Design and study of pressure drop and temperature distribution characteristics in a shell and tube heat exchanger using Computational Fluid Dynamics.

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***Abstract*- Heat exchanger is a specialized device that assists in the transfer of heat from one fluid to the other. In this paper we considered the parallel type of flow arrangement, were the fluids come in from the same end & move parallel to each other as they flow to the other side. The following design parameters are Baffle spacing, Baffle cut, type of baffles, tube arrangement (inline), and single pass. The rate of heat transfer in heat exchanger is the phenomenon depending on the flow characteristics of shell side fluid. The solution of the proposed problem will be done using CAE technique. The solution of the problem will be done using CFD. The results from the CFD software will be compared with analytical solution to draw the conclusion. The following conclusions were drawn. The tube side flow doesn't vary in its flow characteristics irrespective of the baffle cut, but due to the variation of rate heat transfer on the shell side in turn affect the tube rate of heat transfer also. With the increase in the baffle cut rate of heat transfer decreases (3 to 25 %).With the increase in the baffle cut Pressure drop increases (3 to 25 %).The velocity over the length of the heat exchanger on shell side gradually increases from entry to exit compartment.**

***Index Terms*- Shell and tube heat exchanger, Baffles cut, Formulation, computational fluid dynamics (Fluent).**

I. INTRODUCTION

A heat exchanger is a device in which energy is transferred from one fluid to another across a solid surface. Exchanger analysis and design therefore involve both convection and conduction. The most commonly used type of heat exchanger is the shell-and-tube heat exchanger, the optimal design of which is the main objective of this study.

Fig 1.1 shows the Shell and tube heat exchanger [1] are built of round tubes and mounted in large cylindrical shells with the tube axis parallel to shell axis. One fluid flows into the tubes and the other into the shell. The flow of shell side fluid is both parallel and across to the tubes. Shell and tube heat exchangers are the most versatile type of heat exchangers.

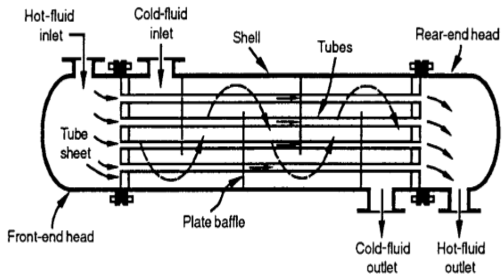


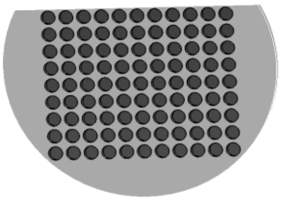
Fig.1 Significant parameters of STHX

Shell and tube heat exchangers can be designed for high pressure relative to the environment and high pressure difference between the fluid streams. Two important problems in heat exchanger analysis are,

(1) Rating existing heat exchangers: Rating involves determination of the rate of heat transfer, the change in temperature of the two fluids and the pressure drop [2] across the heat exchanger.

(2) Sizing heat exchangers for a particular application.: Sizing involves selection of a specific heat exchanger from those currently available or determining the dimensions for the design of a new heat exchanger, given the required rate of heat transfer and allowable pressure drop [2][3], TEMA has designated a system of notations that correspond to each major type of front head, shell side and rear head. The first letter identifies the front head, the second letter identifies the shell type and the third letter identifies the rear head type.

II BAFFLE TYPE AND ITS PATTERN



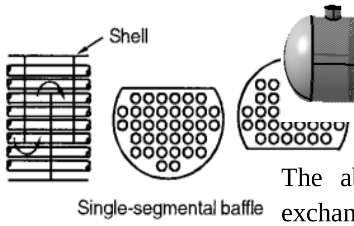


Fig .2 Baffle (a) (b)

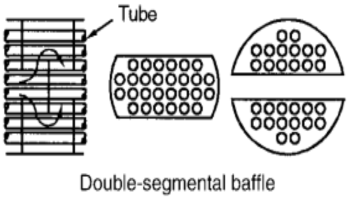


Fig.2.2 Baffle Patter ns

Baffles must generally be employed on shell side to support the tubes, maintain the tube spacing, and to direct the shell side fluid across or along the tube bundle in a specified manner. There are a number of different types of baffles and these may be installed in different ways to provide the flow pattern required for given application.

The single and double segmental baffles are most frequently used. They divert the flow most effectively across the tubes. The baffle spacing however must choose carefully. Optimum baffle spacing is somewhere between 0.4 – 0.6 of the shell diameter, and baffle cut of 25-35% is usually recommended.

Baffles serve two important functions. They support the tubes during assembly and operation and help prevent vibration from flow induced eddies and direct the shell side fluid back and forth across the tube bundle to provide effective velocity and heat transfer rates. The diameter of the baffle must be slightly less than the shell inside diameter to allow assembly, but must be close enough to avoid the substantial performance penalty caused by fluid bypass around the baffles. Shell roundness is important to achieve effective sealing against excessive bypass.

III. FORMULATION OF STHX

CATIA V5 is the leading solution for product success. The shell and tube heat exchanger is modeled using CATIA V5 R20 with the respect parameters of STHX.

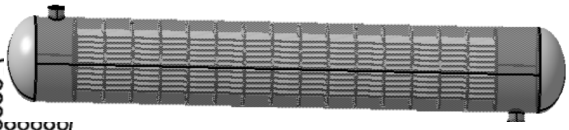


Fig 3.1 Catia STHX model

The above fig shows the shell and tube heat exchanger model where the baffles are spaced for every 250mm and 3% cut is provided for every baffle and all are vertical in the direction of the fluid flow

MESHED MODEL

HYPERMESH 10 is an advanced HyperWorks Desktop course for using HyperMesh to pre-process and HyperView to post-process a CFD model.

Element used: tetrahedron with volume mesh. It consists of 4 vertices and 4 faces. It is used for conduction, structural and transient analysis problems. The following figure shows the Meshed Model of STHX for 3% baffle cut. The mode is meshed using the Tetrahedron Element.

Fig 3.2 Meshed STHX model

IV. METHODOLOGY

The detailed designing methodology shell and tube heat exchangers based on Bell's procedure for determining of both shell side heat transfer coefficient and shell side pressure drop, is presented. In fact the basis for the Bell's method is the model suggested by Tinker (1951), later modified by Palen and Taborek (1969).

it is necessary to have at disposition the following data

- Mass flow rate -
Process fluids operating pressures
- Rate and cold fluid temperatures -
allowed pressure drops

CFD(Computational Fluid Dynamics)

Computational Fluid Dynamics or CFD is the analysis of systems involving fluid flow, heat transfer and associated phenomena such as chemical reactions by means of computer-based simulation.

How Does the CFD code work?

CFD codes are structured around the numerical algorithms that can tackle fluid flow problems. In order to provide easy access to their solving power all commercial CFD packages include sophisticated user interfaces to input problem parameters and to examine the results. Hence all codes contain three main elements: (i) a pre-processor, (ii) a solver and (iii) a post-processor. We briefly examine the function of each of these elements within the context of a CFD code.

Pre-processor

Pre-processor consists of the input of a flow problem to a CFD program by means of fan operator-friendly interface. The user activities at the pre-processing stage involve:

- Definition of the geometry of the region of interest: the computational domain.
- Grid generation –the sub-division of the domain into a number of smaller, non-overlapping sub-domains: a grid (or mesh) of cells (or control volumes or elements).
- Selection of the physical and chemical phenomena that need to be modeled.
- Definition of fluid properties
- Specification of appropriate boundary conditions at cells which coincide with or touch the domain boundary

Solver

There are three distinct streams of numerical solution techniques: finite difference, finite element and spectra; methods. In outline the numerical methods that form the basis of the solver perform the following steps:

- Approximation of the unknown flow variables by means of simple functions.
- Discretisation by substitution of the approximations' into the governing flow equations and subsequent mathematical manipulations.
- Solution of the algebraic equations.

Post-processor

As in pre-processing a huge amount of development work has recently taken place in the post-processing field. The leading CFD packages are now equipped with versatile data visualization tools. These include.

- Domain geometry and grid display Particle tracking
- Vector plots
- View manipulation (translation rotation, scaling etc
- Line and shaded contour plots Colour postscript output
- 2D and 3D surface plots.

V. THEORETICAL CALCULATION FOR SHELL SIDE

i) Mean temperature difference:

$$\Delta T_{ln,cf} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} \quad (1)$$

$$R = \frac{T_{h1} - T_{h2}}{T_{h1} - T_{c2}} \quad \& \quad P = \frac{T_{c1} - T_{c2}}{T_{c1} - T_{c2}}$$

ii) Shell side heat transfer coefficient:

$$D_e = \frac{4(P_t^2 - (\Pi/4 d_o^{\ 2})}{\Pi D_o}$$

$Re_s = D_e G_s/ \mu_s$.

$$N_u = 0.36(Re_s)^{0.55} (C_p\ \mu_s/ k)^{0.33} (\mu_{s/}\ \mu_w)^{0.14} \quad (2)$$

iii) The shell side heat transfer coefficient:

$$h_o = N_u.k / D_e \quad (3)$$

iv) Overall heat transfer coefficient:

$$U_o = \frac{1}{(do/di\ h_i) + d_o \ln(do/di)/2k + (1/h_o)} \quad (4)$$

v) Heat transfer rate

$$Q = m_s Cp(T_{h1} - T_{h2}) \quad (5)$$

vi) Heat transfer rate is also defined:

$A = Q/(U_o F\ T_{ln,cf})$ & $L = A/(Nt\Pi\ D_o)$

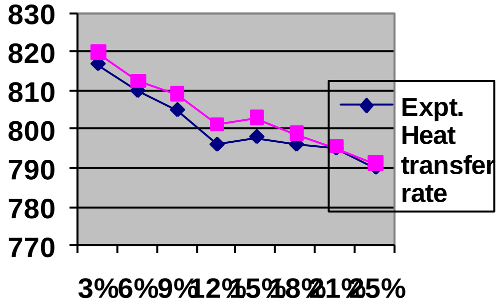
$$Q = U_o AF\ T_{ln,cf} \quad (6)$$

Theoretical and CFD results comparison

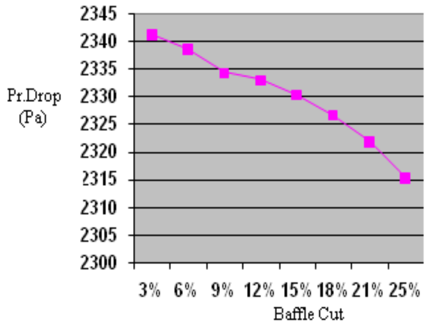
Sl.No	Baffle Percentage Opening (%)	Mass flow rate in kg/sec	CFD Heat transfer (Q)Rate in kw	Theoretical Heat transfer Rate(Q) in kw
1	3	8.3	817	820
2	6	8.3	810	812.5
3	9	8.3	805	808.9
4	12	8.3	796	801.12
5	15	8.3	798	802.7
6	18	8.3	796	798.9
7	21	8.3	795	795.3
8	24	8.3	790	790.9

The following graph show the comparative analysis of variation of rate of heat transfer against different baffles cuts .The rate of heat transfer decreases with increase in the baffle cut which can be seen by the graph. The nature of variation are given by CFD and the theoretical calculation are similar the results from both the approach match exactly 21 to 25 %.

Graphs



Graph 3.1Baffle cut v/s Heat Transfer

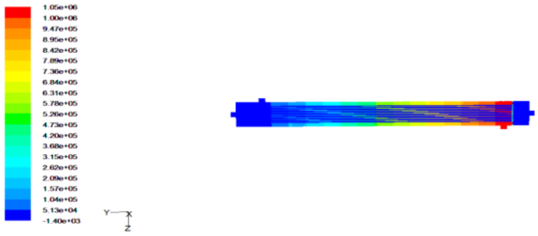


Graph 3.2 Baffle cut v/s Pressure Drop

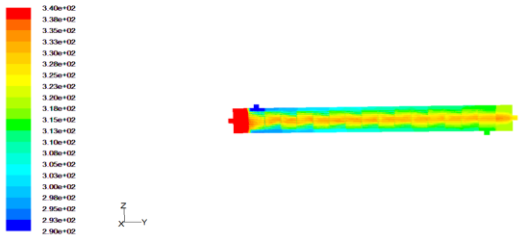
The following fig shows the distribution of Pressure, Velocity and Temperature components within the shell and tube along length of the exchanger. The plots have been developed at the midsection of the 3d analysis results, for which the output files from the fluent are read.

The display contoured model shown clearly the distribution of the above parameter within the shell side fluid at various points i.e, entry of shell side fluid , at baffles, base of the baffles, surface of the shell, tube bundles etc.

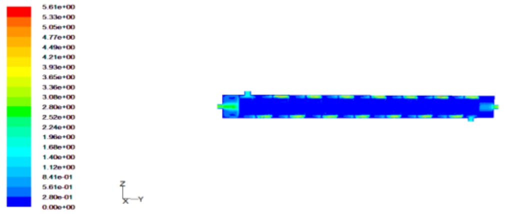
For example of 3% baffle cut of pressure, temperature and velocity



a) Pressurecontour3%



(b) Temperature Contour 3 %



(c)Velocity Contour 3 %

Fig 5. Pressure, temperature and velocity Contours

The colour contour displayed takes at the mid section of the exchanger though does not give the absolute values for the exchanger window section or a display the average values at the window section but help to know the various parameters along the length of exchanger for different **baffle cuts** .referring the display, it can be seen that the different of input and output increases as the **baffle cut** increases.

Also the temperature contour helps as to know the where are high pressure point established within the shell side fluid flow and also helps to know the characteristics of the fluid flow.

VI. CONCLUSION

Going through the Results and Discussion made in the previous chapter on the performance parameters of the shell and tube heat exchanger that is pressure drop, rate of heat transfer, and fluid velocity as shell and tube side, the following conclusion may be drawn

1) The tube side flow doesn't vary in its flow characteristics irrespective of the baffle cut, but due to the variation of rate heat transfer on the shell side in turn affect the tube rate of heat transfer also.
2) With the increase in the baffle cut rate of heat transfer decreases (3 to 25 %) as shown in the graph (3.1).
3) With the increase in the baffle cut Pressure drop increases (3 to 25 %) as shown in the graph (3.2).
4) The velocity over the length of the heat exchanger on shell side gradually increases from entry to exit compartment.

Nomenclature

A - Area, m2
cp - Specific heat capacity, J/kg.K
C - Constant
D_e -Equivalent dia
d - Diameter, m
k - Overall heat transfer coefficient, W/m2K
L - Length, m

m - Number of shell side fluid passes
$\dot{m}$ - mass flow rate, kg/s
n - Number of tubeside fluid passes
N - Number of tubes (baffles)
p - Pressure, Pa
Δp - pressure drop, Pa
Q - Thermal power, W
R - Resistance due to fouling, m2K/W
t - Temperature, oC
Δt - temperature difference, oC
V - Velocity, m/s
α - heat transfer coefficient, W/m2K
k - Thermal conductivity, W/mK
μ - Dynamic viscosity, Pa s
ρ - Density, kg/m3

REFERENCES

[1] Sadik Kalac and Hongtan Liu, Heat Exchangers, Selection, Rating and Design., CRC Press, New York.

[2] Edward S. Gaddis and Volker Gnielinski., Pressure drop on the shell side of shell-and-tube heat exchangers with segmental baffles, Chemical Engineering and Processing, Volume 36, Issue 2, April 1997, Pages 149-159.

[3] Uday C. Kapale and Satish Chand., Modeling for shell-side pressure drop for liquid flow in shell-and-tube heat exchanger., International journal of heat and mass transfer, page 601-610,vol 49,issue3-4,feb2006.

[4] Mica Vukic, Gradimir, Ilic, Nenad, Radojkovic, Velimir Stefanovic., A new approach to prediction and design of shell and tube heat exchangers, University, Mechanical Engineering, Vol 1, No 7, 2000, page 775-787.

[5] B. Gay, N. V. Mackley and J. D. Jenkins**.,** Shell-side heat transfer in baffled cylindrical shell- and tube exchangers—an electrochemical mass-transfer modeling technique**.,** International Journal of Heat and Mass Transfer, Volume 19, Issue 9, September 1976, Pages 995-1002.

[6] Ahmed Fahkeri., A general expression for determination of Log Mean Temperature Correction Factor for shell and tube heat exchanger, Journal of Heat transfer, June 2003, Vol 125, page 527-530.

[7] B. B. Gulyani., The number of shells in shell and tube heat exchangers: A new approach based on temperature cross, Journal of Heat transfer, Aug 2000, Vol 122, page 566-571.

[8] Huadong Li and Volker Kottke., Effect of baffle spacing on pressure drop and local heat transfer in shell-and-tube heat exchangers for staggered tube arrangemen., International Journal of Heat and Mass Transfer, Volume 41, Issue 10, May 1998, Pages 1303-131.

[9] W. H. Emerson., Shell-side pressure drop and heat transfer with turbulent flow in segmentally baffled shell-and-tube heat exchangers., International Journal of Heat and Mass Transfer, Volume 6, Issue 8, August 1963, Pages 649-668.

[10] R. Hosseini, A. Hosseini-Ghaffar, and M. Soltani., Experimental determination of shell side heat transfer coefficient and pressure drop for an oil cooler shell-and-tube heat exchanger with three different tube bundle., Applied Thermal Engineering, Vol 27 , Issue 5-6, April 2007, Pages 1001-1008.