Computer Aided Modeling and Simulation of Pressure Vessel Design

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ABSTRACT

The pressure vessels are used to hold gases or liquids at high pressures. The current studies of pressure vessels indicate that there are some cases of cracked or damaged vessels that can cause rupture or leakage failures which can result in fatal accidents in industry. Since the leaking vessel can cause potential health and safety hazards, the proper design of pressure vessels in agreement with the safety codes and standards is important to human safety and health. This paper focuses on design and development of the pressure vessel using computer aided modeling, computational simulation, and prototype testing to determine the parameters including maximum safe operating pressure, total material deformation, wind velocity streamlines, and wind pressure distribution to assist the pressure vessel design.

Keywords: computer modeling, computational simulation, equivalent stress, total deformation, velocity streamline, pressure distribution.

INTRODUCTION

The pressure vessels are applied to store fluids and gases under pressures. The fluids or gases being stored might undergo a change of state inside the pressure vessel including steam boilers or vessels containing reagents in industry. The pressure vessels must be designed to prevent the rupture of pressure vessels which may cause property damage or human injury. Pressure vessels are applied in many applications including compressed air receivers, hot water storage tanks, recompression chamber, and autoclaves. There are many types of pressure vessels but sphere, cylinder, and cone shapes are commonly applied. A regular pressure vessel design involves the cylinder with end caps, or heads. Head shapes are normally in hemispherical or dished shape. Among these shapes, a sphere is the best shape of pressure vessels. Because of high manufacturing cost of the spherical shape, the common pressure vessel is cylindrical shape with semi-elliptical heads at both ends. Because of the cylindrical or spherical shape, the pressure vessels are subjected to pressure loading from all directions The normal stresses resulting from this internal pressure are functions of element radius, pressure vessel shape, and applied pressure. There are two types of analysis are commonly applied to pressure vessels: (1). the analysis uses a simple mechanics approach that is applicable to the pressure vessels of thin wall with a ratio of inner radius (r) to wall thickness (t) larger than or equal to 10 ($r/t \geq 10$). (2). the methodology applies elasticity solution to pressure vessels regardless of the r/t ratio, especially in thick wall.

COMPUTER AIDED MODELING AND SIMULATION

Loadings or forces cause the stresses in pressure vessels and stresses from the inward radial load are either the primary local stress or secondary stress. The stress is primary local stress if it is generated from the unrelenting loads, or secondary stress if caused by the relenting loads. The stress is redistributed inside the pressure vessel in case of primary stress otherwise the load relaxes inside the vessel unit in case of secondary stress.

Plastic instability or incremental collapse is a cyclic strain accumulation that causes damage and instability of pressure vessel through plastic deformation. Stress corrosion is generated since chlorides cause stress corrosion cracking in steels. Corrosion can significantly decrease material life by pitting the surface and propagating cracks.

(1). Analysis of cylinder thickness in this pressure vessel:

$$t = \frac{Pi \times Di}{2 \times \sigma \times \eta - Pi} + CA \qquad (1)$$

Here,
P -internal pressure
Di -internal diameter
CA - corrosion allowance
η -joint efficiency for the shell of pressure vessel
σ -hoop stress for the cylindrical material of pressure vessel
(2). Analysis of cylinder elliptical heads in this pressure vessel:
Thickness of elliptical heads:

$$t = \frac{Pi \cdot di \cdot W}{2 \cdot \sigma \cdot J} \qquad (2)$$

Here, W is the stress intensification factor is defined as follows:

$$W = \frac{1}{6}(2 + k^2) \qquad (3)$$

Where,

$$K = \frac{0.5 d_i}{c} \qquad (4)$$

di - major axis of ellipse
c – joint geometry factor of head cover of pressure vessel
Figure 1 shows the prototype of pressure vessel.

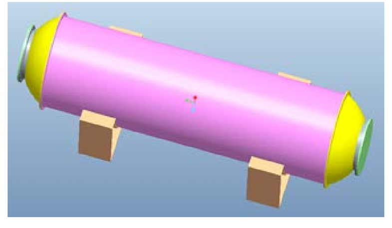

Fig. 1 Prototype of pressure vessel

Considering the circumferential stress of cylindrical shell of vessel:

t = P.Ri / (SE- 0.6P) + CA (5)

Considering the longitudinal stress of cylindrical shell of vessel:

t = P.Ri / (2SE+0.4P) + CA (6)

Under spherical shell situation:

t = P.Ri / (2SE- 0.2P) + CA (7)

In case of conical situation:

t =P.Di / [2cos (α) (SE- 0.6P)] + CA (8)

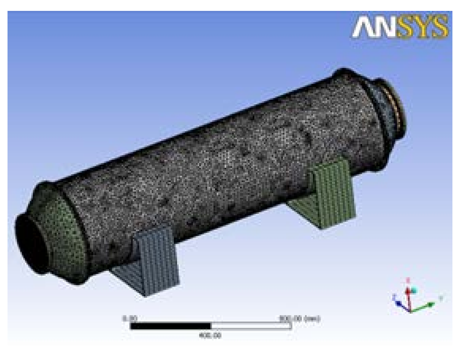

Fig. 2 Model meshing of pressure vessel

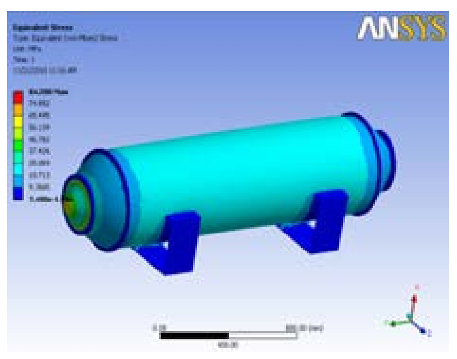

Fig. 3 Equivalent stress generated in pressure vessel

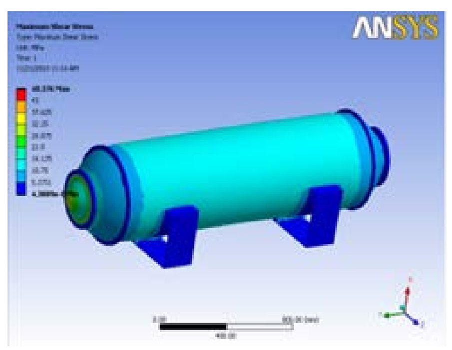

Fig. 4 Maximum shear stress generated in pressure vessel

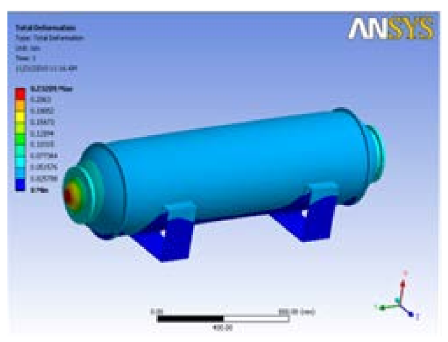

Fig. 5 Total deformation produced in pressure vessel

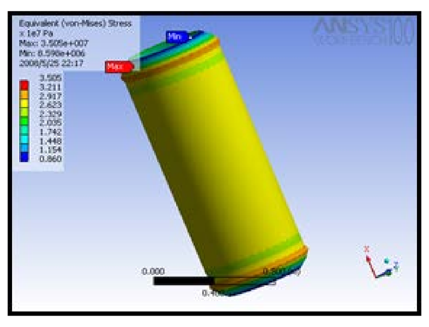

Fig. 6 Equivalent stress contours in pressure vessel

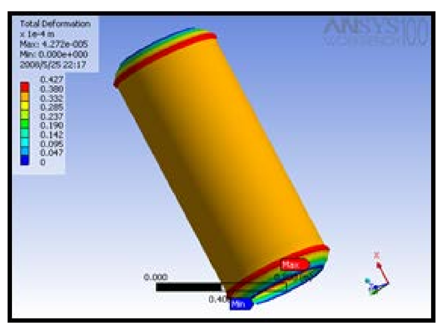

Fig. 7 Total deformation contours in pressure vessel

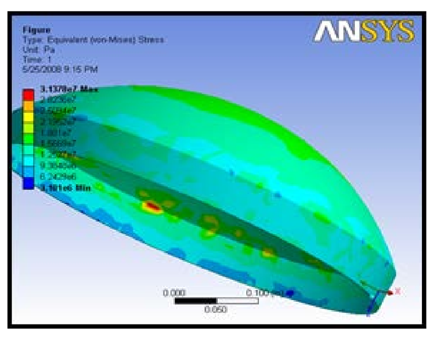

Fig.8 Equivalent stress in heads of pressure vessel

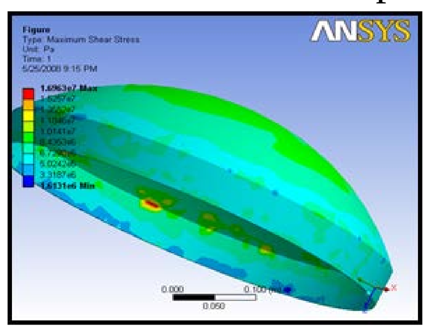

Fig.9 Maximum shear stress in heads of pressure vessel

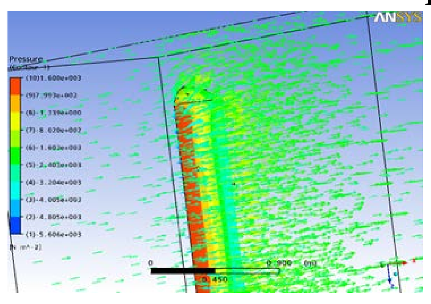

Fig.10 Pressure distribution on external face of pressure vessel in wind analysis

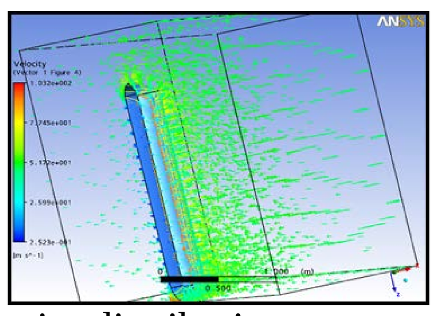

Fig.11 Velocity distribution on external face of pressure vessel in wind analysis

The above computer aided modeling and simulation show the maximum equivalent stress of 35.05 MPa in cylindrical section and 31.378 MPa in heads which are all lower than the material yield strength of 345 MPa. The maximum deformation is 4.272 x 10-5 m which falls within the material spec of allowable deformation. The wind speed of 41 m/s and wind pressure of 730 N/m2 from computational simulation are close to the standard wind load table through interpolation function.

The prototype testing indicated the maximum stress of 37.25 MPa and total deformation of 4.55 x 10-5m in this pressure vessel. The computational simulation and prototype testing have shown the close results that verify the credibility and feasibility of this pressure vessel design.

CONCLUSION

Pressure vessels should be designed to hold the internal pressures due to tensile forces within the walls of the tank. The internal normal stress in the walls of vessels is related to the internal pressure, cylindrical radius, and wall thickness. Pressure vessels must be designed to operate safely at specified pressure to meet safety standard. The computer aided simulation and prototype testing show proper design of this pressure vessel. The proposed computer modeling and computational simulation in this paper provides the feasible methodology to assist future pressure vessel design and development.