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Analysis of different type of tubes to optimize the efficiency of Heat Exchanger

Sunil B. Revagade, Kalyani G. Deshmukh Gopal V. Shejole Vijay R. Nemane, Asst. Prof. Roshan V. Marode

Mechanical Engg Department, MGI-COET, Shegaon (M.S.), India

ABSTRACT

A device which is used to transfer of energy between two fluids is named a heat exchanger. A heat Exchanger may be defined as equipment which transfers the energy from a hot fluid to a cold fluid, with maximum rate and minimum investment and running costs. Shell and Tube heat exchanger are the basic types of heat exchanger one of the fluids flow through a number of tubes enclosed by a shell. The outer fluid is forced through a shell and it flows over the outside surface of the tubes. Such an arrangement is employed where reliability and heat transfer effectiveness. In order to achieve the maximum heat transfer rate an analysis is made on single tube with Water as based fluid in a shell and tube heat exchanger. With relate to same to have a maximum heat transfer rate this project gives various optimal design solutions using computational techniques. To measure the performance of different designs, its model is suitably designed and fabricated so as to perform experimental tests. Thermal analysis has been carried out for different design with base fluids and on the basis of comparative results is made which one give the best heat transfer rates.

Keywords*:* *Heat Exchanger, Water, Al2O3-water based, Optimal Design, Thermal analysis, Computational Techniques.*

1. INTRODUCTION

One of the important processes in engineering is the heat exchange. The means of heat exchanger is that to transfer the heat between flowing fluids. A heat exchanger is the process to transfer heat from one fluid to another fluid. The heat exchanger is devise that used for transfer of internal thermal energy between two or more fluids at different temperatures. In most heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix. Heat exchangers are used in the process, power, petroleum, transportation, air conditioning, refrigeration, Cryogenic, heat recovery, alternate fuels, and other industries.

The beginning of using first heat exchangers for space heating and domestic hot water in district heating substations is early 1980s (1990s in Lithuania). A pioneer is this matter was Swedish company Alfa Laval. A survey of Lithuanian district heating revealed that in 2005 approximately 95% of all heat exchangers were brazed plate type. Although the HE are usually designed for a normal life of more than 10 years, their actual service life, however varies from 2-3 to 6-8 years, depending on the service conditions and of course on the quality of heat transfer media. The type of scale differs from industry to industry, depending on the mineral content of the available water. Despite the enormous costs associated with fail-ure and fouling; only very limited research has been done on this subject. Common examples of heat exchangers familiar to us in day-to-day use are automobile radiators, condensers, evaporators, and oil cooler.

2. LITERATURE REVIEW

In this paper a CFD analysis has been carried out for different material and on the basis of results made which one give the best heat transfer rates. This paper is to analyze the inlet and outlet temperature of two different materials viz. aluminium and copper with that of analytical calculations. From study it was cleared that after performing the calculation the fluid water the output temperature is near to the value mentioned in output temperature of ansys. As we change the material from the aluminium to the brass, temperature difference between input temperature and output temperature.

They figured out the correlations between each parameter and determined proper range of design parameters using the design of experiments (DOE) and approximation model (RSM, Response Surface Model).Because of disadvantage in the pressure loss of flow inside tube, U-tube type heat exchanger was not optimized in feasible region. Lastly it predicted that a U-tube type heat exchanger would be heavier than a straight-tube type heat exchanger by about 10.5% under the same constraints.

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3. BASIC DESIGN PROCEDURE AND THEORY

Tubes: Dimensions

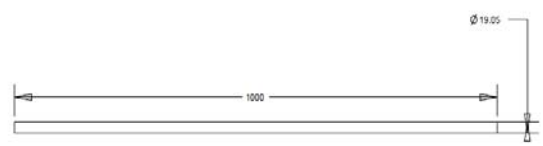
Tube diameters in the range $\frac{5}{8}$ in. (16 mm) to 2 in. (50 mm) are used. The smaller diameters $\frac{5}{8}$ to 1 in. (16 to 25 mm) are preferred for most duties, as they will give more compact, and therefore cheaper, exchangers. Larger tubes are easier to clean by mechanical methods and would be selected for heavily fouling fluids. The tube thickness (gauge) is selected to withstand the internal pressure and give an adequate corrosion allowance. Steel tubes for heat exchangers are covered by BS 3606 (metric sizes); the standards applicable to other materials are given in BS 3274. Standard diameters and wall thicknesses for steel tubes are given in following table :

Outside dia (mm)	Wall Thickness (mm)				
16	1.2	1.6	2.0	-	-
20	-	1.6	2.0	2.6	-
25	-	1.6	2.0	2.6	3.2
30	-	1.6	2.0	2.6	3.2
38	-	-	2.0	2.6	3.2
50	-	-	2.0	2.6	3.2

The preferred lengths of tubes for heat exchangers are: 6 ft. (1.83 m), 8 ft (2.44 m), 12 ft (3.66 m), 16 ft (4.88 m) 20 ft (6.10 m), 24 ft (7.32 m). For a given surface area, the use of longer tubes will reduce the shell diameter; which will generally result in a lower cost exchanger, particularly for high shell pressures. The optimum tube length to shell diameter will usually fall within the range of 5 to 10. If U-tubes are used, the tubes on the outside of the bundle will be longer than those on the inside. The average length needs to be estimated for use in the thermal design. U-tubes will be bent from standard tube lengths and cut to size. The tube size is often determined by the plant maintenance department standards, as clearly it is an advantage to reduce the number of sizes that have to be held in stores for tube replacement.

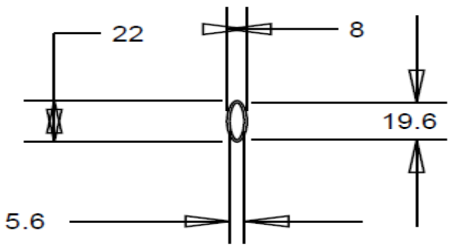
3.1 Round type tube :

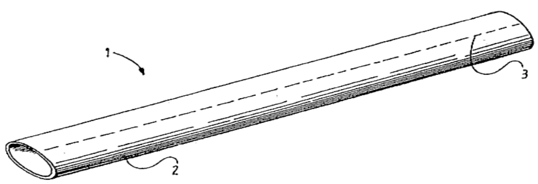
D_i=16.65mm
D_o=19.05mm
Thickness=t=18BWG
Length= 1000mm



3.2 Egg type tube:

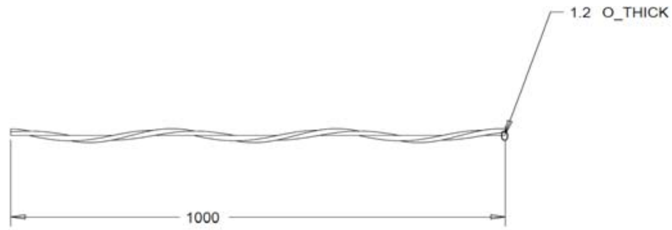
Axis Ratio = R_a=3
Major Axis = 2a=22 mm
Minor Axis =2b=8mm



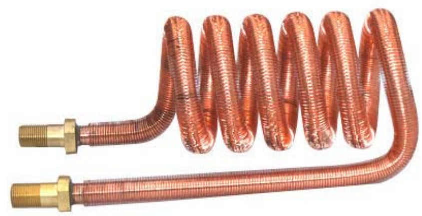


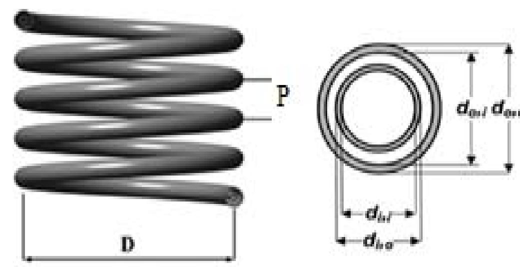
3.3 Rectangular type tube:

Length(L)=1000mm
Thickness(t)=1.2mm
Breadth of rectangular tube(b)=22 mm
Depth of rectangular tube(d)=8mm
Number of twists(Nt)= 05 (Each at 200 mm apart)



3.4 Spring type tube:





Diameter (D_0) =3/4”=19.05mm
Length(L)=1000mm
Number of turns(n)=6
Thickness(t)=1.2mm
Effective coil diameter(D)=52mm
Pitch(p) for helical it is taken as $1.5D_0$≡30mm

To know the unknown parameter, D (Coil Diameter)

Equation is given by,

$$L = N\sqrt{(2\pi R)^2 + (p)^2}$$

$$1000 = 6\sqrt{(2\pi R)^2 + (1.5x19.05)^2}$$

$$\frac{1000}{6} = \sqrt{(2\pi R)^2 + (1.5x19.05)^2}$$

$$\frac{1000}{6} = \sqrt{(2\pi R)^2 + 816.53}$$

$$\frac{26961.24}{4x\pi^2} = R^2$$

Therefore,
R = 26.13mm
D ≡ 52 mm

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4. DETERMANATION AND METHODOLOGY

The general equation for heat transfer across a surface is:
Q = UAΔTm,
where Q = heat transferred per unit time, W,
U = the overall heat transfer coefficient, W/m2□C,
A = heat-transfer area, m2,
ΔTm= the mean temperature difference, the temperature driving force, □C.
For heat exchange across a typical heat exchanger tube the relationship between the overall coefficient and the individual coefficients, which are the reciprocals of the individual resistance.

$$Uo = \frac{1}{ho} + \frac{1}{hod} + \frac{do}{di} x \frac{1}{hid} + \frac{do}{di} x \frac{1}{hi} + \frac{do \ln(\frac{do}{di})}{2kw}$$

Where Uo = the overall coefficient based on the outside area of the tube, W/m2□C,
ho = outside fluid film coefficient, W/m2□C,
hi = inside fluid film coefficient, W/m2□C ,
hod = outside dirt coefficient (fouling factor), W/m2□C ,
hid = inside dirt coefficient, W/m2□C ,
kw = thermal conductivity of the tube wall material, W/mŽC,
di = tube inside diameter, m,
do = tube outside diameter,

Steps for design procedure:

1. Define the tube material (Copper due to high thermal conductivity)
2. Define the duty: Fluid flow-rates, temperatures of hot fluid and cold fluid.
3 Collect together the fluid physical properties required: density, viscosity, thermal
 Conductivity for both fluids (Water & Al2O3-Water Nano fluid)
4. Select each design tube and note down the temperature differences over a length of tube (1000mm) by experimental means.
5. Decide the flow by Reynolds number (viz, Laminar or Turbulent)
6. Calculate the mean temperature difference, ΔTm.
7. Calculate the area of Heat Transfer.
8. Get the correlation for respective type of flow and obtain the value of Nu
9. Calculate the internal heat transfer coefficients and heat transfer rate for each tube.

4. Water –Water as a fluid

Following readings are obtained experimentally for each tube:

4.1 For Round type:

Mass flow rate (Kg/sec)	Temperatures at different points of tube (^{0}C)				
	T1 (A 0mm)	T2 (At 250 mm)	T3 (At 500mm)	T4 (At 750mm)	T5 (At 1000mm)
0.14	67	66.5	65.5	65	64

4.2 For Egg Shape type:

Mass flow rate (Kg/sec)	Temperatures at different points of tube (^{0}C)				
	T1 (A 0mm)	T2 (At 250 mm)	T3 (At 500mm)	T4 (At 750mm)	T5 (At 1000mm)
0.14	67.5	65	64.5	64	63.5

4.3 For Rectangular type :

Mass flow rate (Kg/sec)	Temperatures at different points of tube (^{0}C)				
	T1 (A 0mm)	T2 (At 250 mm)	T3 (At 500mm)	T4 (At 750mm)	T5 (At 1000mm)
0.14	64	62	60	58.5	56.5

4.4 For Spring type:

Mass flow rate (Kg/sec)	Temperatures at different points of tube (^{0}C)				
	T1 (A 0mm)	T2 (At 250 mm)	T3 (At 500mm)	T4 (At 750mm)	T5 (At 1000mm)
0.14	68	68	67	65	63

5. Procedures for estimating the individual heat-transfer coefficients for a tube are given:

Fluid properties for water are:
$\mu=0.467 x 10^{-3}$ Ns/m^2
$\rho=1000$ kg/m^3
Cp=4.18x10^3J/kg□k
k_w=0.625w/m□k

5.1 For Circular type :

$$A_{c/s} = (\pi/4) x [d_0^2 - d_i^2]$$
$$= (\pi/4) x [0.01905^2 - 0.01665^2]$$
$$= 6.73 x 10^{-5} m^2$$

As Reynolds number for circular tube is given by,

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$Re = \frac{\rho V de}{\mu}$ ……………………………………… (1)

to find V,
We know continuity equation,
Q=AxV
As density = mass/volume(ρ=m/vol.)
Therefore, m= A x ρ x V…………………….. (1a)

For mass flow rate =m=0.14kg/sec

$0.14 = Vx1000x6.73x10^{-5}$

$V = \frac{0.14}{1000 X 6.73x10^{-5}} = 2.08m/s$

V= 2.08 m/s

So,

$Re = \frac{1000x2.08x16.65x10^{-3}}{0.467x10^{-3}} = 74158.45$

Re = 74158.45

From Reynolds number, flow is turbulent.(Re>2000)

Correlation used for turbulent flow is;

$Nu = \frac{\check{h}Le}{k} = CRe^a Pr^b \left(\frac{\mu}{\mu m}\right)^{-m}$......................(1b)

where C = 0.021 for gases,
= 0.023 for non-viscous liquids,
= 0.027 for viscous liquids

$\left(\frac{\mu}{\mu m}\right)^{-m}$ this term is generally negligible as value is nearly equal to 1.

The index for the Reynolds number is generally taken as 0.8. That for the Prandtl number can range from 0.3 for cooling to 0.4 for heating. The index for the viscosity factor is normally taken as 0.14 for flow in tubes, from the work of Sieder and Tate (1936), but some workers report higher values. A general equation that can be used for exchanger design is:

$Nu = \frac{\check{h}de}{k} = CRe^a Pr^b \left(\frac{\mu}{\mu m}\right)^{-m}$

$= 0.023xRe^{0.8}Pr^{(1/3)}$ x1

$= 0.023x(74158.45)^{0.8}x(Pr)^{(1/3)}$…………………………(1c)

$Pr = \frac{\mu Cp}{k}$ ………. (Depend only on fluid properties)

$= \frac{0.467x10^{-3}x4.18x10^3}{0.625}$

= 3.12

Equation 1c, → $\frac{\check{h}de}{k} = 0.023 \times (74158.45)^{0.8} x(3.12)^{(1/3)}$

$\check{h} = \frac{0.625 X 0.023 X 74158.45^{0.8} X 3.12^{1/3}}{16.65 X10-3}$

$\check{h}$ = 9932.08 w/m^2□K

5.2 MEAN TEMPERATURE DIFFERENCE (TEMPERATURE DRIVING FORCE)

Before equation 1 can be used to determine the heat transfer area required for a given duty, an estimate of the mean temperature difference Ɵm must be made. This will normally be calculated from the terminal temperature differences: the difference in the fluid temperatures at the inlet and outlet of the exchanger. The well-known "logarithmic mean" temperature difference is only applicable to sensible heat transfer in true co-current or counter-current flow (linear temperature enthalpy curves). For counter-current flow, the logarithmic mean temperature is given by:

$\Theta m = \frac{\Theta 1 - \Theta 2}{\ln(\Theta 1 - \Theta 2)}$;

Where, T_{h1} =Inlet temperature of hot fluid (□C)
T_{h2} = Outlet temperature of fluid (□C)
T_{c1} = Inlet temperature of cold fluid (□C)
T_{c2} = Outlet temperature of cold fluid (□C)
$\Theta_1 = T_{h1} - T_{c2}$
$\Theta_2 = T_{h2} - T_{c1}$

$\Theta_1 = 70 - 38 = 32$□C

$\Theta_2 = 64 - 30 = 34$□C

So, $\Theta m = \frac{\Theta 1 - \Theta 2}{\ln(\Theta 1 / \Theta 2)}$

$= \frac{32-34}{\ln\left(\frac{32}{34}\right)} = 32.98$□C

Heat transfer rate in Kw is given by,

$Q = 9932.08 \times \pi \times 19.05 \times 10^{-3} x1x32.98$

= 19.60 kw

Effectiveness (ϵ) is defined as the actual heat transfer rate to the maximum possible heat transfer rate, and is given by:

The actual heat transfer rate in a heat exchanger can be determined from an energy balance on hot or cold fluids and can be expressed as,

$$Q_{actual} = m_c C_{pc} (T_{h1} - T_{h2})$$
$$= 0.14 \times 4.18 \times 10^3 x(70\text{-}64)$$
$$= 3511.2 \text{ w}$$

$$Q_{maximum} = m_c C_{pc} (T_{h1} - T_{c1})$$
$$= 0.06 \times 4.18 \times 10^3 x(70\text{-}30)$$
$$= 10032 \text{ w}$$

Therefore, $\epsilon = \frac{Qactual}{Qmaximum} = \frac{3511.2}{10032} = 0.35$

6. Comparison of Calculated results:

T Type of Design	V	Re	Pr	h	ΔP	Q	€
Round	2.08	74158.4	3.12	9932.08	31.18	19.6	0.35
Egg	1.7	23516.1	3.12	10213.7	54.91	19.22	0.24
Rectangular	2.11	19952.4	3.12	13100.6	29.3	19.83	0.53
Spring	2.09	23032.5	3.12	12625.1	36.72	21.91	0.34

Fig: Graphical Representation Of Velocity

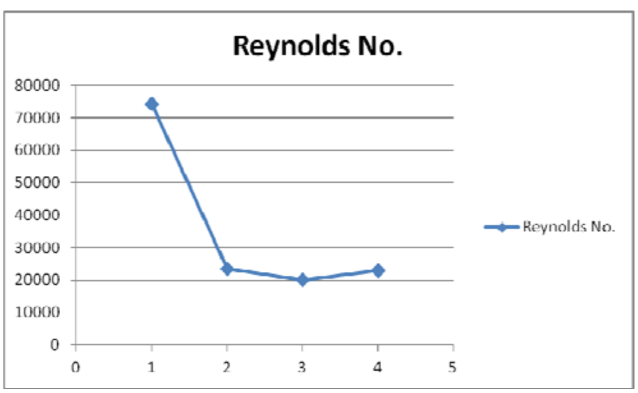


Fig: Graphical Representation Of Renolds No.

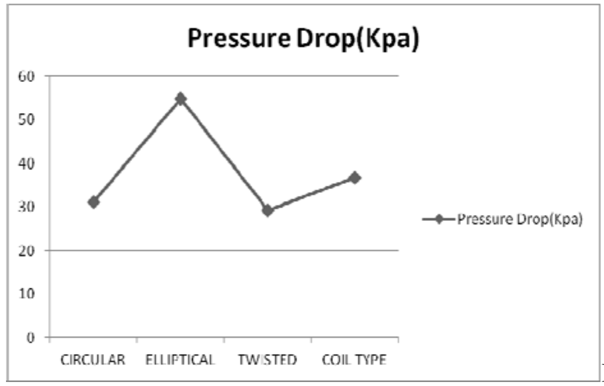


Fig : Graphical Representation Of Pressure Drop.

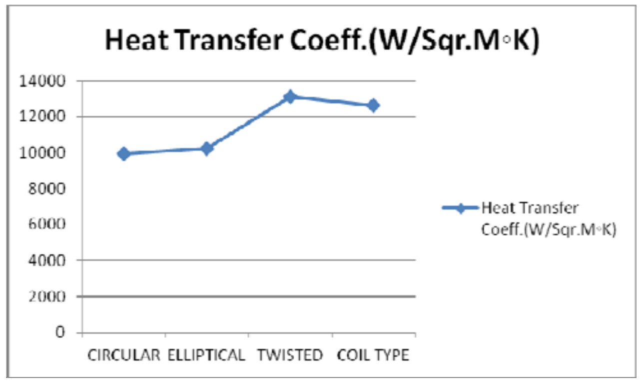


Fig: Graphical Representation Of Heat Transfer Coeff.

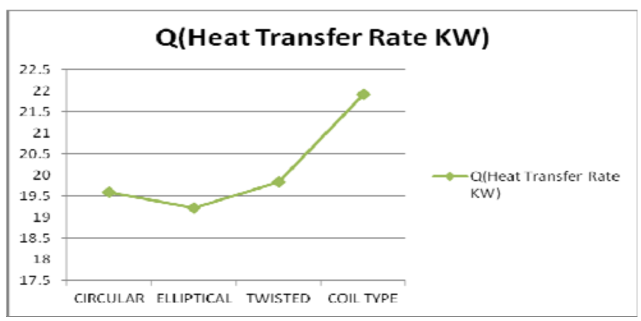
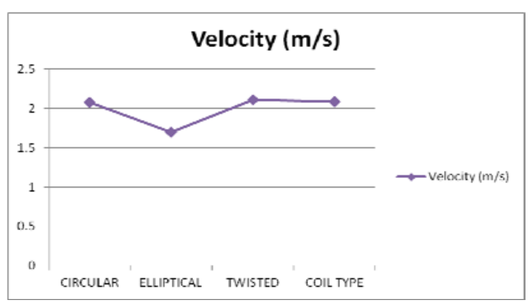


Fig: Graphical Representation Of Heat Transfer Rate.



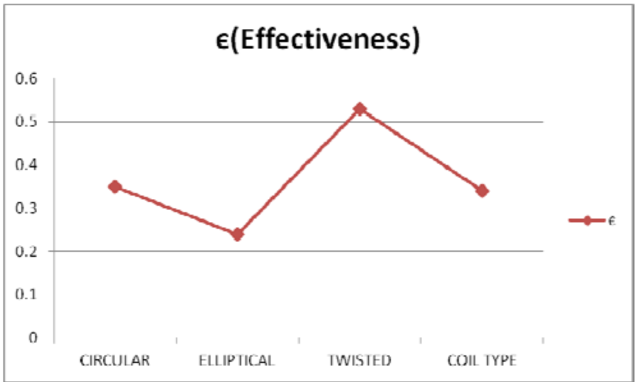


Fig: Graphical Representation Of Effectiveness

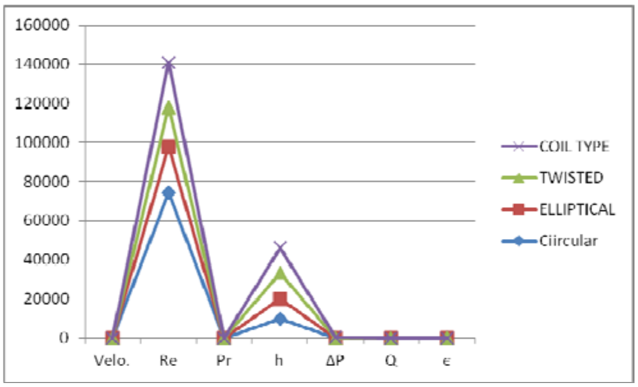


Fig: Graphical Representation Of various parameters for different tubes.

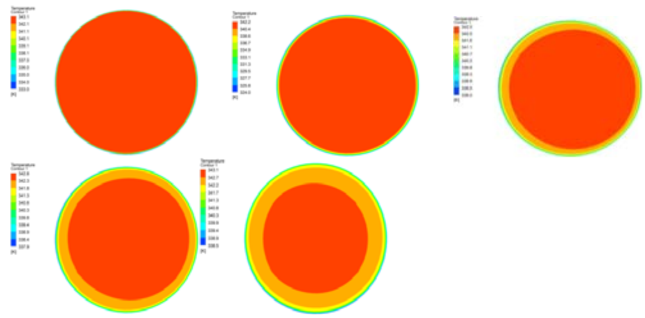
7 A GENERAL PROCEDURE FOR CFD ANALYSIS:

CFD is the process of solving the fluid flow equations of mass, momentum and energy on a computer as applied to a particular geometry and flow conditions. The basic flow variables such as velocity, pressure and temperature are computed at thousands of locations. The CFD solution is based on the first-principle of conservation of mass, momentum and energy.

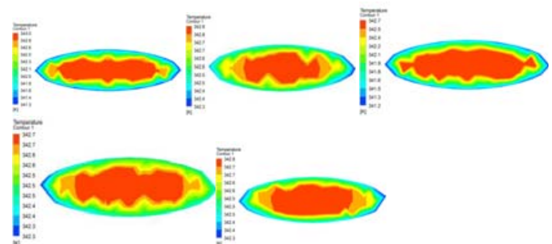
7.1 Thermal Analysis of Tubes:

CFD-Results: Mass flow rate : 0.14 kg/s

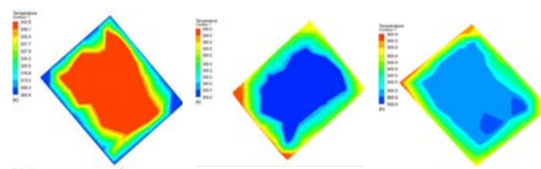
7.1. 1 Round tube

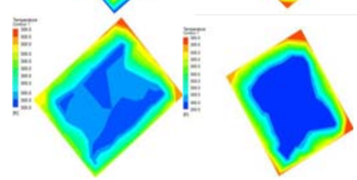


7.1.2 Egg Shape Tube :



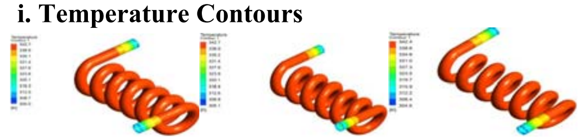
7.1.3 Rectangular Shape Tube:





7.1.4 Spring Type Tube: (For three planes)

i. Temperature Contours



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ii. h-Contours for inner wall

CONCLUSION:

This study shows the design and thermal analysis of different tubes. Experimentally, same designs are made and results are evaluated. With relate to same design tubes are thermally analysed in ANSYS software and compared both the results. After comparing the result for both water-water(Case-I) and water-Al2O3(Case-II) for four different tubes we are in conclusion that twisted type of tube is giving high heat transfer coefficient as compared to other i.e 1.14 more. Along with effectiveness, twisted tube is at higher side by 1.17.So according to my research one should go for twisted tube.However, a good understanding of the underlying principles of exchanger design is needed to use this software effectively.

The possibility to increase in these characteristics using the latest technology and various methods has raised application range of these designs. Modified design tubes are having great applications due to their large heat transfer area and high heat transfer coefficients. They are used in many industrial processes like waste water treatment, refrigeration, wine and beer making, petroleum refining.

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