RESEARCHERID
THOMSON REUTERS

[Nimankar* *et al.*, 6(12): December, 2017]
IC™ Value: 3.00

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

FINITE ELEMENT (FE) ANALYSIS AND OPTIMIZATION OF CONCENTRIC HEATER

Mr. Sachchidanand J Nimankar, Prof. Sachin K. Dahake
Mechanical, MET's Institute of Engineering Bhujbal Knowledge City, India.
Mechanical, MET's Institute of Engineering Bhujbal Knowledge City, India.

DOI: 10.5281/zenodo.1116653

ABSTRACT

The effectiveness of heat exchanger shows its performance. Shell and tube heat exchanger is selected from previous research paper. Its effectiveness is calculated by mathematical modeling. It is replaced by triple concentric tube heat exchanger with same input parameters and effectiveness is calculated by mathematical modeling. Three controlling parameters LDO inlet temp, Crude inlet temp and mass flow rate of crude are selected. L-9 array is formed with three levels of variables. Analysis is carried out for nine experiments. Optimize these controlling parameters. ANOVA is carried out to find the percentage contribution of each controlling parameter.

KEYWORDS: LDO, Crude, mass flow rate, triple concentric heat exchanger, effectiveness.

I. INTRODUCTION

Heat exchangers are one of the most common pieces of equipment found in all plants. Heat exchangers have always been important part to lifecycle and operation of many systems. A heat exchanger is a device built for efficient heat transfer from one medium to another in order to carry and process energy. Typically one medium is cooled while the other is heated. In most heat exchangers, the fluids are separated by a heat transfer surface and ideally they do not mix. They are widely used in petroleum refineries, chemical plants, petrochemical plants, natural gas processing, air conditioning, refrigeration and automotive applications.

II. MATHEMATICAL MODELING

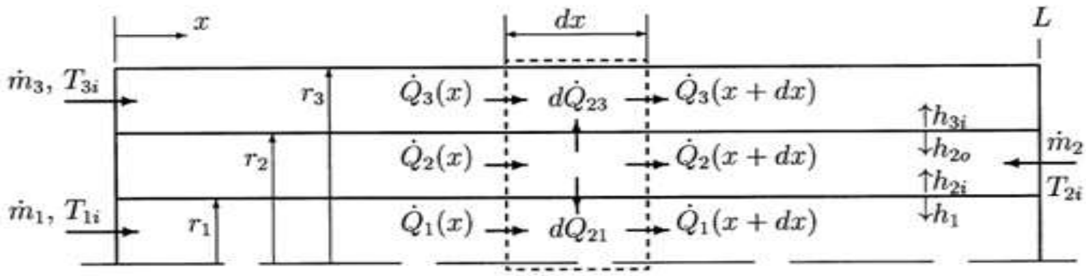

Figure-1: Physical model of a triple concentric tube heat exchanger for counter flow arrangement [5]

Physical model of a triple concentric tube heat exchanger for counter flow arrangement
For simplicity of the mathematical calculations, following assumptions are made;

- Both hot and cold fluids are incompressible in nature.
- Phase change of fluid does not take place during the operation.
- The fluid flows in all three flow passages are hydro-dynamically and thermally fully developed.
- Fluid properties are constant throughout.
- Heat exchanger is properly insulated.

Here h2o and h2i are the convective heat transfer coefficients for middle tube and remain same as the thermal conductivity of material is same, thickness of material is same, fluid streams on both sides are same and velocity of fluids on both sides are also same.

Input parameters

These parameters are taken from the previous research paper entitled above.[6]

Table-1:Input parameters for shell and tube heat exchanger [6]

Sr. No.	Parameters	Units	Shell Side Fluid	Tube Side Fluid
1	Specific Gravity	-	0.85	0.82
2	Viscosity	Ns/m²	0.17	3.2
3	Heat Capacity	KJ/KgK	2.28	2.05
4	Thermal Conductivity	W/mK	0.125	0.134
5	Thermal Conductivity at the wall temp.	W/mK	45	-
6	Material	-	Steel	Copper
7	Mass Flow Rate	Kg/sec	56	116.14
8	Length of Tube	Mm	5560	5560
9	Fouling Factor	-	0.0004	0.0008
10	Outside Diameter	M	-	0.01905
11	Inside Diameter	M	1.1	-
12	No of passes		1	2
13	Fluid stream		Light diesel oil (LDO)	Crude
14	No. of tubes			1256
15	Birmingham WireGage (BWG)		16	
16	Inlet temperature	K	480	365

Mathematical calculations

Effectiveness of Shell and tube heat exchanger

Fluid passes through tubes is Crude
Fluid passes through shell is LDO
Total c/s area of Tube

$= {}^{\pi}/_{4}\ d^2\ * n$

Where d=dia of tube and n=no of tubes.

$={}^{\pi}/_{4} * 0.01905^2$ *1256

=357988.834 mm^2

c/s area of Shell area

$= {}^{\pi}/_{4}\ D^2 - 357988.834$

Where D=dia of shell

$= {}^{\pi}/_{4} * 1100^2 - 357988.834$

=592342.943mm^2

We know that the mass flow rate (m)=ρAV
For LDO,
56 =850*.5923* VL
VL =0.111m/s
For Crude,
116.14 =820*.3579* VC
VC =0.3956m/s
Specific heat for LDO,
CpL =2.28 KJ/KgK
Heat Capacity[1] for LDO,
CL =2.28*56 KW/K
=127.68KW/K (min)
Specific heat for Crude,
CpC =2.05 KJ/KgK
Heat Capacity for Crude,
CC =2.05*116.14 KW/K

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

=238.08KW/K (max)

For LDO,

Reynolds number(Re)[2]=ρVmDh/μ

=850*0.111*686/0.17$*10^{-6}$

=3.8$*10^{5}$

Where ρ= density in Kg/m³

Vm=mean velocity in m/s

Dh=hydraulic diameter [3]

μ=dynamic viscosity in Ns/m²

Prandlt number(Pr)[2]= μcP/k

=0.17*2.28$*10^{3}$/0.125

=3100.8

Where k= thermal conductivity in W/mk

Nussult number(Nu)[2]=0.023$Re^{0.8}Pr^{0.3}$

$=0.023(3.8*10^{5})^{0.8}(3100.8)^{0.3}$

=7.47$*10^{3}$

Where Re, Pr, and Nu are the dimensionless parameters.

Convective heat transfer coefficient (h)

hL =k.Nu/Dh

=7.47$*10^{3}$*0.125/0.686

=1.36$*10^{3}$W/m²

For Crude,

Reynolds number(Re)=ρVmDh/μ

=820*395.6*19.05/3.2$*10^{-6}$

=1.93$*10^{4}$

Prandlt number(Pr)= μcP/k

=3.2*2.05$*10^{3}$/0.134

=48955.22

Nussult number(Nu)=0.023$Re^{0.8}Pr^{0.4}$

$=0.023(1.93*10^{4})^{0.8}(48955.22)^{0.4}$

=4.63$*10^{3}$

Convective heat transfer coefficient(h)

hc =k.Nu/Dh

=4.63$*10^{3}$*0.134/.01905

=3.26$*10^{4}$W/m²

The overall heat transfer coefficient,[1]

$$\frac{1}{U}=\frac{1}{hi}+\frac{1}{ho}+R_{fo}+R_{fi}$$

Where hi and ho are the convective heat transfer coefficients on tube side and shell side respectively. Also Rfi and Rfo are the fouling factors on tube side and shell side respectively. Also note that the length of tube is very large as compared to the tube diameter and the thermal conductivity is very high(i.e. copper=401W/mk) thus conduction heat transfer coefficients are neglected.[1]

$$\frac{1}{U}=\frac{1}{3.26*10^{4}}+\frac{1}{1.36*10^{3}}+0.0008+0.0004$$

=1.965$*10^{-3}$

U =508.65 W/m² k.

Heat transfer area:

As =πdL*no. of tubes

$=\pi*19.05*5560*1256$

=417935520.6mm².

Number of transfer unit,[1]

NTU =UAs/Cmin

=508.65*417.93/127.68

=1665.99

Capacity ratio(C):[1]

= Cmin/ Cmax

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

=127.68/238.08

=0.536

Effectiveness(ϵ):[1]

$$=2(1 + C + \sqrt{1+C^2}\frac{1+\exp\left[-NTU\sqrt{1+C^2}\right]}{1-\exp[-NTU\sqrt{1+C^2}})^{-1}$$

$$=2(1 + 0.536 + \sqrt{1+0.536^2}\frac{1+\exp\left[-1665.99\sqrt{1+0.536^2}\right]}{1-\exp[-1665.99\sqrt{1+0.536^2}})^{-1}$$

=0.748

Effectiveness of Triple concentric heat exchanger[4]

For this calculation we keep the cross sectional area constant for respective fluid flow.

i.e. the total area available for crude is 357988.834 mm^2 and the total area available for LDO is 592342.943mm^2

thickness of tube = 1.651mm as per BWG16 (given)[7]

A1 $=\frac{\pi}{4}d1^2$

A2 $=\frac{\pi}{4}[d2^2- (d1+3.3)^2]$

A3 $=\frac{\pi}{4}[d3^2- (d2+3.3)^2]$

Where A1, A2, A3 are the cross sectional area of inner tube, middle annulus and outer annulus respectively.

Where d1, d2, d3 are the diameters of inner tube, middle annulus and outer annulus respectively.

Here A1+A3=592342.94mm². and A2=357988.834mm².

Thus,

$\frac{\pi}{4}d1^2+\frac{\pi}{4}[d3^2- (d2+3.3)^2]= 592342.94$ (1)

$\frac{\pi}{4}[d2^2- (d1+3.3)^2]= 357988.834$ (2)

Put d1=220mm in equation (2), we get

d2=713.4mm. then put the values of d1 and d2 in equation (1) we get d3=1103.3mm.

thus,

A1 =0.03801m²

A2 =0.3579 m²

A3 =0.5543 m²

We know that the mass flow rate (m)=ρAV

For LDO,

m1 =850*0.03801*0.111

=3.586Kg/s

m3 =850*0.5543*0.111

=52.29Kg/s

For Crude,

m2 =820*3579*0.3956

=116.14Kg/s

Where m1,m2 and m3 are mass flow rates in inner tube, middle annulus and outer annulus respectively.

Heat capacities

C1 = m1*Cp

=2.28*3.586

=8.176KW/K

C2 = m2*Cp

=2.05*116.14

=238.087KW/K

C3 = m3*Cp

=2.28*52.29

=119.22KW/K

Heat capacity ratio,

Cr1 =C1/C2

=8.176/238.087

=0.0343

Cr3 =C3/C2

=119.22/238.087

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

=0.5008

For LDO,

Reynolds number(Re)=ρVmDh/μ

=850*111*610/0.17$*10^{-6}$

=3.39$*10^{5}$

Prandlt number(Pr)= μCp/k

=0.17*2.28$*10^{3}$/0.125

=3100.8

Nussult number(Nu)=0.023$Re^{0.8}Pr^{0.3}$

=$0.023(3.39*10^{5})^{0.8}(3100.8)^{0.3}$

=6820.3375

Convective heat transfer coefficient(h)

h =k.Nu/Dh

h1 =6820.3375*0.125/0.22

=3875.19W/m²K

h3 =6820.3375*0.125/0.389

=2176.57W/m²K

For Crude,

Reynolds number(Re)=ρVmDh/μ

=820*395.6*493.4/3.2$*10^{-6}$

=49801.23

Prandlt number(Pr)= μCp/k

=3.2*2.05$*10^{3}$/0.134

=48955.22

Nussult number(Nu)=0.023$Re^{0.8}Pr^{0.4}$

=$0.023(49801.23)^{0.8}(48955.22)^{0.4}$

=9895.54

Convective heat transfer coefficient(h)

h =k.Nu/Dh

h2 =9895.54*0.134/0.4934

=2700.066W/m²K

Overall heat transfer coefficient,

U1 $=[\frac{1}{h1}+\frac{1}{h2}]^{-1}$

$=[\frac{1}{3875.19}+\frac{1}{2700.066}]^{-1}$

=1591.31 W/m²K

U3 $=[\frac{1}{h2}+\frac{1}{h3}]^{-1}$

$=[\frac{1}{2700.066}+\frac{1}{2176.57}]^{-1}$

=1205.11 W/m²K

The number of transfer units for respective stream,

N1 $=\frac{U1*A1}{C1}$

$=\frac{1591.31*0.0380}{8.176}$

=7.39

N3 $=\frac{U3*A3}{C3}$

$=\frac{1205.11*0.5543}{119.244}$

=5.60

N2 =N1Cr1+N3Cr3

=7.39*0.0343+5.60*.5008

=3.059

F1 =N2-N1

=3.059-7.39

=-4.338

F2 =N2

=3.059

F3 =N2-N3
=3.059-5.60
=-2.54

Where F1, F2 and F3 are the non dimensional parameters

A =N1+N3-N2
=7.39+5.60-3.059
=9.9411

B =N1N3[1-(Cr1+Cr3)]
=7.39*5.60 [1-(0.0343+0.5008)]
=19.27

Where A and B are the non dimensional coefficients

Δ $=A^2-4B$
$=9.9411^2-4*19.27$
=21.745

λ1 $=\frac{-A-\sqrt{A^2-4B}}{2}$
$=\frac{-9.9411-\sqrt{9.9411^2-4*19.27}}{2}$
=-7.30

λ2 $=\frac{-A+\sqrt{A^2-4B}}{2}$
$=\frac{-9.9411+\sqrt{9.9411^2-4*19.27}}{2}$
=-2.6390

Where λ1 and λ2 are the two distinct roots

Δλ = λ2- λ1
=-2.6390-(-7.30)
=4.6629

G1' $=\frac{[N1Cr1(\lambda2-F1)+N3Cr3(\lambda2-F3)](e^{\lambda1}-1)}{\lambda1}$
$=\frac{[7.39*0.0343(-2.639+4.338)+5.60*0.5008(-2.639+2.543)](e^{-7.30}-1)}{-7.30}$
=0.1237

G2' $=\frac{[N1Cr1(F1-\lambda1)+N3Cr3(F3-\lambda1)](e^{\lambda2}-1)}{\lambda2}$
$=\frac{[7.39*0.0343(-4.338+7.30)+5.60*0.5008(-2.543+7.30)](e^{-2.639}-1)}{-2.639}$
=41.611

Where G1' and G2' are the non dimensional parameters

Effectiveness(ϵ):
$=\frac{(G1'+G2')}{[(\Delta\lambda+G1'+G2')+(Cr1+Cr2)]}$ for B≠0 and Δ>0
$=\frac{(0.1237+41.611)}{[(4.662+0.1237+41.611)+(0.343+0.5008)]}$
=0.8644

In the similar fashion Effectiveness is calculated for different inner tube diameters (d1) and tabulated below;

Table-2:Effectiveness for different inner tube diameters

Inner tube dia (d1) mm	160	180	200	220	240
Effectiveness(ϵ)	0.8275	0.8350	0.84623	0.8644	0.82606

It is clear from the above values that the effectiveness is comparable higher at inner tube diameter of 220mm.

Calculation of effectiveness using terminal temperatures received from analysis [4]

for LDO inlet temperature 480K, crude inlet temperature 365K and mass flow rate of crude 116.14Kg/s
For inner tube:
The actual rate of heat transfer:
The actual rate of heat transfer:
Q2 =Cc(Tc,out-Tc,in)

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

=238.087(368.15-365)
=749.97KW

The maximum rate of heat transfer:

Q2max =Cmin(Th,in-Tc,in)
=8.176(480-365)
=940.24KW

Effectiveness(ϵ2)
= Q2 /Q2max
=749.97/940.24
=0.7976 (This is the effectiveness of main heat exchanger)

In the same way we can calculate the effectiveness of heat exchanger for nine different cases and get the maximum effectiveness is as **0.8356** for LDO inlet temperature 580.8K, crude inlet temperature 365K and mass flow rate of crude 140.53Kg/s

III. MODELING DETAILS

In this study, a triple concentric counter flow tube heat exchanger is selected in order to increase the model detail and to make solid observations about the temperature variation inside the tube. The material of all the tubes is Copper with a thermal conductivity of 401 W/mK. Some of the design parameters and the predetermined geometric parameters are presented below.

Geometric parameters

Heat exchanger length: 5560 mm
Inner tube diameter: 220 mm
Middle tube diameter: 713.4 mm
Outer tube diameter: 1103.3 mm
Thickness of all tubes: 1.651 mm

Boundary conditions

- The working fluid passing through inner tube is LDO.
- The working fluid passing through middle tube is Crude.
- The working fluid passing through outer tube is LDO.
- The LDO entering the inner tube flowing from left to right.
- The Crude entering the middle tube flowing from right to left.
- The LDO entering the outer tube flowing from left to right.
- The mass flow rate of LDO entering the inner tube is 3.586Kg/s.
- The mass flow rate of Crude entering the middle tube is 116.14Kg/s.
- The mass flow rate of LDO entering the outer tube is 52.30Kg/s.
- The inlet temperature of LDO entering the inner tube is 480K.
- The inlet temperature of Crude entering the middle tube is 365K.
- The inlet temperature of LDO entering the outer tube is 480K.

Mesh selection

Mesh generation is performed using ANSYS. A relatively coarser mesh is generated for this. It contains mixed elements (Tetrahedral element and Hexahedral element) having both triangular and quadrilateral faces at the boundaries. Care is taken to use structured element (Hexahedral element) as much as possible, for this reason the geometry is divided into several parts for using automatic methods available in the ANSYS meshing client. It is meant to reduce numerical diffusion as much as possible by structuring the mesh in a well manner, particularly near the wall region.

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

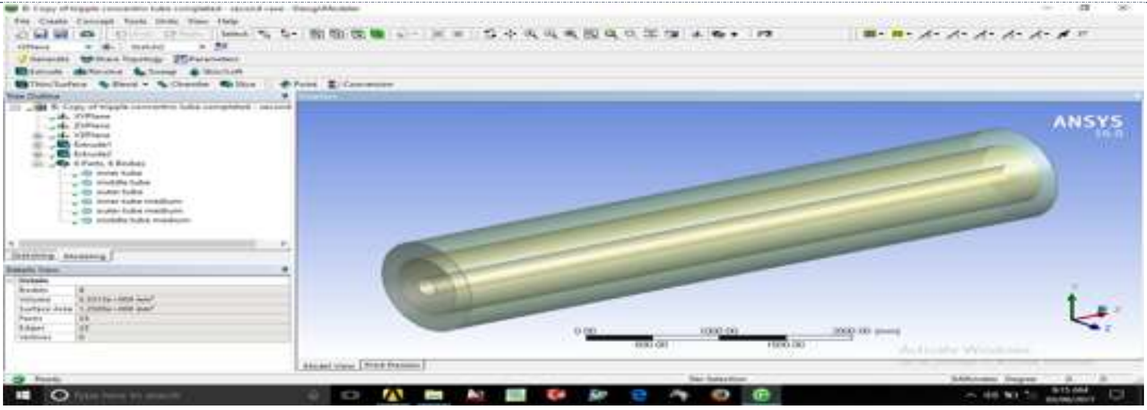

Figure-2: Geometry of triple concentric heat exchanger

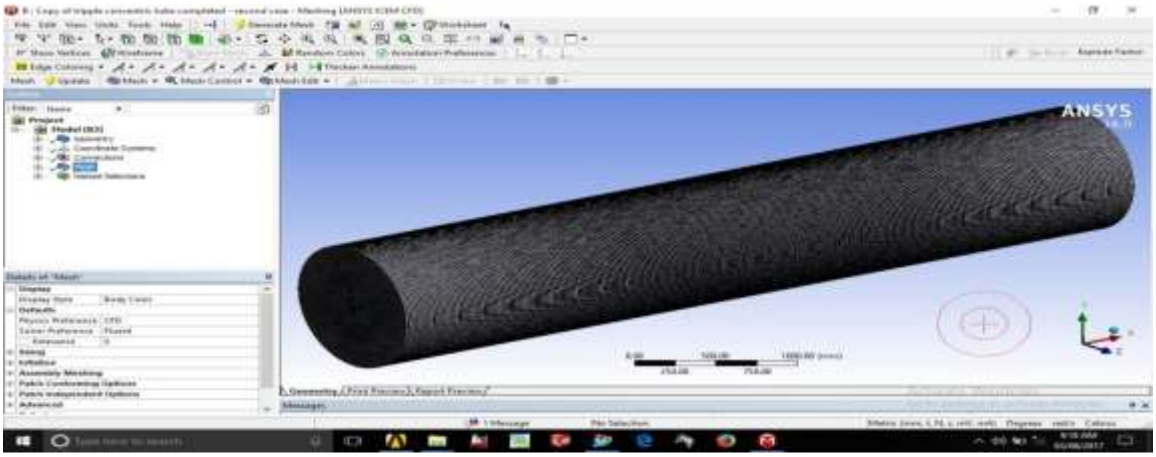

Figure-3: Meshing of triple concentric heat exchanger

Table-3: detailed mesh report

Domain	Nodes	Elements
inner_tube	19740	9835
inner_tube_fluid	69052	63732
middle_tube	62496	31136
middle_tube_fluid	358400	337311
outer_tube	97440	48546
outer_tube_fluid	494388	453418
All Domains	1101516	943978

IV. DESIGN OF EXPERIMENTS

For this Taguchi method is used which reduced the variation in a process through robust design of experiments.

Selection of Process Variable and orthogonal array

The triple concentric tube heat exchanger is taken for the analysis. The mass flow rate of cold fluid, inlet temperature of hot fluid and inlet temperature of cold fluid are the most effective parameters for effectiveness of the triple concentric tube heat exchanger and the selection of orthogonal array L-9 for experiment was done by use Minitab-17 statistical software. The first parameter variation level is LDO inlet temperature 480K, Crude inlet temperature 365K and Mass flow rate of Crude 116.14Kg/s is the input data for heat exchanger. Then increase respective values by 10% in second and third parameter variation level.

Table-4:Selection of variables

Variation level	LDO inlet temp. (K)	Crude inlet temp. (K)	Mass flow rate of Crude(Kg/s)
1	480	365	116.14
2	528	401.5	127.754

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

3	580.8	441.65	140.53

Table-5: Selection of orthogonal array

Sr. No	LDO inlet temperature (K)	Crude inlet temperature (K)	Mass flow rate of Crude(Kg/s)
1	480	365	116.14
2	480	401.5	127.754
3	480	441.65	140.53
4	528	365	127.754
5	528	401.5	140.53
6	528	441.65	116.14
7	580.8	365	140.53
8	580.8	401.5	116.14
9	580.8	441.65	127.754

V. FEA RESULTS

Table-6: FEA Results

LDO inlet-inner(K)	LDO inlet-outer(K)	Crude inlet (K)	$\dot{mc}$ (Kg/s)	LDO outlet-inner(K)	LDO outlet-outer(K)	Crude outlet (K)	ϵ
480	480	365	116.14	472.9	476.4	368.15	0.7976
480	480	401.5	127.754	477.9	478	403.2	0.7809
480	480	441.65	140.53	478	478.9	442.5	0.6936
528	528	365	127.754	517.9	523	369.2	0.8170
528	528	401.5	140.53	520.3	524.1	404.5	0.8120
528	528	441.65	116.14	523	525.4	443.3	0.5564
580.8	580.8	365	140.53	567.4	574.1	370	0.8356
580.8	580.8	401.5	116.14	569.9	575.3	406.5	0.8253
580.8	580.8	441.65	127.754	572.3	576.5	445.2	0.8163

VI. ANALYSIS OF VARIENCE (ANOVA)

Table -7: S/N ratios and mean for triple concentric heat exchanger

LDO inlet temperature	**Crude inlet temperature**	**Mass flow rate**	**Effectiveness (ϵ)**	**SNRA1**	**MEAN1**
480	365	116.14	0.7976	-1.9643	0.7976
480	401.5	127.754	0.7809	-3.17281	0.7809
480	441.65	140.53	0.6936	-2.67425	0.6936
528	365	127.754	0.8170	-1.66776	0.8170
528	401.5	140.53	0.8120	-1.56003	0.8120
528	441.65	116.14	0.5564	-5.09226	0.5564
580.8	365	140.53	0.8356	-1.763	0.8356
580.8	401.5	116.14	0.8253	-1.80888	0.8253
580.8	441.65	127.754	0.8163	-1.76088	0.8163

Table-8: Response Table for Means

Column	**Factors**	**Level 1**	**Level 2**	**Level 3**	**Delta**	**Rank**
1	LDO Inlet Temperature	0.7617	0.7391	0.8152	0.0761	3
2	Crude inlet temperature	0.7263	0.7788	0.8110	0.0847	2
3	Mass flow rate	0.8174	0.7805	0.7182	0.0992	1

Table- 9: Response Table for Signal to Noise Ratios

Column	**Factors**	**Level 1**	**Level 2**	**Level 3**	**Delta**	**Rank**
1	LDO Inlet Temperature	-2.384	-2.773	-1.775	0.998	3
2	Crude inlet temperature	-2.909	-2.199	-1.823	1.086	2

3	Mass flow rate	-1.752	-2.182	-2.997	1.245	1

Main effects plot for triple concentric heat exchanger

From the main effect plots it is clear that the effectiveness is maximum at level 3 of LDO inlet temperature, at level 1 of Crude inlet temperature and at level 3 of mass flow rate of crude.

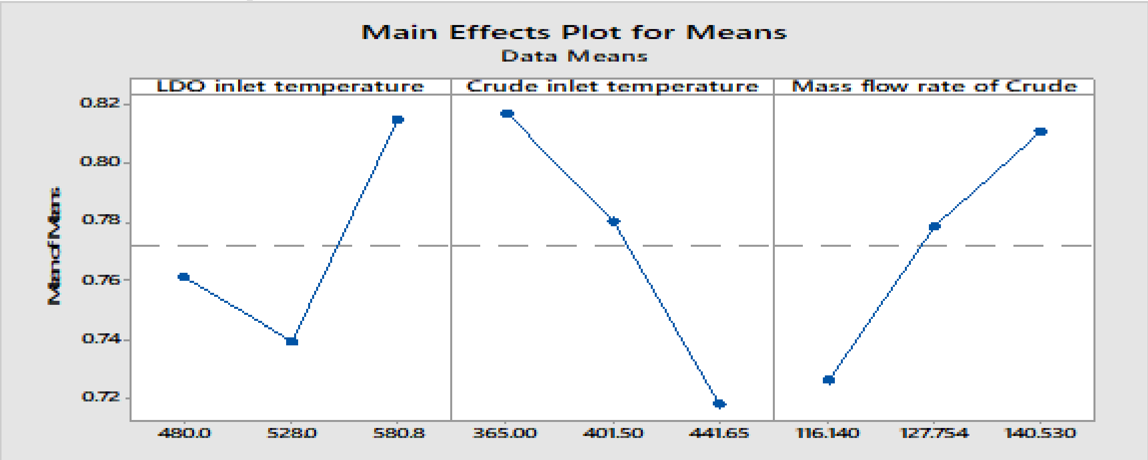

Figure: 4- Main effects plot for means for triple concentric heat exchanger

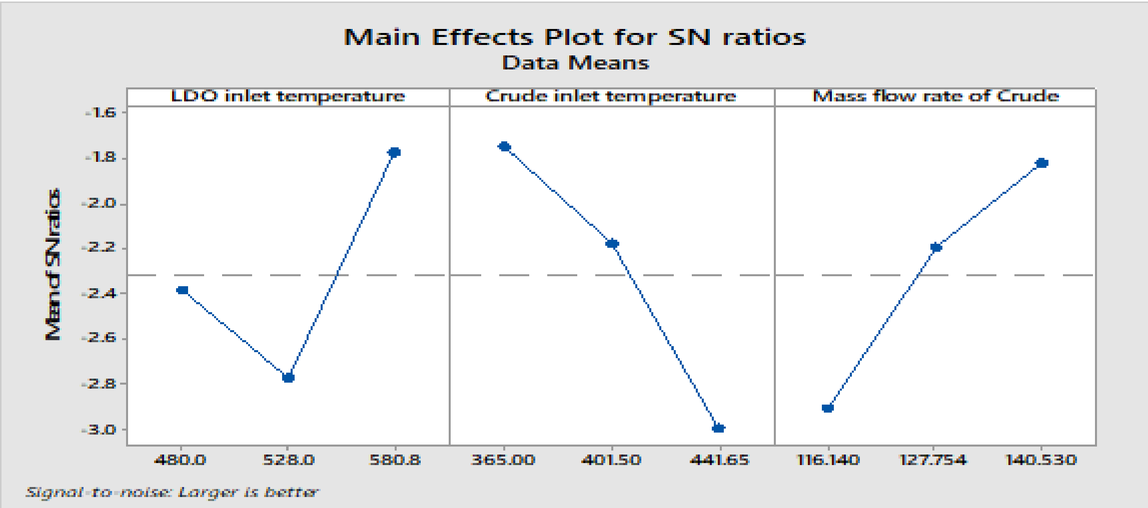

Figure- 5: Main effects plot for S/N ratio for triple concentric heat exchanger

Percent contribution

Table-10: ANOVA for triple concentric heat exchanger

Source	SS	DOF	MSS	F RATIO	% CONTRIBUTION
LDO inlet temperature	0.010975	2	0.005487	0.35	16.46
Crude inlet temperature	0.015068	2	0.007534	0.48	22.60
Mass flow rate	0.031457	2	0.015729	0.71	47.19
Error	0.008916	2	0.004581		13.75
Total	0.066630	8			100.00

VII. CONCLUSION

From the above experimentation following conclusions drawn

•Considering the objective maximum effectiveness of heat exchanger nine experiments were successfully conducted and then its analysis is done with the help of Minitab software

•For shell and tube heat exchanger, the effectiveness calculated by mathematical modeling is ϵ =0.748.

•For triple concentric heat exchanger, the effectiveness calculated by mathematical modeling is ϵ

=0.8644.

•The effectiveness calculated from the terminal temperatures received from analysis for triple concentric heat exchanger is given as, ϵ =0.7976.

•The optimized value of effectiveness of triple concentric heat exchanger is ϵ =0.8356.

•The optimum levels for the parameters LDO inlet temperature, crude inlet temperature and mass flow rate of crude are 580.8K, 365K and 140.53Kg/s respectively.

•The response of S/N ratio with respect to effectiveness indicates the mass flow rate of crude to be the most significant parameter that controls the heat exchanger effectiveness where the crude inlet temperature and LDO inlet temperature are comparatively less significant in this regards.

•The contribution of LDO inlet temperature, crude inlet temperature and crude mass flow rate towards effectiveness are 16.46%, 22.60%, 47.19% as determined by the ANOVA method.

•Thus this experimentation successfully optimize triple concentric heat exchanger parameters for maximum effectiveness which will help to improve the efficiency by selecting the optimum parameters.

VIII. ACKNOWLEDGEMENTS

I have worked with many people around, without whom this work would never have been completed. It is a pleasure to convey my gratitude to all of them in my humble acknowledgment.

First & foremost, I would like to record my gratitude to my project guide, Prof. S. K. Dahake (MET-BKC), who has supported me throughout my work with his patience and knowledge and always allowed me to think in my way and try out my ideas. I would also like to record my gratitude to, Prof. S. V. Ingle (HOD, Mechanical Engineering Department, MET-BKC), for giving me this opportunity to present my work.

Many thanks go to all the friends and all teaching and non-teaching staff of Mechanical Engineering Department, who supported me throughout the year.

Finally, I thank my parents for supporting me throughout all my studies and for making me able to reach at the place where I am.

Mr. Sachchidanand J Nimankar.

IX. REFERENCES

[1] Unus A. Cengel,"Heat Exchangers", Heat transfer,2nd edition,McGraw Hill2003.
[2] Unus A. Cengel,"Fundamentals of Convection", Heat transfer,2nd edition,McGraw Hill2003.
[3] Unus A. Cengel,"Internal forced Convection", Heat transfer,2nd edition,McGraw Hill2003.
[4] Ahmet Unal"Effectiveness NTU relationship for triple concentric tube heat exchangers "Int. Comm. Heat Mass Transfer, vol.30,No.2,pp.261-272,2003
[5] Ahmet Unal "Theoretical analysis of triple concentric tube heat exchangers part-1 mathematical modeling" Int. Comm. Heat Mass Transfer, vol.25,No.7,pp.949-958,1998
[6] Ebieto, C.E and Eke G.B." Performance Analysis of Shell and Tube Heat Exchangers: A case study" Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 3(5):899-903,Scholarlink Research Institute Journals, 2012, ISSN: 2141-7016
[7] https://www.engineeringtoolbox.com/BWG-wire-gage-d_508.html

CITE AN ARTICLE

Nimankar, S. J., & Dahake, S. K., Prof. (n.d.). FINITE ELEMENT (FE) ANALYSIS AND OPTIMIZATION OF CONCENTRIC HEATER . *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, *6*(12), 245-255.