Finite Element Analysis of No Tube In Window Tubesheet And Base Nozzle

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Abstract : The utilization of No Tubes In Window (NTIW) setup in Heat Exchangers (HEX) is legitimized by the decrease in shellside pressure drop. In any case, these designs have a fundamental effect on the mechanical design, the perforated area becomes non-axisymmetric.
techniques proposed in ASME Section VIII Div.1 is broadly utilized for designing the tubesheet with various setup. ASME strategy principally comprises of scientific equations which compensates for varying properties of perforated region and thus models it as an equivalent solid plate. Accordingly this kind of setup (NTIW) is for the most part structure by pressure investigation utilizing limited component examination (FEA) strategy.

***IndexTerms* - NTIW,Heat Exchanger,FEA.**

1. INTRODUCTION

A heat exchanger is a system used to transfer heat between two or more fluids. Heat exchangers are used in both cooling and heating processes. A solid wall to prevent mixing may separate the fluids or they may be in direct contact. They are generally used in applications such as power plants, chemical industries, pharmacy industries, water treatment plants. Tubesheets are plates or forgings penetrated to give openings through which tubes are inserted. Tubes are properly attached to the tubesheet so the liquid on the shell side is kept from blending in with the liquid on the tube side. Holes are drilled in the tubesheet ordinarily in two types, triangular or square. The length between the centre of the tubes opening is known as the tube pitch; ordinarily the tube pitch is 1.25 times the outside diameter of the tubes. Other patterns of tube arrangements are generally used to reduce shell side pressure. Triangular pitch increases heat transfer while square pitch eases the cleaning of the tubes. The analysis of tubesheet becomes very complex due to perforated region, which greatly affects the stress distribution in the tubesheet thus increasing the challenges faced in interpreting the results. The paper reviews the technique of analysing the tubesheets by method of equivalent solid plate as mentioned in ASME BPVC Sec 5, Div VIII. Further paper also studies the effect of loads on conical base, which is also used as an inlet.

2. .1.TUBESHEET AND NOZZLE DETAILS

Tubesheet is made of material SA 965 F 316, with outer diameter of 896 mm. The tubesheet is of NTIW configuration with total number of 396 holes in arranged in triangular pitch. The pitch value of the holes is 21.6 mm. The thickness of the tube is 48 mm. The base conical nozzle with diameter of 634 mm and thickness of 14 mm. it also acts as a reducer.

3. CONCEPT OF EQUIVALENT SOLID PLATE

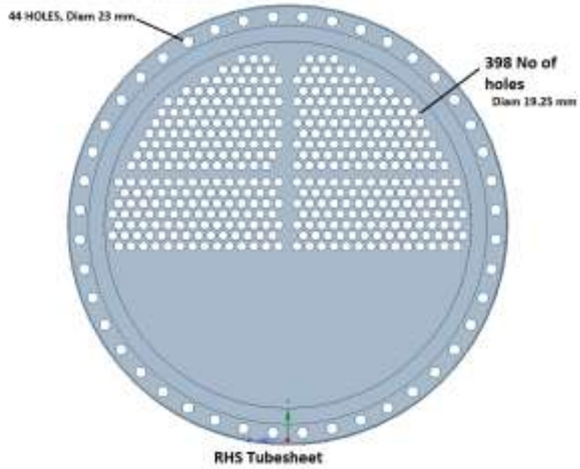

Figure 1: Tubesheet

Figure 1 shows typical NTIW tubesheet. From the figure it can be seen that it is quite difficult and tedious task to take into account each perforation on the tubesheet for finite element analysis. This perforation are known to create highly complex stress distribution. Though the stress distribution is complex, gross deformation is smooth and function of radii and circumferential angle. Thus to avoid this a finite element model is prepared which idealizes the perforated region as equivalent solid plate, which first determines the total deformation, and from this stresses are determined. In this concept the perforated region is considered as orthotropic material with modified elastic constant. Perforated region is so designed that it will behave as if it was solid plate. Step by step procedure for conversion of perforated region in equivalent solid plate is mentioned in ASME BPVC part 5, Div 2, section VIII.

4. DIFFERENT APPROACHES IN ANALYZING TUBESHEETS

ASME BPVC Div 1 gives .guidelines for analyzing tubesheet in its UHX section. This section has proposed the method of analyzing the tubular area as equivalent solid plate with modified elastic constants. This modified elastic constants are derived from effective ligament efficiency of tubular area. In addition to this its takes into account thermal aspect of the analysis. It considers differential thermal expansion between shell and tubesheet as well as shell and tubes. This method covers different configurations of the tubesheet including U-tube tubesheet, fixed tubesheet and floating tubesheet. The major disadvantage of this method is that it only considers nominal diameter of tubular area with complete negligence to untubed lanes.

TEMA (Tubular Exchangers Manufacturers Association) code has one of the basics methods to assess the perforated region. This code also provides, methods to analyze various configuration of tube bundle. In this method, minimum thickness for shear and bending are calculated and in earlier case concept of most shear loaded perimeter is applied on either side of the tubesheet. Futher it only considers differential thermal expansion between tubes and shell. It has similar disadvantage as seen in ASME BPVC Div 1.

German code AD 200 Merkblatt, also presents its approach to analyze the perforated region. However this technique is considered too simple because it does not take into account differential thermal expansion between shell and tubes. Complete negligence of thermal gradient is not acceptable and hence this methodology is very rarely used.

Very commonly used technique for analysis of perforated region is use of ASME BPVC,part 5, Div 2, section VIII. It shares some similarities with Div 1. One of the major difference in both being, in Div 2 perforated region is considered as equivalent solid plate with elastic orthotropic material, whose eastic constants are determined from ligament efficiency as well as untubed length which was neglected in Div1.

5. DETAILS ABOUT ASME BPVC DIV 2 SECTION VIII PART 5

The usual process of analyzing the stresses in perforated plates is based on treating Material as an equivalent solid material with modified elastic constants. This is because for complex equipment or with a large number of tubes, the detailed FE model of Tubesheets require high computational ability and complex geometry, which increases the difficulty of this analysis. The usual alternative to modelling this complex was to use a plate that was equivalent Mechanical properties based on the UHX method. This option, while not fair enough, presents some Problems like considering the pressure and extra stiffness operating in this perforated zone for the given tube bundle. From ASME Eighth Division, 2 Ed. 2007, in its 5th Appendix, it is presented for the first time systematically Design procedures through the analysis method, and especially in the context of Appendix 5E provides reference for Perforated zone pattern or axially symmetrical pattern perforated plates without any limitation as imposed by UHX. The quoted calculations are for anisotropic equivalent material in the perforated zone, as well as acting pressure on each side of the plate will result in less area being reduced. It has also established Extensive method for validating stress classification as well as fatigue assessment.
This method applies to perforated plates that satisfy the Following conditions:
(a) The holes are in an equilateral triangular or square penetration pattern.
(b) The holes are circular and the axis of the hole is perpendicular to the surface of the plate.
(c) There are 19 or more holes.

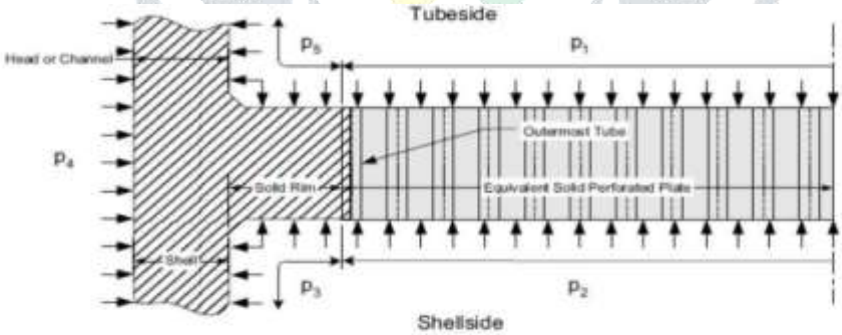

Figure 2: Modified pressure application

Due to change of perforated region into equivalent solid plate, the load application is also changed to match this change in material properties. Effective pressure considering original shell side as well as tubeside are calculated depending upon the area of application on the tubesheet. The values of modified pressure also depends on joint between tube and tubesheet.
Figure 2. shows load application according to this code.
Finally, the code also gives a criterion to check whether the stresses obtained from the analysis are within the permissible values. It imposes the limits for all the stresses.

6. MATERIAL MODELLING

An accurate model of the overall tubesheet behaviour may be achieved by employing the concept of an equivalent elastic material of anisotropic properties. For triangular penetration patterns the in-plane behaviour of the tubesheet is isotropic and the anisotropy of the equivalent material must only be considered for stresses in the thickness direction. The tubesheet can be analyzed using an asymmetrical solid numerical analysis with the effective elastic matrix [E] to simulate the anisotropic behaviour.
There are two ways to determine the effective elastic properties of material
1] The effective elastic constants of the perforated plate are determined as a function of the effective ligament efficiency μ*
2] The effective elastic constants of the perforated plate material are determined based on the hole pattern and thickness of the plate.

$$\begin{pmatrix} \sigma_r^* \\ \sigma_\theta^* \\ \sigma_z^* \\ \tau_{\theta z}^* \\ \tau_{rz}^* \\ \tau_{r\theta}^* \end{pmatrix} = \begin{pmatrix} E_{11} & E_{12} & E_{13} & 0 & 0 & 0 \\ E_{21} & E_{22} & E_{23} & 0 & 0 & 0 \\ E_{31} & E_{32} & E_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & E_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & E_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & E_{66} \end{pmatrix} \begin{pmatrix} \varepsilon_r^* \\ \varepsilon_\theta^* \\ \varepsilon_z^* \\ \gamma_{\theta z}^* \\ \gamma_{rz}^* \\ \gamma_{r\theta}^* \end{pmatrix}$$

7. ANSYS MODELLING

The complete heat exchanger model was first prepared in solidworks and then imported in Ansys for pre-processing. Few of the main steps in these were assignment of material to tubesheet by putting same material properties as determined in the material modelling. The final material matrix was as it given as an input to the Ansys. Next, proper manual contacts were given wherever necessary. Further complete user defined meshing has been done, with all the quality checks for meshing within permissible limits. These quality check include various parameters like aspect ratio, jacobian, skewness, element quality. The achieved values of these parameters with permissible limits are shown in Table 1.

Parameters	Permissible limit	Achieved Valve
Aspect Ratio	<5	2.71
Jacobian Ratio	>0.5	1.89
Skewness	<0.70	0.24
Element Quality	>0.1	0.64

Table 1: mesh parameters

7.1 3D MESH MODEL

Complete heat exchanger with meshing is shown in figure 3. Below

Figure 3: 3D mesh model

8. LOADS, BOUNDARY CONDITION

FE analysis is carried out based on two pressure conditions one being at design pressure and other at vacuum pressure. The design pressure considered here is 0.34324 Mpa while vacuum pressure being -0.1013 Mpa. The ends of nozzle are usually closed and thus apply opposite reaction force due to pressure present inside the heat exchanger. In FE analysis this phenomenon is captured by applying thrust at the openings on the heat exchanger. Further loads are applied on the tubesheet as shown in Figure 2. Once the loads are applied, boundary conditions are also applied as per requirements. Fixed support is applied at base nozzle, also to simulate the effects of baffles that support the tubes constraints are also applied at the positions where baffles are present.

Case 1: Design pressure + shell side pressure

Case 2: Vacuum pressure + shell side pressure

9. RESULTS

According to ASME BPVC VIII Div.2 Ed.2007 the analysis is based on elastic theory. The stress is divided in various categories such as membrane, bending and peak stresses. This process is called stress categorization. For this reason, a stress classification line is plotted at a point of maximum stress on the tubesheet across the thickness of the tubesheet.

Heat exchanger is divided in total 4 parts and different acceptance criteria's are applied for each zone.

Zone 1 : Channel, Zone 2: Rim, Zone 3 : Tubesheet, Zone 4: Shell.

For Zone 1,2 and 4:

$$P_m \le S_m \quad (1)$$

$$P_L \le 1.5S_m \quad (2)$$

$$P_L + P_b \le 1.5S_m \quad (3)$$

For zone 3:

$$\frac{P_m}{\mu^*} \le S_m \quad (4)$$

$$\frac{(P_L + P_b)K_{PS}}{\mu^*} \le 1.5Sm \quad (5)$$

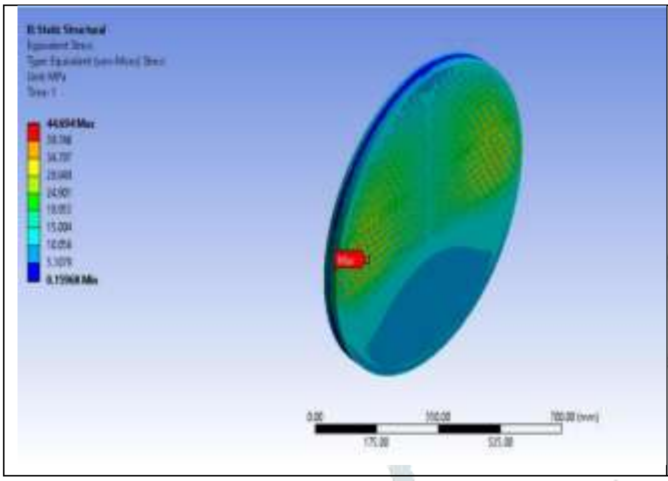

Figure 4 : Case 1 Von mises Stress

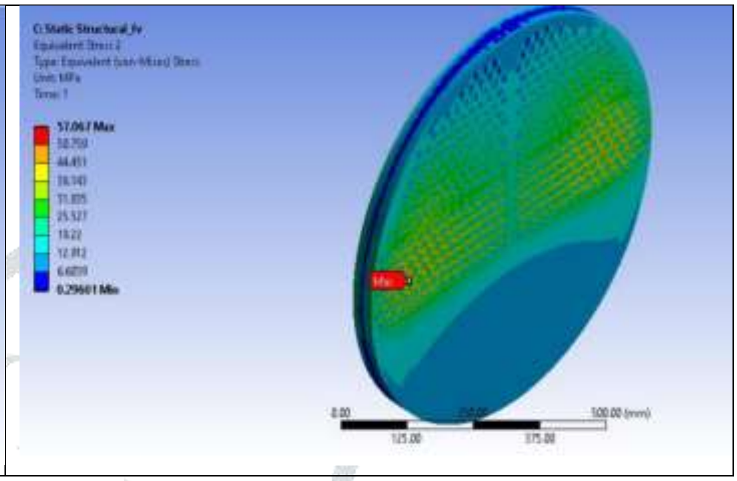

Figure 5: Case 2 Von mises Stress

9.1 Design Case Stresses

Paramaters		Obtained Values	Remarks
Allowable stress	S_m	120.55	
S_{PL}	S_{PL}	361.65	
Radial Stress at Max Stress Location	Sigma_r*	26.589	
Tangential Stress at Max Stress Location	Sigma_theta*	26.245	
Primary Membrane in Equivalent Solid Plate	P_m	2.1146	
Primary Membrane + Primary Bending	P_L+P_b	29.28	
Effective Ligament Efficiency	μ*	0.376	
K_{PS}		1.080726	
Primary Membrane Check	$P_{m/}$ μ*<= Sm	5.6239	SAFE
Primary Membrane + Primary Bending Check	(P_L+Pb) $K_{PS/}$ μ*<= S_{PL}	90.156	SAFE

9.2 Vacuum Case Stresses

Paramaters		Obtained Values	Remarks
Allowable stress	S_m	120.55	
S_{PL}	S_{PL}	361.65	
Radial Stress at Max Stress Location	Sigma_r*	31.14	
Tangential Stress at Max Stress Location	Sigma_theta*	34.061	
Primary Membrane in Equivalent Solid Plate	P_m	2.6193	
Primary Membrane + Primary Bending	P_L+P_b	36.487	
Effective Ligament Efficiency	μ*	0.376	
K_{PS}		1.080726	
Primary Membrane Check	$P_{m/}$ μ*<= Sm	6.966	SAFE
Primary Membrane + Primary Bending Check	(P_L+Pb) $K_{PS/}$ μ*<= S_{PL}	84.1586	SAFE

10. CONCLUSION

It can be seen that the methodology provided ASME Div 2 VIII, part 5, cover all the shortcomings in other methods of analyzing the tubesheets and mainly perforated region. From preprocessing to final stress classification it provides stepwise procedure for analysis. These steps not only ensure accurate but also reliable results from FE analysis.

11. REFERENCES

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