Effect of Wind Load on Pressure Vessel Design by Using Non- Linear Finite Element Analysis (FEA)

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Abstract

Pressure vessel-reactor is to used for production of phenol and acetone by cumene process which is an industrial process of producing phenol (C_6H_5-OH) and acetone (CH_3-CO-CH_3) from benzene (C_6H_6) and propene (C_3H_6). But wind load effect on pressure vessel design is very important. 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. 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. In this paper, the current requirement is to have more floor space. And to simulate the structure for wind load and verify for the safe condition. Hence, it is decided to improvise on the design and introduce angular supports. It has an advantage of increased floor space to mount the controls. The results show that the effect of 6 leg support on the structural stability of pressure vessel behavior is noticeable in optimum design and minimum deformation and minimum stress will be find out for the Cumene Process of the pressure vessel.

Keywords: *FEA, Cumene process, IPV, Wind load,*

Maximum stability, Leg supports.

1. Introduction

Wind Load calculations are based on American Society of Civil Engineers (ASCE) 7-95 obtained from 'Pressure Vessel Design Manual' by D. Moss [ANSI A58.1] .With the development of the industry, high pressure vessels are widely used in the field of the petroleum and chemical industry, and the dimension of the vessel becomes larger and larger. A pressure vessel is a closed container designed to hold gases or liquids at a pressure substantially different from the ambient pressure. Pressure vessels are used to store and transmit liquids, vapours, and gases under pressure. The pressure vessel is being designed to implement the Cumene Process. 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. The pressure vessel-reactor is to have production of phenol and acetone. This process illustrates the benefit of chemical engineering in merely converting two relatively cheap starting materials, benzene and propene into two more valuable ones, phenol and acetone. Other reactants required are oxygen from air and small amounts of a free radical initiator. Most of the worldwide production of phenol and acetone are now based on this method Magnucki et al. [1, 12] have reported that the pressure a 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. Shafique M.A.Khan [2, 13] has presented that analysis of stress distribution in horizontal pressure vessels and saddle supports. A quarter of pressure vessels have modeled with relastic details of saddle support. Physical reasons for favoring of particular valve of ratio of the distance of support from end of the vessels to the length of vessels have outlined. Donatello Annaratone [3] has addressed that the most comprehensive and qualified study about the behavior of a horizontal cylindrical vessel on two symmetrical saddle supports, was the total load on the support, the length of the cylinder measured between the tangency lines of the heads. Troy Alvin Smith [4] 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. E.Gutman et al. [5] have addressed that the stressed state in real metal construction changes in the process of operation even under permanent external loading. This paper presented a method for determine the critical time of stability loss in thin walled high pressure vessels subjected to uniform shell. Imran Jamadar et al. [6,11] have published 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. 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. It has an advantage of increased floor space to mount the controls.

2. Validation of the Finite Element Model

The use of finite element results for design and analysis purposes is only justified if the numerical model has been validated with respect to the quantities of interest. The pressure vessel supports are designed by considering factors in mind such as wind Loads, Internal Pressure, and Self Weight. As wind load cannot be directly tested, FEA analysis becomes critical to ascertain to gauge the performance. Wind Load has to be simulated from several directions, and find weak regions in the structure. Deformation is also an important parameter, cumene process requires control to be precise, this will mean that supervisory personnel will have to regularly visit bottom of the vessel, hence safety is a major concern. In addition to unsymmetrical supports, the angle that it makes with the ground (about 15-180 deg) will add to the complexity of the FEA. FEA simulation will be Non Linear in nature, and needs to be performed according to the standards of the client. The standards will include mesh size, number of iterations etc.

2.1 Wind Load Calculations.

Wind Load calculations are based on American Society of Civil Engineers (ASCE) 7-95 obtained from ‘Pressure Vessel Design Manual’ by D. Moss [ANSI A58.1] .Wind speeds in the zone where the cumene column is to be erected are in the range of 90 mph. Fig 2 shows the wind loads will exert a pressure on the face of the vessel facing the wind and will cause bending of the supports .Wind design is influence on structural stability of pressure vessel. It is important to find out the wind force and moments at each elevation to check if the calculated shell thicknesses are adequate. The overturning moment at the base is used to determine all of the anchorage and support details. These details include the number and size of anchor bolts, thickness of skirt, size of legs, and thickness of base plates. As a loading, wind differs from seismic in that it is more or less constant; whereas, seismic is of relatively short duration. In addition, the wind pressure varies with the height of the vessel. A vessel must be designed for the worst case of wind or seismic, but need not be designed for both simultaneously. While typically the worst case for seismic design is with the vessel full (maximum weight), the worst design case for wind is with the vessel empty. This will produce the maximum uplift due to the minimum restraining weight. The wind forces are obtained by multiplying the projected area of each element, within each height zone by the basic wind pressure for that height zone and by the shape factor for that element. The total force on the vessel is the sum of the forces on all of the elements. The forces are applied at the centroid of the projected area.

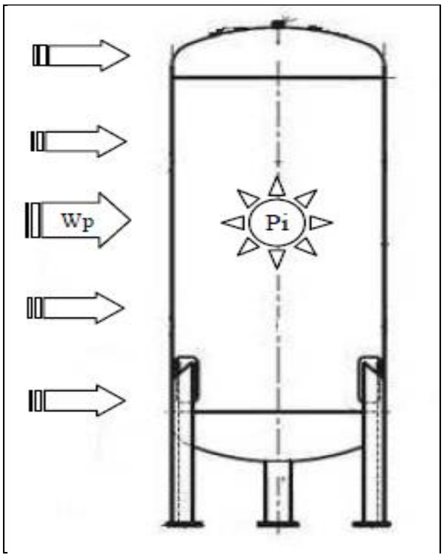

Fig. 1 Wind Load

2.2Calculations.

Structure category= III (Buildings and other structures containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released. Buildings or structures where the primary occupancy is one in which more than 300 people congregate in one area**)**

Exposure category= D (Flat, unobstructed coastal areas directly exposed to wind blowing over open water; applicable for structures within distance from shoreline of 1500ft or 10 times the structure height)

Table 1 Wind Load Calculations Factors [Pressure Vessel Design Manual' by D. Moss Table 3.1& 3.2]

Description	Symbol	Value	Unit
Structure category	-	III	
Exposure category	-	D	
Basic Wind velocity	V	90	mph
Effective diameter	D	5	feet
Importance factor	I	1.15	
Force coefficient	C_f	0.7-0.9	
Velocity Pressure exposure	Kz	1.03	
Topographic Factor	K_{ZT}	1	
Height Of Vessel	H	13.6	feet

First determine vessel is rigid or flexible

a) If h/D < 4, then vessel is rigid.

b) If h/D > 4, then vessel is flexible.

Calculate h/ D ratio = 13.6/5 = 2.72 < 4 then vessel is rigid

Wind Load/ Force (F) = $q_z*G*C_f*A_f$

Calculate,

Velocity Pressure at height z above the ground (q_z) = $0.00256*K_z *K_{ZT} * V^2* I$……………………… (1)

$(q_z) = 0.00256* K_z * K_{ZT} * V^2*$

$(q_z) = 0.00256* 1.03 * 1* 90^2 * 1.15$

$(q_z) = 245.6$ ……….PSF (pounds per square feet)

Hence,

Wind Load/ Force (F) = q_z *G *C_f*A_f………………………………… (2)

Wind Load/ Force (F) = 245.6 * 0.85 * 0.81 *13.6 * 5

Wind Load/ Force (F) = 11500 N

Based on the above calculations wind load used for simulation is 11.5kN in addition to this, the vessel is subjected to internal pressure of 1.03Mpa, self-weight 6820Kg.

3.0 FEA Approach

In dealing with the various modes of failure, the designer must have at his disposal a picture of the state of stress in the various parts. It is against these failure modes that the designer must compare and interpret stress values. But setting allowable stresses is not enough. For elastic instability one must consider geometry, stiffness, and the properties of the material. Material selection is a major consideration when related to the type of service. Design details and fabrication methods are as important as "allowable stress" in design of vessels for cyclic service. The designer and all those persons who ultimately affect the design must have a clear picture of the conditions under which the vessel will operate. This investigation primarily deals with the probable causes of in-service damage of IPV with approximate estimation of stresses.

3.1 Material Selection

Usually material in pressure vessel technology are ductile, the plastic flow does not necessarily restricts the usability. Limited plastic flow in testing and in normal operating load cases is admissible, even if it may occur repeatedly; it is taken into account in constitutive laws of material models.

3.2 Model Geometry

In evaluating the geometry, there are several prime considerations. In addition to the necessity to accurately represent the actual geometry of the vessel or component of the vessel, one must consider the loading and support (boundary) conditions and the mesh to be employed. The extent of the vessel or component modeled is also of prime concern when the decision is made to model only part of an overall system. Modeling of the pressure vessel was done using ANSYS workbench software. Later on to model was imported to ANSYS 12 where symmetric model was prepared, and then accordingly vessel supports was tilted to required inclinations.

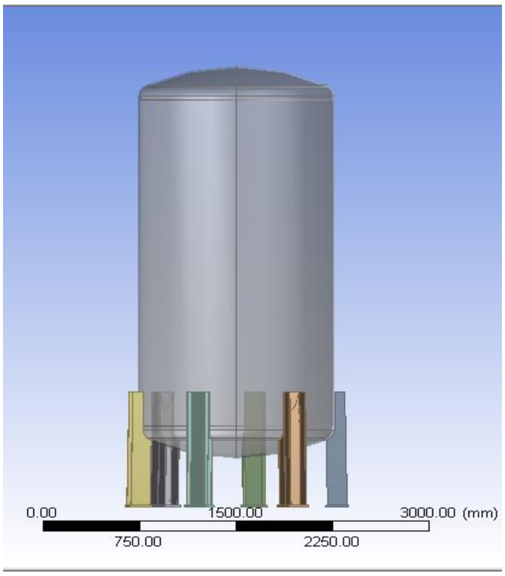

Fig. 2 Modeling of Pressure Vessel with 6 Leg Support.

3.4 Element Selection and Meshing

Once the geometry of the object to be analyzed is defined, the first task is to select the type of element that is to be employed. For most pressure vessel analyses, the element selection is made from three categories of elements: axisymmetric solid elements, shell/plate elements and 3-D brick elements. Although nearly all problems can be solved using 3-D brick elements, the other two types offer significant reductions in the solution time and effort where they are applicable. Often, this reduction in solution effort is significant enough to make the use of FE analysis feasible where it might not be with 3-D bricks. The higher order tetrahedron element was used for meshing. The element is defined by 10nodes.

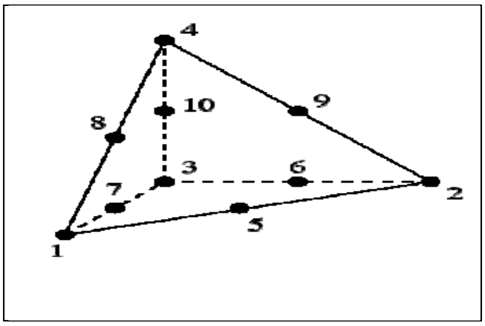

Fig. 4 10 Node Tetrahedron Element

3.5 Meshing of the model

Meshing is the method of dividing the model into the number of element to obtain the good accuracy in the analysis. As the number of element increases the accuracy of analysis increases. In this paper meshing size is taken as 100mm for pressure vessel body and 30 mm for pressure vessel support. Figure 7 shows the meshing of pressure vessel.

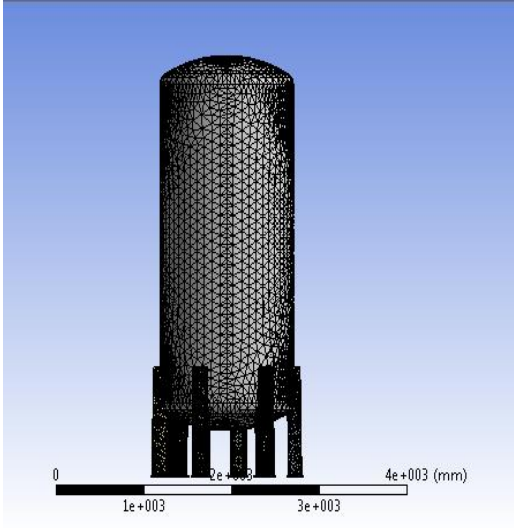

Fig. 6 Meshing Of Pressure Vessel

3.6 Boundary conditions.

Applying the boundary conditions applied to the pressure vessel model. All the supports are fixed. Pressure applied inside the pressure vessel is 150psi.Wind load of 11500 N is applied on one of its face.

4.0 Results and Plots

Area of interest of this paper is to check whether the given material sustain the wind load for maximum structural stability or not. Fig 8 shows the minimum deformation and it is within the limit.

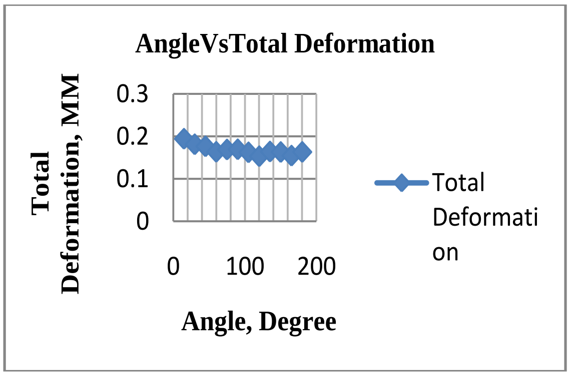

Fig. 7 Total Deformation in mm

By using numerically means finite element method 15-180 degree gives minimum deformation.

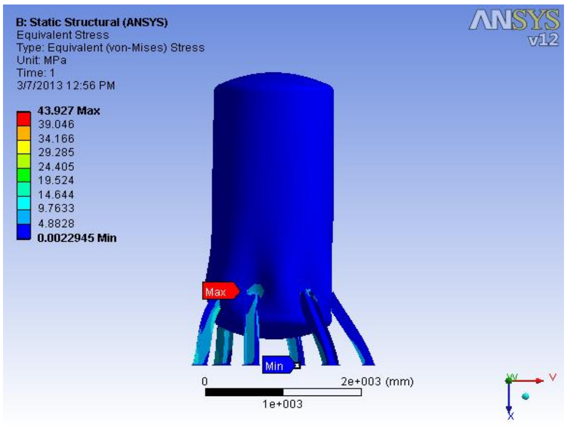

Figure.5 Equivalent Stress at 180 Degree Angle

In this above fig.5 shows the equivalent stress of pressure vessel by simulating the structure for the 15 to 180 degree angle shows the minimum allowable stress of structural stress and hence the structure is safe. Allowable stress for the structural steel is near about 250 Mpa.

5. Experimental

The typical shape of pressure tank is cylindrical to effectively maintain the internal hydrostatic gas pressure. The pressure is near about 1.03 Mpa. The test for pressure vessel leakage finding is hydro test to check the leakage in the pressure vessel.

5.1 Ultrasonic Testing

Weld spot at nozzle vessel intersection tested with an ultrasonic probe positioned on it and transmitting sound pulses into the weld metal, as well as the echo sequence generated on the screen display of the ultrasonic instrument. This sound pulse is transmitted from the probe into the weld spot and partially reflected from the interface between the probe and weld spot. This reflection appears as interface echo at sound entry (1st indication to the farthest left) on the screen display of the ultrasonic instrument. The continuous part of the pulse enters the weld spot and is only reflected from its rear boundary, provided there is no flaw. This reflection is displayed as 1st backwall echo to the right of the interface echo. The sound pulse can run several times back and forth between the front and rear end of the weld spot, and delivers a part of the sound pulse to the probe every time it hits the front end. This ever decreasing part of sound pulse is. Displayed as 2nd, 3rd, 4th backwall echo at the same intervals on the screen. In this connection, the interval between the individual backwall echoes corresponds to twice the material thickness (round trip within the material). If there is a flaw in the weld spot, e.g. in the form of a gas pocket, a part of the sound pulse corresponding to the size of this flaw is additionally reflected from it. As the flaw is situated between the front and rear end of the weld spot, the corresponding flaw echoes also occur between the backwall echoes. In the case of major weld flaws, the flaw echoes are higher and possibly only recognizable.

Hydrostatic testing is also required periodically to re-qualify these pressure vessels for continued service. Vessel was also tested for hydro-test pressure of 1.03Mpa and temperature

Variation of stresses and deformation with respect to inclination of pressure vessel support with 80^0 opening on one side. From this graph conclude that the structure of the 15-180 degree gives the minimum deformation from that considering this as an optimized design. The Value of total deformation in vertical leg support is minimum.

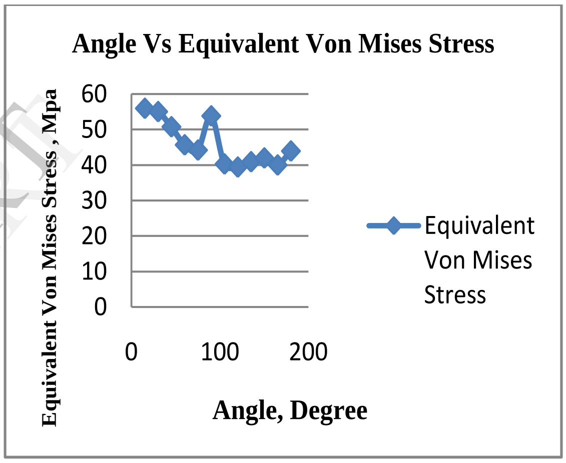

Fig. 8 Graph of Leg Inclination Vs Stress

In fig. 8 graph shows the by simulating angle from 15 to 180 degree structure gives the minimum stress which is less than allowable stress of structural steel(less than 250 Mpa) so, the structure is safe.

7.0 Conclusion

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. In this paper exertion observed that maximum equivalent Von-mises stress observed was about 55MPa around 6 leg supports with vertical inclination on one side 80 degree opening.. By using finite element analysis conclude that due to wind load structure will sustain the wind load and deformation should be within limit. Simulating the structure for the 15 to 180 degree gives minimum stress and it less than allowable stress of structural steel. So structure is safe.

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