International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

Design Criteria for Hot Fluid Flowing in Inner Pipe of a Double Pipe Heat Exchanger

Suresh Babu Koppula
Associate Professor,
Dept. of Mechanical Engineering,
St.Martin's Engineering College,
Hyderabad, India.

Dr. N.V.V.S.Sudheer
Associate Professor,
Dept. of Mechanical Engineering
RVR&JC College of Engineering,
Guntur, India

ABSTRACT

Heat exchanger is a heat transferring device, is used to transfer of heat between two or more fluids available at different temperatures. Heat exchanger is most important device in cooling and heating process such as power, petroleum, transportation, air-conditioning, refrigeration, cryogenic, heat recovery, building and others. The operating efficiency of these exchangers plays a very key role in the overall running cost of a plant. So the designers are on a trend of developing heat exchangers which are highly efficient, compact, and cost effective. A common problem in industries is to extract maximum heat from a utility stream coming out of a particular process, and to heat a process stream. In the present study, the design criteria for inner pipe which contains hot lubricating oil for a double pipe heat exchanger are given. Since, the length and diameter of the inner tube where hot lubricant oil is flowing is very important design criteria apart from other parameters. Optimum values for various parameters for the design of the heat exchanger also taken based on several calculations which are presented in this paper.

Keywords: heat transfer coefficient, Double pipe Heat Exchanger, length, diameter, overall heat transfer coefficient

1. INTRODUCTION

Heat exchanger is a special equipment type because when heat exchanger indirectly fired by a combustion process, it becomes furnace, boiler, heater, tube-still heater and engine. Vice versa, when heat exchanger make a change in phase in one of flowing fluid such as condensation of steam to water, it becomes a chiller, evaporator, boiler, condenser etc. Heat exchanger may be designed for chemical reactions or energy-generation processes which become an integral part of reaction system such as a nuclear reactor, catalytic reactor or polymer. Normally, heat exchanger is used only for the transfer and useful elimination or recovery of heat without changing in phase. The fluids on either side of the barrier usually liquids but they can be gasses such as steam, air and hydrocarbon vapor or can be liquid metals such as sodium or mercury. In some application, heat exchanger fluids may use fused salts.

Horizontal double pipe heat exchanger uses various inserts inside tube so as to enhance heat transfer and hence increase heat transfer coefficient. These types of heat exchangers found their applications in heat recovery processes, air conditioning and refrigeration systems, chemical reactors, and food and dairy processes. The double pipe heat exchanger would normally be used for many continuous systems having small to medium duties. This double pipe heat exchanger is a device which transferred the heat from hot medium to cold medium without mixed both of medium since both mediums are separated with a solid wall generally.

Amol Ashok Patil et al [1] given various techniques for achieving improved heat transfer are usually referred to as "heat transfer augmentation" or "heat transfer enhancement" and the heat exchanger provided with heat transfer enhancement techniques as "Augmented Heat Exchanger". The objective is to reduce as many of the factors as possible: Capital Cost, Power Cost, Maintenance Cost, Space and Weight, Consistent with safety and reliability. In recent years, many of researchers worked on the heat transfer and hydrodynamic characteristics of fluid in double tube heat exchangers. Rennie and Raghavan [2] studied numerically on the heat transfer characteristics of a double tube heat exchanger. They proved that, flow in the inner tube, is the limiting factor of overall heat transfer coefficient of heat exchanger and while stabilizing other parameters, the overall heat transfer coefficient will increase. Rennie and Raghavan [3] studied the heat transfer characteristics of helical double tube heat exchanger to determine the effect of fluid thermal properties on heat transfer. They demonstrated that in lower Dean Number, Nusselt number was more affected by Prandtel number than in higher Dean Number. Mansoor siddique et.al [4] performed a Experimental study of turbulent single-phase flow and heat transfer inside a micro-finned tube. Wen-Lih et.al [5] performed Numerical study on heat transfer characteristics of double tube heat exchangers with alternating horizontal or vertical oval cross section pipes as inner tubes. N.targui et.al [6] performed Analysis of fluid flow and heat transfer in a double pipe heat exchanger with porous structures. Ebru Kavak Akpinar [7] investigates experimently heat transfer enhancement in a concentric double pipe heat exchanger equiped with swirl elements. The heat transfer rate in this increased by 130%. Shou-Shing Shieh et.al [8] proposed heat transfer coefficients of double pipe heat exchanger with helical type roughened surface. Prabhata K. Swamee et al [9] Formulated optimal design of the exchanger as a geometric programming with a single degree of difficulty. For yield problem the optimum values of inner/ outer pipe diameter and utility flow rate used for a double pipe heat exchanger of a given length, when a specified flow rate of process stream is to be treated for a given inlet to outlet temperature. They observed outlet temperature of the process stream is around 323 K which is well below the approachable temperature indicating the practicality of the solution. They found efficiency of the exchanger is around 63.6% which is reasonably high. Shou-Shing HSIEH, et Al [10] worked for single-phase forced convection in double pipe heat exchangers containing a two-dimensional helical fin roughness on the outer surface of the inner tube. From This Study, with a helical angle (α: 65°), a pitch to height ratio (p/e = 1.45), and three aspect ratios (shell side to tube side dia.) of Do/Di- 2.68, 3.48 and 5.1.Three corresponding ratios are taken of roughness height to hydraulic dia. (e/Ds) of 0.192, 0.13 and 0.08, respectively. They found heat transfer performance is to be depended upon both the mass flow rate and the ratio of roughness height to hydraulic dia. (e/DH).They observed that the Nusselt numbers of the ratios of roughness height to hydraulic dia. of 0,192 and 0.13 are found nearly 60 and 40%, respectively, higher than that of the ratio of roughness height to hydraulic dia. of 0.08 for all the flow rates investigated. [11] Timothy J. Rennie, et. al performed an experimental study of double pipe helical heat exchanger with parallel and counter flow configuration. Overall heat transfer coefficients were calculated and heat transfer coefficients in the inner tube and the annulus were determined using Wilson plots. They calculated a Nusselt numbers for the inner tube and the annulus. Heat transfer rates, however, are much higher in the counter flow configuration, due the increased log mean temperature difference. [12] H. A. Mohammed, et al. studied an effect of louvered strip inserts placed in a circular double pipe heat exchanger on the thermal and flow fields utilizing with various types of nano-fluids. The continuity, momentum and energy equations are solved by means of a finite volume method (FVM). Reynolds number range of 10,000 to 50,000. [13] Paisarn. Naphon, Et al. investigated a heat transfer characteristics and the pressure drop in the horizontal double pipes with twisted tape insert. The twisted tape is made from the aluminium strip with thickness of 1 mm and the length of 2000 mm.R22 is used as the refrigerant for chilling the water. They compared tube with twisted insert to without twisted tape. The twisted tape insert has significant effect on enhancing heat transfer rate. However, the pressure drop also increases. The heat transfer rate increases with increasing tube-side Reynolds number. [14] Smith Eiamsa-Ard, et al. carried out an Experimental work on turbulent heat transfer and flow friction characteristics in a circular tube equipped with two types of twisted tapes: (1) typical twisted tapes (2) alternate clockwise and counterclockwise twisted tapes (C–CC twisted tapes). They included the tapes with three twist ratios, y/w = 3.0, 4.0 and 5.0 and each with three twist angles, h = 30°, 60° and 90°.The maximum heat transfer enhancement indexes of the C–CC twisted tapes with h = 90° for y/w = 3.0, 4.0 and 5.0, are 1.4, 1.34 and 1.3, respectively. [15] Hamed Sadighi Dizaji, et al. worked to increase the number of thermal units (NTU) and performance in a vertical shell and coiled tube heat exchanger via air bubble injection into the shell side of heat exchanger. In this Experiment Air bubbles were injected inside the heat exchanger via a special method and at new different conditions.

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The main objective of the present work is:

To determine the suitable design parameters, (like diameter, length for inner pipe in which hot fluid is flowing) to fabricate the double pipe heat exchanger.

2. SELECTION OF PARAMETERS:

To achieve a particular engineering objective, it is very important to apply certain principles so that the product development is done economically. This economic is important for the design and selection of good heat transfer equipment. The heat exchangers are manufactured in different types, however the simplest form of the heat exchanger consist of two concentric pipes of different diameters known as double pipe heat exchanger. In this type of heat exchanger, one fluid flows through the small pipe and another fluid flows through the space between both the pipes. The flows of these two different fluids, one is at higher temperature called hot fluid and another is at lower temperature called cold fluid, can be in same or in opposite directions. If the flows are in same direction then the heat exchanger is called as parallel flow heat exchanger and if the flows are in opposite direction then the heat exchanger is called as counter flow heat exchanger. The counter flow heat exchanger is more effective than parallel flow for the given surface area. Hence a counter flow heat exchanger is taken into consideration for the present study. The same was shown in fig.

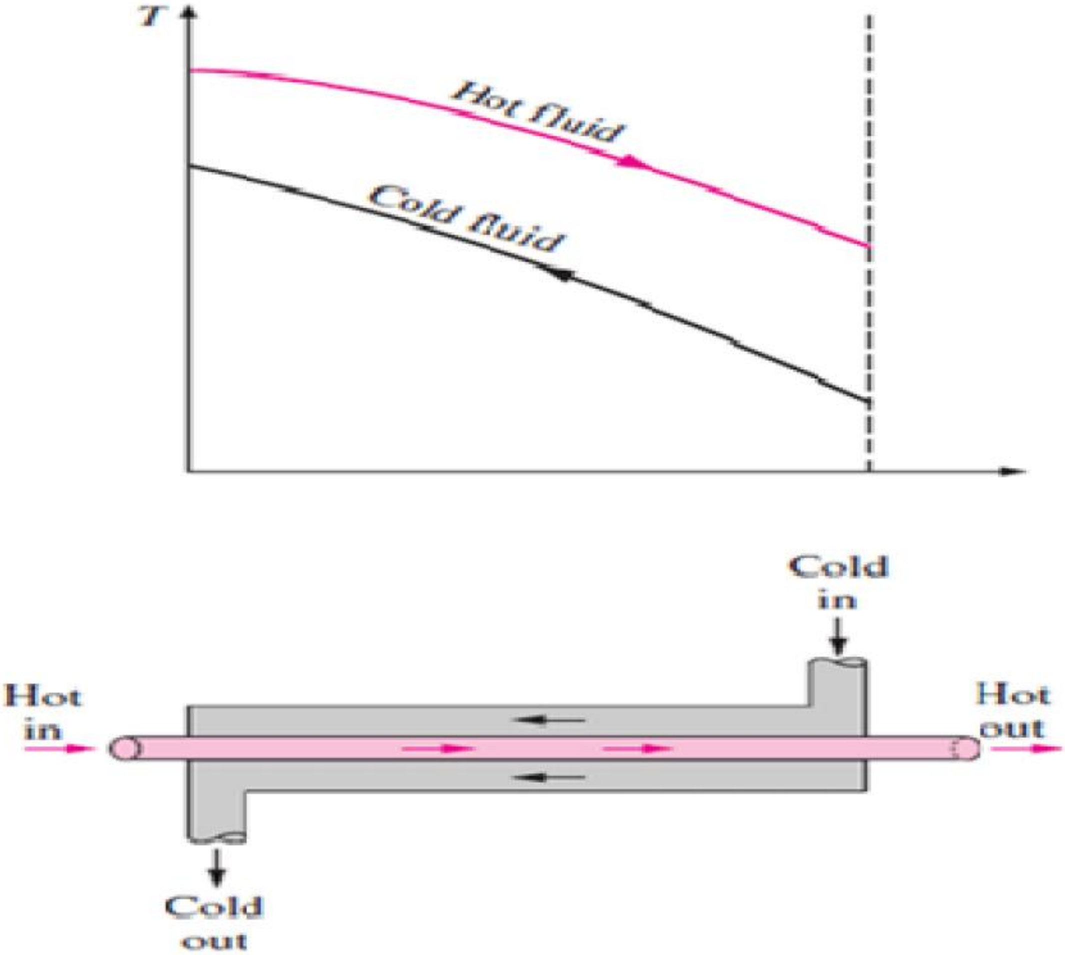

Fig 1: counter flow heat exchanger

For the design purpose, several parameter values are assumed to calculate the diameter and length of pipe. And various iterations are made to optimize the values for diameter and length, the details for these calculations are provided in the next chapter.

Let

D_i= pipe inner diameter in m

m_{hot}=hot fluid flow rate in LPM

m_{cold}=cold fluid flow rate in LPM

L = length of the inner pipe in m

Vfluid =volume of fluid in ml

U= overall heat transfer coefficient in kW/m^2C

C_{pc} = specific heat of cold fluid in KJ/kg K

C_{ph} =specific heat of hot fluid in KJ/kg K

Th,in= hot fluid inlet temperature in °C

Tc,in= cold fluid inlet temperature in °C

m_c =cold fluid in kg/sec

m_h=hot fluid in kg/sec

As = Surface Area in m^2

Cc =Heat capacity of cold fluid in kW

Ch =Heat capacity of hot fluid in kW

Cmin= Minimum heat capacity in kW

Cmax= Maximum heat capacity in kW

C =Capacity Ratio = Cmin/Cmax

Qmax = maximum heat transfer in kW

Q actual= actual heat transfer in kW

NTU= number of transfer units

ε = Effectiveness

Th,out= hot fluid outlet temperature in °C

Tc,out= cold fluid outlet temperature in °C

Thi-Tho= hot fluid temperature difference in °C

Tco-Tci= cold fluid temperature difference in °C

LMTD= log mean temperature difference

ϱ=density of oil, kg/m3

ν=kinematic viscosity, m2/s

Q= discharge, m3/s

A_c=cross sectional area, m2

V=velocity, m/s

Re=reynolds number

f=friction factor

h_f=pressure drop due to friction, bar

3. EXPERIMENTAL SET UP:

The important parts of experimental set-up are the test section containing horizontal concentric copper pipes, hot lubricating oil tank and cold water tank, Rota meters, pumps, sensors etc. All these instruments are selected as per the requirements depending upon their measuring range, accuracy and availability in the market. A line diagram of experimental set up is shown in fig below.

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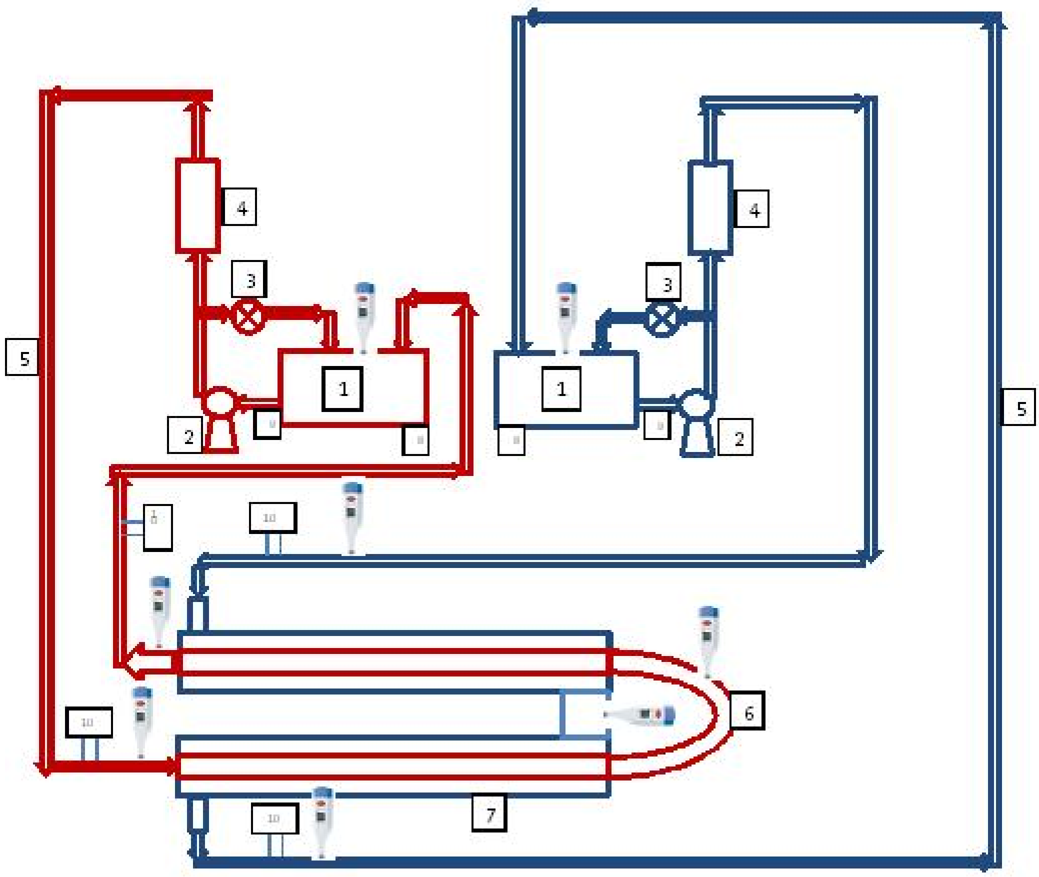


Fig 2: experimental set up

Note: Red color indicates hot fluid, and the other cold fluid

1= fluid tanks:

hot fluid tank & cold fluid tank --- a cylindrical tanks of 3 liter capacity each (syntax tanks)

insulated outside

heater of capacity 1000W (immersion type)

thermocouple is provided to read temperature

2= pumps: Crompton greaves **MINI MASTER IV (size** 13 X 13, 0.125 HP)

3= control valves

4=flow meters

5= suitable pipings

6= copper pipe diameter 8mm and 2m length

7= coper pipe diameter 24mm and 2m length, with insulation (eg: asbestos rope)

8= drains

9= Y-type filters

10= Mano meters are preferable to measure pressure

4. CALCULATIONS TO SELECT SUITABLE PARAMETERS:

s.no	Constant parameters	values
1	D_i	0.008
2	m_{cold}	2
3	m_{hot}	3
4	U	0.2
5	Cpc	4.178
6	Cph	2.219
7	Th,in	100
8	Tc,in	30
9	mc	0.0333
10	mh	0.042
11	Cc	0.1393
12	Ch	0.0932
13	Cmin	0.0932
14	Cmax	0.1393
15	C	0.6692
16	Qmax	6.5239

s.no	parameter	1	2	3	4
1	L	1	1.5	2	2.5
2	V_{fluid}	50.2400	75.3600	100.4800	125.6000
3	As	0.0251	0.0377	0.0502	0.0628
4	Q actual	0.3365	0.4941	0.6452	0.7902
5	NTU	0.0539	0.0809	0.1078	0.1348
6	ε	0.0516	0.0757	0.0989	0.1211
7	Th,out	96.3891	94.6979	93.0768	91.5214
8	Tc,out	32.4164	33.5482	34.6331	35.6739
9	Re	398.0891			
10	h_f	0.0836	0.1254	0.1672	0.2090

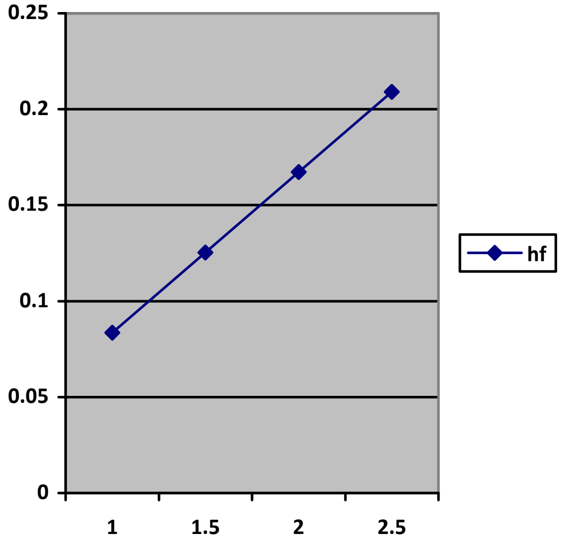


Fig:Variation of h_f along the length

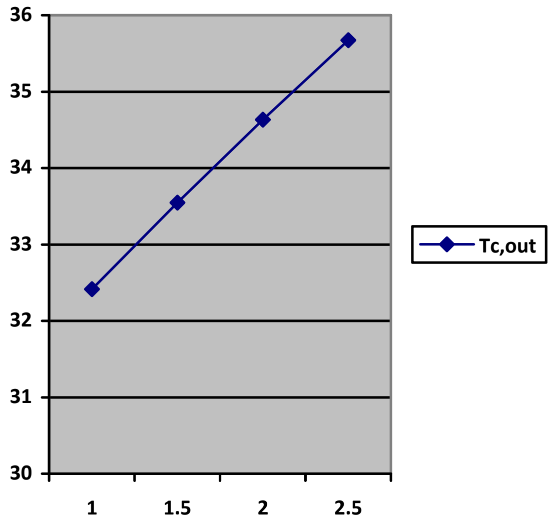


Fig:Variation of $Tc,_{out}$ along the length

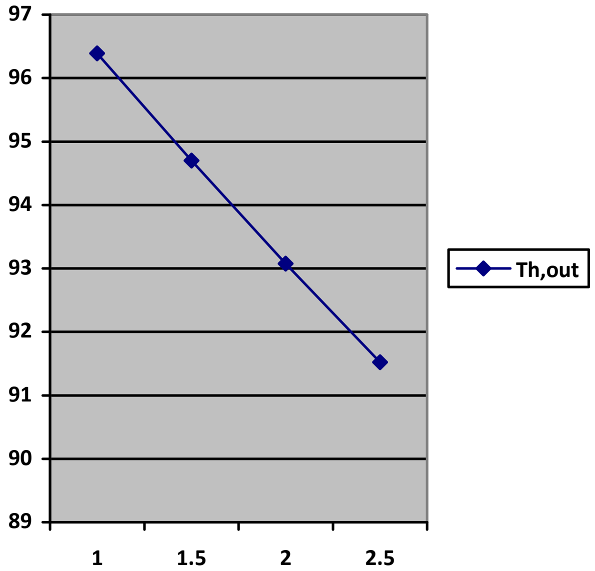


Fig:Variation of $Th,_{out}$ along the length

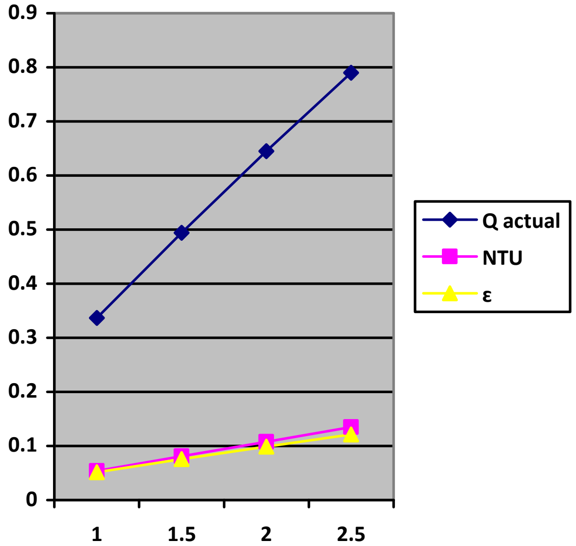
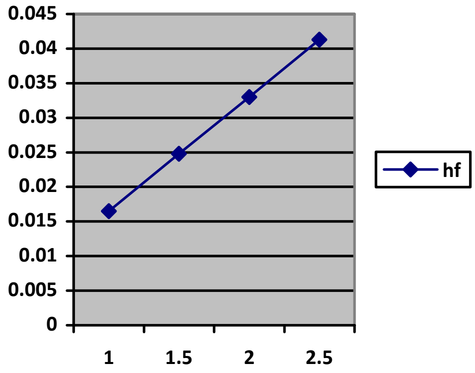


Fig:Variation of Qactual,NTU and ε along the length

From the above diagrams, at constant diameter of pipe 8mm, it was understood that, as the length increases the pressure drop, heat transfer, NTU, effectiveness increases. The gain in temperature of cold fluid increases, whereas the heat loss of hot fluid decreases.

s.no	Constant parameters	values
1	D_i	0.012
2	m_{cold}	2
3	m_{hot}	3
4	U	0.2
5	Cpc	4.178
6	Cph	2.219
7	Th,in	100
8	Tc,in	30
9	mc	0.0333
10	mh	0.042
11	Cc	0.1393
12	Ch	0.0932
13	Cmin	0.0932
14	Cmax	0.1393
15	C	0.6692
16	Qmax	6.5239

s.no	parameter	1	2	3	4
1	L	1	1.5	2	2.5
2	V_{fluid}	113.0400	169.5600	226.0800	282.6000
3	As	0.0377	0.0565	0.0754	0.0942
4	Q actual	0.4941	0.7185	0.9294	1.1281
5	NTU	0.0809	0.1213	0.1617	0.2022
6	ε	0.0757	0.1101	0.1425	0.1729
7	Th,out	94.6979	92.2911	90.0279	87.8961
8	Tc,out	33.5482	35.1588	36.6734	38.1000
9	Re	265.3927			
10	h_f	0.0165	0.0248	0.0330	0.0413



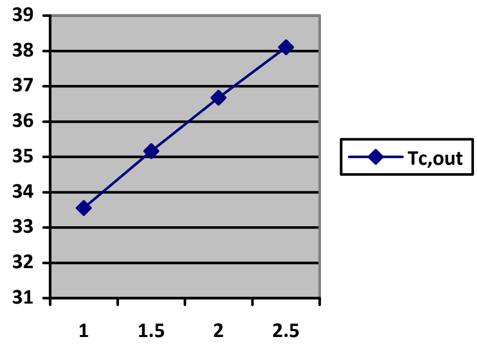
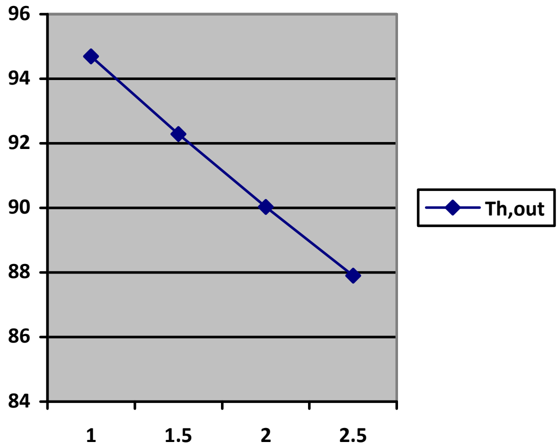


Fig:Variation of h_f along the length

Fig:Variation of $Tc_{,out}$ along the length



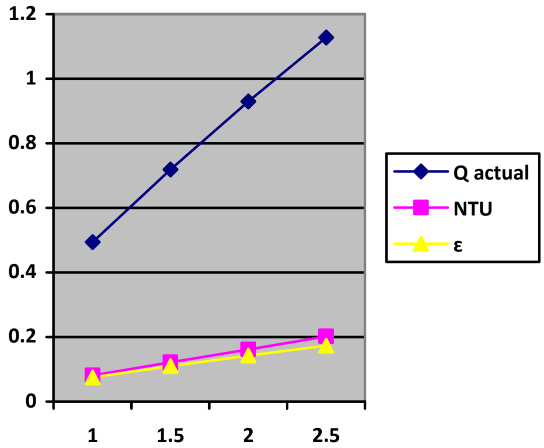


Fig:Variation of $Th_{,out}$ along the length

Fig:Variation of Qactual,NTU and ε along the length

From the above diagrams, at constant diameter of pipe 12mm, it was understood that, as the length increases the pressure drop, heat transfer, NTU, effectiveness increases. The gain in temperature of cold fluid increases, whereas the heat loss of hot fluid decreases.

s.no	Constant parameters	values
1	D_i	0.018
2	m_{cold}	2
3	m_{hot}	3
4	U	0.2
5	Cpc	4.178
6	Cph	2.219
7	Th,in	100
8	Tc,in	30
9	mc	0.0333
10	mh	0.042
11	Cc	0.1393
12	Ch	0.0932
13	Cmin	0.0932
14	Cmax	0.1393
15	C	0.6692
16	Qmax	6.5239

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s.no	parameter	1	2	3	4
1	L	1	1.5	2	2.5
2	V_{fluid}	254.3400	381.5100	508.6800	635.8500
3	As	0.0565	0.0848	0.1130	0.1413
4	Q actual	0.7185	1.0302	1.3155	1.5776
5	NTU	0.1213	0.1819	0.2426	0.3032
6	ε	0.1101	0.1579	0.2016	0.2418
7	Th,out	92.2911	88.9463	85.8847	83.0723
8	Tc,out	35.1588	37.3972	39.4460	41.3281
9	Re	176.9285			
10	h_f	0.0033	0.0049	0.0065	0.0082

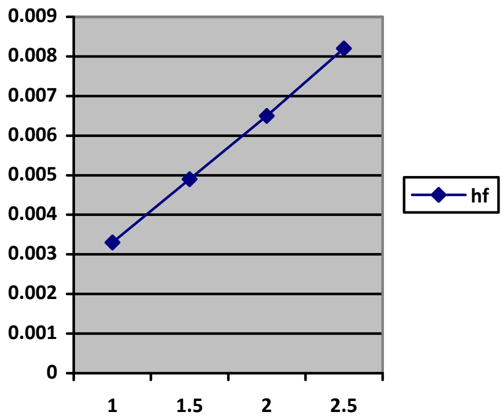

Fig:Variation of h_f along the length

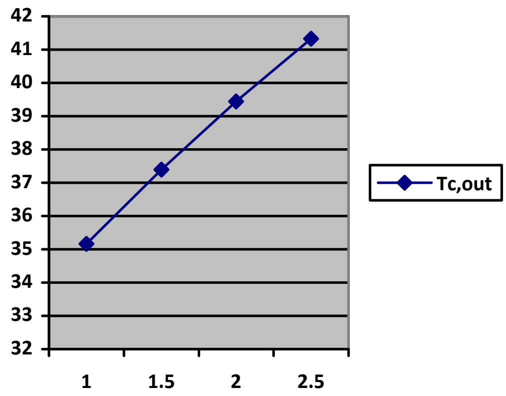

Fig:Variation of $Tc_{,out}$ along the length

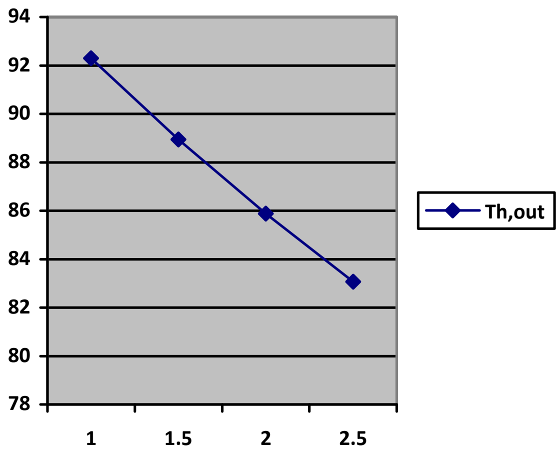

Fig:Variation of $Th_{,out}$ along the length

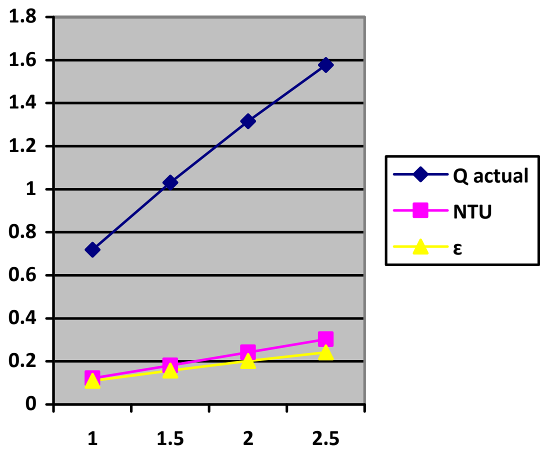

Fig:Variation of Qactual,NTU and ε along the length

From the above diagrams, at constant diameter of pipe 18mm, it was understood that, as the length increases the pressure drop, heat transfer, NTU, effectiveness increases. The gain in temperature of cold fluid increases, whereas the heat loss of hot fluid decreases.

s.no	Constant parameters	values
1	D_i	0.024
2	m_{cold}	2
3	m_{hot}	3
4	U	0.2
5	Cpc	4.178
6	Cph	2.219
7	Th,in	100
8	Tc,in	30
9	mc	0.0333
10	mh	0.042
11	Cc	0.1393
12	Ch	0.0932
13	Cmin	0.0932
14	Cmax	0.1393
15	C	0.6692
16	Qmax	6.5239

s.no	parameter	1	2	3	4
1	L	1	1.5	2	2.5
2	V_{fluid}	452.1600	678.2400	904.3200	1130.4000
3	As	0.0754	0.1130	0.1507	0.1884
4	Q actual	0.9294	1.3155	1.6603	1.9699
5	NTU	0.1617	0.2426	0.3234	0.4043
6	ε	0.1425	0.2016	0.2545	0.3020
7	Th,out	90.0279	85.8847	82.1852	78.8628
8	Tc,out	36.6734	39.4460	41.9218	44.1451
9	Re	132.6963			
10	h_f	0.0010	0.0015	0.0021	0.0026

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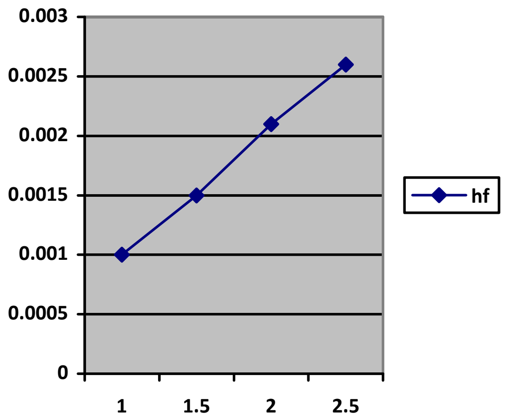

Fig:Variation of h_f along the length

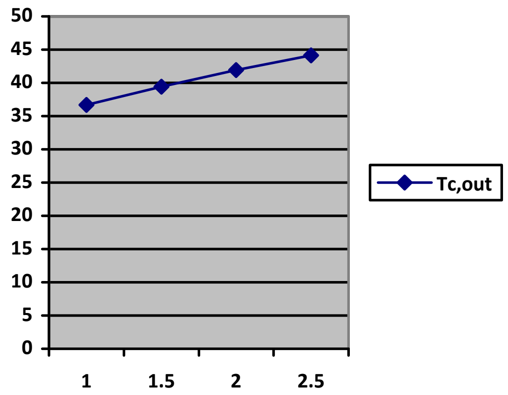

Fig:Variation of $Tc_{,out}$ along the length

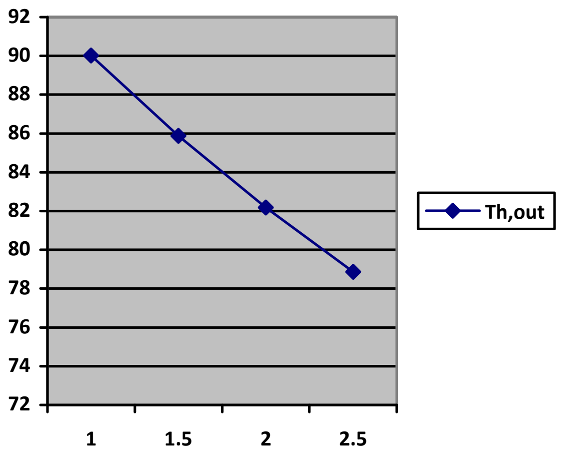

Fig:Variation of $Th_{,out}$ along the length

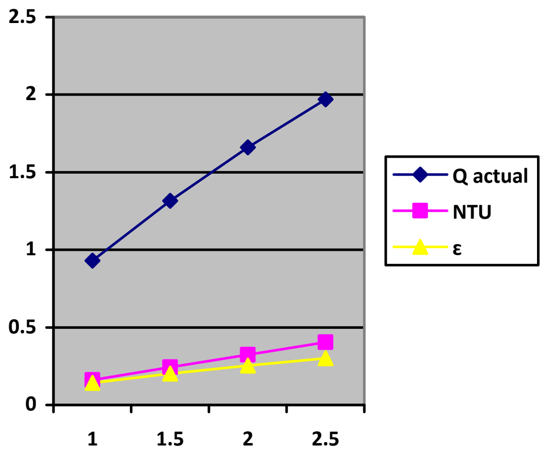

Fig:Variation of Qactual,NTU and ε along the length

From the above diagrams, at constant diameter of pipe 24mm, it was understood that, as the length increases the pressure drop, heat transfer, NTU, effectiveness increases. The gain in temperature of cold fluid increases, whereas the heat loss of hot fluid decreases.

5. RESULTS AND DISCUSSION

s.no	Constant parameters	values
1	D_i	0.008
2	m_{cold}	2
3	m_{hot}	3
4	U	0.2

s.no	parameter	1	2	3	4
1	L	1	1.5	2	2.5
2	Th,out	96.3891	94.6979	93.0768	91.5214
3	Tc,out	32.4164	33.5482	34.6331	35.6739
4	Thi-Tho	3.6109	5.3021	6.9232	8.4786
5	Tco-Tci	2.4164	3.5482	4.6331	5.6739
6	LMTD	66.9845	65.5710	64.2150	62.9133
7	Re	398.0891			
8	h_f	0.0836	0.1254	0.1672	0.2090

s.no	Constant parameters	values
1	D_i	0.012
2	m_{cold}	2
3	m_{hot}	3
4	U	0.2

s.no	parameter	1	2	3	4
1	L	1	1.5	2	2.5
2	Th,out	94.6979	92.2911	90.0279	87.8961
3	Tc,out	33.5482	35.1588	36.6734	38.1000
4	Thi-Tho	5.3021	7.7089	9.9721	12.1039
5	Tco-Tci	3.5482	5.1588	6.6734	8.1000
6	LMTD	65.5710	63.5576	61.6626	59.8757
7	Re	265.3927			
8	h_f	0.0165	0.0248	0.0330	0.0413

s.no	Constant parameters	values
1	D_i	0.018
2	m_{cold}	2
3	m_{hot}	3
4	U	0.2

s.no	parameter	1	2	3	4
1	L	1	1.5	2	2.5
2	Th,out	92.2911	88.9463	85.8847	83.0723
3	Tc,out	35.1588	37.3972	39.4460	41.3281
4	Thi-Tho	7.7089	11.0537	14.1153	16.9277
5	Tco-Tci	5.1588	7.3972	9.4460	11.3281

6	LMTD	63.5576	60.7562	58.1881	55.8253
7	Re	176.9285			
8	h_f	0.0033	0.0049	0.0065	0.0082

s.no	Constant parameters	values
1	D_i	0.024
2	m_{cold}	2
3	m_{hot}	3
4	U	0.2

s.no	parameter	1	2	3	4
1	L	1	1.5	2	2.5
2	Th,out	90.0279	85.8847	82.1852	78.8628
3	Tc,out	36.6734	39.4460	41.9218	44.1451
4	Thi-Tho	9.9721	14.1153	17.8148	21.1372
5	Tco-Tci	6.6734	9.4460	11.9218	14.1451
6	LMTD	61.6626	58.1881	55.0792	52.2809
7	Re	132.6963			
8	h_f	0.0010	0.0015	0.0021	0.0026

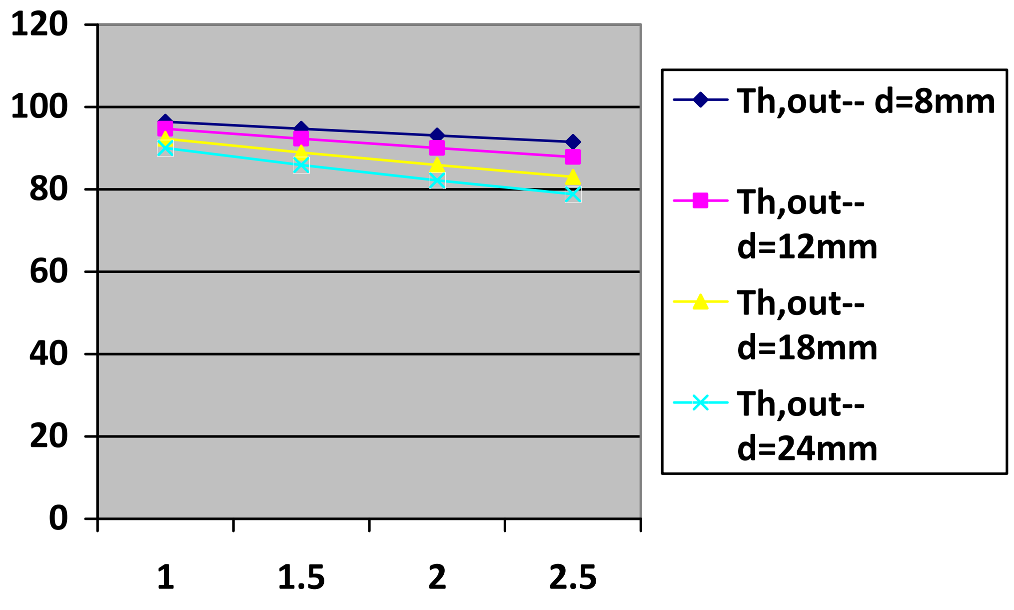

Fig: U=200, m_{cold}=2, m_{hot}=3

From the above diagram, we can understand that for fixed length, same hot fluid input temperature and by keeping other parameters const, the outlet temperature of hot fluid drops well as the diameter of pipe increases. Means more heat heat transfer takes place with the cold fluid. Hence, according to above diagram, it is preferrable to have larger diameter. In this case, for example 8mm, 12mm, 18mm and 24mm are taken. Hence, 24mm diameter is preferable.

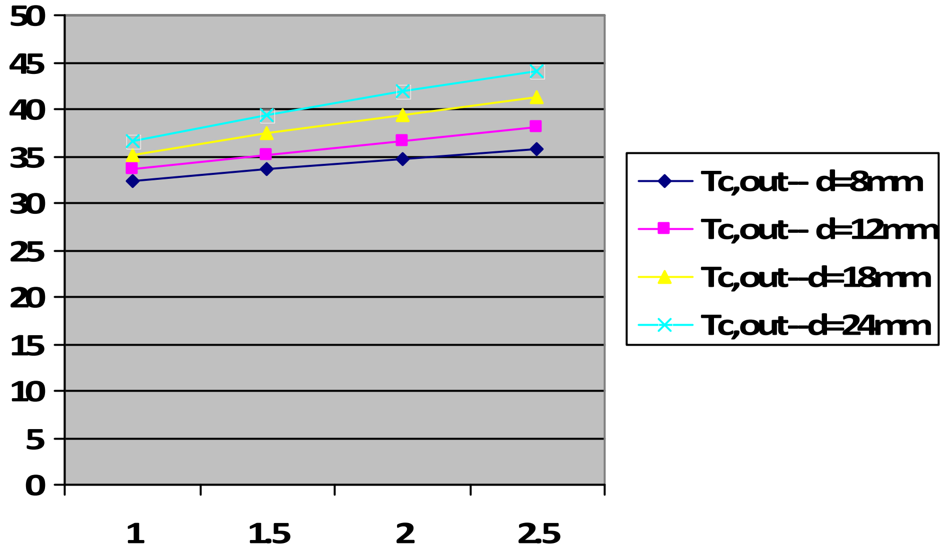

Fig: U=200, m_{cold}=2, m_{hot}=3

From the above diagram, we can understand that for fixed length, same hot fluid input temperature and by keeping other parameters const, the outlet temperature of cold fluid gains well as the diameter of pipe increases. Means more heat heat transfer takes place. Hence, according to above diagram, it is preferrable to have larger diameter. In this case, for example 8mm, 12mm, 18mm and 24mm are taken. Hence, 24mm diameter is preferable.

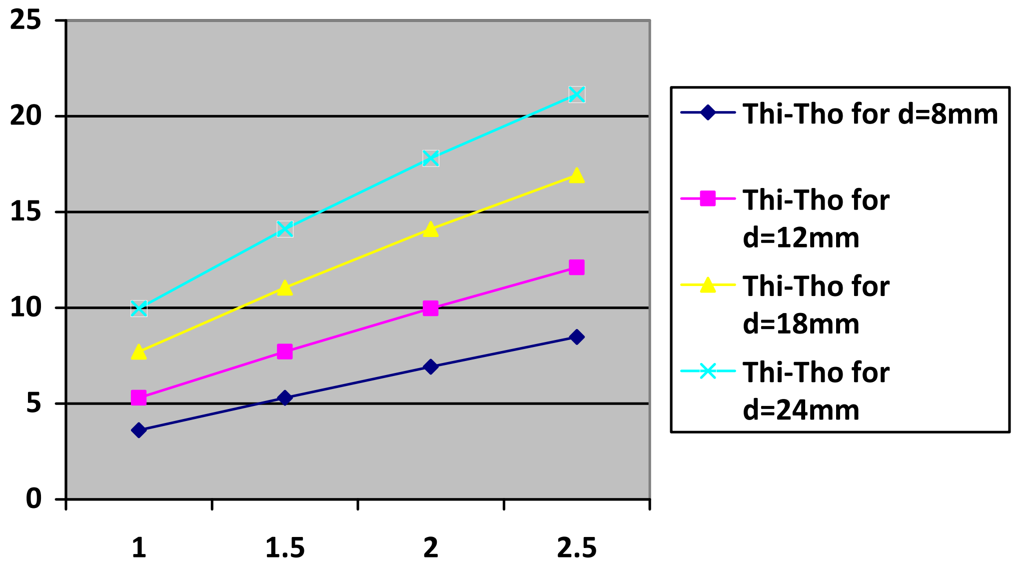

Fig: U=200, m_{cold}=2, m_{hot}=3

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

From the above diagram, we can understand that as the diameter of pipe increases will gives the higher temperature difference for hot fluid. Hence, their will be higher heat transfer rate. Hence, from above diagram we can conclude that for Fig: U=200, m_{cold}=2, m_{hot}=3, the preferable diameter of the pipe can is 18mm or 24mm and the length 2m or 2.5m.

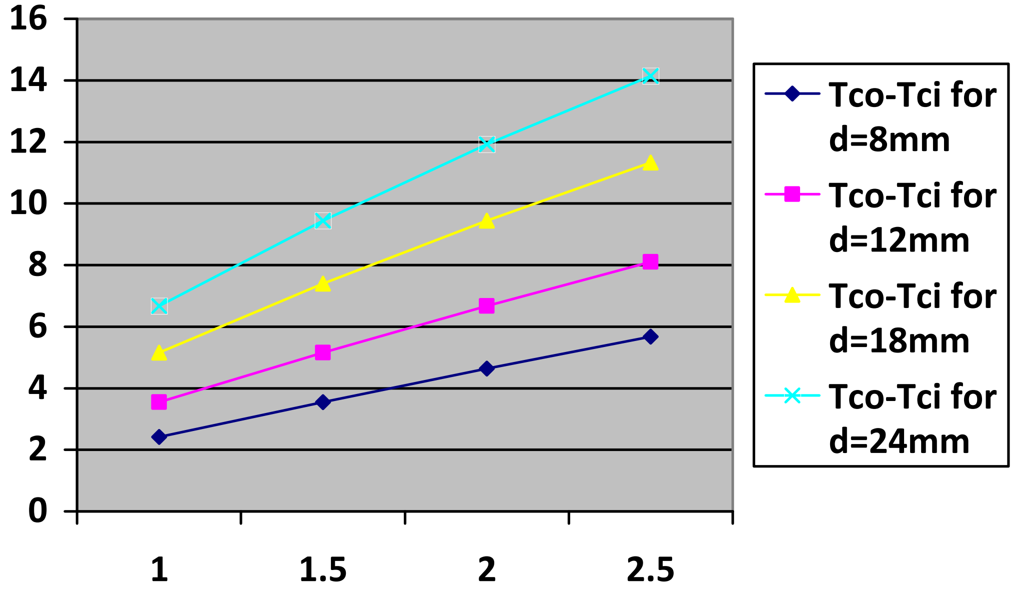

Fig: U=200, m_{cold}=2, m_{hot}=3

From the above diagram, we can understand that the larger the diameter of pipe will gives the higher temperature difference for cold fluid. Hence, their will be higher heat transfer rate. Hence, from above diagram we can conclude that for Fig: U=200, m_{cold}=2, m_{hot}=3, the preferable diameter of the pipe can is 18mm or 24mm and the length 2m or 2.5m.

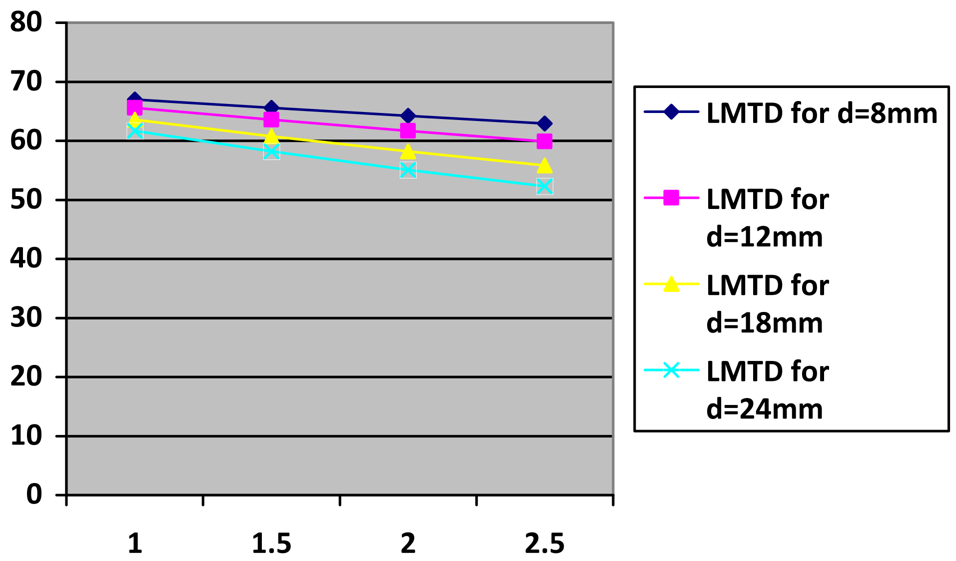

Fig: U=200, m_{cold}=2, m_{hot}=3

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
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From the above diagram, we can understand that the shorter the diameter of pipe will gives the higher logerthemic mean temperature difference. Hence, their will be higher heat transfer rate. Hence, from above diagram we can conclude that for Fig: U=200, m_{cold}=2, m_{hot}=3, the preferable diameter of the pipe can is 8mm or 12mm and the length 1m or 1.5m.

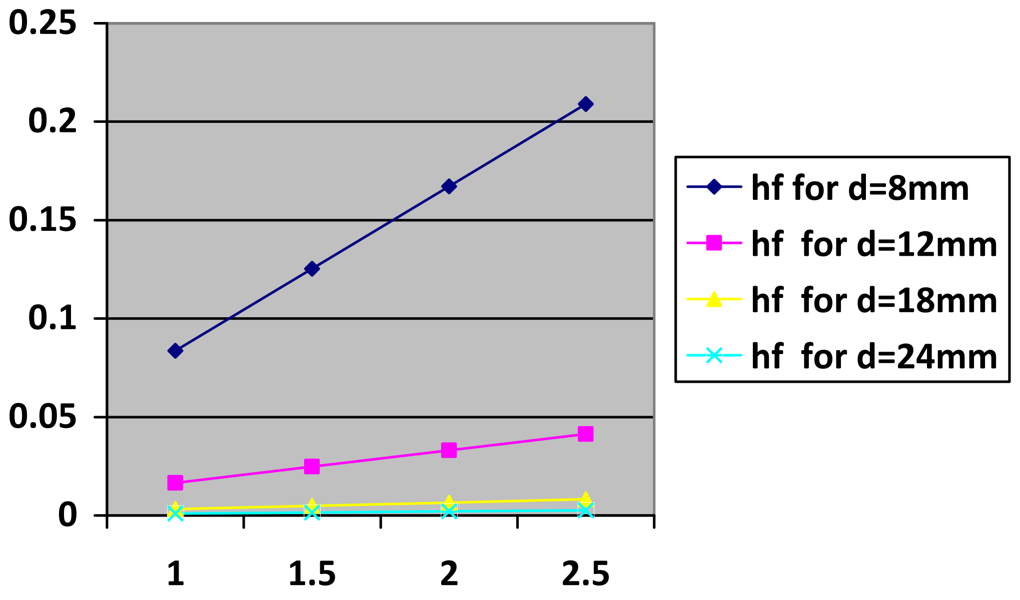

Fig: U=200, m_{cold}=2, m_{hot}=3

From the above diagram, we can understand that the higher the diameter of pipe will gives the lower pressure drop in the pipe. Hence, from above diagram we can conclude that for Fig: U=200, m_{cold}=2, m_{hot}=3, the preferable diameter of the pipe can is 24mm and the length 2m or 2.5m.

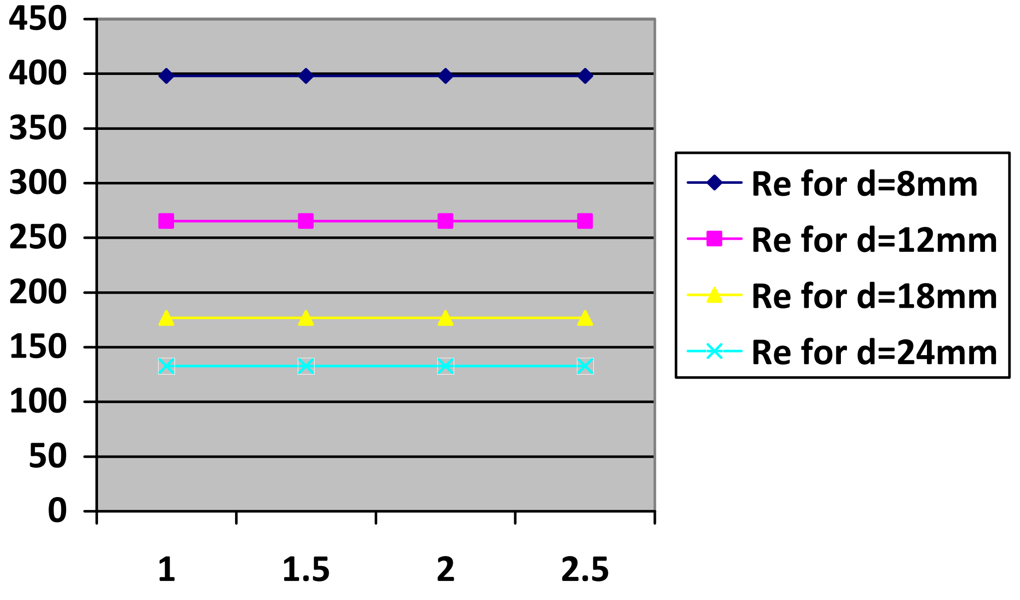

Fig: U=200, m_{cold}=2, m_{hot}=3

From the above diagram, we can understand that the higher the diameter of pipe will gives the lower Reynolds number, indicates the flow in the pipe. It is very imporatant criteria while selecting the diameter, because if the reynolds number is low may cause flow obstruction. Hence, from above diagram we can conclude that for Fig: U=200, m_{cold}=2, m_{hot}=3, the preferable diameter of the pipe can is 8mm and the length 2m or 2.5m.

6. CONCLUSION: from above diagrams and discussion, it was observed that, eventhough there is more pressure drop, more temperature difference exists between fluids, it is very imporatant to have flow as higher as possible to sustain flow in the pipe. Hence, by comprimising other parameters, it was concluded that the dimensions of inner pipe in which hot fluid is flowing is as diameter=8mm and length 2m.

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