

EXPERIMENTAL AND NUMERICAL STUDY OF SHELL AND TUBE HEAT EXCHANGER BY VARYING THE INNER RADII OF CORRUGATED TUBE

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Abstract— *Shell and Tube Heat Exchanger in which It is Fixed Tube-sheet and Counter Flow Type Heat Exchanger. In this research contain the analysis and comparison between plain tubes used Shell and tube heat exchanger and corrugated tube used shell and tube heat exchanger system with different thickness. In this research thermal analysis of the shell and tube heat exchanger. In this solid works 2014 is used for geometrical modelling. And also TEMA standards are used for starting the experimental structure. Which are validate in ansys. Make prototype experiment model of shell and tube heat exchanger in which plain and corrugated tube is use one after one and also take reading for thermal analysis calculation and compare with Experiment Result to CFD Analysis result for validation. In Computational Fluid Dynamics (CFD) Analysis Software use Solid Works for Geometry & Modelling, ICEM CFD (ANSYS) for Meshing and Fluent for Analysis. After doing experiment work & computational work will got the result for increasing heat transfer rate. Shell and Tube Heat Exchangers are used as process heat exchangers in the petroleum-refining and chemical industries. It is used as steam generator, condensers, boiler feed water heater, and oil coolers in power plant.*

Keywords— *Corrugated tube, thickness analysis of tube, shell and tube heat exchanger, thermal analysis, numerical analysis*

I. INTRODUCTION

“A heat exchanger is defined as an equipment which transferred the energy from a hot fluid to a cold fluid with maximum rate.” There are tubes fixed at both side in to the tube sheet. So it is called fixed tube type heat exchanger. One fluid can flow through series of connected horizontal pipe called tube and another fluid can flow over the tubes called shell. Baffle is provide for to direct fluid stream across tube and increase fluid velocity. Tie rod is used for hold baffle assembly together and to reduce vibration. The set of tubes is called a tube bundle, and may be composed by several types of tubes: plain, longitudinally finned, etc. A shell and tube heat exchanger is a rank of heat exchanger designs. It is the most ordinary type of heat exchanger used in oil refineries and other large chemical processes, and is retained for higher-pressure applications. As its name implies, this type of heat exchanger to be made up of a shell (a large pressure vessel) with a bundle of tubes interior it. Shell and tube heat exchangers are designed by the Tabular Exchanger Manufactures Association (TEMA) Standard. In a single pass shell and tube heat exchanger; the fluid enter in one end of tube and out at the other end of tube.

II. LITERATURE REVIEW

Many researcher study on to the subject of shell and tube heat exchanger for improving its heat transfer rate hot fluid to cold fluid. As per the below literature survey we get some conclusion and research gap.

1. Heat transfer characteristics of silver/water nano fluids in a shell and tube heat exchanger(L.Godson, K. Deepak, C.Enoch, B. Jefferson. Raja (2013)):- By using silver/water nano fluid on STH. It is obtained to increase Q , U and η . With ΔP . With compare experiment and correlation data for LMTD, Effectiveness & thermo physical properties. The Reynolds number varying between 5000 & 25000. Particle volume concentration of 0.01%, 0.03%, 0.04% and for heat flux Varied between 800 W/m² & 1000 W/m²
2. Comparative Analysis of Finned Tube and Bare Tube Type Shell and Tube Heat Exchanger (ShivKumarRathore, Ajeet Bergaley, Volume 2, Issue 1, ISSN : 2277-3754 (IJEIT) 2012):- Identify advantages of finned tube and simple bare tube type shell and tube heat exchanger. comparison of this two types of tube for to obtain greater advantage in Q , η , ΔP , weight, cost etc. entire comparisons of this two type of tube explain by thermal design. the results clearly showed that using low finned tube could provide a significant area reduction for given duty.
3. Performance Evaluation of Deep Spirally Corrugated tube type Shell And Tube Heat Exchanger.(Ventsislav Zimparov, Plamen Penchev, Gabrovo Technical University, Bulgaria (1998)):- To assess the benefit of replacing the smooth tubes with deeper corrugated tubes in shell and tube heat exchanger. there are various range of characteristics parameter value for height-to-diameter ratio, relative pitch ratio, relative helix angle. the best thermodynamic efficiency should be search in the range $e/D = 0.05-0.10$, $p/e < 8$, relative helix angle β^* close to unity and $Re < 10^4$.
4. Shell and tube heat exchanger design by VB Language for education purpose.(Chandrakant B. Kothare, Vol.1, Issue 2, pp-652-657, ISSN: 2249-6645, (IJMER)(2010)):- By Using Visual Basic 6.0 Software Cover Mechanical Design.

Mechanical Design Include Sizing , Rating, Vibration. This Paper Cover the rating module. Thermo Physical Properties Can Store in Database. Cover Graph To Easily Show in Last.

5. CFX Validation of Shell And Tube Heat exchanger at Thermal Power Station-UKAI (TPSU) (C. Z. Patel, Prof. K. K. Araniya, Prof. V. Y. Gajjar, Prof. H. B. Nayak, Prof. B.B. Patel , Volume 4, Issue 4, (IJETA). (2014)):- CFX Simulation Of STHX. Validation Done For Oil Cooler Type STHX Where Servo Prome 46 Oil is use. Which is Coming Out at Turbine Casing is Hot. Required to Cool For Further Lubrication Purpose in Power Plant. So , Here Oil is Hot Fluid And Water is Cold Fluid. In Future Use Nano Fluid-water For Performance Improvement of Heat Exchanger.
6. Comparison of numerical heat transfer in conventional and helically baffled heat exchanger (C.Sivarajan, B.Rajasekaran, Dr.N.Krishnamohan ,Vol. 2, Issue 2, (IJERA). (2012)):- Introduction of Helical Baffle Shell And Tube Heat Exchanger (STHXB) and STHX. Numerical Analysis of Helical Baffle Shell and Tube Heat Exchanger (STHXB) and STHX. Compare With Experimental Result and Present Analytical Result. 3D Numerical Analysis Can be done by Using Commercial Code of Gambit 2.3 and Fluent 6.3 for STHXB.
7. Effect of Tube Thickness for Shell and Tube Heat Exchanger in Portable Solar Water Distiller (AliJaber Alkhakani, Dr. Nor Mariah Adam, Dr. Abdul Aziz Hairuddin-2015):- To increase the heat transfer in solar water distiller this paper contains the reducing the length of tube and decrease the thickness. In this paper contain the stainless still for shell and tube heat exchanger for an portable application.
8. PDHonline Course M371 (2 PDH) Shell and Tube Heat Exchangers Basic Calculations (Jurandir Primo, PE-2012):- This paper contain to design the heat exchanger deeply. How to calculate the heat exchanger for different application with using LMTD and overall heat transfer coefficient and area of heat transfer is given into this research.

➤ Research Gap: - The published literature states that the corrugated tube type heat exchanger improves the rate of heat transfer and pressure drop on tube side when compared with plain type heat exchanger. Therefore, there is a need to determine the extent of increase in rate of heat transfer and pressure drop when the plain tube is modified to corrugated tube in shell and tube type heat exchanger. On to the base of different research will help to determine the good results on to the base of thickness varying on corrugated tube when pressure drop is coming less then plain tube design.

III. OBJECTIVE

- For a selected plain tube type shell and tube heat exchanger, determine the rate of heat transfer & pressure drop by using CFD model. To conduct experiment and validate the numerical results with experimental results.
- For the same shell and tube heat exchanger, replace the tube from plain type to corrugated type with varying thickness and determine the rate of heat transfer & pressure drop by using CFD model. To conduct experiment and validate the numerical results with experimental results.
- The objective is to determine the extent of improvement in the rate of heat transfer and pressure drop when the tube is changed from plain to corrugated type tube on thickness changing. Thermal design calculation of shell and tube heat exchanger is done by TEMA standard.
- The goal of this project is numerical simulation & experiment performance for comparison of shell and tube heat exchanger with plain tube and corrugated tube by using water fluid with thickness difference between both tube. (Hot Water & Cold Water).

IV. DESIGN OF SHELL AND TUBE EXCHANGER BY THERMAL ANALYSIS

INPUT PARAMETER FOR PLAIN TUBE					CALCULATED PARAMETER				
SR No	PARAMETER	NOTATION	VALUE	UNIT	SR NO	PARAMETER	NOTATION	VALUE	UNIT
1	inlet temperature for tube side fluid (hot water)	th1	55	°C	1	logarithmic mean temperature difference	$\frac{(th1 - tc2) - (th2 - tc1)}{\ln \frac{(th1 - tc2)}{(th2 - tc1)}}$	11.54	°C
2	outlet temperature for tube side fluid (hot water)	th2	48.41	°C	2	required effective outside heat transfer	$A = \pi \cdot do \cdot L \cdot \Delta T_{lm}$	0.15787	m ²
3	inlet temperature for shell side fluid (cold water)	tc1	37.48	°C	3	bundle diameter (Db)	$N_b \cdot K_d (D_o/d_o)^{0.4}$	48.82	mm
4	outlet temperature for shell side fluid (cold water)	tc2	42.96	°C	4	baffle spacing	Baffle Spacing = 0.5 * Shell Internal Diameter	42	mm
5	tube outside diameter	do	15	mm	5	total area of baffle plate	$(\pi/4) \cdot D_o^2$	1871.91	mm ²
6	tube inside diameter	di	13	mm	6	tube pitch	$P_t = 1.25 \cdot \text{tube OD}$	18.75	mm
7	shell inside diameter	Di	84	mm	7	area of one tube	$L \cdot do \cdot \pi$	39466.3	mm ²
8	shell outside diameter	Do	100	mm	8	total cross sectional area	$(\pi/4) \cdot (d_o)^2$	176.714	mm ²
9	LMTD	θm	11.54	°C	9	provided area	$(\pi/4) \cdot D_o^2$	1963.49	mm ²
10	number of tube	Nt	4		10	required area	$4 \cdot (\pi/4) \cdot d_o^2$	706.8500	mm ²
11	length of tube	L	837.5	mm	11	access area	Provided Area - Required Area	0.00126	mm ²
12	bundle diameter constant	K1	0.319		12	overall heat transfer coefficient	$U = 1 / [(1/h_o) + r_o / (k_s A_o) + (1/h_i) (A_o/A_i)]$	130.02	W/m ² .K
13	bundle diameter constant	n1	2.142		13	tube wall resistance	$r_w = d_i / 24k \cdot \ln(d_o/d_i)$	0.01	°C
14	fouling resistance outside surface of tube	ro	0.003		14	equivalent diameter for shell side (rotated square arrangement)	$De = 4 \cdot [(P_t^2 - \pi \cdot d_o^2) / 4] / (\pi \cdot d_o)$	14.84	mm
15	fouling resistance inside surface of tube	ri	0.001		15	bundle cross flow area at the centre of shell	$A_b = D_o \cdot CB / P_t$	705.60	mm ²
16	density at tube side fluid (at avg. temp)	p	987.71	kg/m ³	16	mass flow density	$G_s = m/A_b$	57.86	kg/m ² .s
17	density at shell side fluid (at avg. temp)	p	992.22	kg/m ³	17	film coefficient at shell side fluid (ho)	$h_o D_o / k_s = 0.36 (D_o G_s / \mu_s)^{0.55} (C_p \mu_s / k_s)^{1/3} (\mu_s / \mu_w)^{0.14}$	1315.77	W/m ² .K
18	specific heat at tube side fluid (at avg. temp)	Cp	4181.4	J/kg.K	18	tube plate area (Atp)	$A_{tp} = [(m/4) \cdot d_o^2] \cdot (N_b/2)$	2.654 10 ⁻⁴	m ²
19	specific heat at shell side fluid (at avg. temp)	Cp	4178.85	J/kg.K	19	Reynold Number	$Re = (p \cdot u_{min} \cdot d_o) / \mu$	3571	
20	dynamic viscosity at tube side fluid (at avg. temp)	μ	0.0005539	Ns/m ²	20	Nusselt Number	$N_{uk} = [(h/2) \cdot (Re_k - 1000) Pr] / [1 - 12.7 \cdot (h/2)^{0.5} (Pr)^{0.47}]$	178.9	
21	dynamic viscosity at shell side fluid (at avg. temp)	μ	0.0006532	Ns/m ²	21	friction factor (f)	$f = [1.58 \ln Re - 3.28]^2$	0.01	
22	thermal conductivity of tube side fluid (at avg. temp)	k	0.6424	W/m.K	22	film coefficient at tube side fluid (hi)	$h_i = [N_{uk} \cdot k] / d_i$	8840.00	W/m ² .K
23	thermal conductivity of shell side fluid (at avg. temp)	k	0.6305	W/m.K	23	heat transfer rate	$Q = m \cdot h \cdot c_{ph} \cdot (th1 - th2)$	1428.65	W
24	Prandtl number (Pr) of tube side (at avg temp)	Pr	3.644		24	shell side pressure drop	$\Delta P_s = [f \cdot G_s^2 \cdot (N_b + 1) D_o] / 2 \cdot p \cdot \phi_s \cdot D_o$	10.27	Pa
25	Prandtl number (Pr) of shell side (at avg temp)	Pr	4.3289		25	friction factor (f)	$f = \exp(0.578 - 0.19 \ln Re_s)$	0.96	
26	ratio of outside to inside surface of tubing	doldi	1.153		26	tube side pressure drop	$\Delta P_t = (4 \cdot f \cdot L \cdot N_b \cdot G_s^2) / (d_o \cdot 2p)$	2.78	Pa
27	mass flow rate of cold side fluid	mc	0.03833	kg/s	27	efficiency	$\eta = Q_c / Q_h$	61.39	%
28	fluid flow velocity	umin	0.1557	m/s	28	Heat Flux (q)	$q = Q/A$	1484.75	W/m ²
29	tube thickness	t	1.62	mm	29	effectiveness	$\epsilon = Ch (th1 - th2) / Cmin (th1 - tc1)$	38	%
30	mass flow rate of hot side fluid	mh	0.04063	kg/s					

Table: 4.1 all calculation and design parameter for plain tube

INPUT PARAMETER FOR CORRUGATED TUBE					CALCULATED PARAMETER				
SR No	PARAMETER	NOTATION	VALUE	UNIT	SR NO	PARAMETER	NOTATION	VALUE	UNIT
1	inlet temperature for tube side fluid (hot water)	th1	55	°C	1	logarithmic mean temperature difference	$[(th1-tc2-(th2-tc1))/\ln \{(th1-tc2)/(th2-tc1)\}]$	13.53	°C
2	outlet temperature for tube side fluid (hot water)	th2	45.71	°C	2	required effective outside heat transfer surface area	$A = \pi \cdot do \cdot L \cdot Nt \cdot (p/c)$	0.3273982	m ²
3	inlet temperature for shell side fluid (cold water)	tc1	37.48	°C	3	bundle diameter (Db)	$N_b = K_b [(D_o/d_o)^2]^*$	56.4	mm
4	outlet temperature for shell side fluid (cold water)	tc2	43.24	°C	4	baffle spacing	Baffle Spacing = 0.5*Shell Internal Diameter	50	mm
5	tube outside diameter	do	15	mm	5	total area of baffle plate	$(\pi/4) \cdot D_o^2$	2438.32	mm ²
6	tube inside diameter	di	13	mm	6	tube pitch	$Pt = 1.25 \cdot \text{tube OD}$	18.75	mm
7	shell inside diameter	Di	84	mm	7	area of one tube	$L \cdot do \cdot \pi$	33466.25	mm ²
8	shell outside diameter	Do	100	mm	8	total cross sectional area	$(\pi/4) \cdot (d_o)^2$	176.114	mm ²
9	LMTD	ΔT_m	13.53	°C	9	provided area	$(\pi/4) \cdot (p/c) \cdot D_o^2$	54977.87	mm ²
10	number of tube	Nt	4		10	required area	$4 \cdot (\pi/4) \cdot d_o^2$	706.8500	mm ²
11	length of tube	L	820	mm	11	access area	Provided Area-Required Area	0.54271	mm ²
12	bundle diameter constant	K1	0.319		12	overall heat transfer	$U = 1/[(1/h_o) + r_o \cdot (1/E_o) + r_o \cdot (1/A_o \cdot A_i) + \{1/h_i(A_o/A_i)\}]$	158.39	W/m ² .K
13	bundle diameter constant	n1	2.142		13	tube wall resistance	$rw = d/24k [\ln(d/d-2t)]$	0.09	Ω
14	fouling resistance outside surface of tube	ro	0.003		14	equivalent diameter for shell side (rotated square bundle cross flow area at the centre of shell)	$D_e = 4 \cdot [P \cdot r^2 \cdot \pi \cdot d_o^2/4] / (\pi \cdot d_o)$	14.84	mm
15	fouling resistance inside surface of tube	ri	0.001		15	mass flow density	$A_s = D_o \cdot CB/P_t$	1000.00	mm ²
16	density at tube side fluid (at avg. temp)	ρ	987.71	kg/m ³	16	film coefficient at shell side fluid (ho)	$G_s = m/A_s$	46.66	kg/m ² .s
17	density at shell side fluid (at avg. temp)	ρ	392.22	kg/m ³	17	film coefficient at shell side fluid (ho)	$h_o/D_o/k = 0.36(D_o/G_o \mu)^{1/4} (C_p \mu/k)^{1/4} (\mu_o/\mu_s)^{1/4}$	1169.43	W/m ² .K
18	specific heat at tube side fluid (at avg. temp)	Cp	4181.4	J/kg.K	18	tube plate area (Atp)	$A_{tp} = [(\pi/4) \cdot d_o^2 \cdot N_b]/2$	2.654*10 ⁴	m ²
19	specific heat at shell side fluid (at avg. temp)	Cp	4178.85	J/kg.K	19	Reynold Number	$Re = (\rho \cdot u_{m,i} \cdot d_o) / \mu$	4371.4	
20	dynamic viscosity at tube side fluid (at avg. temp)	μ	0.0005539	Ns/m ²	20	Nusselt Number	$N_{u,i} = [(f/2) \cdot (Re - 1000) \cdot Pr] / [1 + 12.7 \cdot (f/2)^{1/4} \cdot (Pr^{1/4} - 1)]$	268.94	
21	dynamic viscosity at shell side fluid (at avg. temp)	μ	0.0006532	Ns/m ²	21	friction factor (f)	$f = [1.58 \ln Re - 3.28]^2$	0.01	
22	thermal conductivity of tube side fluid (at avg. temp)	k	0.6424	W/m.K	22	film coefficient at tube side fluid (hi)	$h_i = [N_{u,i} \cdot k] / d_o$	13290.00	W/m ² .K
23	thermal conductivity of shell side fluid (at avg. temp)	k	0.6305	W/m.K	23	heat transfer rate	$Q = mh \cdot c_p h \cdot (th1-th2)$	1934.30	W
24	Prandtl number (Pr) of tube side (at avg temp)	Pr	3.644		24	shell side pressure drop	$\Delta P_s = [f \cdot G_s^2 \cdot (N_b + 1) \cdot D_o] / 2 \cdot \rho \cdot s \cdot D_o$	15.38	Pa
25	Prandtl number (Pr) of shell side (at avg temp)	Pr	4.3289		25	friction factor (f)	$f = \exp(0.576 - 0.19 \ln Re_o)$	0.47	
26	ratio of outside to inside surface of tubing	do/di	1.153		26	tube side pressure drop	$\Delta P_t = (4 \cdot f \cdot L \cdot N_b \cdot G_o^2) / (d_o \cdot 20)$	4.67	Pa
27	mass flow rate of cold side fluid	mc	0.04666	kg/s	27	efficiency	$\eta = Q_{act}/Q_{th}$	73.11	%
28	mass flow rate of hot side fluid	mh	0.05	kg/s	28	effectiveness	$\epsilon = Ch(th1-th2)/Cmin(th1-tc1)$	54	%
29	fluid flow velocity	umin	0.1906	m/s	29	heat flux (q)	$q = Q/A$	2150.42	W/m ²
30	tube thickness		0.88	mm					
31	relative height to diameter ratio (horizontal tube)	e/Di	0.05-0.07						
32	relative pitch to height ratio (horizontal tube)	p/e	4.6-18.2						
33	helix angle of rib (β) (horizontal tube)	β = β/30	0.40-0.94						

Table: 4.2 all calculation and design parameter for corrugated tube

- All above solution is taken by general equation and literature-^[15,18,19]

V. CFD ANALYSIS OF PLAIN TUBE AND CORRUGATED TUBE STHE

CFD analysis

Cfd analysis contain the main three equation to solve and analyzed the fluid flow, temperature difference and pressure in particular volume. The CFD analysis has been done using the software module ANSYS Fluent 14.5. The CFD results involve comparison of obtained temperature contours with experimentally observed temperatures. The basic main equation for CFD is based on Mass, Momentum and Energy equation, which set is called the Navier-Stock equation. Which govern the all CFD analysis of particular volume.

Modelling

In modelling of shell and tube heat exchanger for thermal analysis, first geometry is prepare in solid works software and make 3D of that part can also make in solid work. After completing geometry preparation in this software geometry clean up needed so unwanted part which is unnecessary is remove out and finally that model of file applied for meshing in ICFM CFD. Modelling is the process of creating the model which is representation of the construction and working of some system of interest. Our propose of a model is make able to the analyst to find the effect of changes to the system. A model should be close estimate to the real system and incorporate most of salient features, it should not be so complex that is impossible to understand and experiment with it.3D Model is prepared in the Solid Works 2014. The modelling of plain and corrugated tube is shown in below figure,

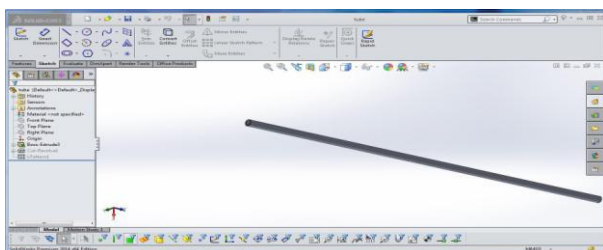


Fig-5.1 Modelling section of Plain tube

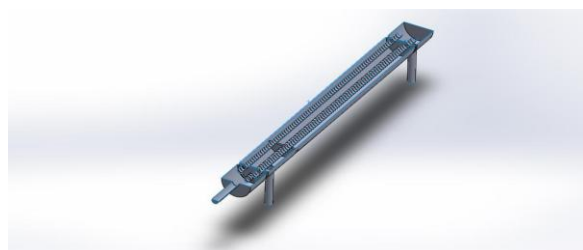


fig-5.2 Modelling section of Corrugated tube

Meshing

The partial differential equations that manage fluid flow and heat transfer are not ordinary submissive to analytical solutions, except for very simple cases. Therefore, in order to analyze fluid flows, flow domains are split into smaller sub domains (made up of geometric original like hexahedra and tetrahedral in 3D and quadrilaterals and triangles in 2D).The

governing equations are discretized & solved inside each of these sub domains. One of the three methods is used to solve the approximate version of the system of equations: finite volumes, finite elements, or finite differences. Care must be taken to ensure proper continuity of solution across the common interfaces between two sub domains, so that the nearly solutions inside various portions can be put together to give a complete picture of fluid flow in the entire domain. The sub domains are often called elements or cells, and the collection of all elements or cells is called a mesh or grid. Meshing for this case is done in the Ansys ICEM 14.5.

Meshing for the plain tube STHx:-

Importing a parasolid file from solidworks 2014. Then making a part wise differentiate and then making a global mesh, tri-mesh and prism mesh on assembly of plain tube model and plain tube.

Create prism mesh near the wall surface. After computing the all mesh, the numbers of prism mesh are 1164606.

Sr. No.	Element	Number of elements
1	Prism mesh	1164606
2	Tetrahedral mesh	2103972
3	Triangle mesh	294164

Table 5.1 No of elements of different type of mesh

Element parts :
 CURVE : 2565
 FLUIDHOT : 1022112
 FLUID_COLD : 2246636
 INLET_COLD_WATER : 200
 INLET_HOT_WATER : 236
 OUTLET_COLD_WATER : 218
 OUTLET_HOT_WATER : 214
 POINTS : 8
 WALL_TUBE : 1586
 WALL_TUBE_INLET_C : 4735
 WALL_TUBE_INLET_H : 4187
 WALL_TUBE_INTERIOR : 94660
 WALL_TUBE_OUTLET_C : 4811
 WALL_TUBE_OUTLET_H : 4720
 WALL_WATER_C : 138311
 WALL_WATER_H : 40682
 Total elements : 3565881
 Total nodes : 984206

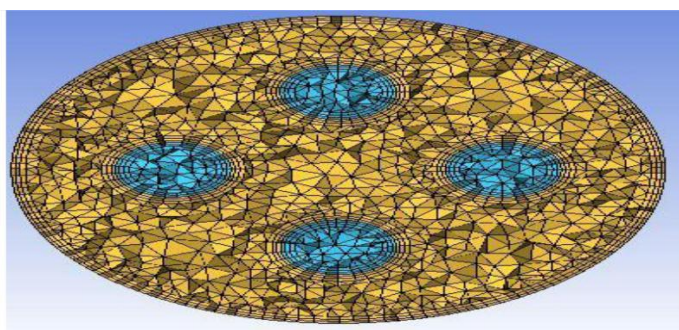


Fig:-5.6 Meshing near Wall on plain tube STHx

Quality of the Mesh

1. Aspect Ratio:

All elements are fall in the range between 0 to 20. But maximum of number of node come in range 0 to 11. So it can be say that quality of mesh is good.

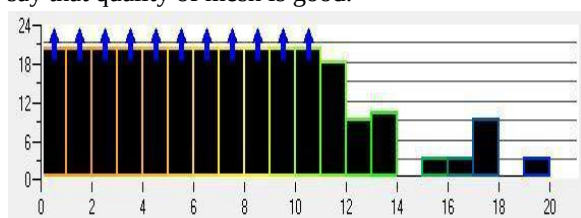


Fig:-5.7: aspect ratio value for plain tube STHX

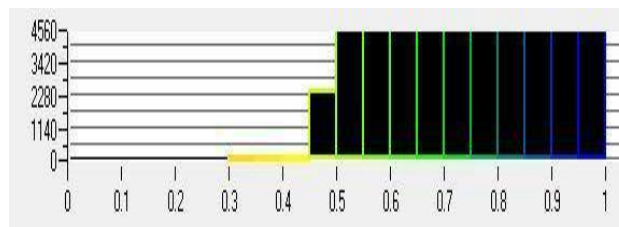


Figure 5.8: Quality Value of Mesh for plain tube STHx

2. Quality :

Quality of mesh is in range of 0 to 1. Quality is 0.45. But maximum numbers of node come in range 0.5 to 1. So it can be say that quality of mesh is good.

Meshing for the corrugated tube STHx:-

Importing a parasolid file from solidworks 2014. Then making a part wise differentiate and then making a global mesh, tri-mesh and prism mesh on assembly of plain tube model and corrugated tube.

Create mesh near the wall surface. After computing the all mesh, the numbers of mesh elements are in table 8.1 & also figure as below :

Sr. No.	Element	Number of elements
1	Tetrahedral mesh	4473784
2	Triangle mesh	303146

Table 5.2 No of elements of different type of mesh in corrugated tube

Element parts :
COLD_FLUID : 2892350
CURVES : 42555
HOT_FLUID : 1581434
INLET_COLD_WATER : 299
INLET_HOT_WATER : 256
OUTLET_COLD_WATER : 304
OUTLET_HOT_WATER : 302
POINTS : 8
WALL_COLD_WATER : 62267
WALL_HOT_WATER : 18736
WALL_INLET_TUBE_COLD_WATER : 2135
WALL_INLET_TUBE_HOT_WATER : 2158
WALL_OUTLET_TUBE_COLD_WATER : 2140
WALL_OUTLET_TUBE_HOT_WATER : 2192
WALL_TUBE_EXT : 2818
WALL_TUBE_INT : 209539
Total elements : 4819493
Total nodes : 771499

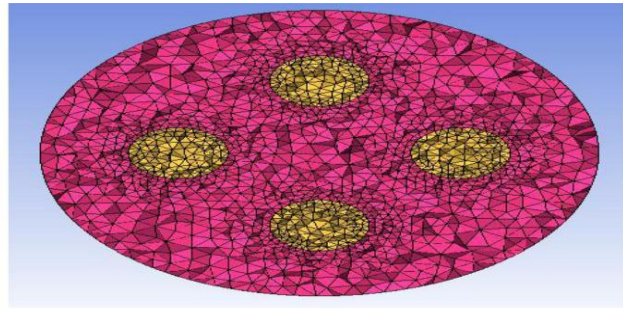


Fig:-5.6 Meshing near Wall on corrugated tube STHx

Quality of the Mesh

1. Aspect Ratio:

All elements are fall in the range between 0 to 20. But maximum of number of node come in range 0 to 11. So it can be say that quality of mesh is good.

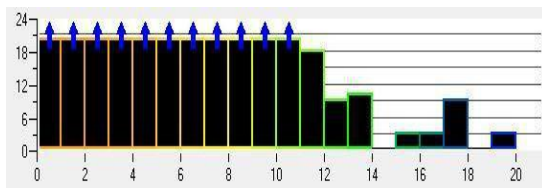


Fig:-5.7: aspect ratio value for corrugated tube

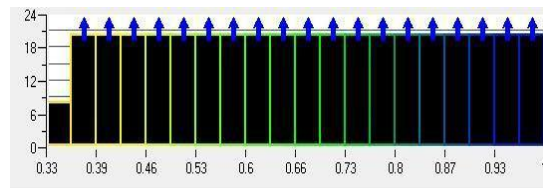


Figure 5.8: Quality Value of Mesh for corrugated tube

2. Quality :Quality of mesh is in range of 0 to 1. Quality is 0.33. But maximum numbers of node come in range 0.39 to 1. So it can be say that quality of mesh is good.

Boundary Conditions :

Boundary conditions applied to the different parts of the geometry. Parts are created during the process of meshing in the ICEM.

Mass flow rate	0.04083 kg/s
Temperature inlet	328.25 K
Density	987.71 kg/m ³
Dynamic viscosity	0.00055985 Ns/m ²
Specific heat	4181.4 J/kg K
Thermal conductivity	0.6424 W/mK

Table 5.3:- Boundary Conditions for Tube

Mass flow rate	0.0383 kg/s
Temperature inlet	310.48 K
Density	992.22 kg/m ³
Dynamic viscosity	0.0006532 Ns/m ²
Specific heat	4178.5 J/kg K
Thermal conductivity	0.6305 W/m K

Table 5.4 Boundary Condition for Shell

MATERIAL SELECTION

Property	Value
Density	987.71 kg/m ³
Dynamic viscosity	0.00055985 Ns/m ²
Specific heat	4181.4 J/kg K
Thermal conductivity	0.6424 W/m K

Table 5.5:- Properties of Fluid (Hot Water - Tube Side)

Property	Value
Density	992.22 kg/m ³
Dynamic viscosity	0.0006532 Ns/m ²
Specific heat	4178.5 J/kg K
Thermal conductivity	0.6305 W/m K

Table 5.6:- Properties of Fluid (Cold Water - Shell Side)

CASE I- PLAIN TUBE 1.62 MM THICKNESS STHx

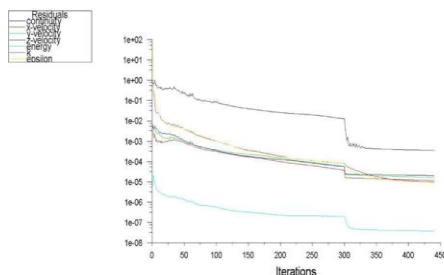


Fig:-5.9 Scale residuals of 1.62 mm plain tube STHx

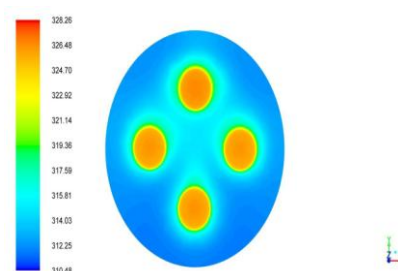


Fig:-5.10 Temperature Variations 1.62 mm plain tube in STHx

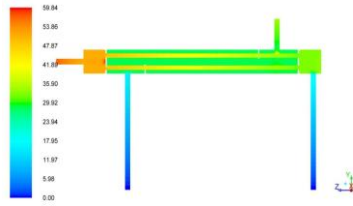


Fig:-5.11 Static Pressure Variations in Shell and Tube Heat Exchanger

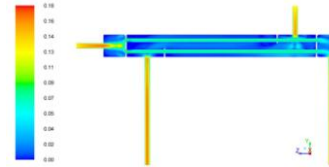


Figure 5.12: Velocity Variation in Shell and tube Heat Exchanger

Parts	Operating parameter	Parameter value
Tube inlet	Static temperature	328.25 K
	Static pressure	57.49 Pa
	Velocity	0.1311 m/s
	Area	0.00031195983 m ²
Tube outlet	Static temperature	323.0408 K
	Static pressure	13.14 Pa
	Velocity	0.1395 m/s
	Area	0.00031193078 m ²
Shell inlet	Static temperature	310.48001 K
	Static pressure	34.49 Pa
	Velocity	0.1230 m/s
	Area	0.00031184437 m ²
Shell outlet	Static temperature	316.03424 K
	Static pressure	11.89 Pa
	Velocity	0.1322 m/s
	Area	0.00031189778 m ²

Table 5.7:- CFD RESULTS FOR PLAIN TUBE 1.62 MM

CASE II- CORRUGATED TUBE 0.88 MM THICKNESS STHx

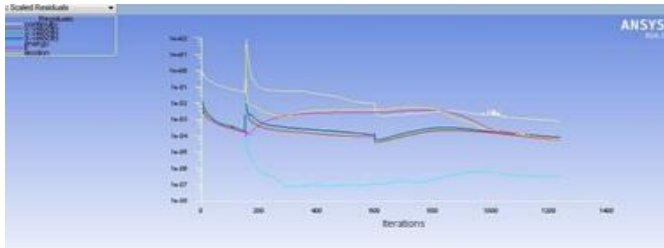


Fig:-5.13 Scale residuals of corrugated tube 0.88 mm STHx

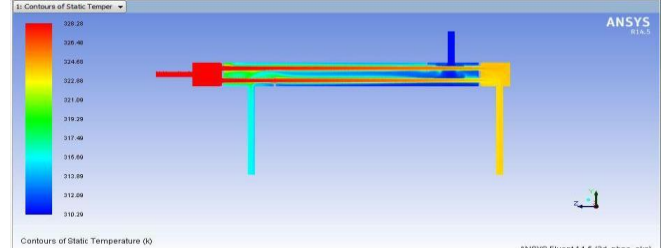


Fig:-5.14 Temperature Variations in 0.88 mm tube STHx

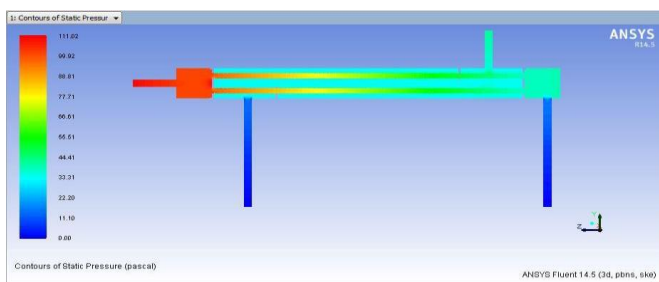


Fig:-5.15 Static Pressure Variations in 0.88 mm tube STHx

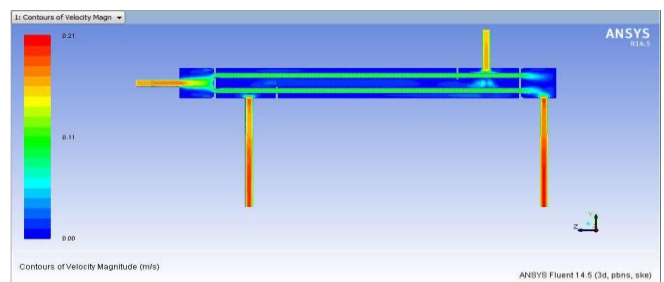


Figure 5.16: Velocity Variation in 0.88mm tube STHx

Parts	Operating parameter	Parameter value
Tube inlet	Static temperature	328.25 K
	Static pressure	109.82466 Pa
	Velocity	0.16028699 m/s
	Area	0.00031250296 m ²
Tube outlet	Static temperature	321.70 K
	Static pressure	10.783895 Pa
	Velocity	0.16021301 m/s
	Area	0.00031282400 m ²

Shell inlet	Static temperature	310.48001 K
	Static pressure	41.702805 Pa
	Velocity	0.14951903 m/s
	Area	0.00031263 m ²
Shell outlet	Static temperature	315.38669 K
	Static pressure	9.9446163 Pa
	Velocity	0.14945887m/s
	Area	0.00031282406 m ²

Table 5.8:- CFD RESULTS FOR CORRUGATED 0.88 MM

CASE III- CORRUGATED TUBE 1.00 MM THICKNESS STHx

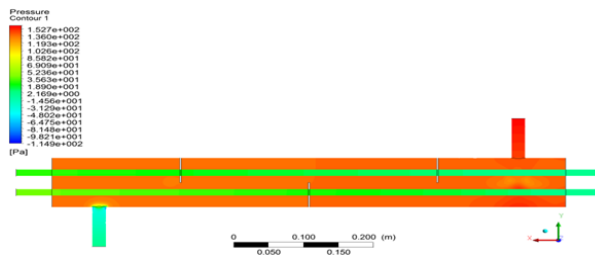


Fig:-5.17 Pressure Profile Variations in1.00 mm tube STHx

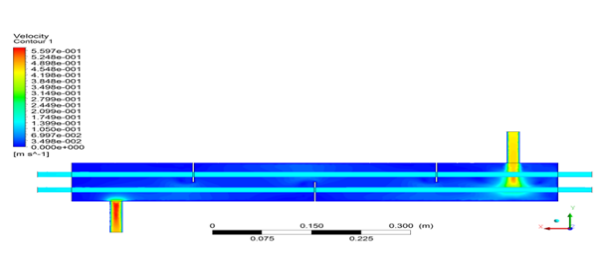


Fig:-5.18 Velocity Variations in 1.00 mm tube STHx

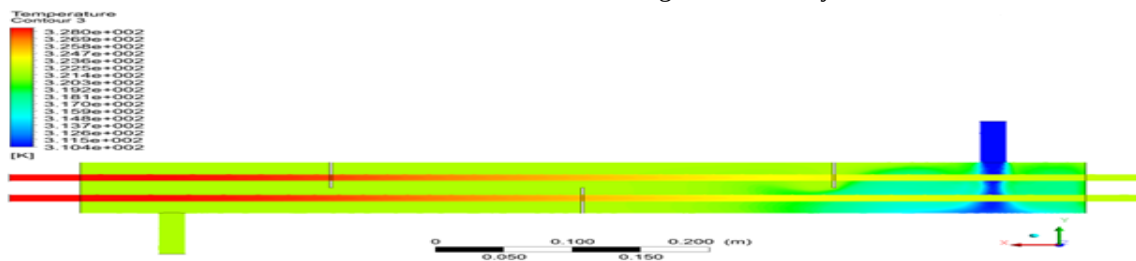


Figure 5.19: Temperature Variation in 1.00mm corrugated tube STHx

CASE IV- CORRUGATED TUBE 1.25 MM THICKNESS STHx

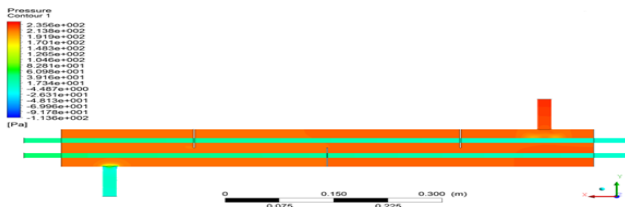


Fig:-5.20 Pressure Profile Variations in1.25 mm tube STHx

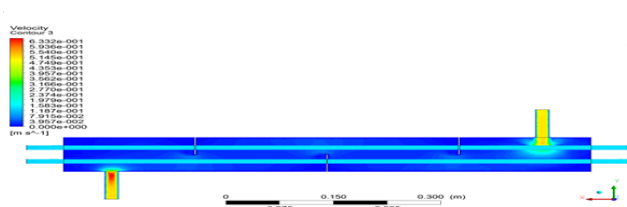


Fig:-5.21 Velocity Variations in 1.25 mm tube STHx

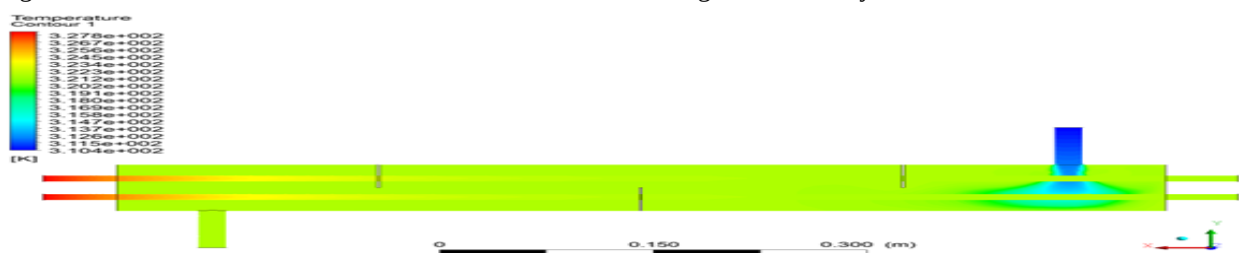


Figure 5.22: Temperature Variation in 1.25mm corrugated tube STHx

Parameters	Plain tube thickness 1.62 mm	Corrugated tube thickness 0.88mm	Corrugated tube thickness 1 mm	Corrugated tube thickness 1.25 mm
Hot Water Inlet Temperature	328.25 K	328.25 K	328.25 K	328.25 K
Hot Water Outlet Temperature	321.41 K	320.68 K	321.2 K	321.39
Cold Water Inlet Temperature	310.48 K	310.48 K	310.48 K	310.48 K
Cold Water Outlet Temperature	315.96 K	316.24 K	315.80K	315.30 K

Table 5.9:- CFD RESULTS FOR ALL CASES

VI. EXPERIMENTAL SETUP AND METHODOLOGY

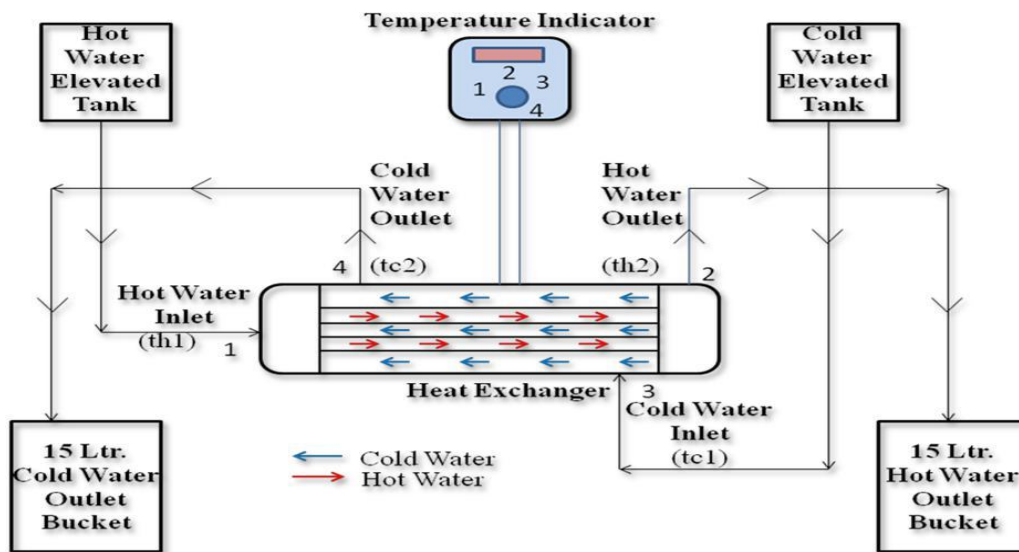


Figure 6.1: Schematic Diagram of Experimental Layout

Here in this schematic diagram of experiment layout is in which there is one shell and tube heat exchanger is use in which first take plain tube having number of four. Here hot side fluid flow in tube side and cold side fluid flow in shell side. Hot fluid is hot water and cold fluid is cold water. Each having tube side and shell side inlet-outlet is connected and entire both fluid flow in counter flow arrangement for high heat transfer area. Both fluid flow can be indicated by red and blue color. Red for hot tube side fluid and blue for cold shell side fluid. Here in this experiment hot side and cold side tank is put at gravity level so fluid flow at respective inlet of heat exchanger in pipe line. Here two 15 litre capacity pail is taken for outlet fluid of hot side (at 2 point) and cold side (at 4 point) which is filled with outlet hot and cold water in respective bucket. Reading is taken at every 5 min interval and temperature reading is taken and flow measure from 15 litre capacity pail after 5 min. One advantage is that in this model is there is glass wool is provided on shell for to minimize heat loss. And a tape is winding over it. There is sensor with thermo couple (TP 100) is provided at respective inlet- outlet at shell side and tube side and measure common temperature indicator is provide so we take easily reading with accuracy. In this temperature indicator four reading is take first reading is for th_1 (hot side inlet temp.) Second is for th_2 (hot side outlet) , third is for tc_1 (cold side inlet) , fourth is for tc_2 (cold side outlet). Here figure show model of shell and tube heat exchanger in which cold and hot side fluid tank is put at some gravity level up to 3 foot from ground level. In hot tank water is heated by immersion water heater. Each at every inlet outlet of shell and tube side is pointed as respective 1,2,3,4 point labelled. Four tube is arranged in rotated square arrangement in this type of heat exchanger. Tube having material is aluminium.

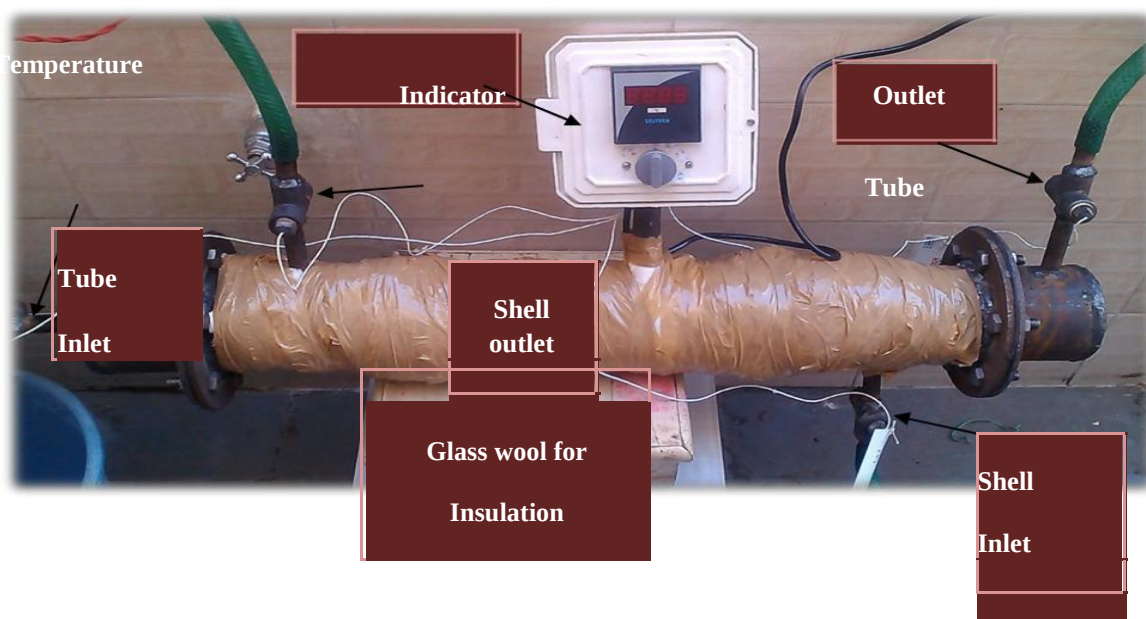


Figure 6.2 : Model of Shell And Tube Heat Exchanger

Shell material is MS. Temperature indicator will indicate reading in 5min. Interval as th_1 , th_2 , tc_1 , tc_2 . Here sensor wire made of Teflon so which is safe for against any cause. Here rotated square arrangement in shell and tube heat exchanger with for plain and corrugated tube is shown below figure 6.3 & also Entire tube arrangement section in shell and tube heat exchanger show as below figure 6.4.

TECHNICAL SPECIFICATION

- Outer diameter of tube = 15 mm
- Length of tube = 837.5 mm
- No. of tube = 4 (single pass)
- Shell material = MS
- Shell cover = 4 inches
- Shell side temp. (cold water) by measure : (a) Inlet temp. = 37.48 °C (b) Outlet temp. = 42.96 °C
- Tube side temp. (Hot water) by measure : (a) Inlet temp. = 55.25 °C (b) Outlet temp. = 48.41 °C

Thickness of tube = 1.62 mm
 Shell outer diameter = 100 mm
 No. of baffle = 2
 Tube material = aluminum
 Thickness of baffle = 1.54mm

No.	Th ₁	Tc ₁	Th ₂	Tc ₂
1	47.9	36.2	44.2	42
2	48.2	36.2	44.2	44.3
3	48.8	36.2	44.2	39.3
4	51.9	38.4	48	42.2
5	52.2	35.8	46.5	41.4
6	52.2	36.2	48.1	41.8
7	53.2	40.2	49.7	43.6
8	53.5	38.5	47	42
9	53.8	35.8	46.8	39.8
10	55.3	38.4	48	43.7
11	55.5	40.2	49.9	45.1
12	56.4	38.6	47.5	43.2
13	56.5	36.3	47.9	42
14	57.8	36.4	51.3	45.2
15	58.5	39.3	51.3	43.5
16	58.5	39.2	50.8	44.9
17	63.5	38.4	51.6	43.2
18	70.8	38.4	54.5	46.2
Avg	55.25	37.48	48.42	42.97

No.	Th ₁	Tc ₁	Th ₂	Tc ₂
1	55.5	40.2	47.8	43.6
2	54.8	37.5	43.8	42
3	54.4	40.8	42.8	42
4	57.6	40	49.9	45.1
5	55.2	34.6	40.2	42.2
6	52.5	42.4	46.4	43.5
7	57.3	40.5	44.2	41.8
8	56.7	38.9	46.2	39.8
9	53.7	38.5	45.8	44.3
10	60.6	30.7	42.5	45.2
11	51.3	33.6	41.3	42
12	51.4	36.8	43.6	43.2
13	55.7	36.3	44.8	46.2
14	57.4	37.6	50.7	43.7
15	55.4	35.6	47.4	43.2
16	55.1	36.5	46.8	44.3
17	56.4	37.6	49.9	44.9
18	53.5	36.5	48.7	41.4
Avg	55.25	37.48	45.71	43.24

Table 6.6 Temperature Reading(C) (PLAIN Tube)

Table 6.7 Temperature Reading(C) (Corrugated Tube)

VII. COMPARATIVE RESULTS ANALYSIS AND CONCLUSION

After taking experiment reading on model of shell and tube heat exchanger with plain tube and corrugated tube, calculation & thermal analysis is do according to TEMA standard and comparative result is obtain for plain tube and corrugated tube. Entire calculation is cover in previous Chapter - 6. Result show on graph for better comparative result. There is comparison between shell and tube heat exchanger with plain tube and corrugated tube for parameter like heat flux, heat transfer rate, overall heat transfer coefficient, efficiency, effectiveness, temperature difference, pressure drop etc.

Heat Flux vs. LMTD:

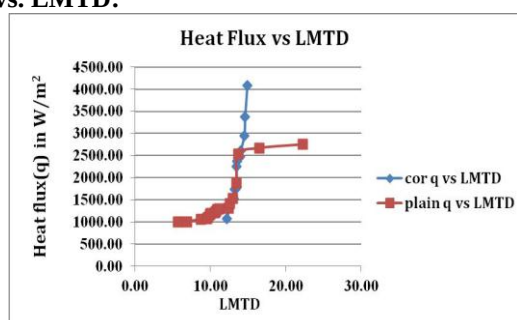


Figure 7.1 : Heat Flux vs. LMTD graph

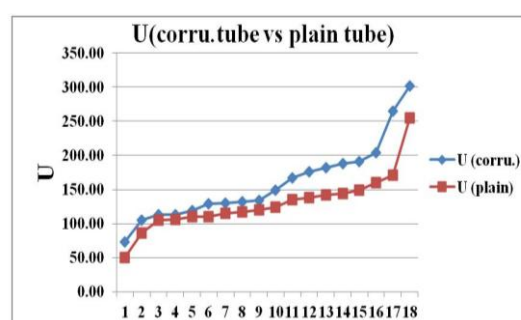


Figure 7.2 : U vs. LMTD graph

This Graph show comparative result of heat flux vs. LMTD for Shell and Tube Heat-exchanger with plain and corrugated tube. Graph show that heat flux is increase for shell and tube heat exchanger with corrugated tube compare to plain tube.

Overall Heat Transfer Coefficient vs. LMTD:

This Graph show comparative result of Overall Heat Transfer Coefficient (U) vs. LMTD for Shell and Tube Heat Exchanger with plain tube and corrugated tube. Graph show that overall heat transfer coefficient for corrugated tube is more compare to plain tube result. overall heat transfer coefficient vs. LMTD for corrugated tube is shown by blue colour and for plain tube red colour is indication.

Effectiveness:

This Graph show comparative result of effectiveness for shell and tube heat exchanger with plain tube and corrugated tube. Graph show that effectiveness of corrugated tube is more compare to plain tube effectiveness.

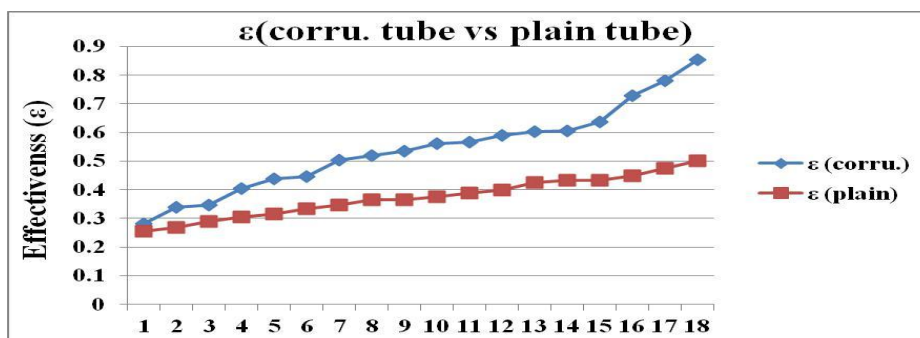


Figure 7.3 : Effectiveness (Corru. Tube vs. Plain Tube)

Parameters	Corrugated tube	Plain tube	Remark
Hot Water Inlet Temperature	328.25 K	328.25 K	-
Hot Water Outlet Temperature	320.68 K	321.41 K	Temperature is increase in plain tube
Cold Water Inlet Temperature	310.48 K	310.48 K	-
Cold Water Outlet Temperature	316.24 K	315.96 K	Temperature is increase in corrugated tube
Heat transfer rate (Q)	1666.28 W	1167.76 W	Q is increase in Corrugated tube
Effectiveness (ε)	43 %	38 %	ε is increase in Corrugated tube.
Efficiency (η)	67.42 %	61.39 %	η is increase in Corrugated tube.
LMTD	13.53 C	11.54 C	LMTD is increase in Corrugated tube.
Pressure drop at shell side (ΔPs)	15.98 Pa	10.27 Pa	(ΔPs) is increase in corrugated tube
Pressure drop at tube side (ΔPt)	4.67 Pa	2.78 Pa	(ΔPt) is increase in corrugated tube

Table7.2: (Comparison of Experiment Result)

From above calculated result we say that **Q**, **η**, **ε** is increase for Shell and Tube Heat Exchanger with Corrugated Tube compare to with Plain Tube. Pressure Drop is reducing by using corrugated tube instead of plain tube. So satisfied design result obtain from theoretical calculation and graphs.

Parameters	Corrugated tube	Plain tube	Remark
Hot Water Inlet Temperature	328.25 K	328.25 K	-
Hot Water Outlet Temperature	321.70 K	323.040 K	Temperature is increase in plain tube
Cold Water Inlet Temperature	310.48 K	310.48 K	-
Cold Water Outlet Temperature	315.38669 K	316.0342 K	Temperature is increase in plain tube
Heat transfer rate (Q)	1869.44 W	1292.45 W	Q is increase in Corrugated tube
Efficiency (η)	69.76 %	64 %	η is increase in Corrugated tube.
LMTD	14 C	12.39 C	LMTD is increase in Corrugated tube.
Pressure drop at shell side (ΔPs)	31.76 Pa	22.6 Pa	(ΔPs) is increase in corrugated tube
Pressure drop at tube side (ΔPt)	60.048 Pa	28.04 Pa	(ΔPt) is increase in corrugated tube

Table10.2: Comparison of CFD Result

From above CFD Analysis result we say that heat transfer rate, efficiency and temperature difference for corrugated tube is high more compare to that of plain tube. Comparison of experiment result and CFD Analysis result for validation of Shell and Tube Heat Exchanger with plain tube and corrugated tube are as shown in below graphs for heat transfer rate, effectiveness, efficiency and overall heat transfer coefficient.

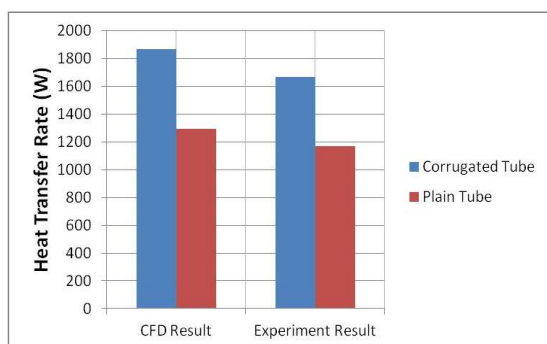


Figure 7.4: Variation in Heat Transfer Rate (W)

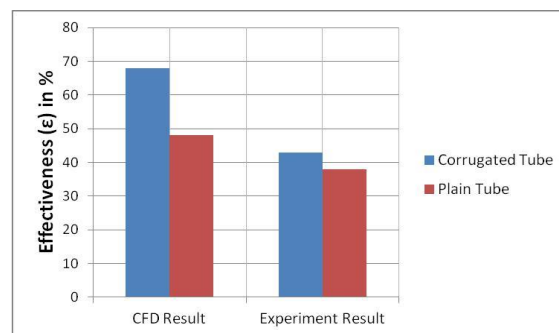


Figure 7.5: Variation in Effectiveness (%)

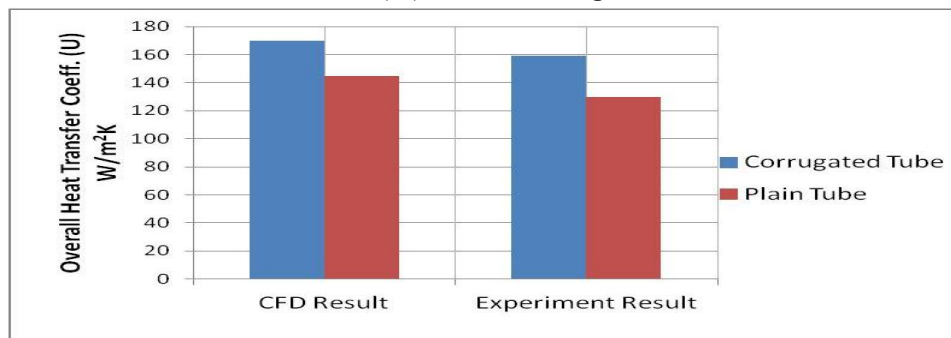


Figure 7.6: Variation in Overall Heat transfer Coefficient (U)

VIII. CONCLUSIONS

- From above results of CFD analysis and experimental analysis show that the 0.88 mm thickness of corrugated tube increase the pressure drop than plain tube of 1.62 mm thickness tube.
- It is reducing the cost of manufacturing and also reduce the weight of material.
- Heat transfer rate will be increased in corrugated tube due to the increased pressure drop.
- Effectiveness of corrugated tube is more than plain tube.
- With the varying the inner radii of tube of plain tube to corrugated tube there is a different results of heat transfer rate. But into the corrugated tube there is a pressure of water will decreased so the pressure sustain capacity of material will increased. So the inner radii of tube will be changed.

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