NUMERICAL ANALYSIS OF THE TUBE BANK PRESSURE DROP OF A SHELL AND TUBE HEAT EXCHANGER

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Abstract : The main parameters describing the efficiency and acceptance of a particular shell and tube heat exchanger in any application is its pressure drop. More the pressure drop across the tube side less is the heat transfer and hence more is the pumping power required and more is the cost. Though the pressure drop on the tube side can be split into three parts namely pressure drop due to Inlet nozzle, pressure drop in the tube bank, and pressure drop in the outlet nozzle. This report provides an overview of the research done on the analysis of the pressure drop in the tubes of a shell and tube heat exchanger. Though a large contribution has been done through analytical relations governing the pressure drop and the numerical analysis of the pressure drop on the shell side of a shell and tube heat exchanger, significant contribution can be made numerically on the tube side. The methodology provided enables us to study detailed flow behavior (pressure drop) in the tubes using the TEMA BEM i.e. a Elliptical Head Single Pass SHTX numerically i.e. the use of computation for the mentioned research. Hence to accomplish the task numerically the use of Ansys 14.5 has been made use of keeping in mind that the flow is steady and isothermal . Two different pressure zones have been identified i.e. (1) High pressure drop zone (2) Low pressure drop zone across the tube banks. Nearly fifty percent of the tubes lie under each category was observed. The pressure drop has been evaluated numerically at a particular inlet velocity and then compared at different inlet velocities for a parametric study.

Important Names : Pressure drop; Shell and tube heat Exchangers; Tube Side; numerically

I. INTRODUCTION

A heat exchanger is a device used to transfer heat from one medium to another by separating them to prevent mixing or allowing them to mix and transfer the heat. One such exchanger which prevents the mixing of the mediums is a shell and tube heat exchanger. There are various types of shell and tube heat exchangers based on their geometrical specifications. However for the present analysis a TEMA BEM [1] has been used. The various tube side of a SHTX consists of the inlet nozzle, inlet header, tube bank, outlet header and the outlet nozzle. The pressure drop plays an important role in the overall efficiency of a SHTX. The total tube-side pressure drop ΔPT for a single pass comprises the pressure drop in the straight tubes (ΔPTT), pressure drop in the tube entrances, exits and reversals (ΔPTE), and pressure drop in nozzles (ΔPTN) [2].

The uniform distribution of flow in tube bundle of shell and tube heat exchangers is an assumption in conventional heat exchanger design as claimed by Bejan and Kraus [3]. Traub

[4] found that increased turbulence levels lead to an improvement in the heat transfer for tube banks with a few rows of plain circular tubes at small pitch to diameter ratios. On the other hand, passive techniques aim to alter the flow by changing the geometry of the arrangement itself. Achenbach [5] found that rough surfaces on the tubes of in-line arrangements in cross-flow have the potential to decrease the pressure drop while simultaneously improving heat transfer, at least within a specific range of Reynolds numbers, which is determined by the roughness parameter.

I. PHYSICAL MODELLING

In order to create the geometry of an actual tube side arrangement a large no of manufacturing industries had been visited of which CANAAN Engineering Works provided the drawing of an actual manufactured shell and tube heat exchanger which was to be used in an industry located at Hazira , Surat.

The geometrical specifications for the heat exchanger are shown in Table - 1

Table – 1: Geometrical Specification

Sr No	Geometrical Parts	Specifications
1	Inlet/Outlet Header	Elliptical Ends 2: 1
2	Shell or Header I.D	304.8 mm
3	No of Tubes	77
4	Tube O.D	19.05 mm
5	Tube Thickness	1.65 mm
6	Inlet and Outlet Nozzle I.D	66.64 mm
7	Nozzle Lengths	212 mm
8	Tube Pitch	25.4 mm
9	Tube Layout	Triangular (60^0)
10	Tube Length	1518 mm
11	Fluid circulated	Water
12	Fluid Density	998.2 kg/m^3
13	Fluid Viscosity	0.001003 kgm/s

The pictures of the AutoCAD drawings used are as shown:

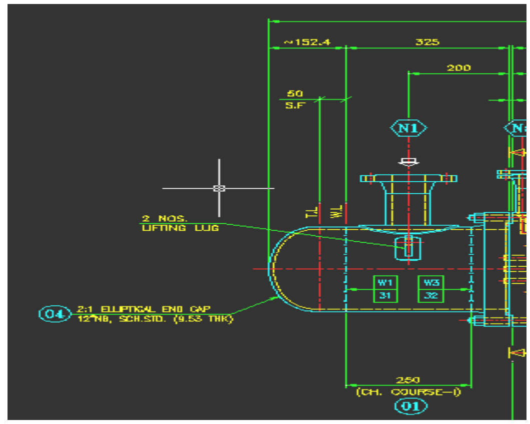

Fig – 1: Geometrical specification

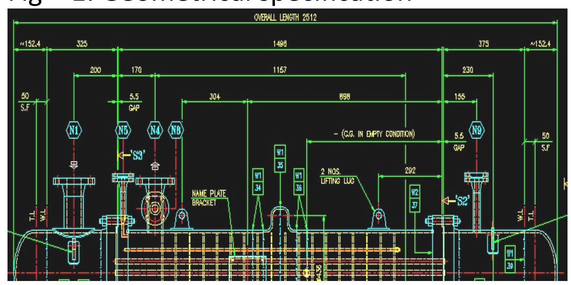

Fig – 2 : Geometrical Specification

Based on the above dimensional specification and the two dimensional drawing the three dimensional physical models was created using Ansys ICEM 14.5 version

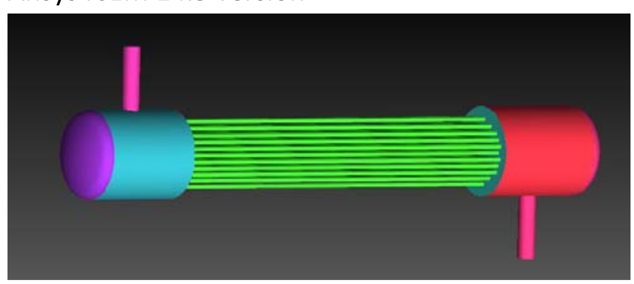

Fig – 3 : 3 –D model of SHTX

The figure numbers 1, 2, 3 represent the geometrical dimension and the actual model for analyses. However the thickness was not taken into consideration as the research to be carried out for pressure drop is irrespective of the thickness of the model.

II. MESHING

- Both the elliptical end and the flat face headers were meshed in ICEM.
- The global mesh setup, surface mesh setup and the curve mesh setup were done initially to create surface mesh. The method used for volume mesh setup was tetra/mixed robust octree.

- After the Surface mesh was created, it was further meshed for 3-D mesh using prism mesh with two layers created near the curve surfaces to capture the boundary layer flow accurately.
- A number of smoothening iterations were done in order to improve quality of the mesh. The quality of the mesh thus obtained was quite acceptable.

The fig – 4 is that of the meshed geometry:

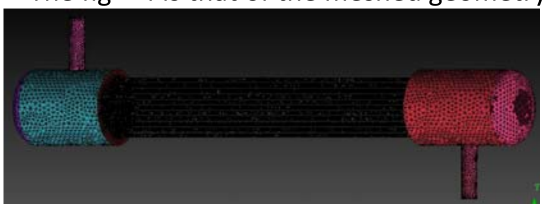

Fig – 4 : Meshed Geometry

The mesh thus obtained consisted of 2519375 cells or 489085 nodes. The mesh was obtained with a very good quality with the minimum value of 0.25. However there were a very few nodes which had a slightly lesser quality than that indicted which was neglected as they were very very small in number. The meshed file was then imported in ANSYS FLUENT for analysis

IV. SOLVER SETUP

The governing equations used by the solver shall include the Continuity and the Navier Stokes Equation i.e. the Momentum Equations in three dimension.

The boundary conditions used for the solver setup are as shown in table no – 2.

Table – 2: Boundary conditions for various parts

Sr No	Name of the Zone	Boundary Condition	Boundary Characteristics
1	Inlets	Velocity Inlet	3.31 (m/s)
2	Outlets	Pressure Outlets	0 Gauge Pressure
3	Inlet Wall	Wall	No Slip, Surface Roughness 0.5, Stationary
4	Outlet Wall		
5	Tubewalls		
6	Header Walls		

The solution method used was the "SIMPLE" Algorithm and the spatial discretization was based on Second Order Upwind Scheme. The turbulence model used was the standard k-ε model. The solution was run for 1000 iterations.

5. RESULTS AND ANALYSIS

A. Analytical Pressure drop across the tubes

The input velocity to the nozzle was chosen as 3.31 m/s. The tube side pressure drop comprises of the pressure drop due to friction losses inside the tubes plus the pressure losses due to sudden expansion and contractions which is accounted by four velocity heads per pass [6]. Therefore the total pressure drop for the tube side fluid flow is given by

$$\Delta P_t = 4 * f * L * N_p * \rho * U^2_m / (2 * d_i)$$

$$\Delta P_r = 4 * N_p * \rho * U^2_m / 2$$

$$\Delta P_{total} = (4 * f * L * N_p / d_i + 4 * N_p) \rho * U^2_m / 2$$

Where

ΔP_t and ΔP_r are the pressure losses due to friction and sudden expansions and contraction respectively

L – Length of the tubes (1.518 m)

N_p - No of passes (One Pass)

d_i - Inner diameter of the tubes (0.01575 m)

U_m – Mean velocity of Fluid in the tubes

f – friction factor, ρ – Density of the fluid (998.2 kg/m^3)

The friction factor f is given by Moody's chart for turbulent flow through uniform circular pipes [7] i.e. $f = 0.079Re^{-0.25}$ where Re is the Reynold no for the fluid.

As per the given conditions the pressure drop for a single pass tube side was found to be analytically = 2038 Pascal.

Another correlation for the tube side pressure drop was given by R. W Serth[2] who suggests that the total tube-side pressure drop ΔPT for a single pass comprises the pressure drop in the straight tubes (ΔPTT), pressure drop in the tube entrances, exits and reversals (ΔPTE).

ΔPT = (ΔPTT) + (ΔPTE)

Where

$\Delta PTT = K_{PT1} * N_P * L * u_T^{(2 + m_f)}$

$K_{PT1} = 2 * F_C ((\rho * d_1 / \mu) \wedge m_f) * \rho / d_1$

$F_C = 0.0791$, $m_f = - 0.25$ for $Re \geq 3000$

$\Delta PTE = K_{PT2} * u^2_T$

$K_{PT2} = 8 * \alpha_R * \rho$

$\alpha_R = 2 N_p - 1.5$

u_T - mean velocity of the fluid through the tubes which is the same as that obtained above

It was observed that using the above correlation also the pressure drop was found to be 2038 Pascal.

B. Numerical Pressure drop across the tube bundle

The meshed file was imported and after doing so the Solver setup mentioned earlier the 1000 iteration were run. The solution converged in less than 300 iteration. Figure 5 represents the tube array in the geometric mode

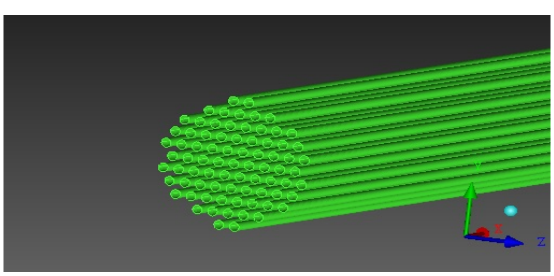

Fig – 5 : Tube bundle Array

The origin for the geometry was at the tip of the Elliptical wall at the inlet header. The distance between the origin and the start of the tube bundle is 392 mm. Inorder to find the numerical pressure drop a number of Z-Coordinates i.e. vertical sections in the X – Y plane passing through the tube arrays through the center were created with the center one being the Z – 0.

Moving along the positive Z axis as shown in fig 5 each vertical tube bundle is separated from each other by half a pitch i.e. 25.4/2 = 12.7 mm.

Therefore a total of 19 such Z Coordinates were created inorder to capture the 77 tubes of which 9 were along the positive Z – axis and 9 along the negative plus the center one.

Also an X coordinate at a distance of 5 mm away from the tube start was created. Thus combustion of the various Z Coordinates and the single X Coordinate the pressure at the inlet of each and every tube was found out. A gap of 4 mm was left between the tube start and the X Coordinate inorder to capture the pressure changes due to entrance effect of fluid inside the tube from the header.

The fig 6 shows the Z – 0 coordinate of contours of total pressure which captures the centermost array of tubes 5 in numbers

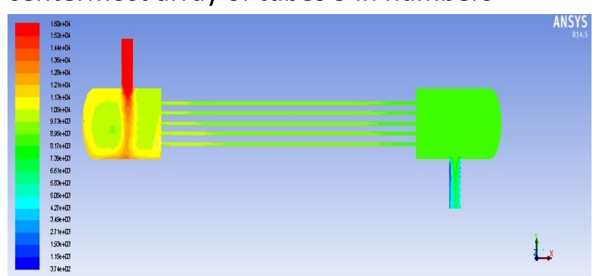

Fig – 6 : Z-0 Coordinate

The fig 7 shows the X – Coordinate.

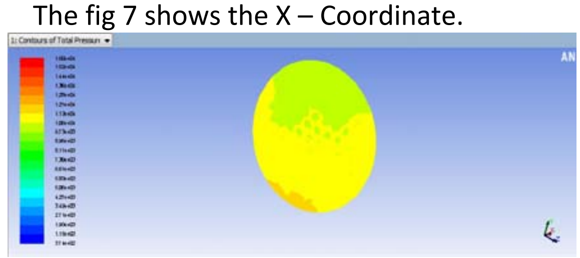

Fig – 7 : X-Coordinate 4 mm away from tube bundle

C. Grid Sensitivity Test

Before running the simulation an optimized mesh needs to be found out in terms of the accuracy of the results and the lesser number of nodes inorder to reduce the computation cost.

The geometrical model was meshed for three different dimension inorder to obtain a coarse, medium and a fine mesh. The numbers of cells thus obtained are mentioned in the table no– 3

Table – 3 : Grid Independence Test

Sr No	Mesh Type	Number of Cells	Average pressure Drop Across Tube Side
1	Coarse Mesh	1986668	1918
2	Medium Mesh	2519375	1943
3	Fine Mesh	3709885	1912

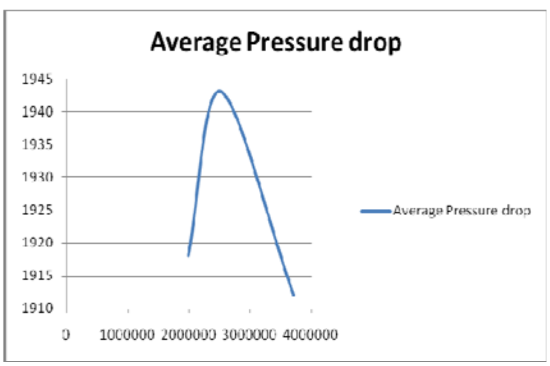

Fig – 8 : Grid Independence Test

The fig no - 8 indicates that the average pressure drop first increases reaches optimum and then starts decreasing as the fineness goes on increasing. Thus the optimum mesh used for further simulations was the medium

mesh which gave maximum accuracy with a -4.6 % deviation from the theoretical results. The medium mesh chosen also helps to reduce the computation cost compared to that of the fine mesh.

D. Inferences

- A two set of pressure values were obtained at the inlet of the tubes.
- The tubes with green color at the start of the tubes in the fig no 6 and 7 indicates a pressure value of 10506 Pa while the yellow color indicates 11285 Pa.
- All the 77 tubes were observed at the inlet side with the help of Z and X Coordinates to get the inlet pressures of the respective tubes.
- 38 tubes were having a pressure inlet of 11285 Pa while 39 tubes were having a pressure inlet of 10506 Pa.
- It can be observed from fig no 6 as well as all the Z Coordinates that at the outlet all the tubes had a uniform pressure i.e. there is not much variation.
- The outlet pressure was observed as 8947Pa
- Therefore the average pressure drop can be calculated as [(39 * 10506 + 38 * 11285) – 77* 8947)] / 77.
- From the above calculation the average pressure drop was found to be 1943.5 Pa while the theoretical average pressure drop is 2038 Pa.
- The difference between the theoretical and the numerical analysis is less than 10% which is within the acceptable range, hence the results are validated.

E. Parametric Study

The simulations were run for different input velocities of 2m/s, 5m/s and 7 m/s at the inlet nozzle and a relationship between the theoretical and numerical pressure drops were observed. Table no – 5 indicates the parametric study.

Table No- 5 : Parametric study with different velocities

Input Velocities	2 m/s	3.31 m/s	5 m/s	7 m/s
ΔP_{theor} (Pa)	787.4	2038	4467	8468
ΔP_{num} (Pa)	720	1943	4431	8421

% Differenc e	-8. 5	-4.6	-0. 8	-0. 5

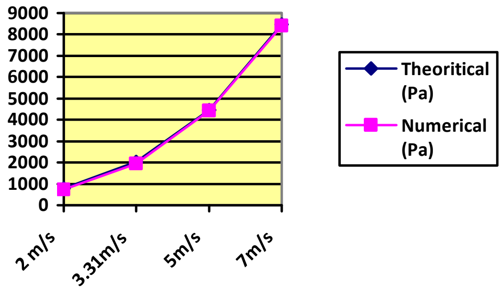

Chart – 1 : Parametric study of various Velocities

- Purple colored line in chart 1 indicates pressure drop line for theoretical values at various velocities while the pink one is for numerical.
- As the inlet velocity goes on increasing the % difference goes on decreasing as indicated in table no – 5.

VI.CONCLUSIONS

- The theoretical expressions just provide us with the average pressure drops across the tube banks; however the numerical study gave an idea of the pressure drop taking across each tube.
- Numerical analysis helped us to identify the two pressure zones at the inlet header i.e. a low pressure drop zone approximately at the upper half while a high pressure drop at the lower half.
- The numerical results were very validated against the theoretical results.
- This study can further be used for other research work related to the tube side.

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