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Research Paper

FINITE ELEMENT ANALYSIS: PRESSURE VESSEL WITH ANGULAR LEG SUPPORTS

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The objective of the pressure vessel is to have production of phenol and acetone. Cumene process is an industrial process of producing phenol (C6H5-OH) and acetone (CH3-CO-CH3) from benzene (C6H6) and propene (C3H6). The term stems from isopropyl benzene or cumene (C6H5-CH (CH3)2), the intermediate material during the process. With the help of this process two relatively cheap materials, benzene and propene are converted into two more valuable products such as phenol and acetone. For this process other required reactants are oxygen from air and small amounts of a free radical initiator. The pressure vessel is being designed to implement the cumene process. The process is extremely sensitive to pressure and temperature conditions and requires a lot of control systems to monitor it. These control systems are to be placed below the vessel for effective monitoring.

Keywords: Non-linear, Supports, Stability, Vessel, FEA

INTRODUCTION

Type of support used depends on the orientation and pressure of the pressure vessel. Support from the pressure vessel must be capable of withstanding heavy loads from the pressure vessel, wind loads and seismic loads. Pressure on pressure vessel design is not a consideration in designing support. Temperature can be a consideration in designing the support from the standpoint of material selection for the different thermal expansion. The current range of Pressure Vessels in the market of AZ'series, come either in skirt support or supported by 8 legs equidistance from each other. However, a custom made pressure vessel has been ordered for the cumene process. The custom made vessel has to have a lot of controls for the cumene process; hence 8 legs are not feasible. Six legs support with a non-symmetric distribution was tried out initially. However the current requirement is to have more floor space.

OBJECTIVE OF WORK

Typically most of the pressure vessels are either skirt or leg supported and observation is that legs are primarily vertical. However in

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case vertical expansion of the vessel either due to thermal expansion or due to vertical loading the legs are susceptible to buckling. Hence, objective of this work is to determine whether creating an angle in the legs in combination with unsymmetrical distribution affects the structural stability of the system.

LITERATURE SURVEY

After going through various literatures on pressure vessel supports some of the selected papers are cited below and which are considered as basis for developing structural analysis methodology for vertical pressure vessels

Flexible Saddle Support of Horizontal Cylindrical Pressure Vessel

K Magnucki *et al*. (2003) have reported that the pressure vessel was treated as an integrated system, including the deformable support with stiffness adjusted to minimize the stress concentration in the vessel shell. The support should be of appropriate shape. Simple design and suitable thickness relative to thickness of vessel shell. The use of supports of high stiffness was certainly unfavourable taking into account the strength of vessels.

Stress Distributions in a Horizontal Pressure Vessel and Saddle Supports

Shafique M A Khan (2010) has mentioned that the analysis of stress distribution in horizontal pressure vessels and saddle supports. A quarter of pressure vessels have been modelled with realistic details of saddle support. Physical reasons for favouring of particular value of ratio of the distance of support from end of the vessel to the length of vessel have been outlined. This paper has been a basis for deciding the support length and total length of vessel.

Three Dimensional Finite Element Analysis of Saddle Supported Pressure Vessels

N El-Abbasi *et al*. (2000). A three-dimensional finite element analysis is made of a pressure vessel resting on flexible saddle supports. The analysis is carried out using a newly developed thick shell element and accounts for frictional contact between the support and the vessel. The seven-parameter shell element is capable of describing the variation of the stress and the strain fields through its thickness. A variable inequalities based formulation is utilised for the accurate description of this class of frictional contact problems. Different pressure vessel configurations are considered and the resulting contact stresses are examined. The effect of saddle radius, saddle width, plate extension, and support overhang on the resulting stress field in both the vessel and support are evaluated and discussed. Since we are having leg supports for our pressure vessel and for constant single pressure vessel analysis is done.

Analysis of Axisymmetric Shell Structures in Axisymmetric Loading by the Flexible Method

Troy Alvin Smith (2008) has presented that the method developed for the static stress and deformation analysis of axisymmetric shells under axisymmetric loading by reduction of the shell to ring sections. The distribution of stresses in the meridional direction of the ring element is assumed to be linear with each element. By using the derived influence coefficients, the unknown forces at the juncture of the ring elements are found by the standard flexibility method of indeterminate structural analysis. Subsequently, the displacements and internal stresses.

Stability of Thin Walled High Pressure Vessels Subjected to Uniform Corrosion

E Gutman *et al*. (2000) have addressed that the stressed state in real metal construction changes in the process of operation even under permanent external loading. It takes place due to changes in the cross section of the loaded elements resulting from the surface corrosion. This paper presented a method for determine the critical time of stability loss in thin walled high pressure vessels subjected to uniform shell. Since our pressure vessel is supported with I section beam and uniform shell structure resulting into stability and safe design.

Structural Analysis of Inclined Pressure Vessel Using FEM

R M Tayade *et al*. (2012) have presented inclined pressure vessel (IPV) study using finite element analysis using ANSYS to find out stresses in the vessel for its structural stability was done in this paper. Inclined pressure vessel was used for production of nitrous oxide by ammonium nitrate pyrolysis reaction by passing the steam at around 200°C and 1.37895 MPa over the ammonium nitrate contained in the cylindrical vessel. Here design challenge inclined nature of vessel as, ASME code enables design of Horizontal or a Vertical vessel but there was no provision for an Inclined Vessel in it. The above paper suggests structural analysis for inclined pressure vessel which is close with our vessel having inclined leg supports which are under consideration.

Stresses in Large Horizontal Cylindrical Pressure Vessels on Two Saddle Supports

L P Zick (1951) has presented that approximate stresses that exist in cylinder vessels. Supports on two saddles at various exist in cylinder vessels supported on two saddles at various locations knowing these stresses. It has possible to determine which vessels may design for internal pressure vessels and to design structurally adequate and economical stiffing for the vessels which require it. As far as vertical pressure vessel is considered the stress at each leg and shell contact will decided the stability of vessel.

Support Leg Stress in Pressure Vessels Mounted on Arbitrary Legs Subjected to Lateral Loadings

Cai Zengshen and Lin Jun (1966). A pressure vessel mounted on arbitrary leg-type supports forms a complicated support system with respect to lateral loadings such as wind loads and horizontal seismic motion which do not have a predefined direction of action and this problem has not been solved exactly. In the present paper an exact solution is firstly proposed which is derived from an arbitrary number of legs with the leg inclined at an arbitrary angle with the horizontal. The solution showed that: (1) in the general case as to the support systems, the most vulnerable direction of the horizontal loading which maximizes support leg stress is not in the symmetrical plane of the system (2) the most vulnerable direction is independent of the number of the legs in the system and (3) it is not the best case for the system that the angle between the legs and the horizontal direction should be 90°. By numerical results, when the angle is about 87° the support leg stress level is near to its lowest value. Since this paper features about the stress induced in the legs due to lateral loading which will give exact idea about possible values of stress as in case of pressure vessel supported by angular positioning of legs.

Stress Analysis of Conical Shell Skirt Support for High Pressure Vessel Using Finite Element Method

K Tamil Mannan *et al*. (2009) Pressure vessel is a closed cylindrical vessel for storing gaseous, liquids or solid products. The stored medium is at a particular pressure and temperature. The cylindrical vessel is closed at both ends by means of dished head, which may be hemispherical, ellipsoidal. The pressure vessels may be horizontal or vertical. The supporting system of this vertical vessel plays an important role in the performance of the equipment. Proper supporting system gives better efficiency. The bottom supports are critical components since they are to be designed with much care to avoid failure due to internal pressure with temperature. In this analysis, skirt support for vertical vessel was analysed as per the guidelines given in the ASME (American Society of Mechanical Engineering) section VIII division 2 and IBR (Indian Boiler Regulations) standards. The stress analysis was carried out for this support using a general purpose FEM code, ANSYS macros. The coupled field (Structural and Thermal) Analysis was carried out for skirt support to find out the stresses in the support. The analysis results were compared with ASME code allowable stress. The above paper gives analysis for skirt support and resulting stress induced in the support with ASME section VIII division 2 and IBR (Indian Boiler Regulations) standards. With similar approach analysis has been performed on inclined leg supports with the help of FEM method.

DESIGN CONSIDERATIONS

Design Pressure

A vessel must be designed to withstand the maximum pressure to which it is likely to be subjected in operation. For vessels under internal pressure, the design pressure is normally taken as the pressure at which the relief device is set. This will normally be 5 to 10 per cent above the normal working pressure, to avoid spurious operation during minor process upsets. When deciding the design pressure, the hydrostatic pressure in the base of the column should be added to the operating pressure, if significant. Vessels subjected to external pressure should be designed to resist the maximum differential pressure that is likely to occur in service. Vessels likely to be subjected to vacuum should be designed for a full negative pressure of 1 bar, unless fitted with an effective, and reliable, vacuum breaker. The pressure inside our vertical pressure vessel is taken as 150 Mpa.

Design Temperature

The strength of the metal decreases with increasing temperature so the maximum allowable design stress will depend on the material temperature. The design temperature at which the design stress is evaluated should be taken as the maximum working temperature of the material. The temperature inside our vertical pressure vessel is taken as 120°C.

Materials

Pressure vessels are constructed from plain carbon steels; low and high alloy steels, other alloys, clad plate, and reinforced plastics. Selection of a suitable material must take into account the suitability of the material for fabrication (particularly welding) as well as the compatibility of the material with the process environment. The pressure vessel design codes and standards include lists of acceptable materials, in accordance with the appropriate material standards. The material is selected as Structural Steel for analysis purpose.

Design Stress (Nominal Design Strength)

For design purpose it is necessary to decide a value for the maximum allowable stress (nominal design strength) that can be accepted in the material of construction. This is determined by applying a suitable factor of safety to the maximum stress that the material could be expected to withstand without failure under standard test conditions. The design stress factor allows for any uncertainty in the design methods, the loading, the quality of the materials, and the workmanship. For those materials not subjected to high temperature the design stress is based on the yield stress (or proof stress), or the tensile strength (ultimate tensile stress) of the material at the design temperature. For materials subjected to conditions at which the creep is likely to be considered, the design stress is based on the creep characteristics of the material.

FINITE ELEMENT ANALYSIS PROCEDURE

Selection of Material

As per the ASME code for manufacturing of pressure vessel numbers of materials are specified but the selection depends purely upon nature of application. In accordance with number of material selection factors and rules and regulation led down by ASME code specifications material need to be decided. Since this work primarily focus on the analysis of vertical leg supports. Finally end user will decide which material to be used. The material used for this vessel is structural steel and its properties are listed below.

Table 1: Material Properties

Sl.No.	Material	Structural Steel
1	Young'sModulus (Mpa)	2e5
2	Density (Kg/m3)	7850
3	Poissions Ratio	0.3
4	Yield Strength (Mpa)	250
5	Tensile Strength(Mpa)	460

Geometry Creation

The vessel geometry modelling has been done in Ansys 12.01 workbench itself.

Meshing

Meshing has been done by using the method of Tetrahedron. The accuracy of results will largely depends upon the extent of correct meshing. In Tetrahedron method the component is been divided into small triangle on its surface which gives no of nodes and elements of that component. The meshing has been done by changing the mesh size of the various component of the pressure vessel. Due to change in the density of the meshing, it results in the variation of the no of nodes and elements of the meshed parts. The result of this mesh density change affects the value of the stress and deformation of the component. For fine meshing that is for small mesh size the values of no of nodes and elements are high but as the element size is gradually increased it result in increase in the value of no of nodes and elements. For small variation in mesh size that is of 1E-03 m the values are showing small variation in no of nodes and elements and also it shows the same amount of variation in the values of stress and deformation for the given mesh size. But for large variation in mesh size the values of no of nodes and elements are also vary in large amount.

Steps Involved in Meshing Pressure Vessel Assembly

- Creating CAD model in CATIA V5R20.
- Repairing CAD geometry data
- Import geometry
- Creating simplified parts
- Meshing the part

After performing the meshing it is equally important that the connectivity associated between the element and each node of the element will be smooth and it will not result into the formation of triangular elements. And thus we are getting desirable mesh pattern for different element.

Boundary Condition

Defining correct boundary conditions is primary requirement for all the FEA analysis. The boundary condition applied for particular analysis must be correct or it may cause misleading results. The nature of analysis will decide the boundary conditions need to be applied. As in this work the leg supports are more important from analysis point of view and sine pressure vessel is vertically standing on ground the following boundary conditions were applied.

1. Wind load acting on the vessel
2. Internal pressure of the vessel
3. All the supports need to be fixed to the ground

Structural Analysis

The Ansys 12.01 workbench will give the results in terms of the maximum deformation as well as the stress subjected by the pressure vessel assembly. Here, in this work there will be small increment in the angular positioning of legs by 1 degree up to 30 degree. This increment will result in the considerable amount of deformation as well as stress in the leg supports. The nature of this analysis is based upon Section VIII Division I for the targeted compliance of the stress values in the pressure vessel assembly.

FUTURE SCOPE

The analysis is mainly focused on the amount of maximum deformation and Von Misses Stress. The further study may be carried out in terms of the amount of bending stresses induced in the leg supports for given load.

CONCLUSION

As per the solid structural analysis performed above it is found that the values of stress and deformation are safe for all the values of the increment in the angle. The analysis shows that even though varying angle from 0 to 30 degree the optimum value of stress and deformation will be achieved for 18 degree model for the given boundary conditions. This 18 degree model is also satisfying the project objective that even though creating the unsymmetrical distribution in the leg supports will be resulting into the structural stability. Also, important consideration for this work is the increased floor space which also can be achieved for the optimum value of stress and deformation. So considering all above things this above model is also simulated for the various positions of angular wind load. The pressure vessel assembly is rotated from 15 to 180 degree. This will show that the values of stress and deformation within this modified boundary condition are also within limiting values.

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