

## THERMO-MECHANICAL ANALYSIS FOR SKIRT OF PRESSURE VESSEL USING FEA APPROACH

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### ABSTRACT

In oil, gas and petrochemical industries, in pressure vessels, excessive temperature gradient near the junction of skirt to head in hot operating cases, can cause unpredicted high thermal stresses. Then fracture of the vessel may occur as a result of cyclic operation. Providing an air pocket (hot box) in crotch space is an economical, applicable and easy mounting method in order to reduce the intensity of thermal stresses, due to which, radiation due to temperature difference between the wall of pocket, will absorb heat near the hot wall and release it near the cold wall then the skirt wall conducts heat to the earth as a fin. This conjugated heat transfer removes the temperature gradient boundary and converts its step form to approximately ramp form. This paper demonstrated the profit of hot box over vessel without hot box according to Simulation. It has been seen that radiation has important effect on heat transfer in this triangular cavity and thereby heat conduction in the vertical wall (skirt) is the most important parameter to keep convection in steady state condition.

FEA is a proven cost saving tool and can reduce design cycle time therefore it can be used as accurate tool to investigate stresses in skirt support. The analysis is accomplished in accordance with ASME B & PV code, section VIII, division 2. This provides sound basis for classification of calculated stress intensities.

**KEYWORDS:** Air Pocket, Pressure Vessels, Support Skirt, Thermo-Mechanical FEA

### INTRODUCTION

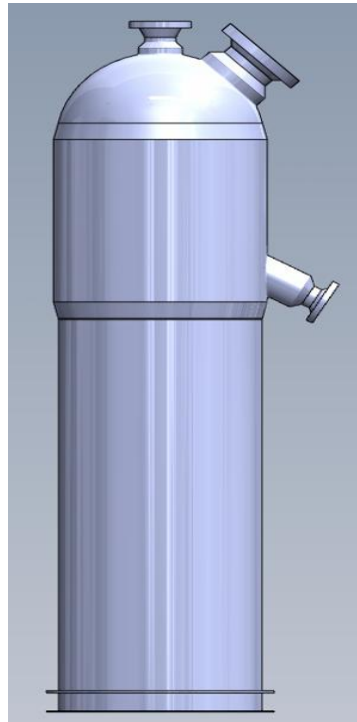
Pressure vessel is a closed cylindrical vessel for storing gaseous, liquids or solid products. The stored medium is at a particular pressure and temperature. The cylindrical vessel is closed at both ends by means of dished end, which may be hemispherical, ellipsoidal and torispherical. The pressure vessels may be horizontal or vertical. The skirt supporting system of this vertical vessel plays an important role in the performance of the equipment. Proper skirt supporting system gives the safety and better efficiency. The bottom skirt supports are critical components since they are to be designed with much care to avoid failure due to temperature gradient. Vessel is mostly used in storage or pressure vessel in industry.

In pressure vessel whenever expansion or contraction would occur normally as result of heating or cooling an object is prevented, thermal stresses are developed. The stress is always caused by some form of mechanical restraint. There are many types of stresses are developed in the element but they are categorized into primary stresses and secondary stresses. Primary stresses are generally due to internal or external pressure or produced by sustained external force and moments these are not self limiting. Thermal stresses are secondary stresses because they are self limiting. That is yielding or deformation of the part relaxes the stress (except thermal stress ratcheting). Thermal stresses will not cause failure by rupture in ductile materials except by fatigue over repeated applications.

The objective of this paper is modified the design of pressure vessel by providing hot box in the crotch area, in order to avoid the failure of skirt support due to thermal and mechanical loading. Thermo-mechanical analysis of skirt

support is done by using FEA software Ansys 14.5 and benefit of pressure vessel design with hot box over without hot box is find out.

**GEOMETRY**

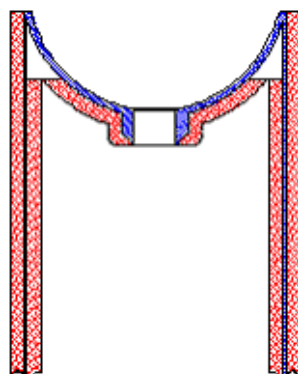


The relevant part for analysis are entire skirt, shell to dished end junction, the bottom of head of vessel and length of cylindrical portion of vessel. The simulated pressure vessel is modeled in solid works, as shown in the Figure 1 below.

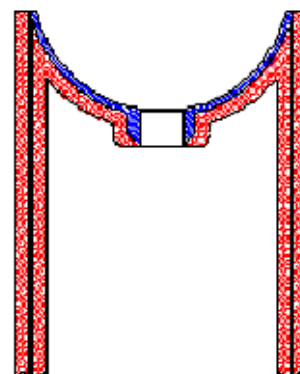
**Modelling Data**

**Table 1**

Component Description	Dimensions in mm
Shell Inner Diameter	1700
Shell thickness	90
Skirt thickness	16
Skirt Inner Diameter	1754
Insulation Thickness	140



**Figure 1(a) Without Hot Box**



**Figure 1(b) With Hot Box**

**Figure 1: Shell and Dished End Portion of Pressure Vessel**

## Material Properties

Design code: ASME Sec II, D, Edition 2007, Addenda 2009

Table 2

Component	Material	Allowable Stress N/mm <sup>2</sup> at 570 <sup>o</sup> C	Chemical Composition
Head and skirt	SA 387 GR.22 CL.2	148	2.25Cr-1Mo

## Meshing of Geometry

A 3-dimensional FE Model has been made by using SOLID186, 3-D 20-Node Structural Solid. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities.

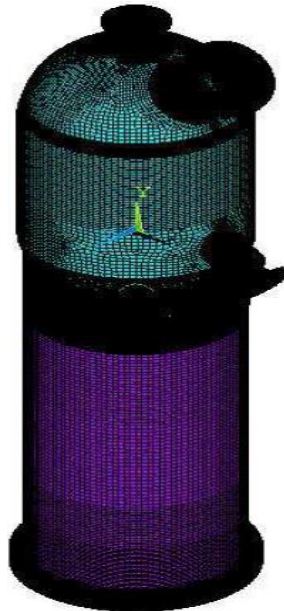


Figure 2

## Thermal Analysis

This analysis has been performed in order to determine the overall temperature level in the Pressure vessel. The temperature found from this analysis is then used to determine the thermal Stresses in the Pressure vessel

### Thermal Boundary Condition for Pressure Vessel without Hot Box

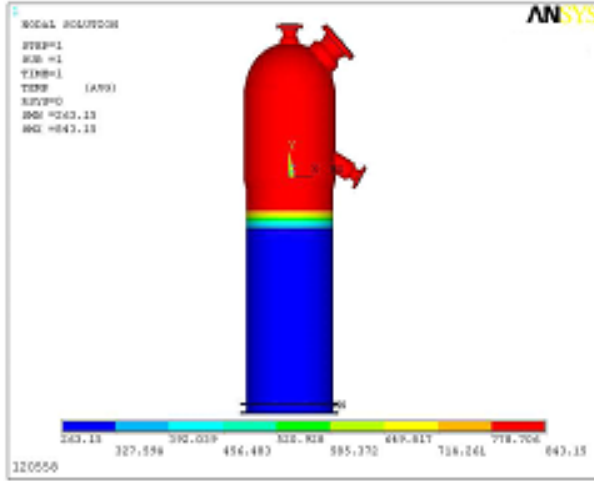
- Inside surface of reactor has been set at design temperature of 570° C.
- Since the insulation has not been considered in FE analysis, hence for taking the effect of insulation in FE analysis, Equivalent heat transfer coefficient of 0.5757 W/m<sup>2</sup>K with bulk temperature of 263.15 K (-10°C) has been set at outer surface of the shell and dished end where 140 mm thick insulation is present.
- The heat transfer coefficient of 25 W/m<sup>2</sup>K with bulk temperature of 263.15 K (-10°C) has been set to the outer surface of the skirt direct exposed to air (no fireproofing).

### Thermal Boundary Condition for Pressure Vessel with Hot Box

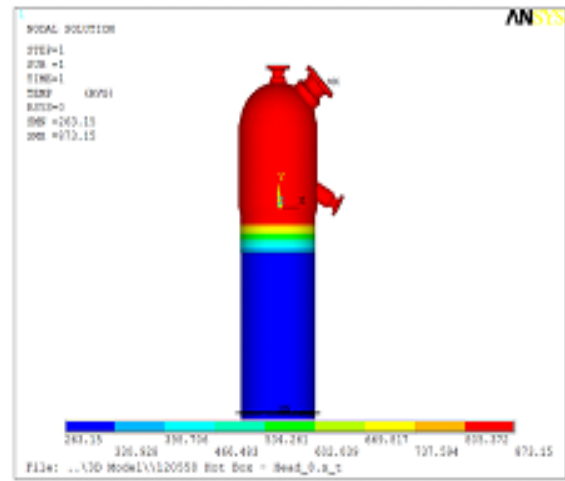
All above boundary conditions are same except in the hot box region radiation loads considered as source is part

of the Dish-end external surface within the hot box and target is internal surface of skirt at the internal of the hot box. Emissivity of the surface is 0.8 and Stefan-Boltzmann constant is  $5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$

**Temperature Distribution**

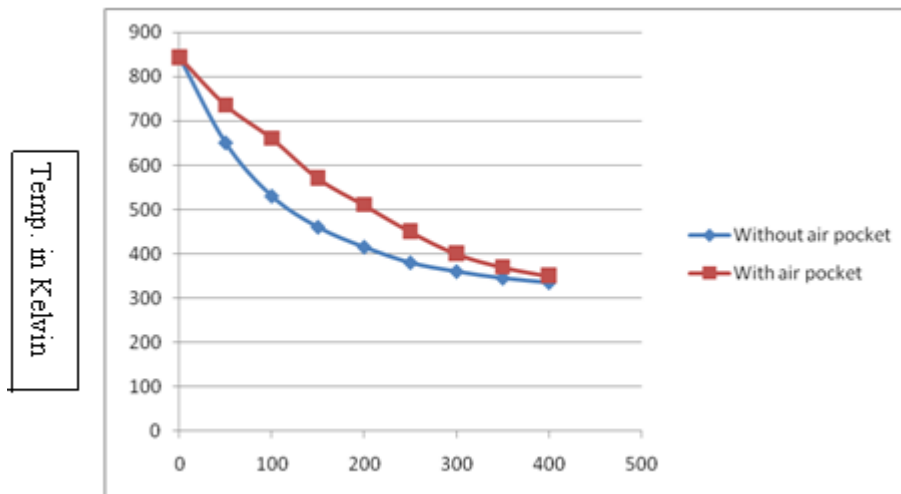


**Figure 3a: Temperature Distribution Without Hot Box**



**Figure 3b: Temperature Distribution with Hot Box**

**Comparison between Temp. Distribution in Pressure Vessel without Hot Box and with Hot Box**



**Graph 1: Distance of Skirt from Junction in mm**

Graph of temp in skirt support versus distance of Skirt from Junction

**DISCUSSIONS BASED ON TEMP DISTRIBUTION PLOTS**

From above graph clear that temperature gradient in case of without hot box is higher than temperature gradient in case of with hot box

**THERMO-MECHANICAL ANALYSIS**

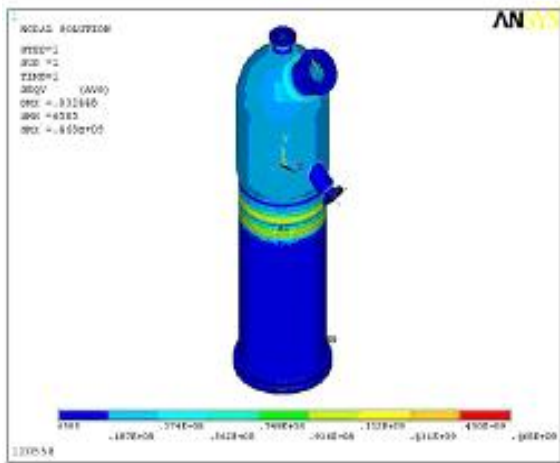
**Boundary Conditions**

Mechanical loading are same for both cases are as follows

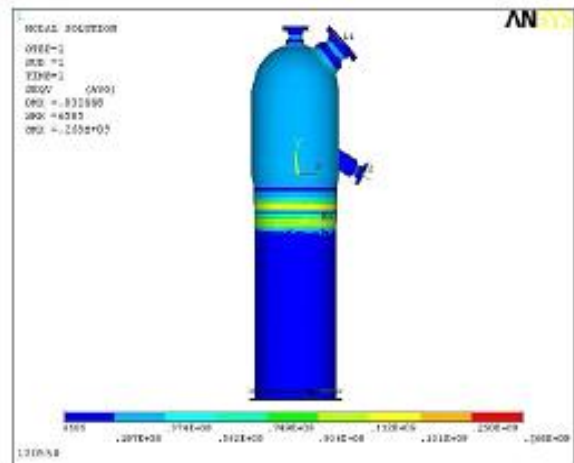
- Operating weight (260KN) has been considered in this analysis
- The Wind load has been applied at a distance 3.44m from the bottom surface of vessel

- For thermal loads, the Nodal temperature distribution obtained from the thermal analysis has been transferred as an input body load boundary condition to structural analysis.
- The nodes of the bottom surface of the base ring have been clamped in longitudinal and hoop direction but allow to move in radial direction

**Von Mises Equivalent Stress Plot for Thermo-Structural Analysis**



**Figure 4a: Von Mises Equivalent Stress Plot with Hot Box**



**Figure 4b: Von Mises Equivalent Stress Plot with Hot Box**

**Design Criteria**

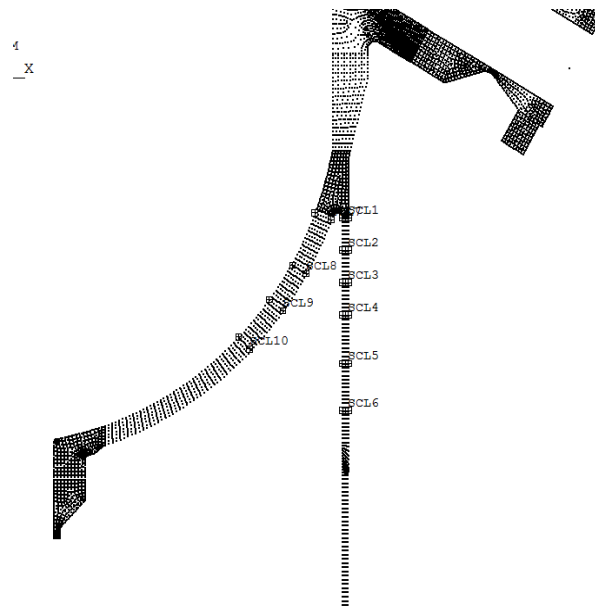
Allowable stress as per design code ASME Sec VIII, Div-2, Edition 2007, Addenda 2009 as follows

Membrane stress < 1.5 Allowable stress

Bending stress + Membrane stress < 3 Allowable stress

**Stress Linearization**

The following Figure shows the locations for Stress Linearization across the thickness at various locations



**Figure 5**

Table 3

Summary of Linearized Equivalent Stress (SEQV) Results in MPa				
Classification Lines	Type of Stress	Linearized Equivalent Stress (Mpa) without Hot Box	Linearized Equivalent Stress(Mpa)with Hot Box	Limit on Stress Categories (MPa)
SCL-1	Membrane	80.36	70.2	222
	Membrane + Bending	260.3	200.3	444
SCL-2	Membrane	120.06	110	222
	Membrane + Bending	350	210	444
SCL-3	Membrane	160.45	150	222
	Membrane + Bending	360.12	220	444
SCL-4	Membrane	190.63	160	222
	Membrane + Bending	468	268.2	444
SCL-5	Membrane	165.45	122	222
	Membrane + Bending	360.12	165	444
SCL-6	Membrane	130.5	90	222
	Membrane + Bending	260.3	150	444

## RESULTS AND DISCUSSIONS

### For Without Hot Box Case

- The maximum value of the general membrane stress ,was found to be equal to 190.63 MPa which is lower than 1.5Sm i.e.,222 MPa. (refer Clause 5.2.2.4 of ASME Sec VIII Div2,edition 2007)
- The maximum value of the Membrane + Bending, was found to be equal to 468 MPa which is higher than 3Sm i.e., 444 MPa. (refer Clause 5.2.2.4 of ASME Sec VIII Div2,edition 2007)
- Thus, Stress limits of ASME Sec VIII Div.2 are not met, thus demonstrating that the design is under not safe for the specified operating conditions.

### For with Hot Box Case

- The maximum value of the general membrane stress , was found to be equal to 168.2 MPa which is lower than 1.5Sm i.e., 222 MPa. (refer Clause 5.2.2.4 of ASME Sec VIII Div2,edition 2007)
- The maximum value of the local membrane stress ,was found to be equal to 268.2MPa which is lower than 3Sm i.e., 444 MPa. (refer Clause 5.2.2.4 of ASME Sec VIII Div2,edition 2007)
- Thus, Stress limits of ASME Sec VIII Div.2 are met, thus demonstrating that the hot box design is safe for the specified operating conditions.

## CONCLUSIONS

From above result we can see that by providing small air pocket at the shell and skirt junction the temperature stress and overall stress concentration can reduce considerable. As per the calculation, reduction in peak stress is almost around 30% as compared to without hot box. The alternative stress becomes lower and hence fatigue life of the component increases.

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