Preparation of Wilson chart:

$1/Ui= 1/ h_i + di / (do*ho) + x_{w*} di / k_w*di + Rd + Rd_0$

Where Rd and Rd_o are 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 in the form: hi=A ×Re0.8

5. After acknowledgment applicable experimental values of Nusselt number in smooth tube with standard equations, heat transfer studies with inserts were conducted. The heat transfer observations & results for all the cases are presented in Tables A.3.1 – A.3.9 and Figures 5.1-15.11 respectively.

3.7 STANDARD EQUATIONS TO BE USED:

For Turbulent Zone:

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

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

Viscosity correction Factor $(\mu b * \mu w)^{0.14}$ is assumed to be equal to 1 for all calculations 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 adjusted properly to measure flow rate accurately for a given rotameter reading.

2. RTDs should be observed carefully. This is accomplished by measuring temperature of normal water by all RTDs at the one particular time and assuming one of the reading as reference at steady state equation.

3. Temperatures are noted only when the inlet as well as the outlet temperature of both the liquids attain some fixed value.

4. Preparation of Wilson chart:

$1/u = 1/h_i + di / (do*ho) + x_{w*} di / k_{W*}di + Rd + Rd_0$

Where Rd and Rd_o are 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: $h_i = A \times Re^{0.8}$

$1/Ui = 1 / A*Re^{0.8} + K$

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.3.1 – A.3.8 and Figures 15-19 respectively.

CHAPTER 4

4.1 HEAT TRANSFER CALCULATION

For 10mm Circular [MS] rod insert with β=15 cm (Table A.3.8)

m_c= 0.0972 kg/sec $m_{h=}$ 0.2778 kg/sec

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

T1= 31.1

T2= 35.4

T3= 51.7

T4= 49.0

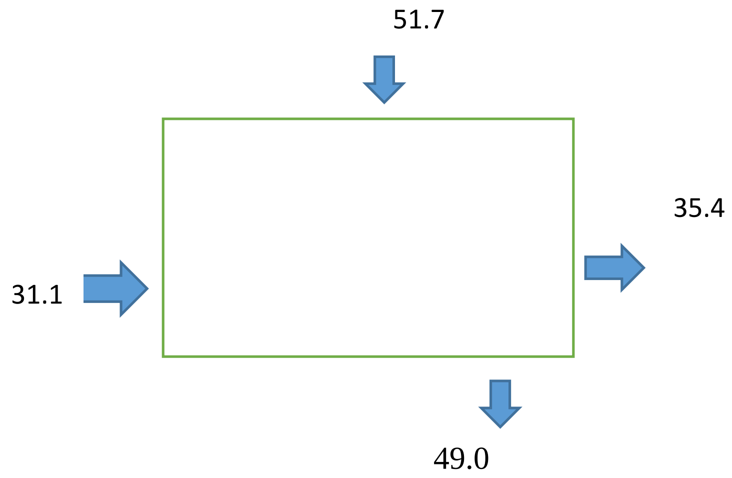

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Fig 4.1: Line Diagram of heat exchanger

ΔT1 = (T4-T1) =17.9

ΔT2 = (T3-T2) =16.3

LMTD = (ΔT1-ΔT2)/ln (ΔT1/ΔT2) = 17.08

Q1= m_c* C_{pc} * (T2-T1) = 0.1111* 4187 * 6.6 = 3500W

Q2 = m_h* C_{ph} * (T3-T4) = 0.2778* 4187 * 2.9 = 3141 W

Heat Balance Error = 3070-3363 / 3363 * 100 = 10.27%

Qavg = Q1+Q2/2 = 3070 +3363 / 2= 3320

Heat Transfer Area = π * di * L = 3.14 * 0.022 * 2.43 = 0.168 m^2

Ui = Qavg/ A *LMTD = 3217 / 0.168 * 16.9 =1157W/m^2 ^{0}C

Re = 4 *m / π * di * μ = (4*0.1111) / 3.14 * 0.022 * 0.0007 = 14596

h_a can be calculated using eqn.

$1/Ui = 1/h_a + K$

K for Wilson chart are found using intercept on Y-axis

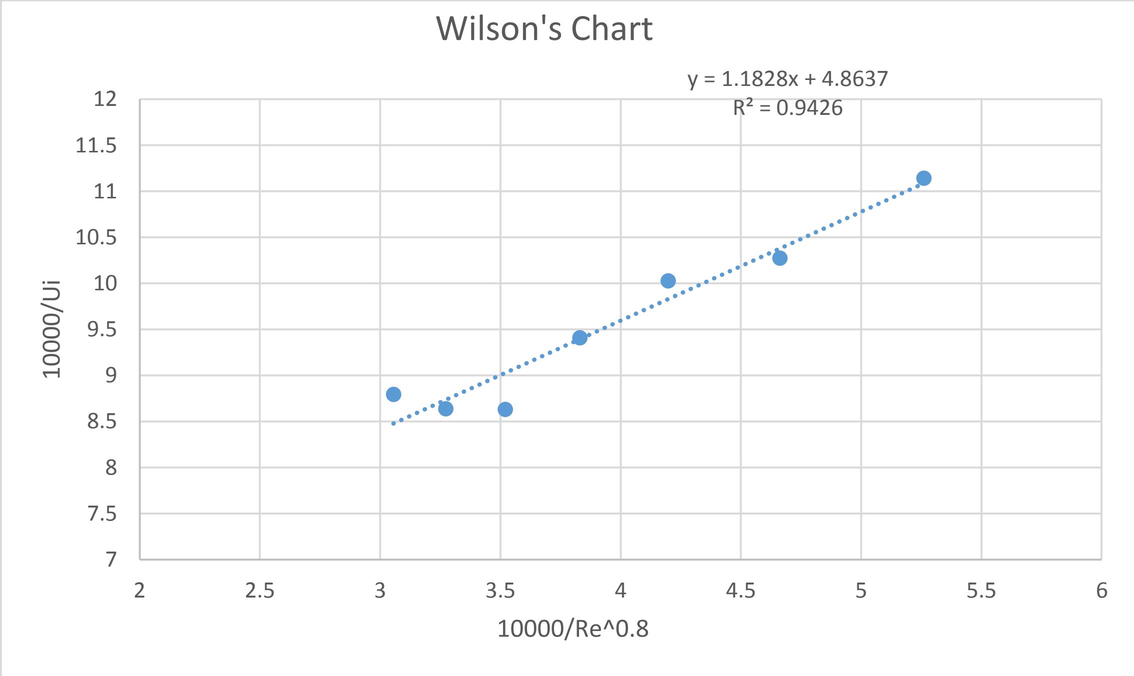

Fig 4.2: Wilson chart for smooth tube

$1/h_a = 1/Ui – K$

$h_a = 1/Ui – 0.00048736$

$Nu_a = (h*di)/k = 84.77$

Theoretical calculation for smooth tube;

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

$ha*di / k = 0.023 * Re^{0.8} * Pr^{1/3}$

$h_o = 0.023 * k / di * Re * Pr^{1/3}$

For prandlt number calculation Fig 4.3 is used

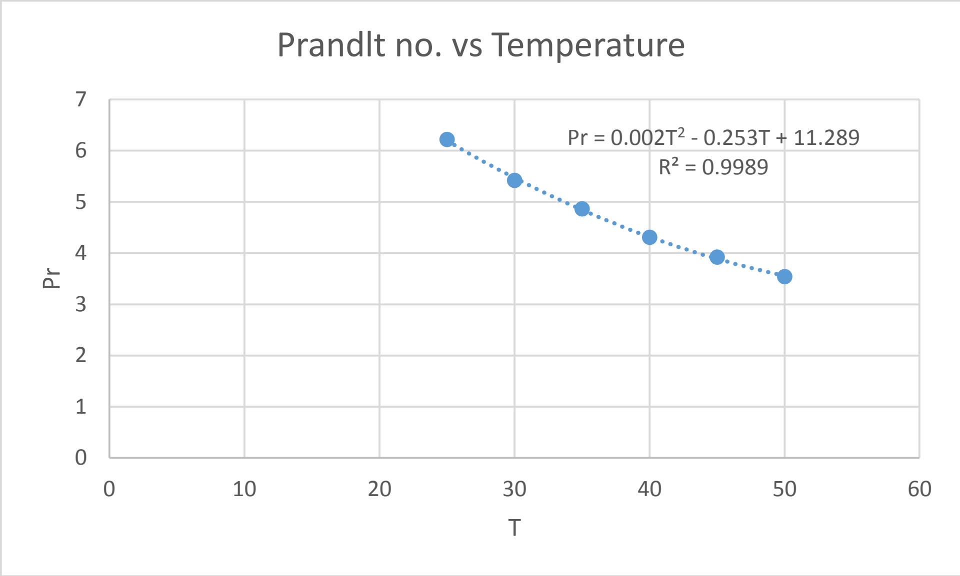

Fig 4.3: Pr vs. Temp Chart

$Pr = 0.002T^2 - 0.253T + 11.2289$

Tavg = 31.1 + 35.4 / 2 = 33.2

Pr = 4.02

For viscosity calculation Fig 4.4 is used

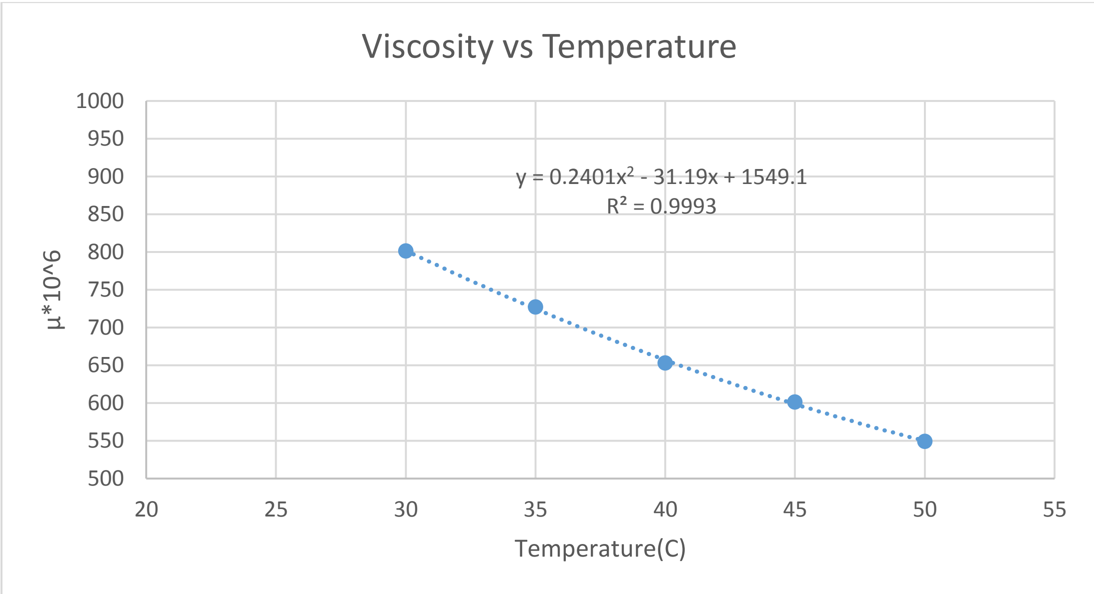

Fig 4.4: Viscosity vs. Temperature Chart

CHAPTER
5

RESULTS AND DISCUSSION:

5.1 HEAT TRANSFER RESULTS FOR SMOOTH TUBE

Appendix A.3.1-A.3.9 refers to the heat transfer results for smooth tube, 8mm and 10mm Circular[ms] rods insert without any baffle and with baffles having baffle spacing (=7.5cm, 15cm, 30cm) along with the performance evaluation aspects for each of the readings.

As shown in Appendix A.3.1 and Figure 5.1, the difference between the experimental values and the values calculated using the empirical equations is within 5% for Re >10,000. So the experimental setup can be considered to produce reliable heat transfer results.

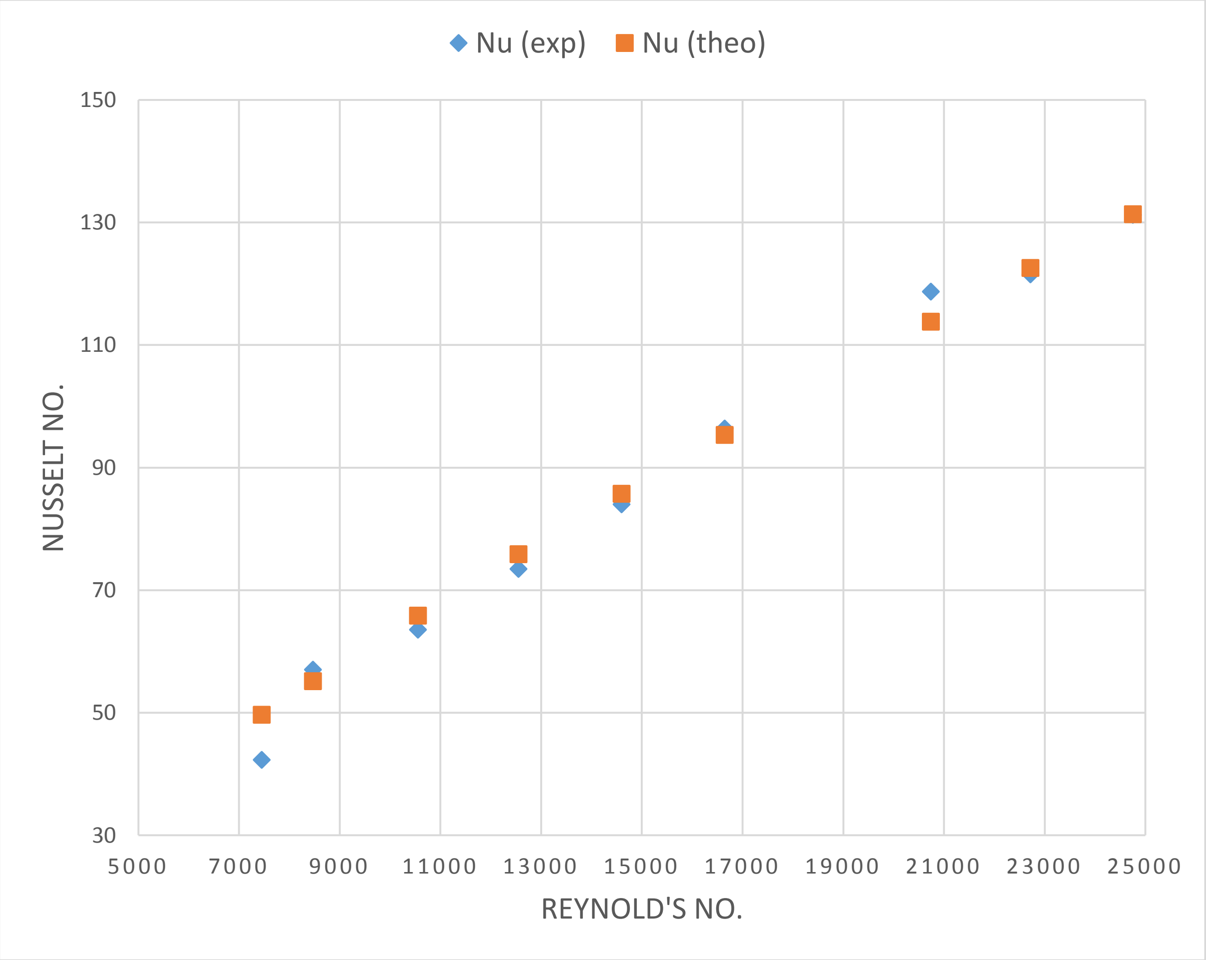

Figure 5.1 : Nusselt number comparison for smooth tube.

5.2 HEAT TRANSFER RESULTS FOR CIRCULAR [MS] RODS INSERT WITHOUT AND WITH BAFFLE BAFFLES

Figures below show the comparision of heat transfer results for smooth tube, 8mm and 10mm Circular [MS] rods insert without any baffle and with baffles having baffle spacing (=7.5cm, 15cm and 30cm).

Figure 5.2 represents the variation of Nusselt number for smooth tube and 8mm Circular [MS] rod insert without baffles against variable Reynolds number.

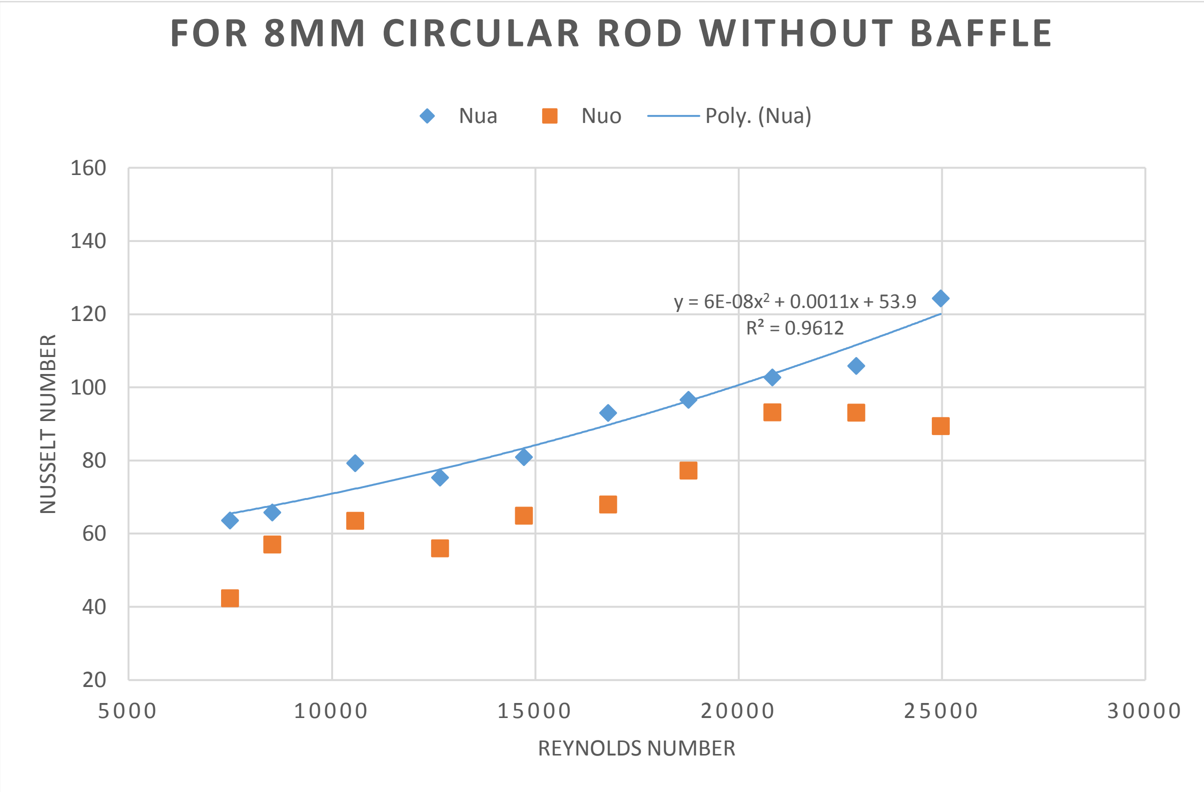

Figure 5.2: Comparison of Nusselt number for smooth tube and 8mm Circular[MS] rod without baffles

From figure 5.2 and Appendix A.3.2 it can be concluded that the Nusselt number for 8mm Circular [MS] rod insert with no baffle is having performance criteria 1.10-1.50 times better than equivalent smooth tube.

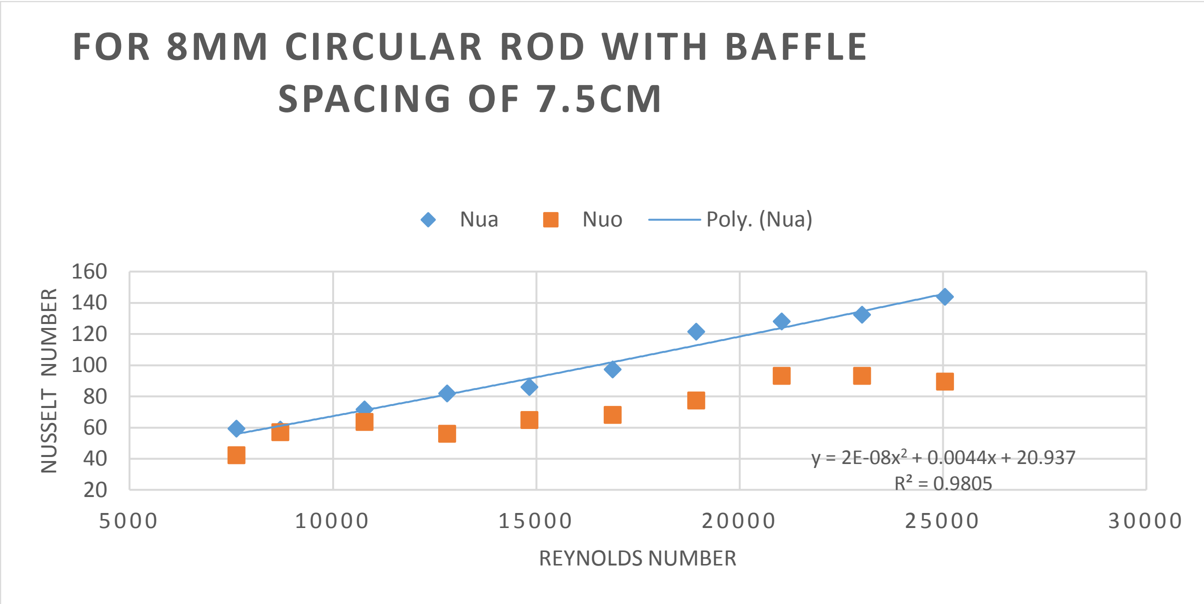

Figure 5.3: Comparison of Nusselt number values for smooth tube and 8mm Circular [MS] rod with baffles having baffle spacing 7.5cm.

From figure 5.3 and Appendix A.3.3 it can be concluded that the Nusselt number for 8mm Circular [MS] rod insert with 7.5cm baffle spacing is having performance criteria 1.102-1.6 times better than equivalent smooth tube.

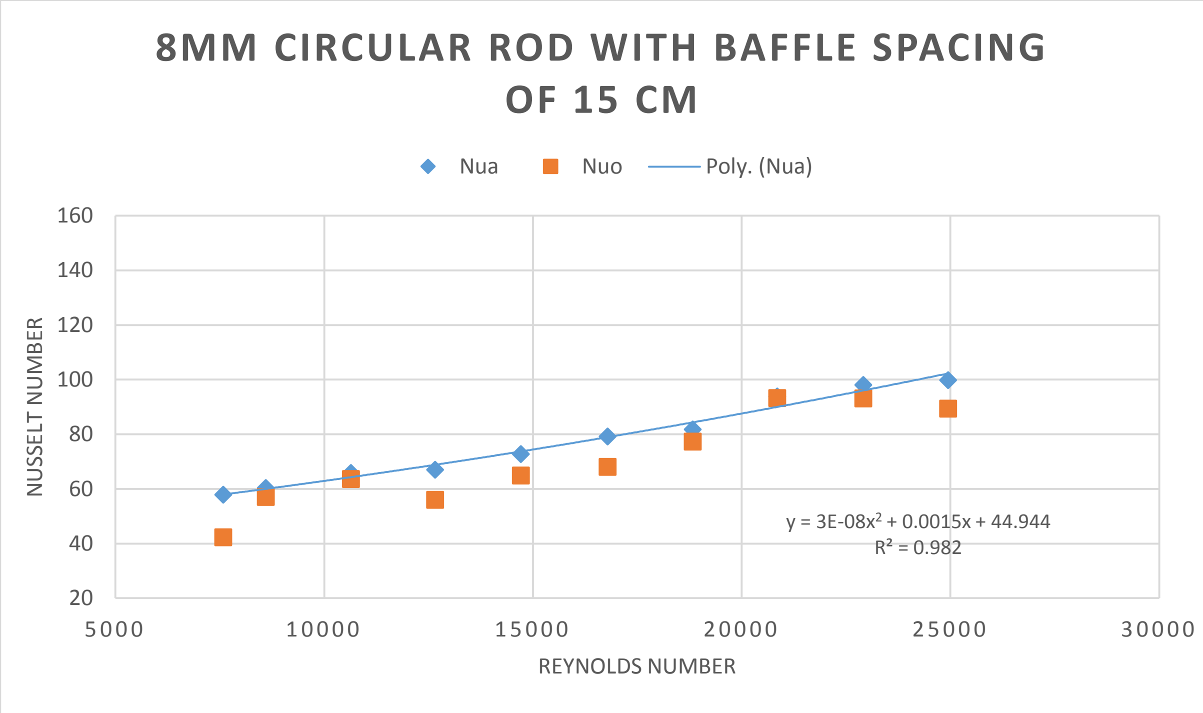

Figure 5.4: Comparison of Nusselt number values for smooth tube and 8mm Circular [MS] rods with baffles having baffle spacing 15cm.

From figure 5.4 and Appendix A.3.4 it can be concluded that the Nusselt number for 8mm Circular [MS] rod insert with 15cm baffle spacing is having performance criteria 1.07-1.37 times better than equivalent smooth tube.

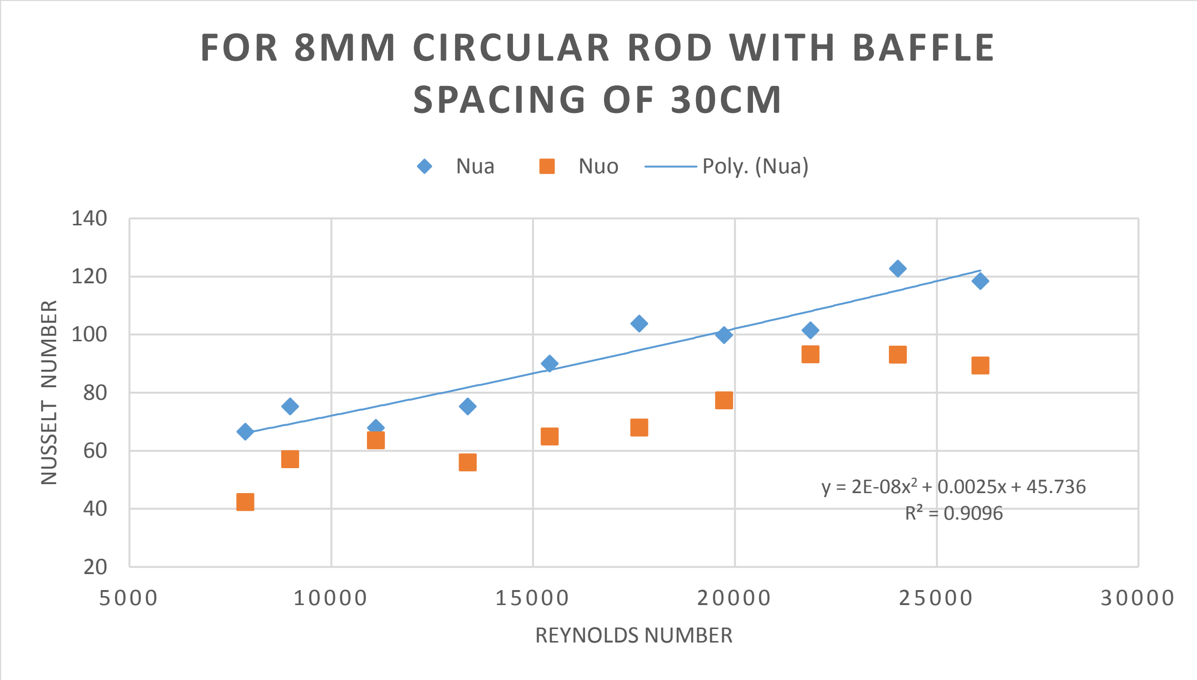

Figure 5.5: Comparison of Nusselt number values for smooth tube and 8mm Circular [MS] rods with baffles having baffle spacing 30cm.

From figure 5.5 and Appendix A.3.5 it can be concluded that the Nusselt number for 8mm Circular [MS] rod insert with 30cm baffle spacing is having performance criteria 1.08-1.65 times better than equivalent smooth tube.

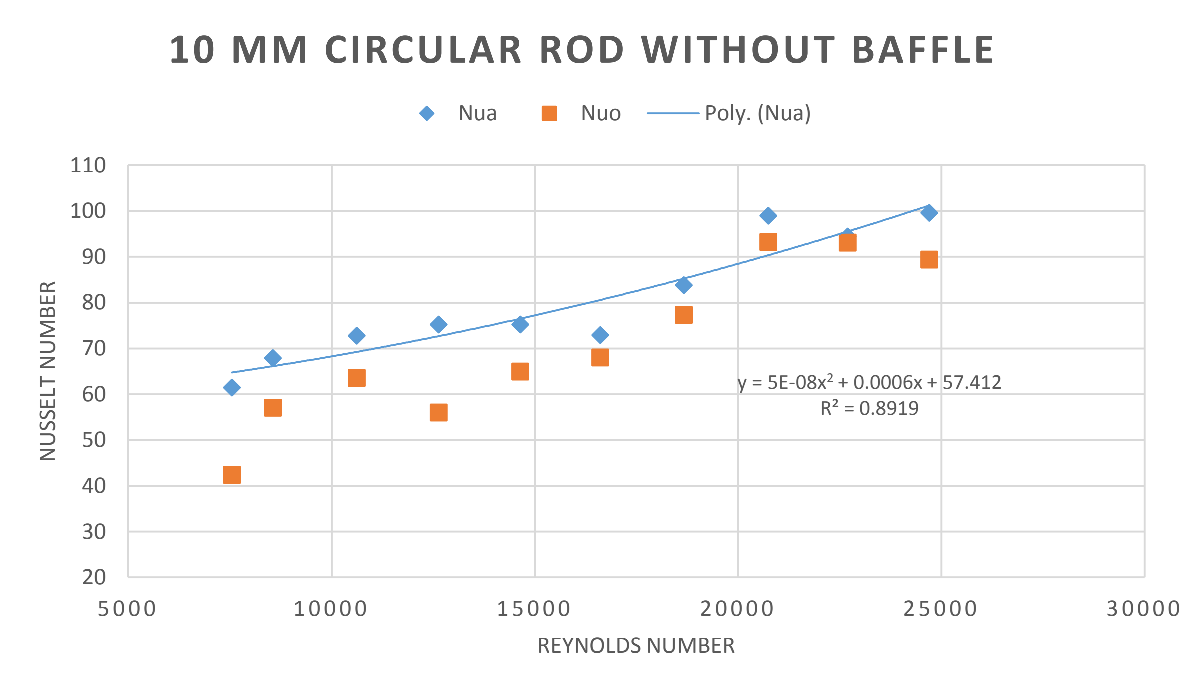

Figure 5.6: Comparison of Nusselt number values for smooth tube and 10mm Circular [MS] rod with no baffles.

From figure 5.6 and Appendix A.3.6 it can be concluded that the Nusselt number for 10mm Circular [MS] rod insert with no baffle spacing is having performance criteria 1.01-1.50 times better than equivalent smooth tube.

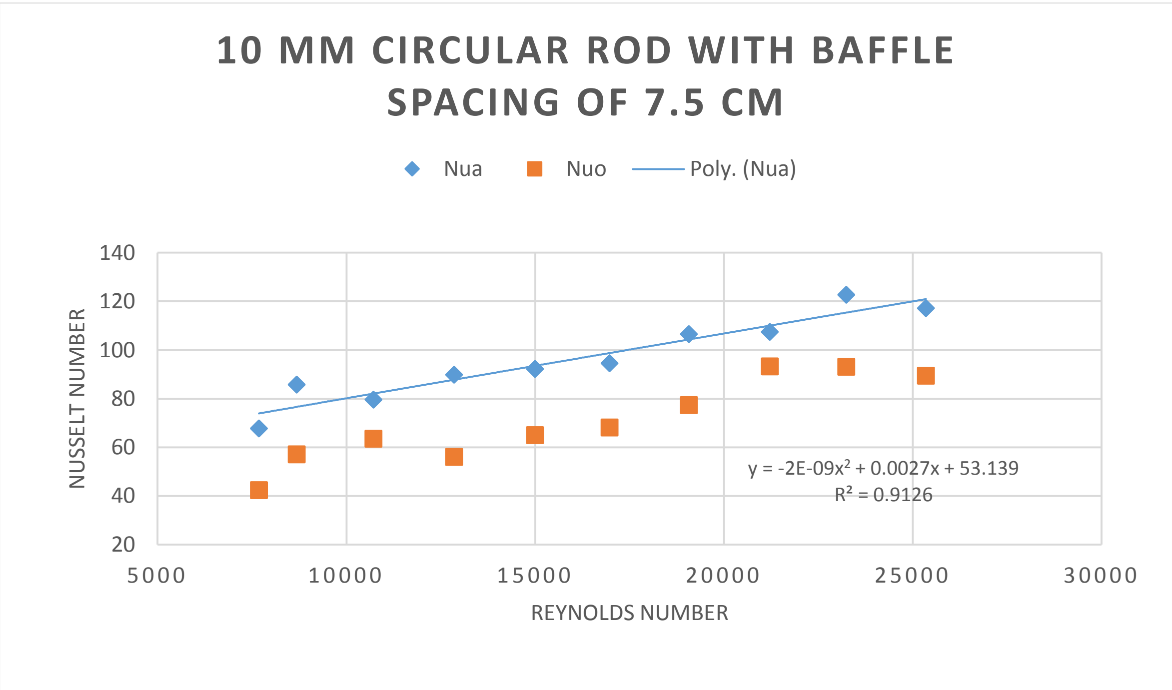

Figure 5.7: Comparison of Nusselt number values for smooth tube and 10mm Circular [MS] rod with baffles having baffle spacing 7.5cm.

From figure 5.7 and Appendix A.3.7 it can be concluded that the Nusselt number for 10mm Circular [MS] rod insert with 7.5cm baffle spacing is having performance criteria 1.24-1.81 times better than equivalent smooth tube.

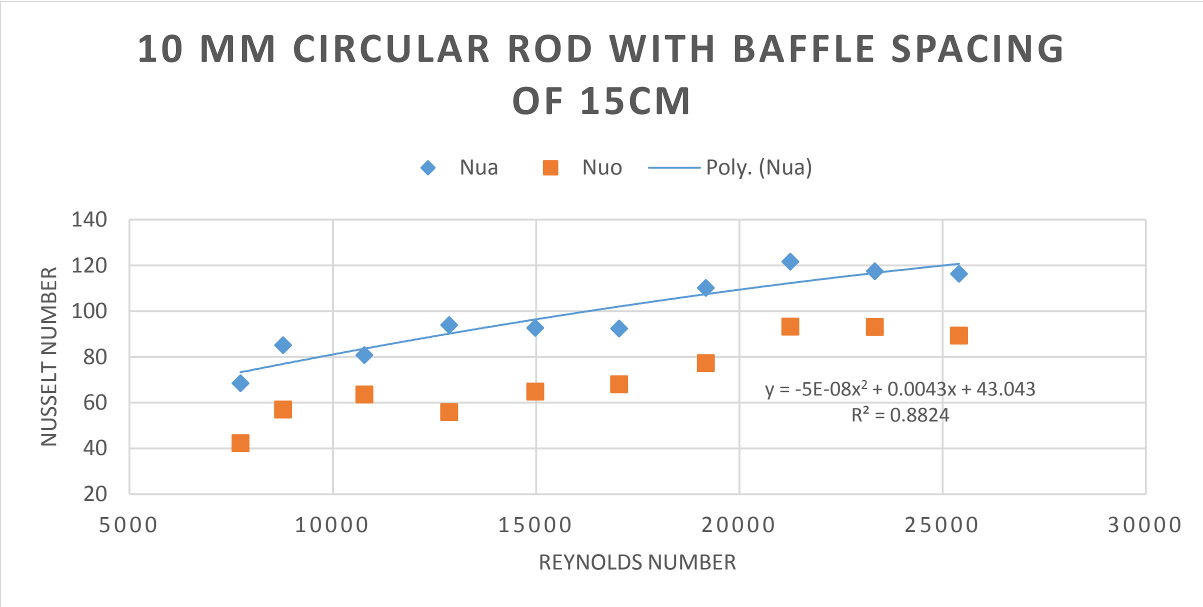

Figure 5.8: Comparison of Nusselt number values for smooth tube and 10mm Circular [MS] rods with baffles having baffle spacing 15 cm.

From figure 5.8 and Appendix A.3.8 it can be concluded that the Nusselt number for 10mm Circular [MS] rod insert with baffle spacing 15cm is having performance criteria 1.26-1.81 times better than equivalent smooth tube.

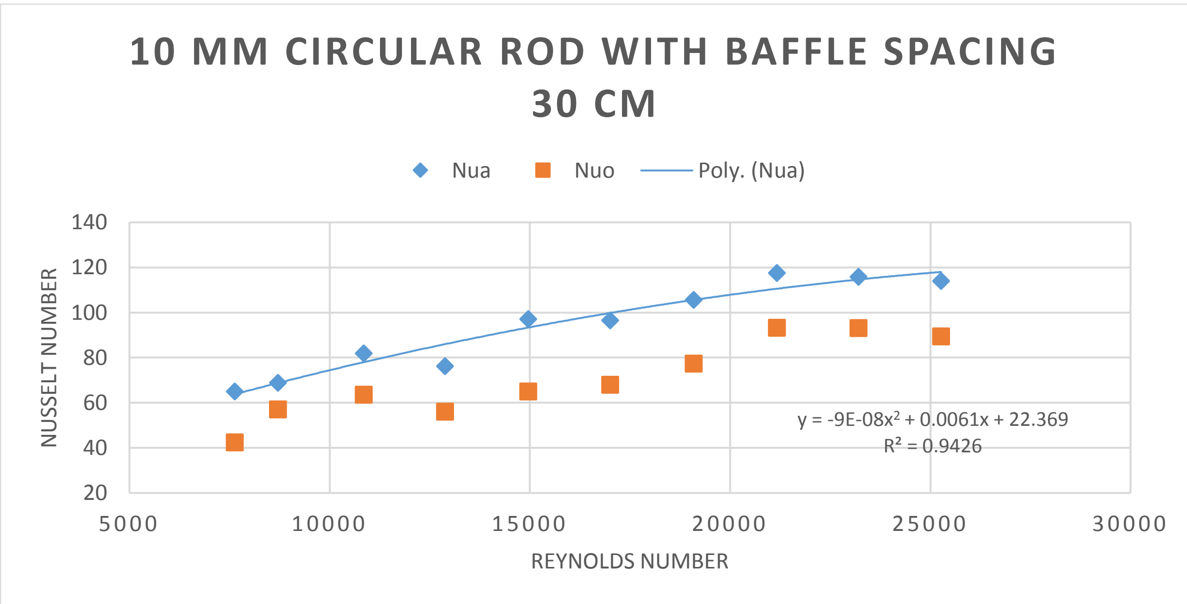

Figure 5.9: Comparison of Nusselt number values for smooth tube and 10mm Circular [MS] rod with baffles having baffle spacing 30cm.

From figure 5.9 and Appendix A.3.9 it can be concluded that the Nusselt number for 10mm Circular [MS] rod insert with baffle spacing 30cm is having performance criteria 1.21-1.54 times better than equivalent smooth tube.

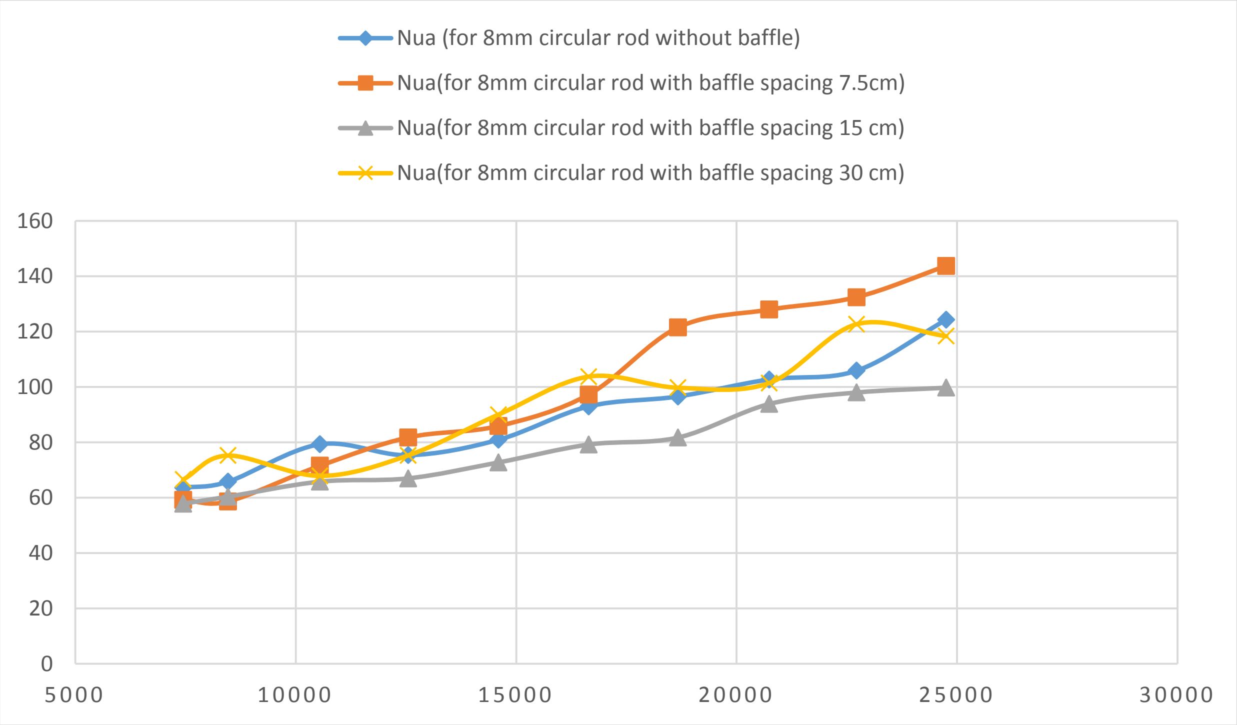

Figure 5.10: Comparison of Nusselt number for all types of inserts of 8mm rod.

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

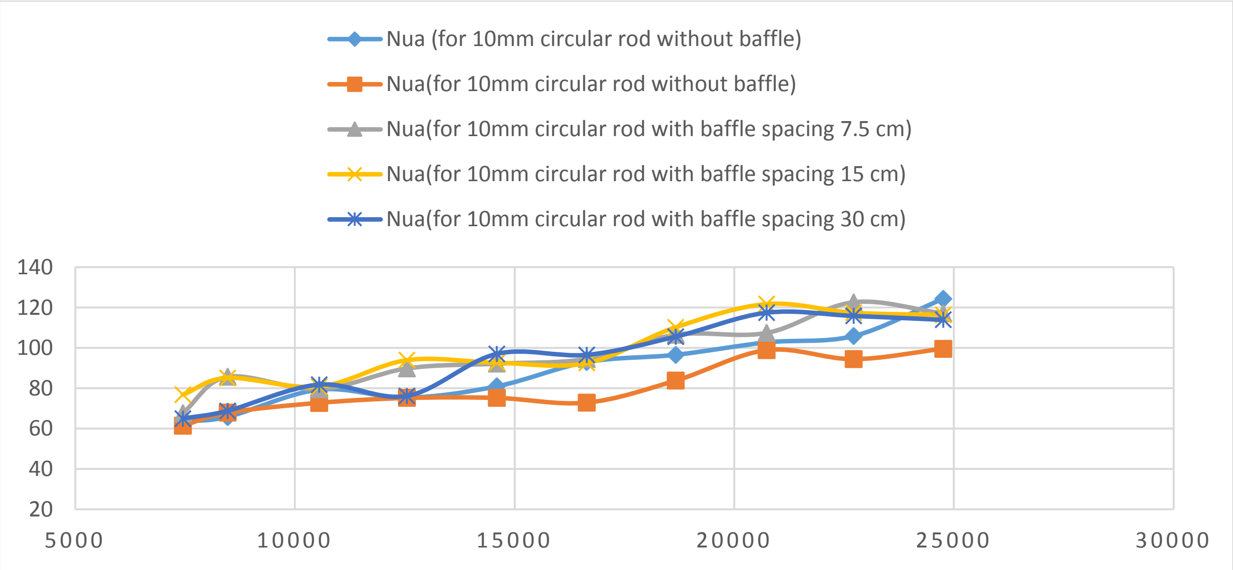

Figure 5.11: Comparison of Nusselt number for all types of inserts of 10 mm rod.

Similarly from this graph it can be observed that as baffle spacing ß increases a lower degree of turbulence is created in the tube & hence the Nusselt number increases as the baffle spacing increases.

CHAPTER 6

CONCLUSION

The scope of Nusselt number and performance evaluation criteria is given in the table underneath

Table 6.1: Summary of the results of 8 mm rods as inserts.

S.no	**Insert**	**Nusselt number**	**Performance Evaluation Criteria**
1	8mm Circular rod with no baffle	63-124	1.10 - 1.50
2	8 mm Circular rod with baffle Spacing 7.5cm.	59-143	1.02 - 1.60
3	8 mm Circular rod rod with baffle Spacing 15cm	57-100	1.00 -1.40
4	8 mm Circular [MS] rod with baffle Spacing 30cm	67-118	1.06 – 1.60

Table 6.2: Summary of the results of 10 mm rods as inserts.

S.no	**Insert**	**Nusselt number**	**Performance Evaluation Criteria**
1	10mm Circular [MS] rod with no baffle	61-100	1.01 - 1.45
2	10 mm Circular [MS] rod with baffle Spacing 7.5cm.	67-117	1.15 - 1.76
3	10 mm Circular [MS] rod with baffle Spacing 15cm	76-121	1.26 - 1.65
4	10mm Circular [MS] rod with baffle Spacing 30cm	66-118	1.2 – 1.60

On the basis of performance evaluation criteria, it can be unmistakably watched that the 10mm Circular [MS] bar embed with baffle space 7.5 cm is the best among all the setups utilized according to it gives the most configurations estimation of highest value of performance evaluation criteria value.

It can likewise be reasoned that with in expansion in baffle spacing ß, the Nusselt number increments. It shifts in the scope of 66-121, the base being for addition of rod with and without baffles and greatest being for rod with baffle space 15cm. In any case, this change goes with an augmentation in estimations of pressure drop too. Hereafter it would not be dependable to judge an embed's similarity on the estimation of Nusselt number alone

SCOPE FOR FUTURE WORK

Further change could be conceivable taking this study as the reason. A bit of the possible scopes of Examination may be:

1. Design of baffle can be changed to watch the impact they have on heat exchange coefficient of the tube and consequently its Nusselt number.

2. The separation between baffles can further be expanded as expanding the separation gives great results .

3. Different material for creation of perplexes can be utilized.

4. Different distances across of wires can be utilized to modify the thickness of the fundamental supplement and consequently changes in the Nusselt number can be noted

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APPENDIX

TABLE A.1: CALIBRATION RESULTS

TABLE A.1.1: RTD CALIBRATION

Table A 1.1: Temperature readings

S.NO.	TEMPERATURE READINGS							
	T1	Corrected T1	T2	Corrected T2	T3	Corrected T3	T4	Corrected T4
1	20.3	20.3	20.2	20.3	20.5	20.3	20.5	20.3
Correction	0		+0.1		-0.2		-0.2	

A.2: PROPERTIES OF SATURATED WATER

T(^{o}c)	μ*10^6	K	Pr
25	902.7	0.6085	6.22
30	801.2	0.618	5.42
35	727.15	0.626	4.865
40	653.1	0.634	4.31
45	601.15	0.641	3.925
50	549.2	0.648	3.54

Table 2.1: Saturated water properties

TABLE A.3: HEAT TRANSFER RESULTS

TABLE A.3.1: STANDARDISATION OF SMOOTH TUBE (Nu_o vs. Re)

S.No.	m(kg/hr)	m(kg/sec)	T1	T2	T3	T4	LMTD	Ui	Nu_o(exp)	Nu_i(th)	Re	%diff
1	350	0.0972	30.1	35.9	52.4	50.4	18.3	760	42.35	49.69	7447	14.77
2	400	0.1111	30.0	35.5	52.8	50.1	18.7	907	57.07	55.17	8466	-3.46
3	500	0.1389	30.0	35.2	51.8	49.4	18.0	962	63.56	65.86	10549	3.49
4	600	0.1667	30.3	34.8	52.3	49.5	18.3	1037	73.50	75.91	12551	3.18
5	700	0.1944	30.2	34.6	52.2	49.4	18.4	1105	84.02	85.76	14595	2.02
6	800	0.2222	30.3	34.2	52.1	49.0	18.3	1175	96.39	95.34	16645	-1.10
7	900	0.2500	30.2	34.0	51.9	48.8	18.2	1235	108.73	104.61	18645	-3.94
8	1000	0.2778	30.3	33.9	51.8	48.7	18.1	1276	118.26	113.81	20739	-3.91
9	1100	0.3056	30.2	33.7	51.5	48.6	18.1	1289	121.55	122.60	22715	0.85
10	1200	0.3333	30.2	33.4	51.3	48.2	17.9	1337	134.27	131.37	24753	-2.20

TABLE A.3.2: Nu VS Re FOR 8 MM CIRCULAR ROD INSERT WITH NO BAFFLES

Sl no	m	T1	T2	T3	T4	LMTD	Ui	Re	Nu_a	Nu_o	R1 = Nu_a / Nu_o
1	0.0972	30.2	36.4	53.0	50.1	18.20	962.71	7496	63.63	42.35	1.502
2	0.1111	30.2	36.0	52.2	49.5	17.70	979.99	8530	65.81	57.07	1.153
3	0.1389	30.3	35.1	52.3	49.1	17.99	1075.89	10572	79.32	63.56	1.248
4	0.1667	30.3	34.9	52.7	49.8	18.64	1049.73	12659	75.38	55.98	1.347
5	0.1944	30.4	34.5	53.0	49.9	19.00	1086.30	14722	80.95	64.92	1.247
6	0.2222	30.5	34.2	52.7	49.4	18.70	1157.09	16789	93.01	68.05	1.367
7	0.2500	30.6	33.5	52.1	48.5	18.25	1176.08	18766	96.58	77.31	1.249
8	0.2778	30.6	33.4	52.8	49.0	18.90	1207.10	20829	102.75	93.21	1.102
9	0.3056	30.6	33.3	53.0	49.2	19.14	1222.13	22887	105.90	93.12	1.137
10	0.3333	30.6	33.3	53.2	49.2	19.24	1300.35	24968	124.35	89.40	1.391

TABLE A.3.3: Nu VS Re FOR 8 MM CIRCULAR ROD INSERT WITH ß= 7.5 CM

Sl no	m1	T1	T2	T3	T4	LMTD	Ui	Re	Nua	Nuo	R1=Nua/Nuo
1	0.0972	30.7	37.5	52.4	50.2	17.10	926.0247	7624	59.22	42.35	1.398
2	0.1111	30.7	37.4	52.3	50.4	17.19	921.2667	8704	58.66	57.07	1.028
3	0.1389	30.7	36.5	52.0	49.8	17.24	1022.904	10776	71.55	63.56	1.126
4	0.1667	30.8	35.5	52.0	49.3	17.48	1091.542	12809	81.78	55.98	1.461
5	0.1944	30.8	34.8	51.9	49.0	17.64	1116.639	14832	85.90	64.92	1.323
6	0.2222	30.7	34.5	51.8	48.8	17.70	1179.762	16879	97.29	68.05	1.430
7	0.2500	30.8	34.1	52.5	48.7	18.15	1289.192	18928	121.49	77.31	1.571
8	0.2778	30.9	34.0	52.5	48.7	18.15	1314.066	21031	127.98	93.21	1.373
9	0.3056	30.8	33.6	52.6	48.6	18.39	1330.28	23011	132.46	93.12	1.422
10	0.3333	30.8	33.4	52.7	48.5	18.49	1368.274	25049	143.77	89.40	1.608

TABLE A.3.4: Nu VS Re FOR 8 MM CIRCULAR ROD INSERT WITH ß= 15 CM

Sl no	m1	T1	T2	T3	T4	LMTD	Ui	Re	Nua	Nuo	R1=Nua/Nuo
1	0.0972	30.6	37.1	52.8	50.4	17.67	914.45	7584	57.88	42.35	1.367
2	0.1111	30.6	36.4	52.6	50.1	17.80	936.01	8603	60.39	57.07	1.058
3	0.1389	30.7	35.3	52.4	49.6	17.98	980.06	10640	65.82	63.56	1.036
4	0.1667	30.5	34.7	52.2	49.5	18.24	989.20	12659	67.00	55.98	1.197
5	0.1944	30.5	34.3	52.1	49.3	18.30	1031.54	14706	72.76	64.92	1.121
6	0.2222	30.5	34.2	51.9	49.2	18.20	1075.31	16789	79.23	68.05	1.164
7	0.2500	30.5	33.9	51.8	49.1	18.25	1091.20	18827	81.73	77.31	1.057
8	0.2778	30.5	33.6	51.7	48.7	18.15	1161.76	20851	93.88	93.21	1.007
9	0.3056	30.6	33.4	51.6	48.5	18.05	1183.51	22912	98.02	93.12	1.053
10	0.3333	30.5	33.3	51.5	48.6	18.15	1192.33	24941	99.76	89.40	1.116

TABLE A.3.5: Nu VS Re FOR 8 MM CIRCULAR ROD INSERT WITH ß= 30CM

Sl no	m1	T1	T2	T3	T4	LMTD	Ui	Re	Nua	Nuo	R1=Nua/Nuo
1	0.0972	32.5	38.7	52.5	50.2	15.67	986.04	7867	66.59	42.35	1.572
2	0.1111	32.5	38.6	52.4	50.1	15.62	1048.78	8982	75.24	57.07	1.318
3	0.1389	32.6	37.4	52.1	49.9	15.96	996.04	11099	67.90	63.56	1.068
4	0.1667	32.6	37.8	52.0	50.3	15.89	1049.23	13375	75.31	55.98	1.345
5	0.1944	32.7	36.5	52.2	49.5	16.24	1140.58	15409	90.03	64.92	1.387
6	0.2222	32.6	36.7	52.4	49.9	16.49	1212.05	17629	103.78	68.05	1.525
7	0.2500	32.6	36.2	52.3	49.8	16.64	1192.30	19728	99.75	77.31	1.290
8	0.2778	32.7	35.9	52.3	49.7	16.70	1200.81	21874	101.46	93.21	1.088
9	0.3056	32.6	35.9	52.2	49.6	16.65	1293.87	24036	122.68	93.12	1.317
10	0.3333	32.6	35.4	52.4	49.5	16.95	1276.74	26083	118.39	89.40	1.324

TABLE A.3.6: Nu VS Re FOR 10 MM CIRCULAR ROD INSERT WITH NO BAFFLES

Sl no	m	T1	T2	T3	T4	LMTD	Ui	Re	Nu_a	Nu_o	$R1=Nu_a/Nu_o$
1	0.0972	30.3	37.0	52.3	49.9	17.36	944.71	7552	61.43	42.35	1.450
2	0.1111	30.3	36.2	52.6	49.8	17.91	996.02	8557	67.90	57.07	1.190
3	0.1389	30.3	35.5	52.8	49.9	18.43	1031.69	10617	72.78	63.56	1.145
4	0.1667	30.2	34.8	53.0	50.0	18.99	1048.46	12632	75.19	55.98	1.343
5	0.1944	30.2	34.2	53.2	50.1	19.45	1048.65	14643	75.22	64.92	1.159
6	0.2222	30.2	33.5	53.0	49.8	19.55	1032.43	16610	72.88	68.05	1.071
7	0.2500	30.2	33.4	52.8	49.5	19.35	1103.87	18666	83.78	77.31	1.084
8	0.2778	30.2	33.4	52.7	49.3	19.20	1188.18	20740	98.93	93.21	1.061
9	0.3056	30.2	32.9	52.5	49.0	19.20	1164.85	22691	94.45	93.12	1.014
10	0.3333	30.2	32.7	52.4	48.8	19.14	1191.49	24701	99.59	89.40	1.114

TABLE A.3.7: Nu VS Re FOR 10 MM CIRCULAR ROD INSERT WITH ß= 7.5 CM

Sl no	m1	T1	T2	T3	T4	LMTD	Ui	Re	Nua	Nuo	R1=Nua/Nuo
1	0.0972	30.8	38.1	52.6	50.3	16.88	994.46	7680	67.69	42.35	1.598
2	0.1111	30.9	37.0	52.0	49.1	16.55	1115.28	8685	85.67	57.07	1.501
3	0.1389	30.7	36.0	53.0	50.0	18.13	1077.38	10719	79.55	63.56	1.252
4	0.1667	30.9	35.7	52.3	49.4	17.53	1139.53	12850	89.85	55.98	1.605
5	0.1944	31.1	35.5	52.0	49.3	17.34	1152.57	14991	92.19	64.92	1.420
6	0.2222	31.1	34.6	51.9	48.8	17.50	1165.35	16969	94.55	68.05	1.389
7	0.2500	31.1	34.5	51.4	48.4	17.10	1225.05	19070	136.53	77.31	1.760
8	0.2778	31.1	34.6	52.3	49.4	18.00	1229.30	21212	107.45	93.21	1.153
9	0.3056	31.0	34.3	52.5	49.3	18.25	1293.75	23233	122.65	93.12	1.317
10	0.3333	31.1	34.2	52.1	49.2	18.00	1271.51	25346	117.12	89.40	1.310

TABLE A.3.8: Nu VS Re FOR 10 MM CIRCULAR ROD INSERT WITH ß= 15 CM

Sl no	m1	T1	T2	T3	T4	LMTD	Ui	Re	Nua	Nuo	R1=Nua/Nuo
1	0.0972	30.0	38.5	52.8	50.5	17.21	1059.41	7648	76.81	42.35	1.814
2	0.1111	31.1	37.8	52.6	49.9	16.72	1112.21	8777	85.15	57.07	1.492
3	0.1389	31.1	36.1	51.9	49.1	16.88	1085.48	10776	80.82	63.56	1.272
4	0.1667	31.2	35.5	51.8	48.7	16.89	1162.09	12863	93.94	55.98	1.678
5	0.1944	31.1	35.4	51.7	49.0	17.09	1155.16	14975	92.66	64.92	1.427
6	0.2222	31.2	34.9	52.4	49.4	17.85	1154.28	17042	92.50	68.05	1.359
7	0.2500	31.2	34.9	52.5	49.4	17.90	1241.86	19172	110.22	77.31	1.426
8	0.2778	31.3	34.6	52.6	49.2	17.95	1290.19	21257	121.74	93.21	1.306
9	0.3056	31.2	34.5	53.0	49.8	18.55	1272.83	23333	117.44	93.12	1.261
10	0.3333	31.3	34.2	53.2	49.8	18.75	1268.45	25400	116.38	89.40	1.302

TABLE A.3.9: Nu VS Re FOR 10 MM CIRCULAR ROD INSERT WITH ß= 30CM

Sl no	m1	T1	T2	T3	T4	LMTD	Ui	Re	Nua	Nuo	R1=Nua/Nuo
1	0.0972	31.0	37.2	52.8	50.1	17.29	973.41	7624	64.97	42.35	1.534
2	0.1111	31.1	37.0	52.5	49.9	17.10	1002.74	8704	68.79	57.07	1.205
3	0.1389	31.0	36.8	52.3	49.8	17.10	1091.87	10845	81.83	63.56	1.287
4	0.1667	31.0	35.8	52.3	49.8	17.62	1055.23	12877	76.19	55.98	1.361
5	0.1944	31.0	35.4	52.2	49.3	17.54	1178.58	14959	97.06	64.92	1.495
6	0.2222	31.0	34.9	52.1	49.2	17.70	1176.02	17006	96.57	68.05	1.419
7	0.2500	31.1	34.6	52.1	49.0	17.70	1220.63	19091	105.58	77.31	1.366
8	0.2778	31.1	34.4	52.0	48.8	17.65	1273.01	21166	117.48	93.21	1.260
9	0.3056	31.0	34.2	51.9	48.9	17.80	1266.29	23209	115.87	93.12	1.244
10	0.3333	31.1	33.9	51.8	48.7	17.75	1258.12	25264	113.94	89.40	1.274