Forced Convection Heat Transfer Augmentation using Passive Techniques

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- Introduction
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- Literature Review
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Problem Definition

- To increase the heat transfer co-efficient of heat exchanger.
- Reduce pumping power required to overcome friction losses.

Objective

- To reduce pumping power.
- Upgrade the capacity of existing heat exchanger.
- Reduce size of heat exchanger.
- To save energy and material.

Introduction

The study of improved heat transfer is termed as heat transfer augmentation.

$$\mathbf{Q = h * As * (T_s - T_f)}$$

$$\mathbf{N_u = 0.023\ R_e^{\ 0.8} * P_r^{\ n}}$$

$$\frac{hD}{k} = 0.023\left(\frac{\rho V D}{\mu}\right)^{0.8}\left(\frac{C_p \mu}{k}\right)^{n}$$

h= heat transfer co-efficient.

Methods of Heat Transfer Augmentation

Methods of heat transfer Augmentation are :

- Passive Techniques
- Active Techniques
- Compound Techniques

1. Passive Technique : These techniques generally use surface or geometrical modifications to the flow channel with the help of inserts or additional devices

2. Active Technique : This method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer.

3. Compound Technique : In this method more than one of the above mentioned techniques is used in combination to increase heat transfer rate.

Literature Review

1. **Suhas V. Patilet** : this paper is a review of research work in last decade on heat transfer enhancement in a circular tube and square duct.
2. **A Dewan** : 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.
3. **Sandeep S. Kore** : the experimental investigation has been carried out to study heat transfer and friction coefficient by dimpled surface.

4. **Arthur E. Bergles** : focuses on characterization of twisted-tape-induced helical swirl flows for enhancement of forced convective heat transfer in single-phase and two phase flows.
5. **Dr. Anirudh Gupta :** In this journal Dimple, protrude and rough surfaces etc passive methods are used in heat exchangers, air heaters and heat sinks to enhance heat transfer.
6. **Giovanni Tanda :** This paper focuses on cooling techniques for vanes and blades of advance gas turbine operate at high entry gas temperature.

Specification Of Component

- Blower – 1 HP, centrifugal type
- Orifice meter – Diameter 12.5 mm
- Water Tube Manometer
- Test section 0.5m length, 25mm diameter
- Heater- Band type Nichrome wire with GI gladding
- Control panel:
    a) Temp. Indicator digital
    b) Dimmer state 2 amps & 0 to 200 volt
    c) Ammeter digital 0 to 2 amp
    d) volt meter digital 0 to 200 volt
    e) Selector switch
- Thermocouples - Copper constant type (Qty 10)
- Flow control valve

Inserts Used

Group 1

- Stream line body and twisted strip

Group 2

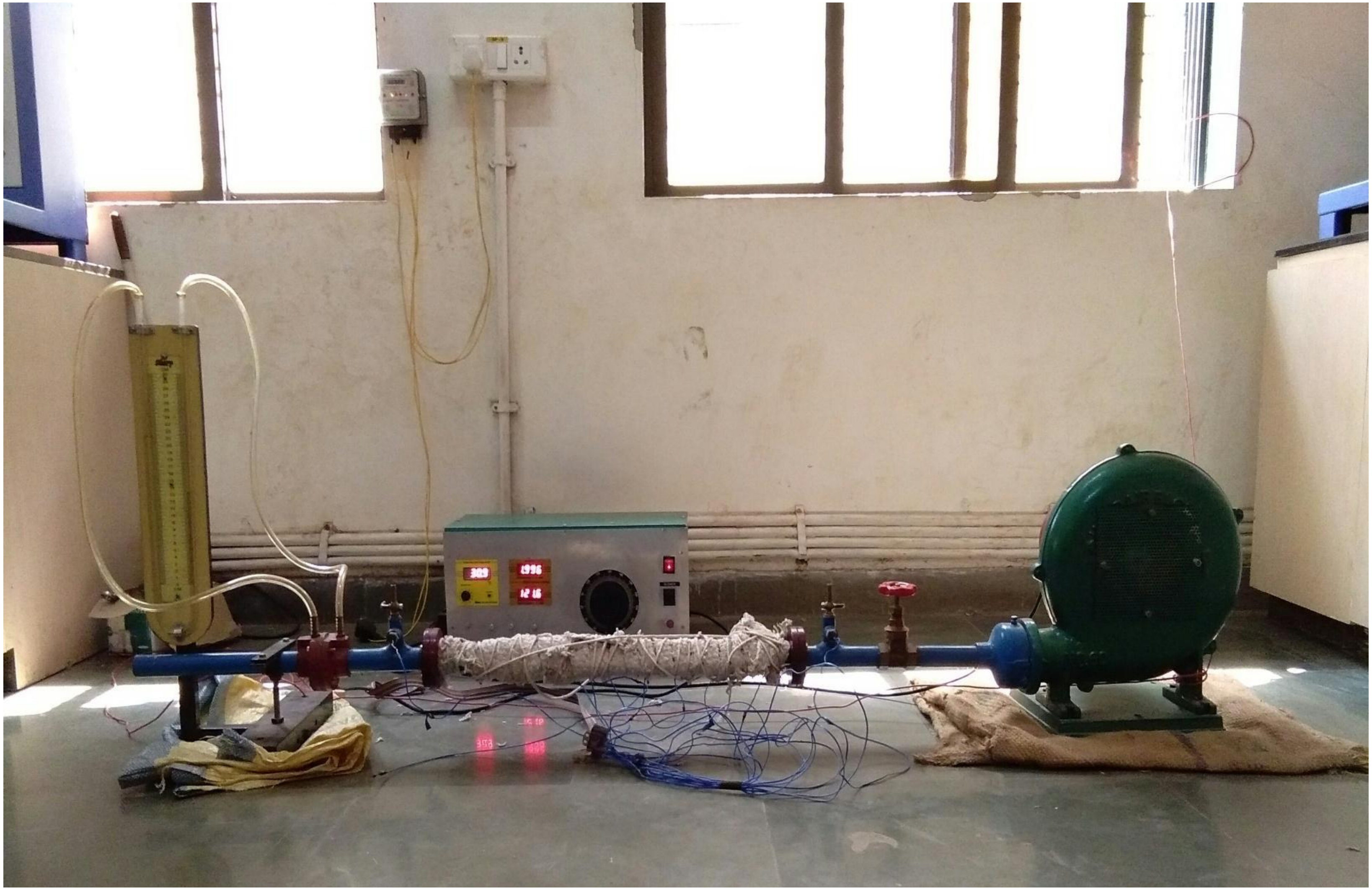
- Annular blockages

  20%

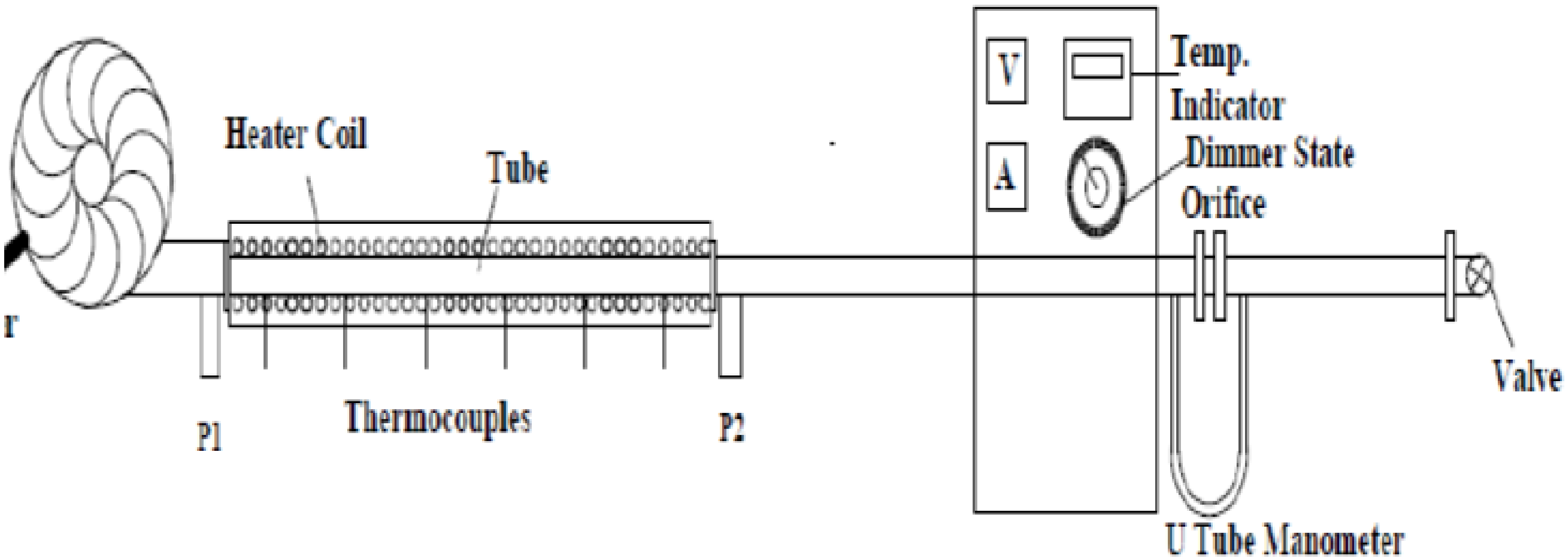
  30%

  40%

Experimental Setup



General layout

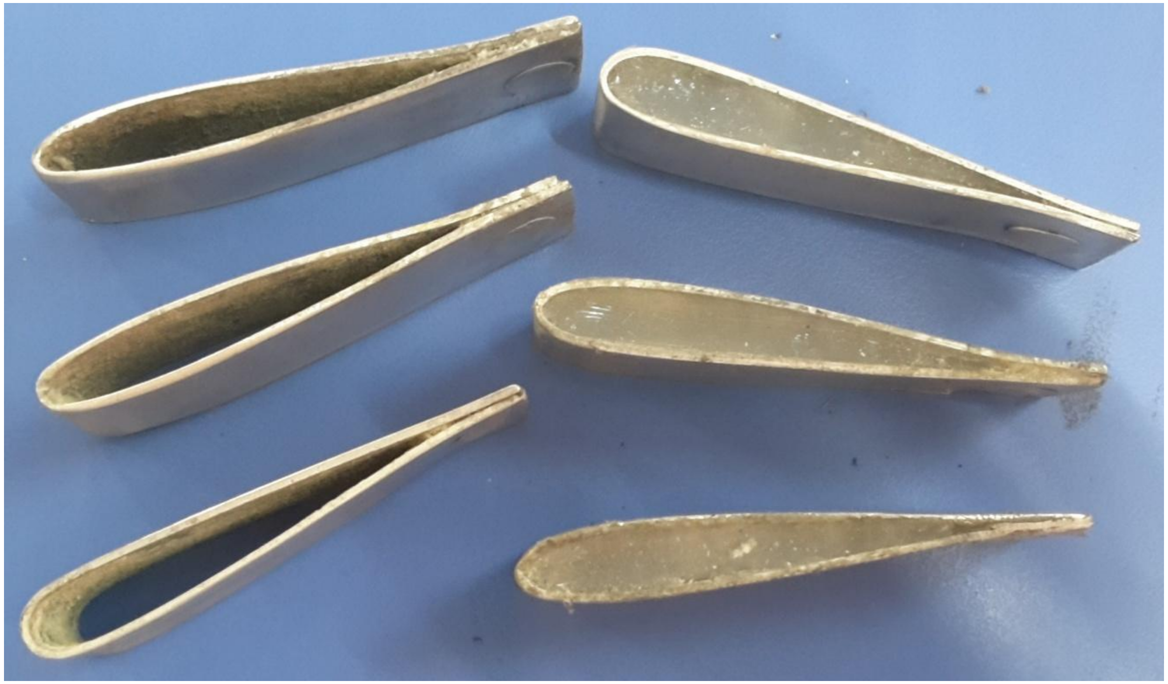


Twisted Strip

- Swirl flow
- Uniform wall temperature
- Commonly used
- Pressure drop

Streamlined Body

- Reduced friction drag
- To overcome pressure drop
- To reduce power consumption



Annular Blockages

20 %

30%

40%

Data Reduction

- AVERAGE TEMP OF TUBE WALL :

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

- BULK TEMPERATURE: $Tb = \frac{T1 + T10}{2}$

- The mass flow rate of air is determined from the pressure drop across the orifice meter, using a following relation:

$$m = C_D \times a_o \times \frac{\rho_{air} \times \sqrt{2gHa}}{\sqrt{1-\beta^4}}$$

- The useful heat gain of the air is calculated as:

$$Q = m \times C_p \times (T_{FO} - T_{FI})$$

- The heat transfer coefficient for the test section is:

$$h = \frac{Q}{As} \times (T_{pm} - T_{Fm})$$

- Nusselt number is given by:

$$Nu = 0.023\, R_e^{\ 0.8} . P_r^{\ n} \qquad \frac{hD}{k} = 0.023 \left(\frac{\rho V D}{\mu}\right)^{0.8} \left(\frac{C_p \mu}{k}\right)^{n}$$

The Properties k, ρ, μ and Cp are evaluated at local bulk mean temperature.

- Power consumption $$P = \frac{10}{t} \times \frac{3200}{1000}$$

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.

Observation Table(Plain Tube)

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

Result Table (Plain Tube)

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

Observation Table(Blockages/20%-30%)

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	41.2	48.4	53.4	55.3	55.7	56.5	53.2	45.3	37.1
60	6	30	43.8	48	51.1	51.8	52.8	53.7	51.1	44.1	38.1
60	8	30	40.7	46.9	50.7	52.5	53.5	52.8	50.1	43.2	37
90	4	30	46.9	66.9	78	81	84.5	86.1	78.3	59.5	42.5
90	6	30	48.8	70.6	81.5	84.1	86.5	89.2	82	61.9	44.9
90	8	30	45.1	61.2	69.8	71.0	73	78.7	69.5	54.8	42.5
120	4	30	56	90.5	112	114.9	121.4	123.7	111.3	79.7	50.6
120	6	30	54.1	86	103	106.2	109.7	113.3	103	74	42
120	8	30	51.5	79.9	93.9	96.2	100.3	102.4	91.3	66.3	44.6

Result Table (Blockages/20%-30%)

Input in Watt	Manometer Readings	Reynolds Number	Tb	Ts	h (W/m2K)	Nu	Nuthe	Power Consumption (kW)
60	4	6635.862	35.05	51.125	16.15058	15.37934	23.11046	0.9778
60	6	8095.734	36	49.55	24.00276	22.79551	27.09172	1.134
60	8	9371.07	35.4	48.8	21.37354	20.33282	30.45792	0.8629
90	4	6543.959	38.5	72.65	14.75319	13.91338	22.84276	1.2698
90	6	7978.275	39.65	75.575	22.50243	21.15359	26.76282	1.538
90	8	9256.398	38.45	65.3875	26.78329	25.2622	30.14622	0.9696
120	4	6422.853	43.2	101.1875	15.95309	14.85014	22.48798	1.5414
120	6	7860.186	36.5	93.6625	17.19331	16.30563	30.34419	1.7563
120	8	9216.149	39.55	85.225	19.66158	18.48817	30.03658	1.2485

Observation Table(Blockages/20%-40%)

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	40.8	48.7	56.3	58.7	57.7	59.1	54.5	46.8	38.7
60	6	30	40.7	47.5	54.6	54.2	53.8	53.8	51.1	44.3	37.3
60	8	30	40.3	46.3	52.2	53.4	52.7	53.3	49.8	43.7	38.5
90	4	30	46.7	65	86	85.1	84.7	84.7	77.7	61.2	44.5
90	6	30	47.6	61.1	75.3	77.4	77	77	71	56.8	44.7
90	8	30	44.7	59.5	71.4	72.9	73.1	72	66.5	53.4	42.6
120	4	30	56.8	86.9	114.9	122.3	120.5	121	108.5	83.3	54.3
120	6	30	51.5	78.1	101.8	105.7	106	104.4	94.1	68.8	46.9
120	8	30	50.8	75.7	98.2	102.2	101.8	99.3	90.2	65.4	47.6

Result Table (Blockages/20%-40%)

Input in Watt	Manometer Readings	Reynolds Number	Tb	Ts	h (W/m2K)	Nu	Nuthe	Power Consumption (kW)
60	4	6594.058	36.6	52.825	16.35155	15.50298	22.98881	0.8046
60	6	9289.761	37.55	50	25.07582	23.71128	30.23701	0.8080
60	8	9314.102	36.9	48.9625	23.68732	22.43917	30.3032	0.8040
90	4	6511.671	39.75	73.8875	17.49097	16.43795	22.7488	1.0217
90	6	7952.85	40.45	67.9	23.80995	22.33302	26.69137	1.0034
90	8	9254.305	38.55	64.1875	28.13691	26.53154	30.14082	1.0174
120	4	6376.724	45.05	101.775	20.32434	18.82329	22.3523	1.2265
120	6	7947.897	40.7	88.8	19.807	18.5595	26.67578	1.3039
120	8	9155.563	41.2	85.45	25.6523	24.0111	29.87104	1.2598

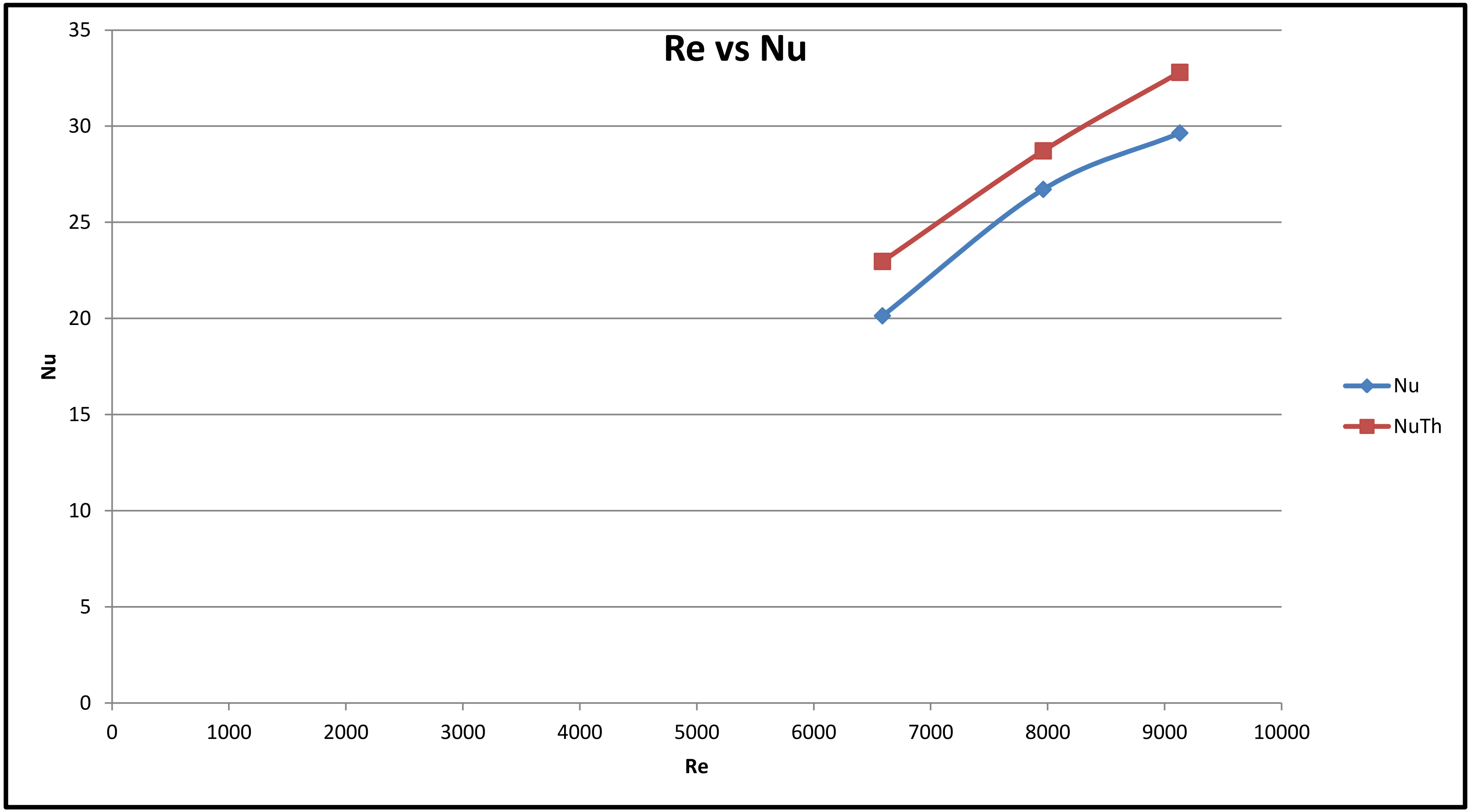
Observation Table(Alternate/20%-30%)

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	43.6	50.5	60.5	59.9	60.5	59.7	57.5	48.4	39.7	39.06
60	6	31	47	59.3	64	66.6	64.8	68.9	62.8	54.5	40.7	41.92
60	8	31.3	53.6	62.8	70.1	81.2	83.2	93.1	82.3	57.3	43.8	40.7
90	4	30.7	50.8	64.2	81.3	83	83.2	84.5	79.7	60.4	43	31.36
90	6	30.9	57.1	68.3	89.7	94.6	99.7	107	100.2	76.8	49.4	30.99
90	8	31.5	62.2	70.8	91.2	96.7	101.7	115.2	103.3	80.4	52.3	31.09
120	4	31.4	60.7	94.8	115.4	118.2	122.5	159.5	111.5	78.9	50.4	26.01
120	6	31.5	65.9	100.1	102.4	125.2	136.9	160.3	116.7	84.5	57.6	25.85
120	8	32.2	67.3	105.3	108	126.9	140.3	169.4	120.4	92.5	63.7	26.89

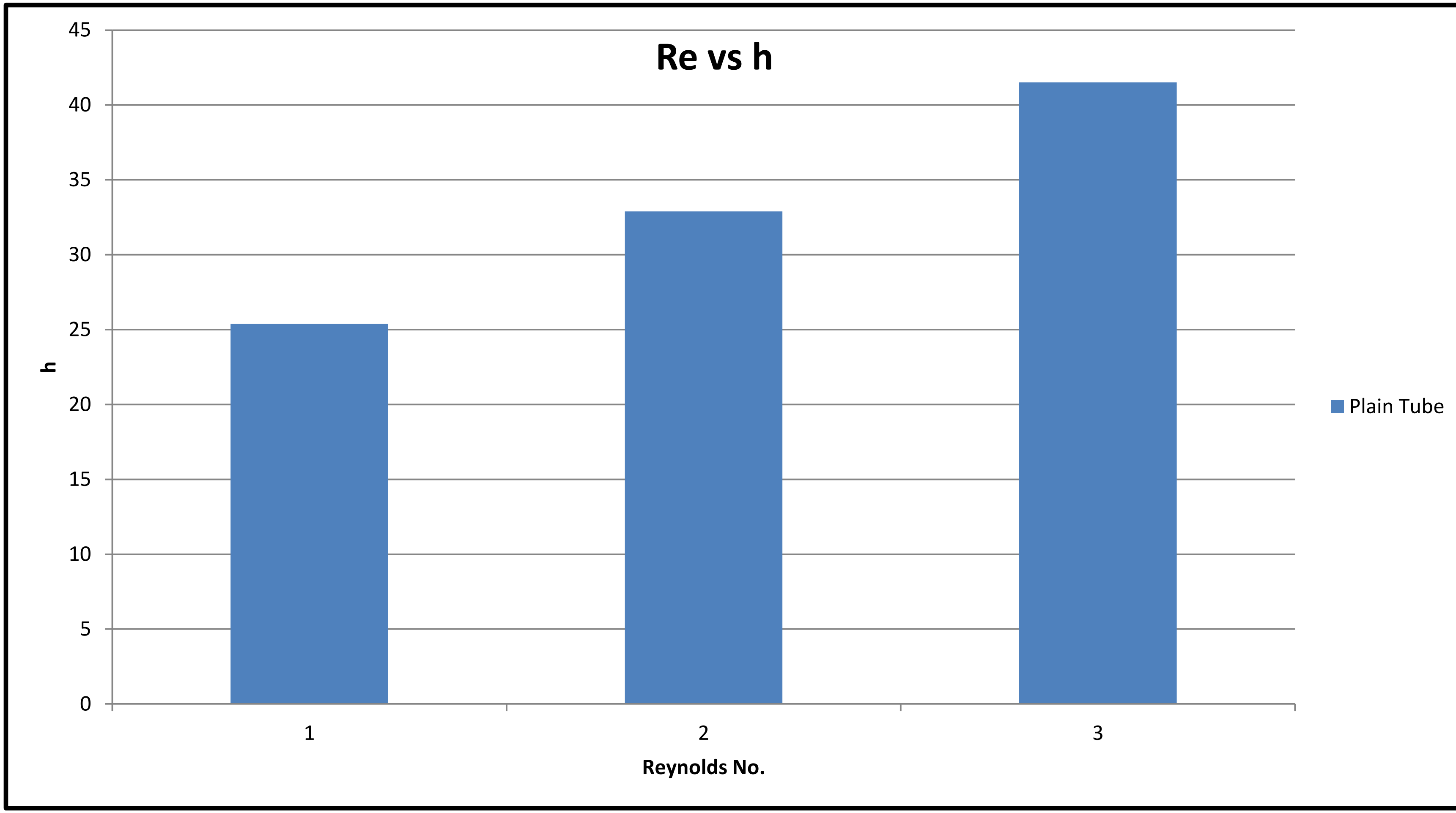
Result Table (Alternate/20%-30%)

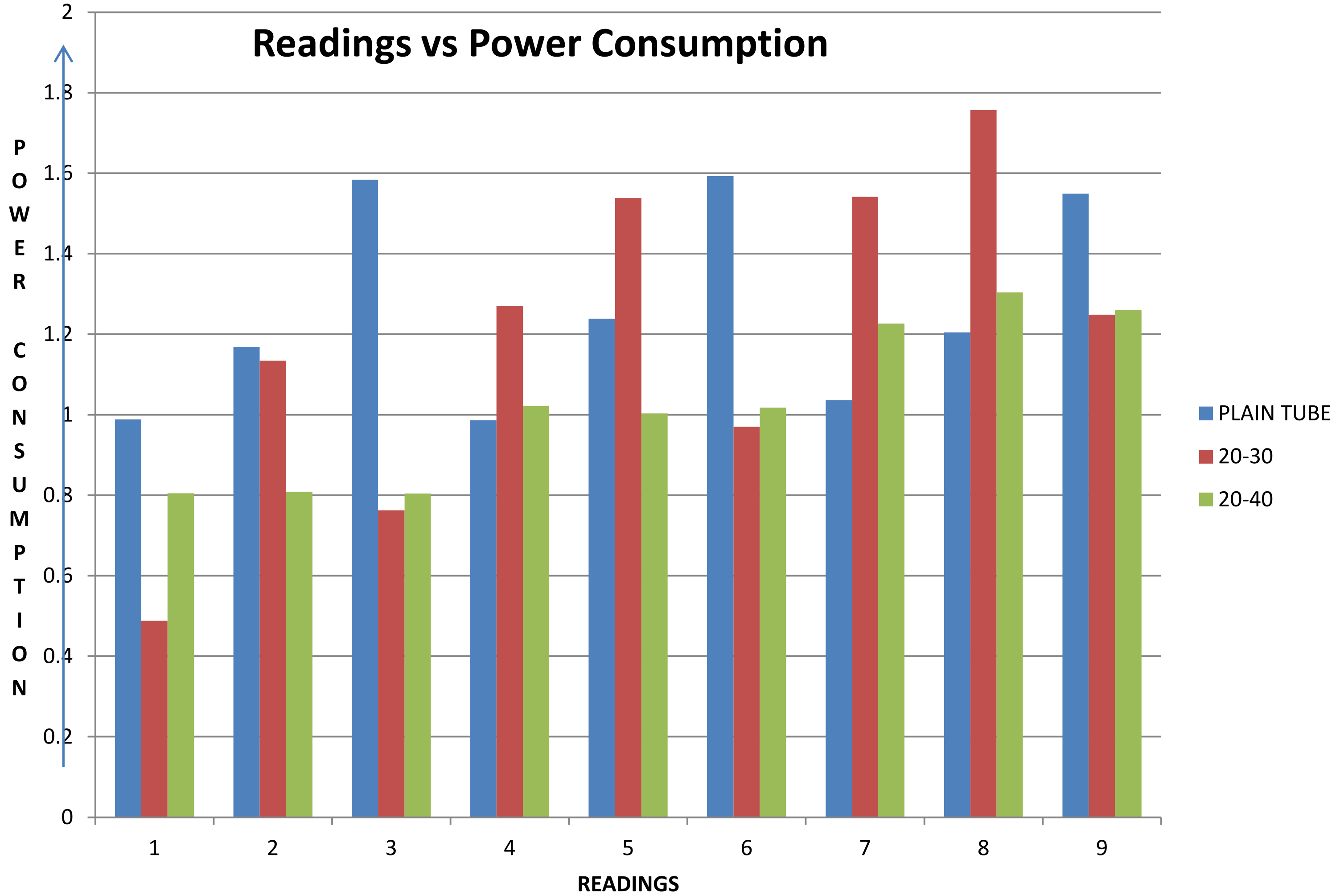
Input in Watt	Manometer Readings	Reynolds Number	Tb	Ts	h (W/m2K)	Nu	Nuthe	Power Consumption (kW)
60	4	6641.2	34.85	55.075	25.38	23.945	28.126	0.8192
60	6	8100.7	35.85	60.988	32.888	27.397	28.106	0.7633
60	8	9289.8	37.55	72.95	41.497	29.783	30.237	0.7862
90	4	6587.4	36.85	73.388	21.256	20.139	22.969	1.0204
90	6	7962.5	40.15	86.675	30.59	26.716	28.718	1.0325
90	8	9130.1	41.9	90.188	38.157	29.646	32.801	1.0232
120	4	6481.7	40.9	107.69	17.848	16.72	22.661	1.2303
120	6	7825	44.55	111.5	29.779	26.617	27.331	1.2379
120	8	8916.6	47.95	116.26	35.458	29.182	30.216	1.1300

Graphical Representation

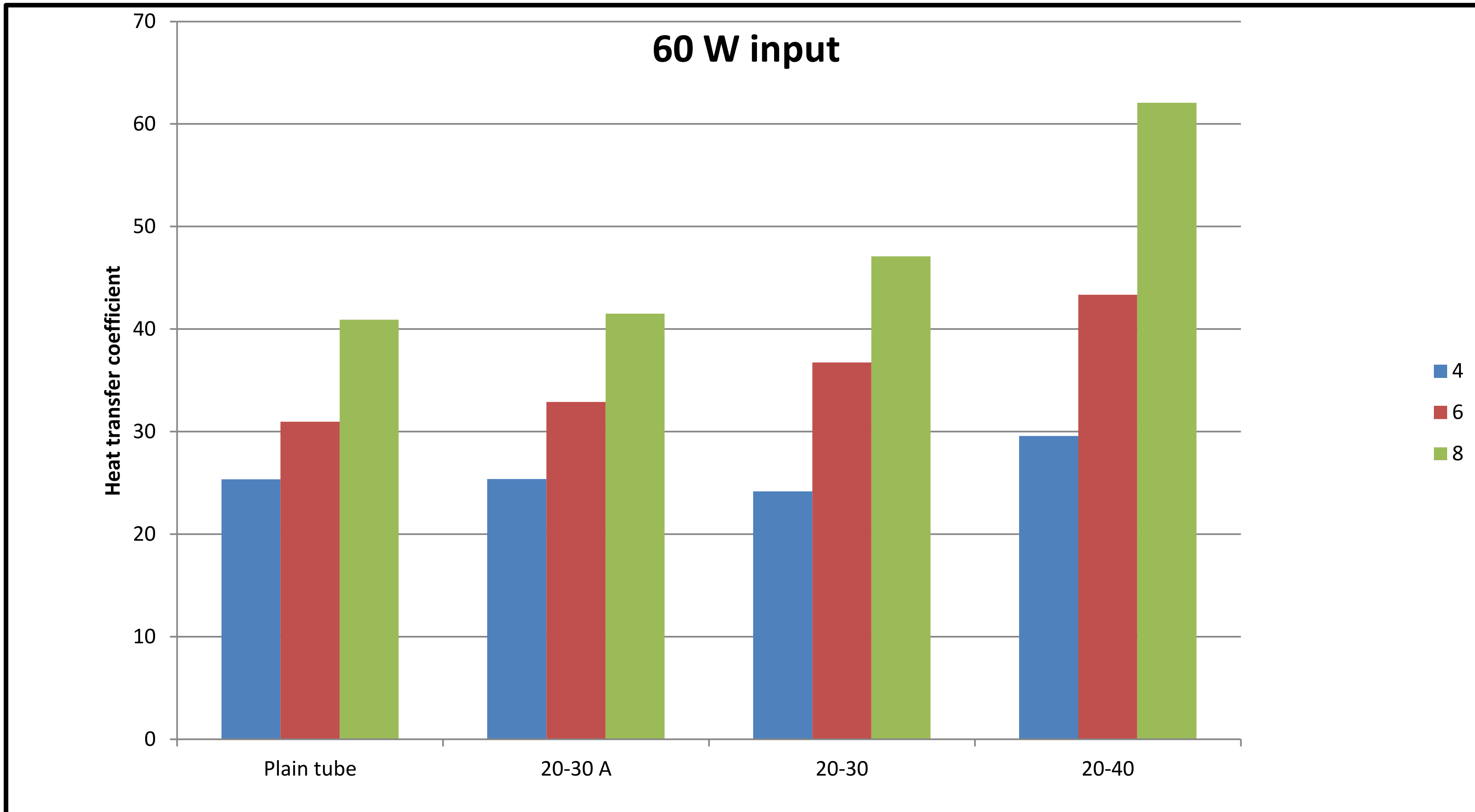


Reynolds No v/s Heat Transfer Co-efficient




Readings vs Power Consumption
POWER CONSUMPTION
READINGS
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
1
2
3
4
5
6
7
8
9
PLAIN TUBE
20-30
20-40

Different Inserts v/s Heat Transfer Co-efficient



Observation Table(Twisted Strip)

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

Result Table (Twisted Strip)

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

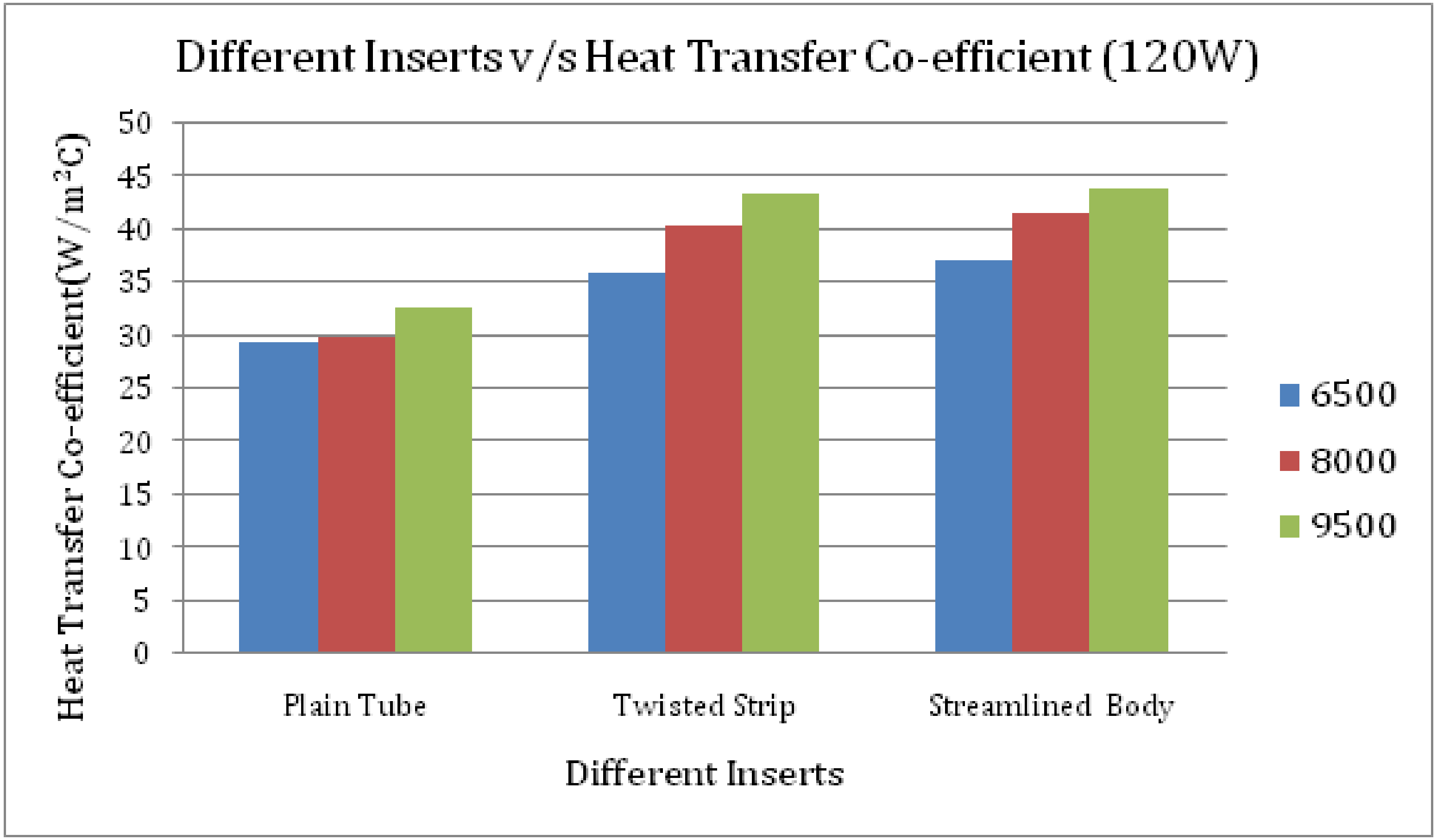
Observation Table(Streamlined Body)

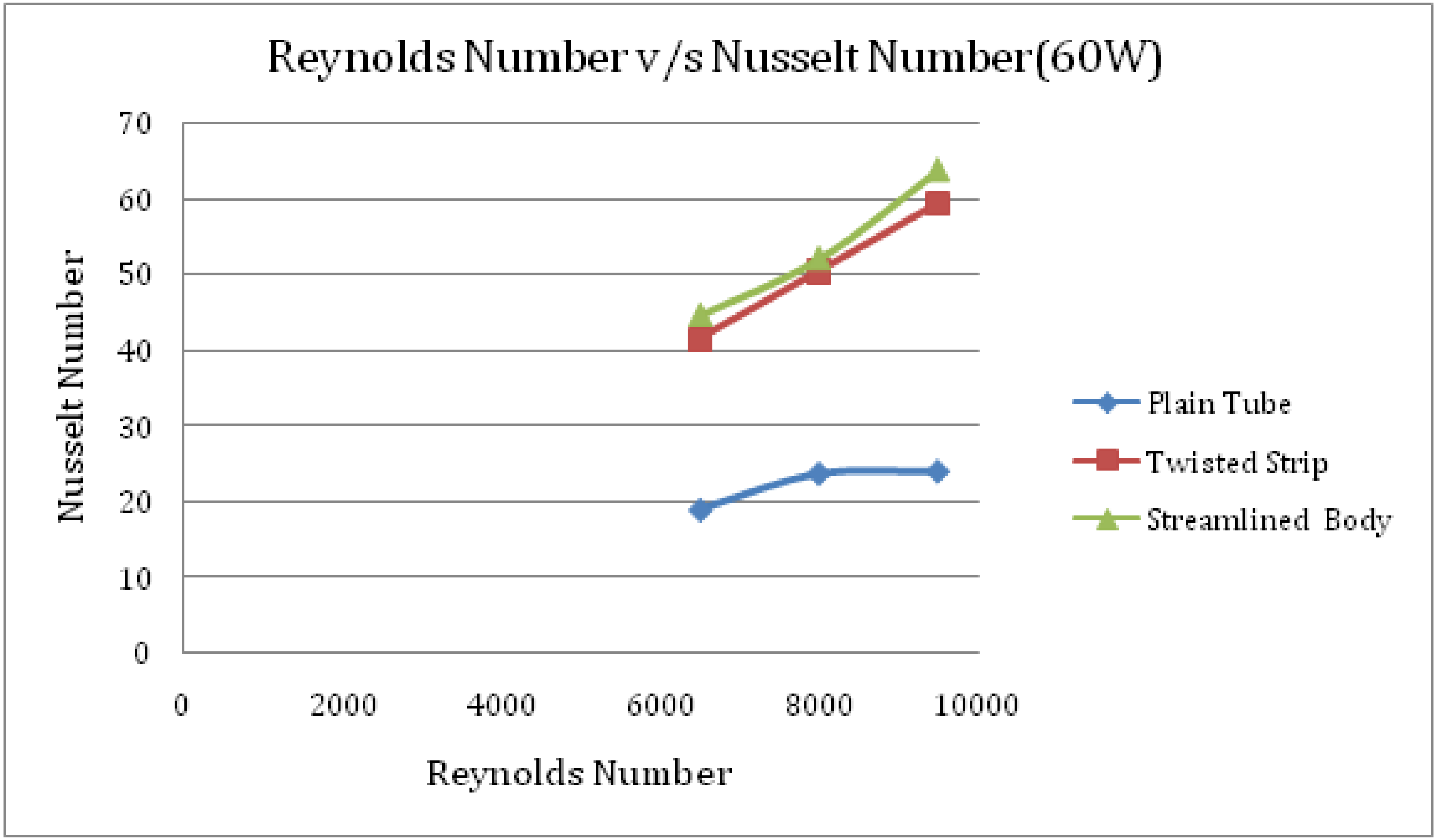
Input in Watts	Mano-meter Reading	Temperature (Degree centigrade)									
		T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
60	4	30	55.1	58.4	59	58.3	62.2	48.1	38.8	35.7	41.9
60	6	30	45.8	51	54.2	53.1	57.5	46.7	45.1	43	40.2
60	8	30	43	48.7	51.3	52	52.4	46.1	43	36	39
90	4	30	75.2	81	84.5	85.3	86.6	72	64.2	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

Result Table (Streamlined Body)

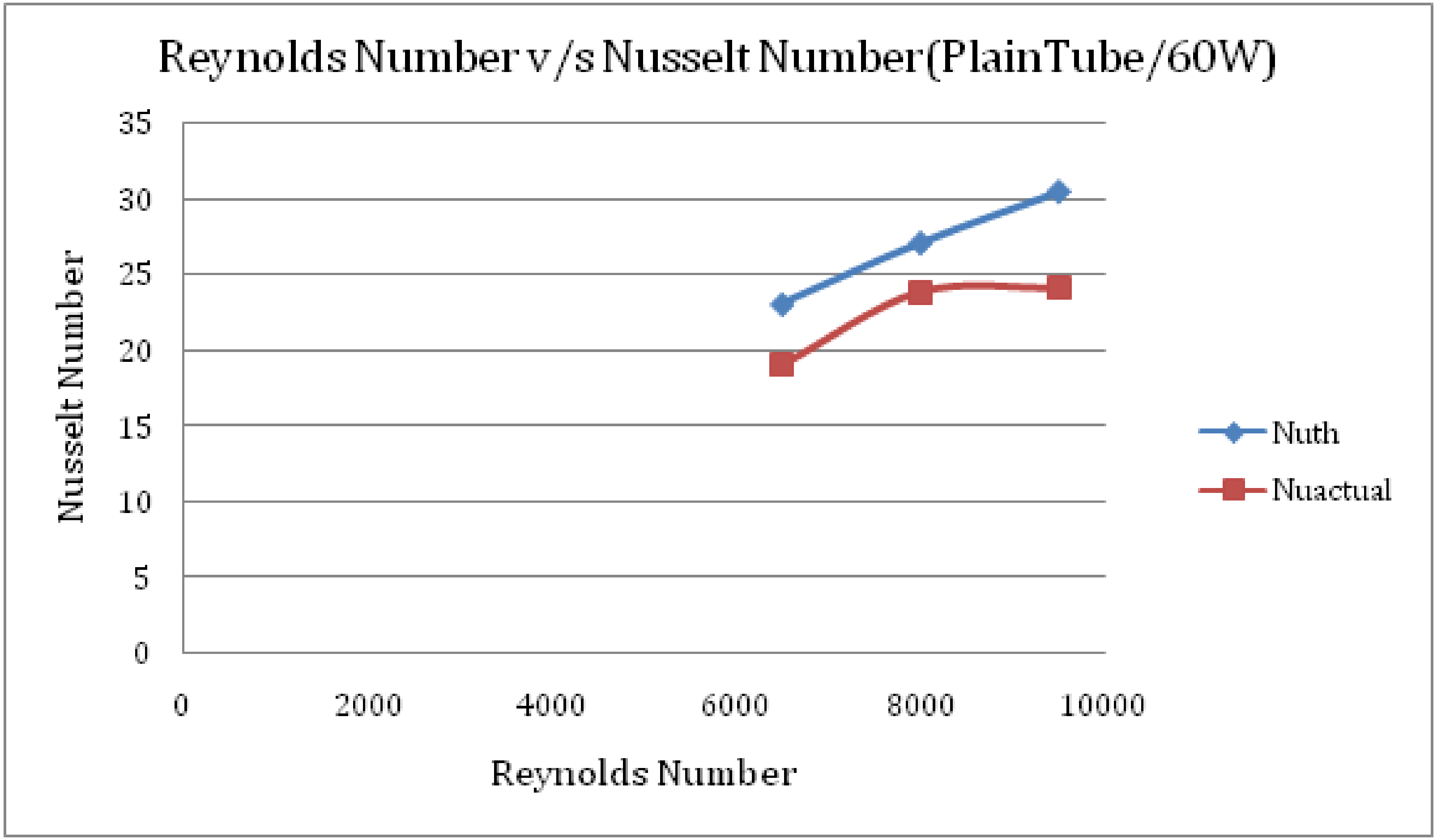
Input in Watts	Mano-meter Readings	Re	T_b	T_s	Nu_{act}	Nu_{th}	h_{actual}	h_{th}	Power Consumption	F_{act}	F_{th}	Over all Enhancement
60	4	6611	35.9	51.9	44.67	23.03	47.02	24.25	0.278	0.0366	0.3328	0.9297
60	6	8125	35.1	49.5	52.11	27.17	54.73	28.54	0.279	0.0358	0.3698	0.8813
60	8	9405	34.5	46.5	63.78	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

Graphical Representation

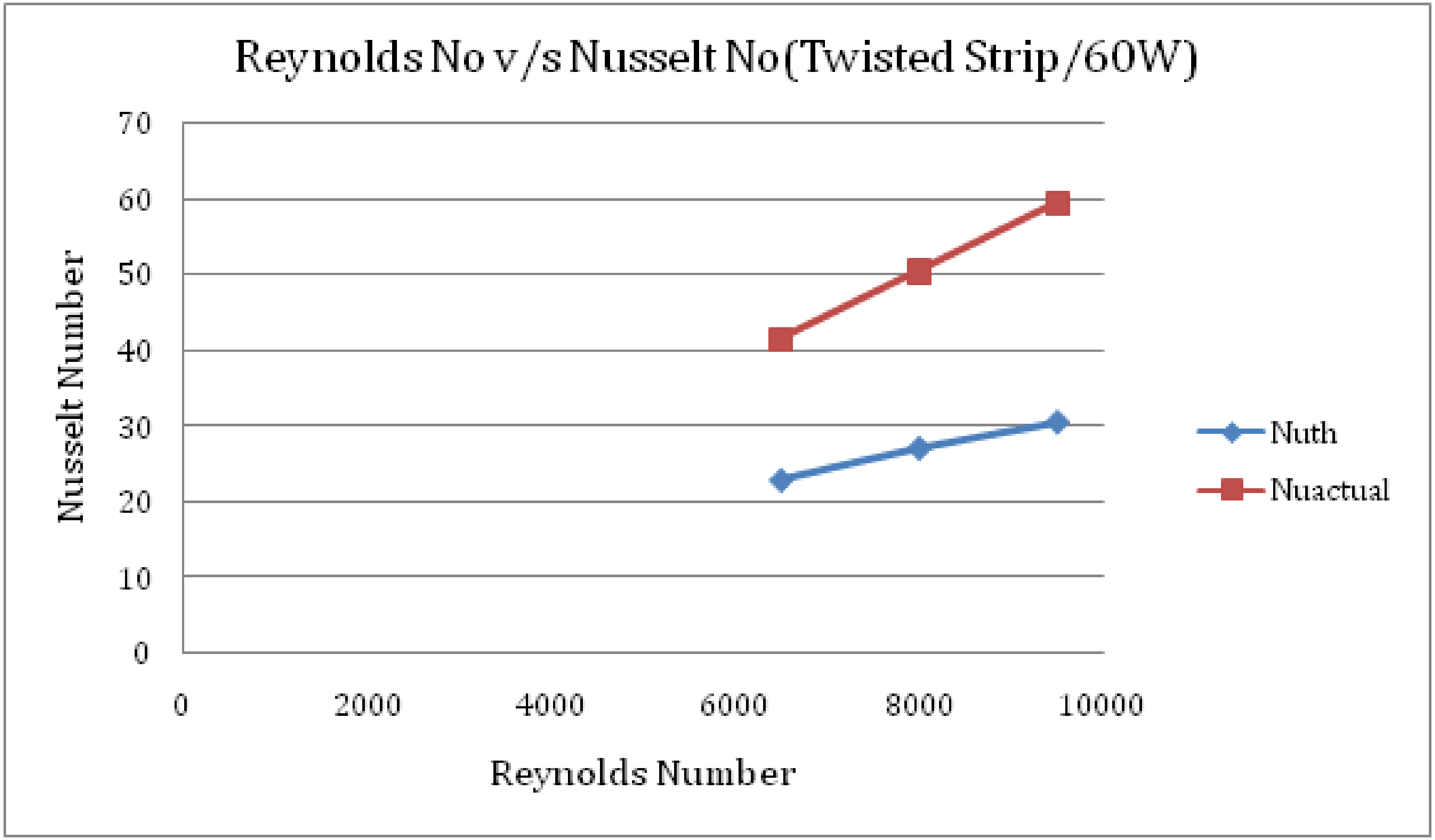




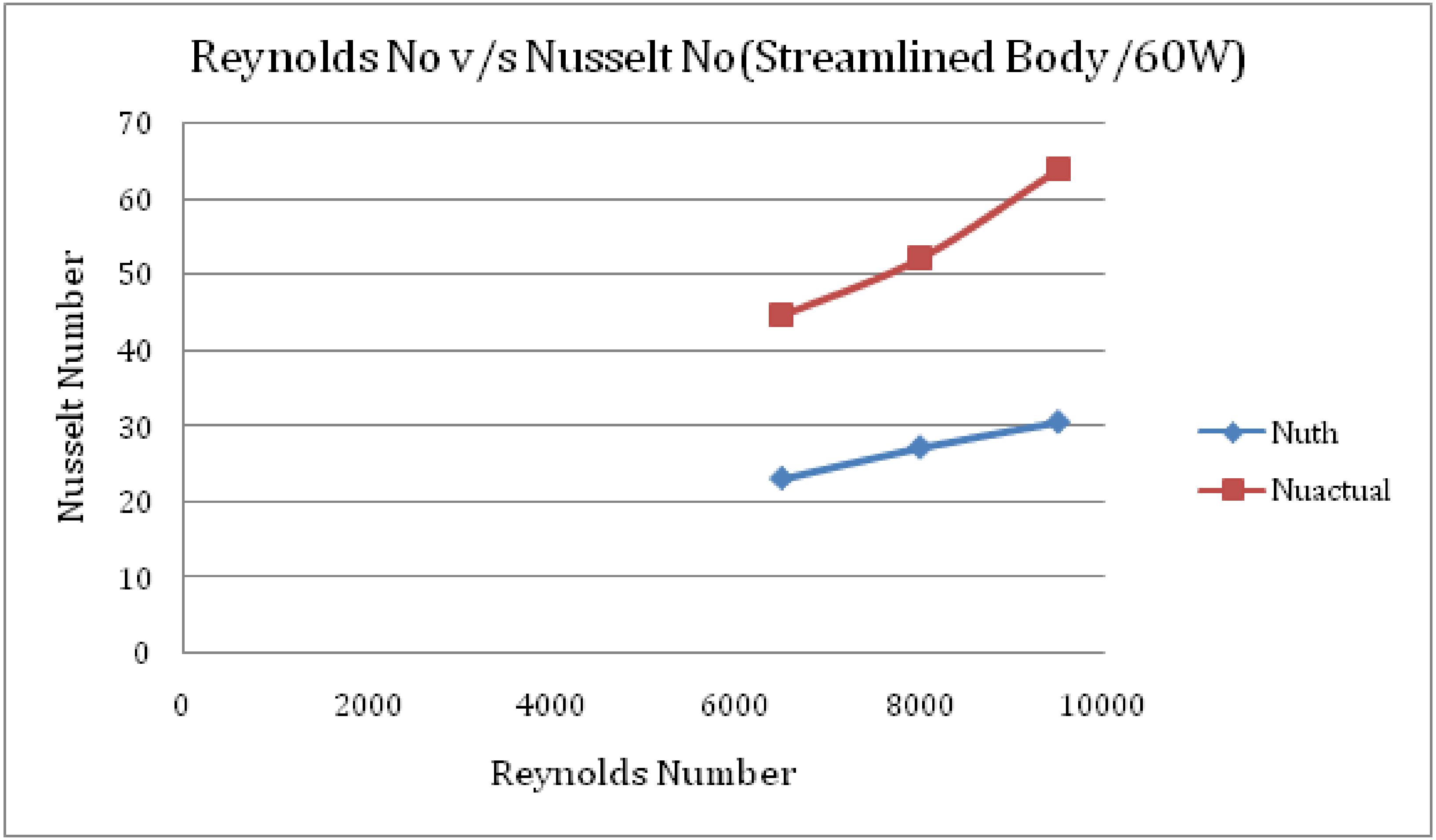
Reynolds Number v/s Nusselt Number(60W)
70
60
50
40
30
20
10
0
Nusselt Number
0
2000
4000
6000
8000
10000
Reynolds Number
Plain Tube
Twisted Strip
Streamlined Body



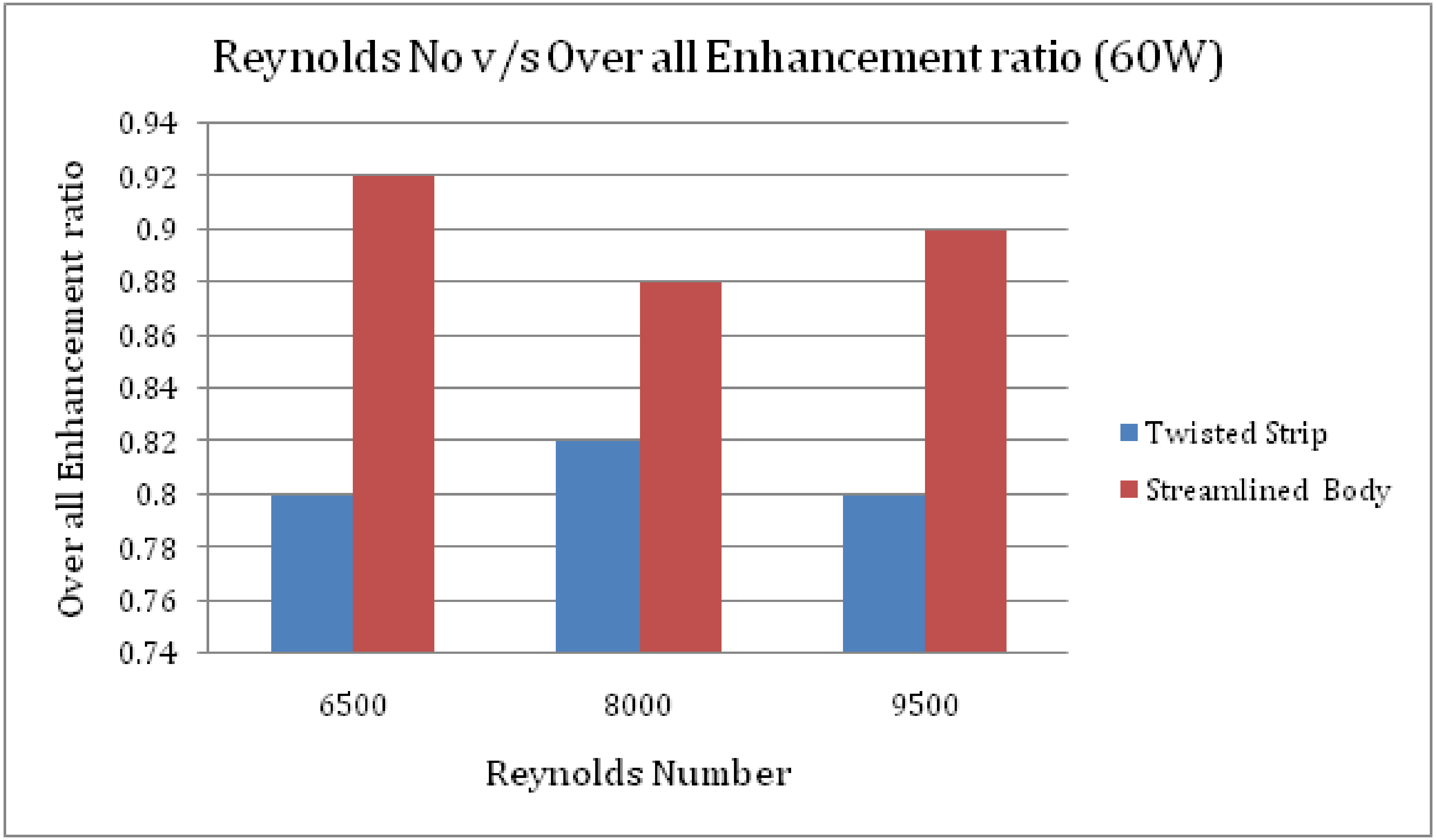
Reynolds Number v/s Nusselt Number(PlainTube/60W)
Nusselt Number
35
30
25
20
15
10
5
0
0
2000
4000
6000
8000
10000
Reynolds Number
Nuth
Nuactual



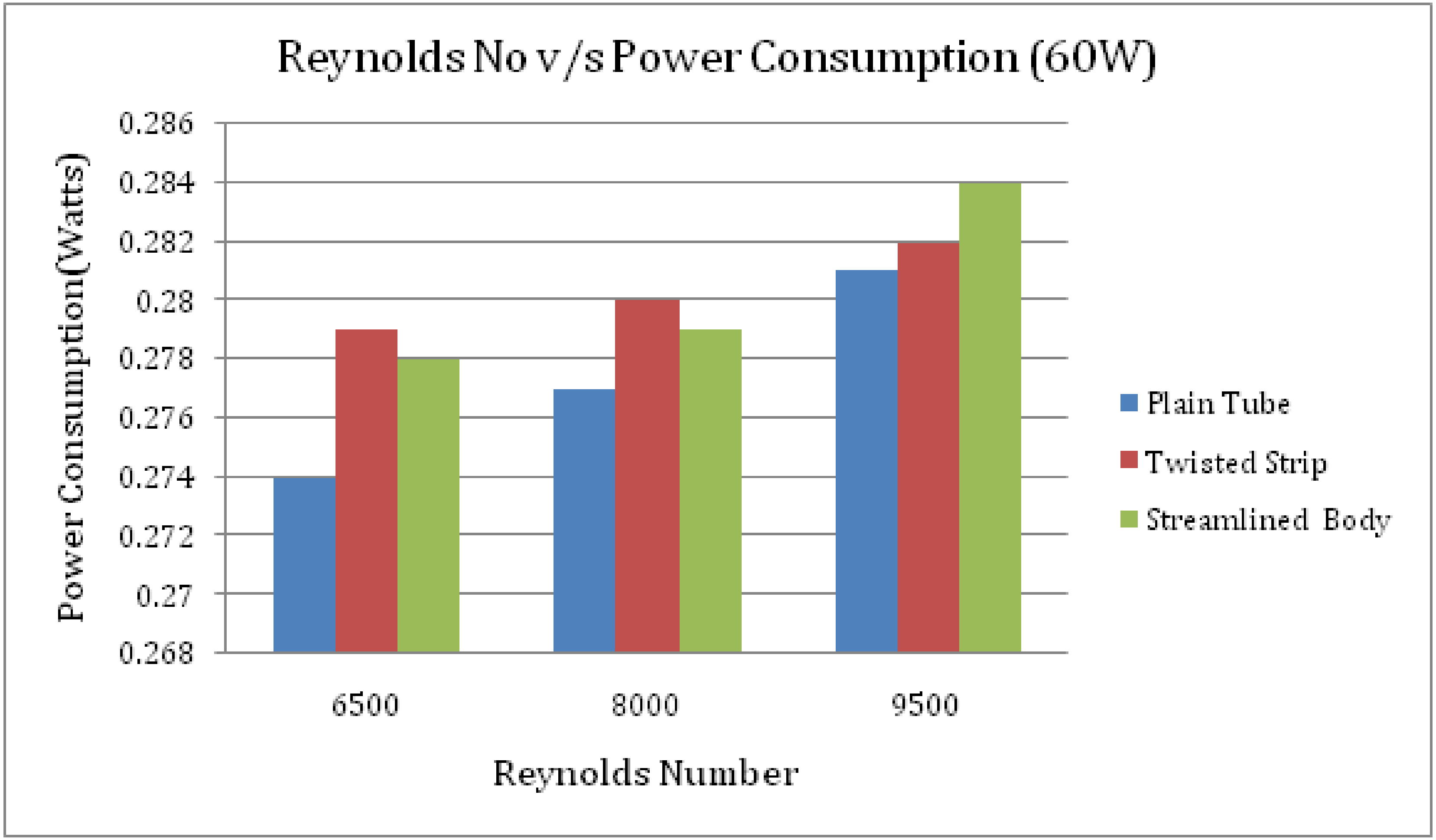
Reynolds No v/s Nusselt No (Twisted Strip/60W)
Nusselt Number
70
60
50
40
30
20
10
0
0
2000
4000
6000
8000
10000
Reynolds Number
Nuth
Nuactual



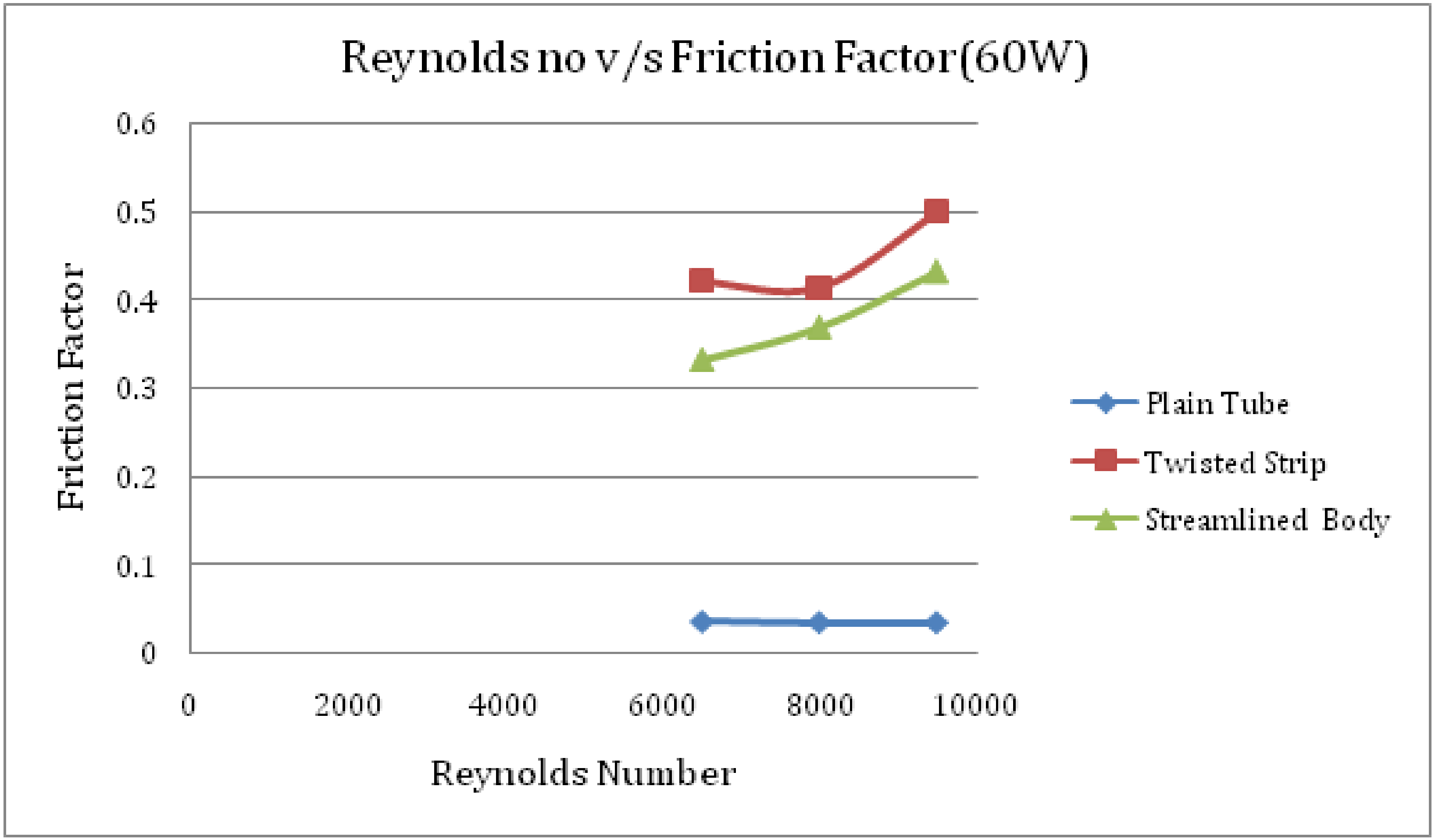
Reynolds No v/s Nusselt No(Streamlined Body/60W)
70
60
50
40
30
20
10
0
Nusselt Number
0
2000
4000
6000
8000
10000
Reynolds Number
Nuth
Nuactual



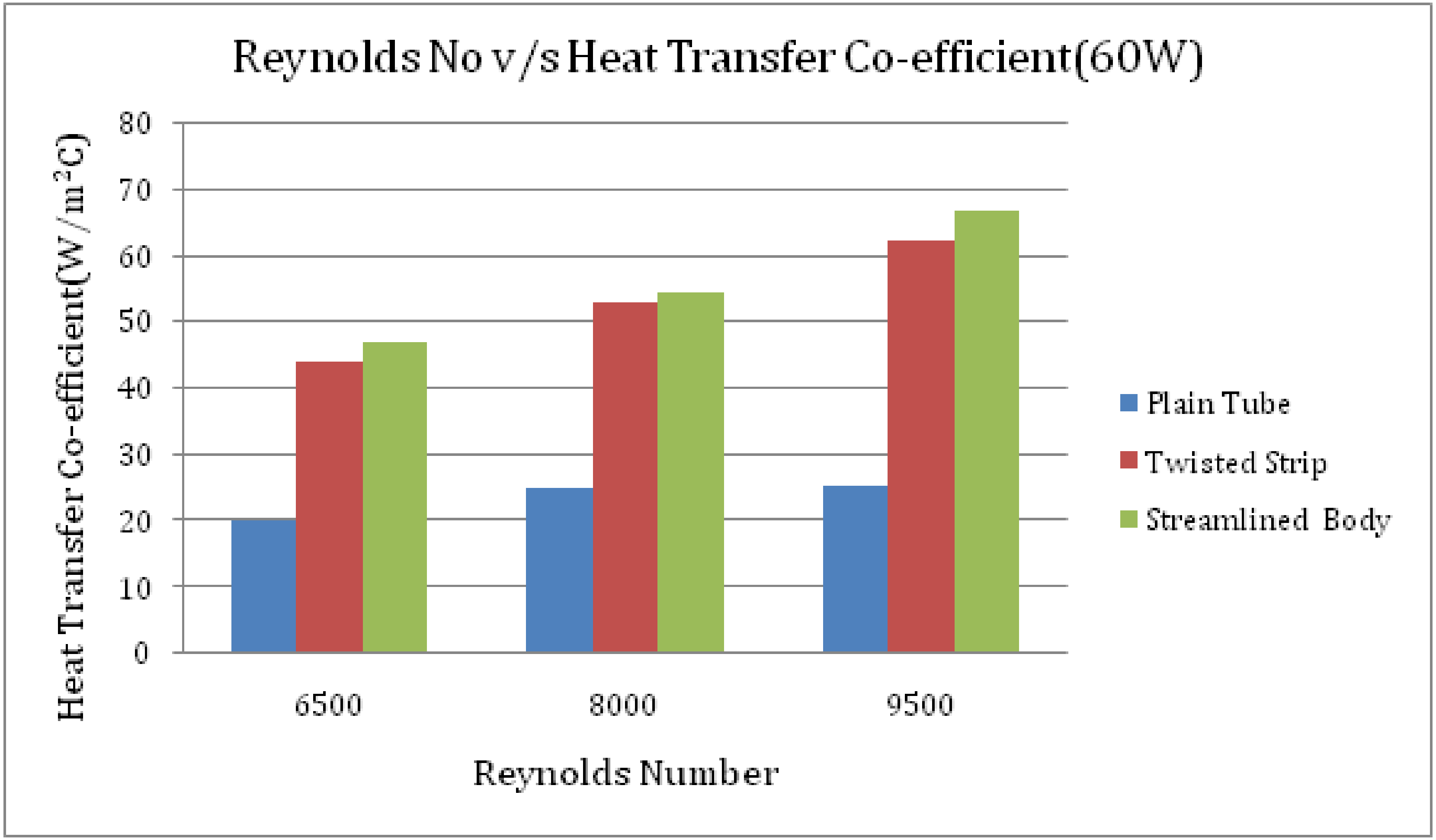
Reynolds No v/s Over all Enhancement ratio (60W)
Over all Enhancement ratio
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0.78
0.76
0.74
6500
8000
9500
Reynolds Number
Twisted Strip
Streamlined Body



Reynolds No v/s Power Consumption (60W)
Power Consumption(Watts)
0.286
0.284
0.282
0.28
0.278
0.276
0.274
0.272
0.27
0.268
6500
8000
9500
Reynolds Number
Plain Tube
Twisted Strip
Streamlined Body



Reynolds no v/s Friction Factor(60W)
Friction Factor
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2000
4000
6000
8000
10000
Reynolds Number
Plain Tube
Twisted Strip
Streamlined Body


Reynolds No v/s Heat Transfer Co-efficient(60W)
Heat Transfer Co-efficient(W/m2C)
80
70
60
50
40
30
20
10
0
6500
8000
9500
Reynolds Number
Plain Tube
Twisted Strip
Streamlined Body

Conclusion

- With increase in Reynolds number, nusselt number also increases.
- For annular blockages it was observed that the heat transfer enhancement can be achieved up to 2.2 times than that for plain tube
- For twisted strip it was observed that the heat transfer enhancement can be achieved up to 2 times than that for plain tube.
- For streamlined body it was observed that the heat transfer enhancement can be achieved up to 2.3 times than that for plain tube.
- Over all enhancement ratio for streamlined body is higher than twisted strip and annular blockages.
- The pressure drop increases with different inserts, but the pressure drop for streamlined body is less as compared with the twisted strip & annular blockages.

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Thank You