ISSN 2395-1621

Stress analysis of tube sheet and shell joint by Finite Element Method and Equivalent Beam Method

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ABSTRACT

Stress analysis for heat exchanger tube or any other mechanical component is usually done by finite element method. It is a 3 dimensional analysis, so required more time, computer memory and cost to process the data, but the same equivalent results can be achieved by using Equivalent beam method which is 2 dimensional analysis overcoming drawbacks of a finite element methods. In this paper finite element analysis of tube sheet of heat exchanger is done with two models and compared for results. It is found time required for existing methods is more in terms of modeling, meshing and solving the problem due to large no. of element and complexity of geometry. But it is comparatively very much less in Equivalent beam method. And results give good match with existing methods.

Keywords— Analysis, Beam, Equivalent, Modelling, Shell, Tube sheet.

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. INTRODUCTION

Nowadays, the analysis of mechanical components is done by using finite element method. It is a numerical technique for finding approximate solutions to boundary value problem for partial differential equations. It uses variation methods (the calculus of variations) to minimize an error function and produce a stable solution. Analogous to the idea that connecting many tiny straight lines can approximate a larger circle, FEM encompasses all the methods for connecting many simple element equations over many small sub domains, named finite elements, to approximate a more complex equation over a larger domain. Tube sheet is an important component in heat exchangers so design and analysis of tube sheet plays very important role in safety of heat exchangers. Today's global market is highly dependent on solid modeling for product design, product development, analysis and manufacturing. This is obvious, Finite element analysis reduces the expensive physical prototyping and hence product development time and cost, but for solid it is of interest to develop reduced model that are capable of giving optimal solution by significantly reducing the computational time. A shell and tube heat exchanger is a class of heat exchanger designs. It is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. The reason of this general acceptance is several. The shell & tube heat exchanger provides large ratio of heat transfer area to volume and weight. As its name implies, this type of heat exchanger consists of a shell (a large pressure vessel) with a bundle of tubes inside it. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. The set of tubes is called a tube bundle, and may be composed of several types of tubes: plain, longitudinally finned, etc.

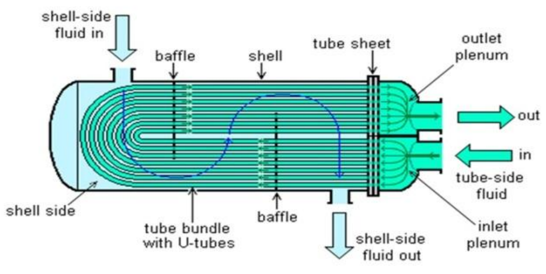


Fig.1 Shell and tube heat exchanger

finite element model takes a significant Amount of computer time and memory if entire element is subdivided into a finer mesh. He introduced a effective analytical method to reduced computational time with accurate result named as equivalent beam method[1]. H. Sereshteh etal study the effect of structural characteristics, including stiffness, geometry and weight on tunnel–adjacent structure interaction. Ground materials, tunnel geometry and excavator device are related to a part of metro tunnel of Tehran. To describe the ground behavior due to tunneling, a 3D FE code with an elastoplastic soil model was used. The adjacent building was modeled in two ways: one as an equivalent beam or shell and the other as a real geometry (3D frames[5]. Gaurav R. focuses on Finite Element Analysis of Expansion Joint in heat Exchangers using ANSYS. The main Purpose of Expansion joint is to withstand axial Deformation (thermal Expansion) & loads inside a High Pressure heat Exchanger. Hence the design of Expansion joint becomes critical[6] Linear analysis is first conducted by taking account into the tapering effects of web-tapered I-beams, where the deformation compatibilities of the two flanges and web are considered in terms of the basic assumptions of thin-walled members. Subsequently, the total potential for the lateral buckling analysis of web-tapered I-beams is developed, based on the classical variational principle for buckling analysis [9]. Thermo-mechanical stress in tube to tube–sheet joints including welding effect should be determined in this situation for failure analysis. In this paper, the Finite Element Method (FEM) is used to predict the thermo-mechanical stresses including welding residual stress in a tube to tube–sheet weld [18].

II. EXPERIMENTAL WORK

According to type and application of heat exchanger complexity of tube sheet solid modeling in finite element analysis varies and ultimately in early stages of design and analysis the product development time is increased. In this project the finite element analysis of tube sheet has been done in ANSYS 14 by solid modeling and equivalent beam modeling method. The results are compared and found that tubes heat analysis by equivalent beam modeling reduces the computational time and complexity of solid model. In next pages solid modeling and equivalent beam modeling has been done separately and compared for the sample input data. Same geometrical and material data is used in Equivalent Beam Method and Solid modeling. As both data inputs are same, it will be easy to compare the result. The sample data has been taken for waste heat recovery heat exchanger in Kirlosker Pneumatic Cooperative Limited. Total numbers of tubes are 80. For a selected tube sheet, Input data

TABLE I
INPUT PARAMETERS

Sr. No.	Design Pressure in Kg/mm^2 g	
1	Shell Side	12.7
2	Tube Side	9.8

TABLE II
DIMENSIONS OF TUBESHEET

Sr.No	Dimensions of Tube sheet in mm	
1	Shell Internal Diameter	254.46
2	Shell Thickness	9.27
5	Tube Outer Diameter	20
6	Tube Length	2100

III.MODELING

A. Solid modelling

The overall design of the equipment already exists. The equipment modelling was carried out with same geometrical and material properties in ANSYS. The overall equipment dimensions are very high and the parts, which plays important role during operation, comparatively small to overall dimension. This increased the modelling complexity. As the high pressure was acting from the shell side, only shell side of equipment modelled. Practically equipment was manufactured horizontally but for simplicity in modelling and analysis it was modelled vertically. The advantage of symmetry took while modelling. Using symmetric condition, only quarter section of equipment was modelled.

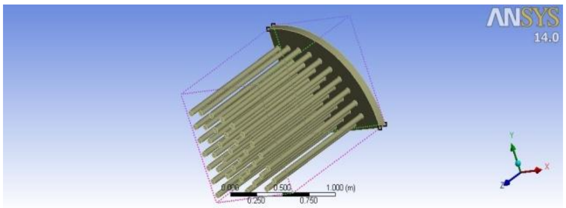


Fig1.Displacement contour plot

B. Meshing

The model meshed with help of the Solid Element. The geometrical size is very high, so going for free mesh that increased the number of element drastically. To reduce the solving time and post processing difficulties, a good control require over the mesh. Therefore the manual mesh was performed on the solid model. Care was taken during meshing of tube and tube sheet junction. Nodes were merging with each other to get effect of full penetration weld.

C. Materials and Its Properties

The materials properties for the component were selected as per the ASME Boiler and Pressure Vessels Code. For solid model analysis only three material properties were required.

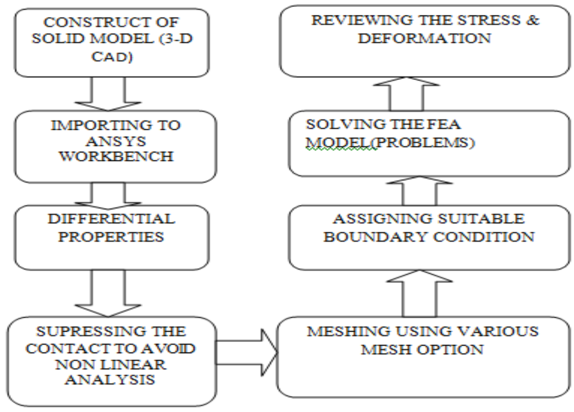
1. Modulus of Elasticity
2. Poisson ratio
3. Coefficient of thermal expansion.

D. Boundary and Loading Condition

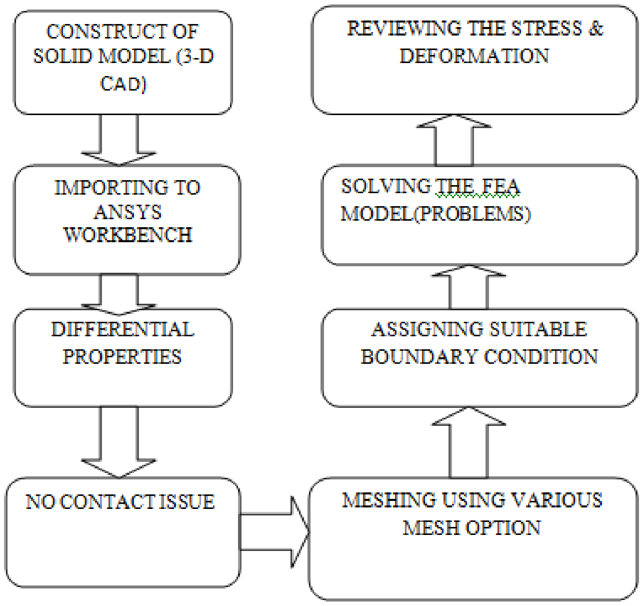
During operation, shell side was subjected to high internal pressure and channel side subjected comparatively less pressure. Therefore the effective pressure on expansion element was the difference between Shell side pressure and channel side pressures. But for analysis most awful condition considered i.e. only shell side pressure. High-pressure from inside forces the shell to expand in radial but shrinks down in axial direction due to Poisson effect. Tubes were subjected to internal pressure and external pressure. There were difficulties to apply the internal and external pressure on the tube therefore expansion effect of pressure converted into equivalent temp effect and applied on tubes. Concurrently all components were subjected to high temp as they comes in contact with saturated steam whereas tube with the hot gas. Temperature directly applied on the component. Even if temperature gradient exits across thickness or length of individuals, temperature was considered uniform in component. Here only structural effect due to change in temperature considered. Analysis does not go in detailed for thermal analysis. Only co-efficient of thermal expansion provided as thermal properties, no additional thermal material properties were provided to any of this material.

The basic interest in results of analysis is stress value and stress distribution. As per ASME boiler and pressure vessel code, analysis must satisfy the stress criteria as stress categorization in the ASME 2010(II)[7]and BIS [8].From the analysis, gives all basic output used for post analysis activities. As per the code, the stress intensity distribution used further study. The result of displacement contour plots is shown in figure. The displacement plot shows behavior of equipment when subjected to internal pressure and Operating temperature. Tubes were relatively free to expand more than fixed tube sheet design. Because of this reason, the tubes were not subjected to any compressive loading. Plot of stress intensity shows maximum stress induced at the tube to tube- sheet junction. But most of time full penetration weld used so less chance for occurrence of complete failure. The design of the thin tube sheet with flexible expansion element was governing total design of equipment. As expected maximum stress was induced in expansion element as it was subjected to high pressure and high thermal differential expansion between shell and Tube sheet. But it is advantageous that no other part subjected to local bending near shell to tube sheet joint. Stress Value in the expansion element shows that stress value crossed the yield limit. Concurrently, in some outer tubes also cross stress value near the tube-to-tube sheet joint. As per requirement of ASME code, material was considered as perfectly elastic. So even if it passes the yield limit, plastic properties were not considered. The output of stress categorization values must be below the specified limit. Stress categorization was carried out using Stress linearization. After linearization total stress induced in expansion element classifies into Membrane, Membrane plus bending, and Total stress.

IV. ANALYSIS BY SOLID MODELLING METHOD



V. ANALYSIS BY EQUIVALENT BEAM METHOD



VI. CONCLUSION.

Analysis heat exchanger tube sheet with the help of equivalent beam method (2D) can save a lot of computational time as compare to finite element analysis (3D).

Heat Exchanger Tube sheet optimization can also being done by this equivalent beam method. By reducing the use of high end computers, ultimately we can reduce the overall designing cost.

ACKNOWLEDGEMENT

I would very much like to gratefully extend my sincere thanks to all peoples, who gave their time, take one and all especially thanks to my guide & head of mechanical department Prof. A.K. Mishra, for his valuable guidance. They showed me right throw and give his for his valuable contribution in developing the IJRSD article template.

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