Design and FEA Analysis of Jacketed Type Pressure Vessel

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Abstract – **Design and analysis of jacketed type pressure vessels is very critical due to complexity of their heads or ends. This paper deals with design, modelling and thermo-structural FEA analysis of jacketed type pressure vessel with pressure and temperature variations as they undergone external heating or cooling periodically. They are widely used in chemical reactors and pharmaceutical industry to improve homogeneity of fluid properties. Due to variation in pressure and temperature, such pressure vessels undergo failures. In this paper, design of jacketed type Mild Steel Glass Lined (MSGL) pressure vessel is carried out using ASME section VIII, division 1. The design of tori-spherical head along with jacket is also carried out analytically. The pressure vessel is modeled using high end software followed by Finite element thermo-structural analysis for different operating conditions. Steady-state thermal coupled with static structural analysis are also simulated and reported in this paper.**

Keywords— jacketed type; pressure vessel; tori-spherical; pressure and temperature variation

I. INTRODUCTION

A pressure vessel is a closed container designed to hold gases or liquids at a pressure substantially higher or lower ambient pressure. The pressure vessels (i.e. cylinders or tanks) are used to store fluids under pressure. The term pressure vessel refers to vessels operating above the atmospheric pressure, or subject to external pressure. In pharmaceutical industry different process are carried out at different pressures and temperatures. The pressure vessels are designed with great care because rupture of a pressure vessel means an explosion which may cause loss of life and industrial property. Yogeshwar Hari [1] has worked on qualification of a jacketed vessel using finite element analysis but they use simple pressure vessel for analysis and they not use glass lined pressure vessels. Z.W.Wang [2] has carried out his work with thermomechanical analysis of pressure vessels with functionally graded material coating and reported a thermo mechanical analysis. Masato Kano [3] has carried out his work with Plastic Collapse Load for vessel with external flaw simultaneously subjected to internal pressure and external bending moment with experimental and FEA Results. Mingjue Zhou [4] has carried out his work with design optimization of pressure vessel in compliance with elastic stress analysis criteria for plastic collapse using an integrated approach. Defu Nie [5] has carried out his work with fracture behavior simulation of a high pressure vessel under monotonic and fatigue loadings. Jianfeng Mao [6] has carried out his work with investigation on structural behaviors of reactor pressure vessel with the effects of critical heat flux and internal pressure for the analysis aspect they consider heat flux and internal pressure. Arturs Kalnins [7] has carried out his work with fatigue analysis in pressure vessel design by local strain approach. They used local strain approach for the calculating fatigue cycle. Guian Qian[8] has investigated on constraint effect of reactor pressure vessel subjected to pressurized thermal shocks. Due to the pressurerized thermal shock fatigue damge occurred in the pressure vessel. In this paper, design and FEA analysis of Mild Steel Glass Lined (MSGL) jacketed type pressure is carried out with different boundary conditions. Jacketed type and glass lined pressure vessels are rarely reported with such type of analysis.

II. DESIGN OF PRESSURE VESSEL

The pressure vessel design is done by using ASME section VIII division 1 and ASME section II Part-D. There are different types of rules described in ASME section VIII division 1. The design parameters such as thickness of four main components like main shell, jacketed shell, tori-spherical dish end and jacket dish end are computed on the basis of these rules.
DESIGN INPUT DATA:
Material: SA516 GR415
Design pressure: 0.6 Mpa

TABLE-1 MECHANICAL MATERIAL PROPERTY

Property	Nomenclature	Value	Unit
Tensile strength	σ_t	415-580	N/mm^2
Yield strength	σ_y	250	N/mm^2
Maximum allowable stress at 200^{0}C	**S**	118	Mpa
Joint efficiency	**E**	1	

A. Thickness of shell under internal pressure (UG-27)- [12].

When the thickness does not exceed one-half of the radius, or p does not exceed 0. 385 SE then thickness of shell under internal pressure is,

$$t = \frac{PR}{SE-0.6P} \; or \; p = \frac{SEt}{R+0.6t} \qquad (1)$$

B. Thickness of shell and tubes under external pressure (UG-28) [12].

Thickness of shell and tubes under external pressure is determined by,

$$P_a = \frac{4B}{3\left(\frac{D_o}{t}\right)} \; or \; P_a = \frac{2AE}{3\left(\frac{D_o}{t}\right)} \qquad (2)$$

C. Design of formed head under internal pressure (Appendix 1-4) [12]

For the tori-spherical head the thickness of the head is calculated by,

$$t = \frac{PL_0M}{2SE + P(M - 0.2)} \quad (3)$$

D. Formed Heads and Section pressure on convex side (UG-32) [12]

$$A = \frac{0.125}{\left(\frac{R_0}{t}\right)} \; or \; P_a = \frac{B}{\left(\frac{R_0}{t}\right)} \quad (4)$$

DESIGN OUTPUT DATA:
Length of main shell – 1745 mm
Internal diameter of pressure vessel -1766 mm
Crown radius – 1760 mm
Knuckle radius – 350 mm
Thickness of closer dish – 14 mm

TABLE 2 CALCULATED THICKNESS.

	Under Internal Pressure(Mpa)	Under External Pressure(Mpa)
Main shell	5.49	22
Top and bottom head	7.92	25
Jacket shell	6.77	12
Jacket head	5.86	14

Based on above design, three dimensional model of jacketed type MSGL pressure vessel is developed using high end software using different features and assembly constraints as shown in Fig. 1. The developed model is imported to FEA analysis software for design validation purpose.

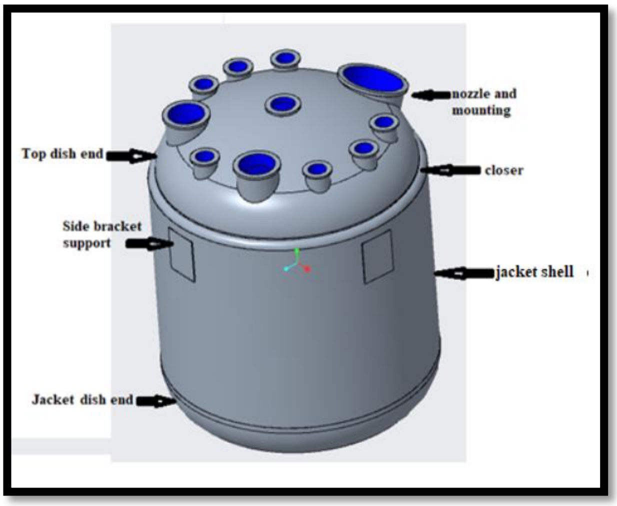

Fig. 1 3D model of MSGL jacketed type pressure vessel

III. MESHING AND BOUNDARY CONDITIONS

Total number of nodes are 230688 and elements are 100071 for a pressure vessel having capacity of 8000 liters. Automatic mesh control method uses the patch conforming tetrahedrons elements for mesh. It uses 'Delaunay tetra meshing algorithm' with an advancing-front point insertion technique for mesh refinement results in accurate surface mesh. Mesh sizing is defined by global and/or local controls. Patch Independent method uses a 'spatial subdivision meshing algorithm'. It performs mesh refinement wherever necessary, but maintains the mesh with larger element lengths wherever possible results in defeatured surface mesh. Method Details contain sizing controls and Automatic curvature & proximity refinement options are available.
Patch conforming method is used for analysis of GL pressure vessel as shown in Fig. 2,

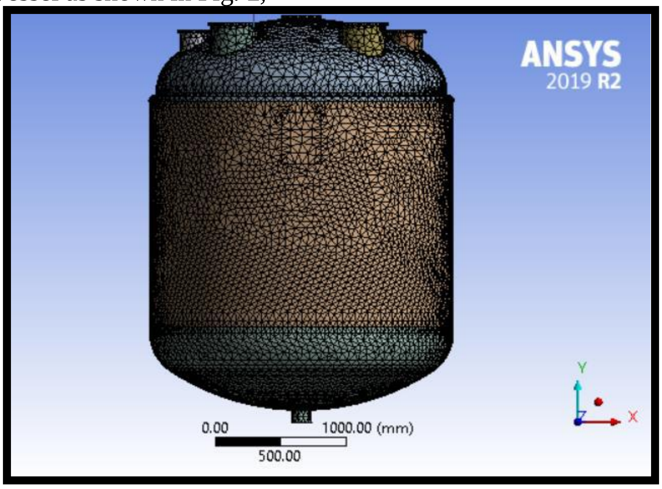

Fig. 2 Meshing model of pressure vessel

BOUNDARY CONDITIONS:

For solution of any static or transient problem. Boundary condition must be specified. The boundary conditions are essential component of a mathematical model. They control or direct the load which lead to a unique solution in the ANSYS workbench. Process chemistry in the pharmaceutical is carried out at different temperatures and pressures. Hence, various boundary conditions are taken based on processing of sterile and non-sterile liquids.

Three boundary conditions are considered for FEA analysis as shown in table 3.

TABLE 3 BOUNDARY CONDITIONS

	Vessel		**Jacket**	
	Temp. (°C)	**Pressure (Mpa)**	**Temp. (°C)**	**Pressure (Mpa)**
Condition 01 (For cooling)	70	0.6	-20	0.7
Condition 02 (For Heating)	-20	0.6	50	0.7
Condition 03 (For Heating)	-25	0.6	95	0.7

TABLE 4 actual position of temperature and pressure

		Condition 01 (For cooling)		Condition 02 (For Heating)		Condition 03 (For Heating)	
	Position of temperature and pressure	**Temp. (^{0}C)**	**Pres-sure (Mpa)**	**Temp. (^{0}C)**	**Pres-sure (Mpa)**	**Temp. (^{0}C)**	**Pres-sure (Mpa)**
1	**Inner side of bottom dish end**	70	0.6	-20	0.6	-25	0.6
2	**Inner side of main shell**	70	0.6	-20	0.6	-25	0.6
3	**Inner side of top dish end**	70	0.6	-20	0.6	-25	0.6
3	**Outer side of bottom dish end**	-20	0.7	50	0.7	95	0.7
4	**Outer side of main shell**	-20	0.7	50	0.7	95	0.7
5	**Inner side of jacket**	-20	0.7	50	0.7	95	0.7
6	**Inner side of jacket dish end**	-20	0.7	50	0.7	95	0.7
7	**Inner side of closer**	-20	0.7	50	0.7	95	0.7
8	**Full outer body**	22	0.1	22	0.1	22	0.1

The different temperatures on the surface of the pressure vessel is shown in Fig. 3 as a steady state thermal conditions, while Fig. 4 represents various pressures to be maintained during the chemical process as a static structural conditions

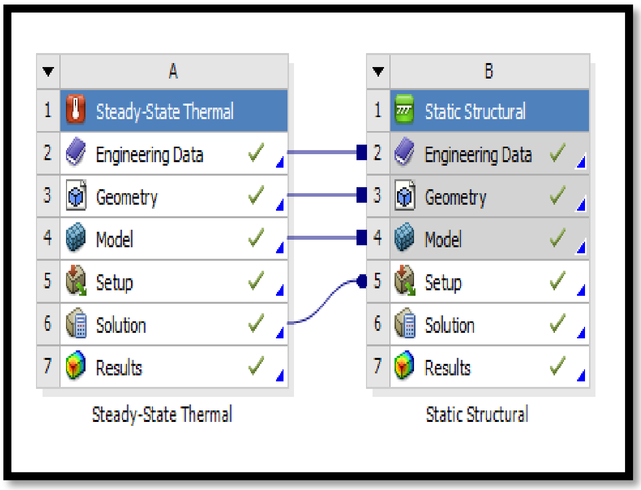

Fig. 3 Steady-state thermal coupled with static structural

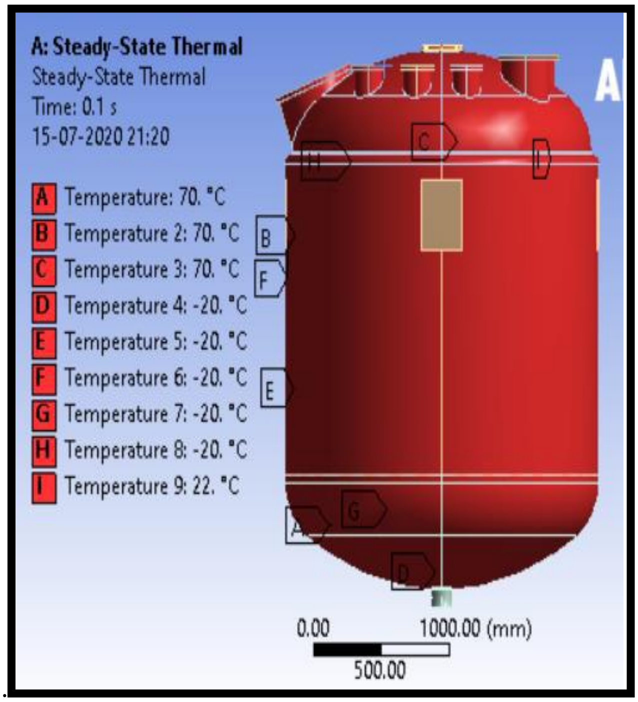

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Fig.4 Steady-state thermal condition.

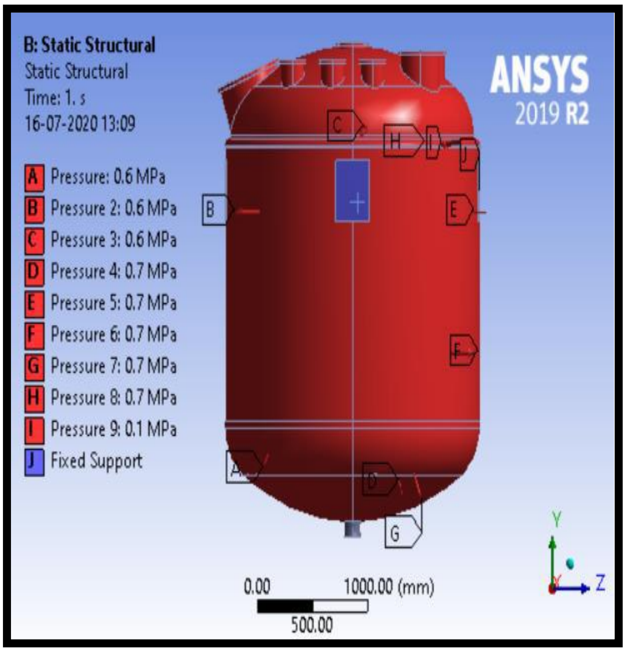

Fig. 5 Static structural condition.

IV. FEA ANALYSIS AND RESULT

FEA analysis is carried out using ANSYS workbench software. The main purpose of analysis is to determine maximum principal stress, total deformation, temperature behavior of jacketed type pressure vessel.

Temperature behavior:

The maximum temperature in pressure vessel wall is 109.12^{0}C. and minimum temperature is -34.863^{0}C. The maximum temperature induced is located at bottom dish end as shown in Fig. 5.

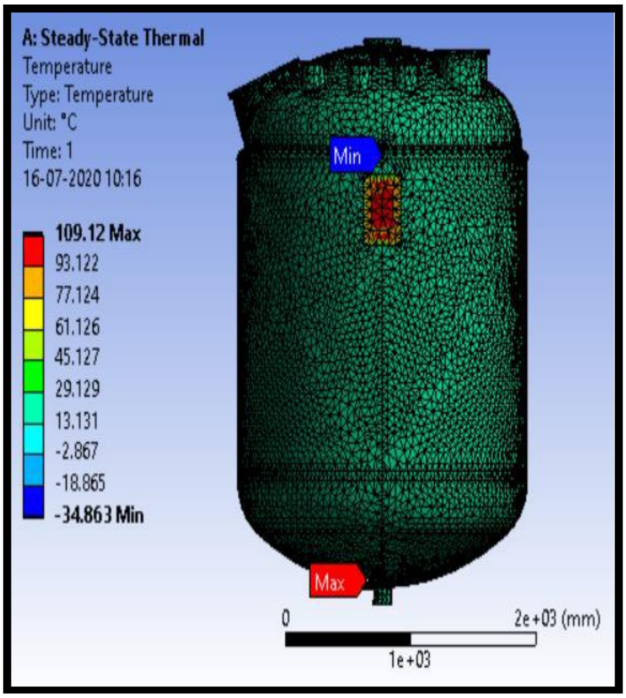

Fig. 6 Temperature Behavior

Total deformation:

Maximum deformation is 1.8221mm, which is also induced at jacket dish end as shown in Fig. 6.

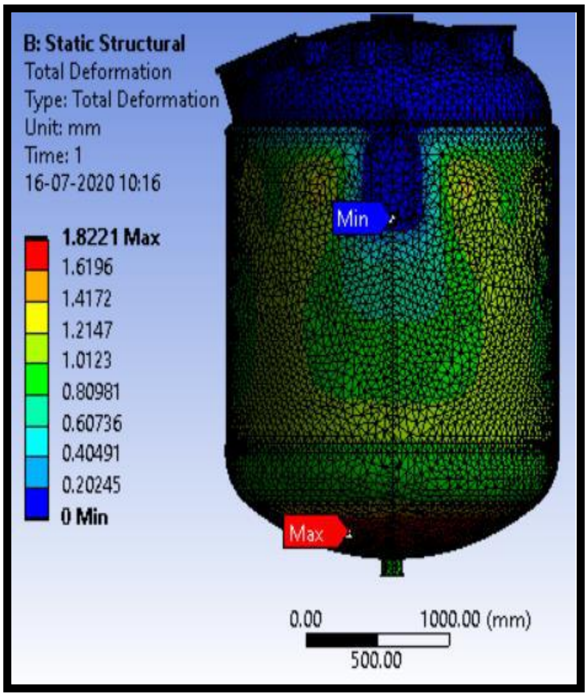

Fig.7 Total deformation

Maximum principal stress:

Maximum principal stress is induced at closer with a magnitude of 344.95 Mpa as shown in Fig. 7.

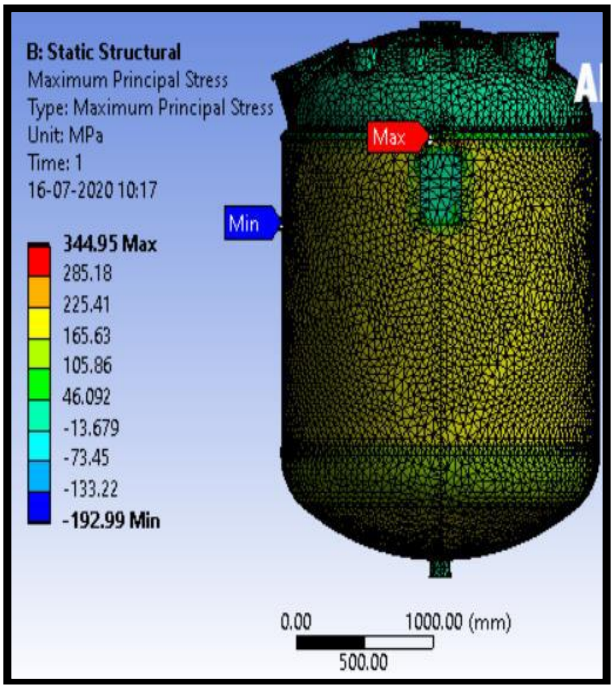

Fig.8 Maximum principal stress.

FEA output is compared for all three conditions and output results are presented in table 4.

TABLE 5 RESULT OF FEM ANALYSIS WITH DIFFERENT CONDITIONS

	Max. Principal Stress (Mpa)	Total Deformation (mm)	Temperature (^{0}C)	
			Max.	Min.
Condition 01	296.26	0.7171	129.87	-20.847
Condition 02	257.34	1.0693	59.44	-72.337
Condition 03	**344.95**	**1.8221**	**109.12**	**-34.863**

V. CONCLUSION.

Thermo-structural analyses with different boundary conditions are carried out for Mild Steel Glass Lined (MSGL) jacketed type pressure vessels. The obtained results are of importance as design rules are not available in ASME Sec. VIII Div.1 for calculating thermal stresses for such pressure vessels. FEA analysis is one the analysis as permitted by U2(g) of code for complex geometries of pressure vessel.

Material has been considered as SA-516 Gr 415 with allowable stress value of 118Mpa. Hence, in line with UG23(e) allowable value for this shell 3 times the above stress value e.g. 118*3= 354 Mpa as thermal stress are secondary stresses. Maximum actual stress is 344.95 Mpa, which is within allowable value as calculated above.

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