Design and Analytical Calculation of Reactor Pressure Vessel

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Abstract: ***In today's scenario pressure vessel is used for many purposes all over the world and for that pressure vessel manufacturers try to make best pressure vessel which fulfills all most all requirements of industry. Today many types of pressure vessels are available with different capacities. Pressure vessel storage the liquid and discharge it with required pressure and temperature. Life of the pressure vessel has less due to some losses like residual stresses and distortion on the weld joint and creeping is done on pressure vessel parts. So we would like to check the design of existing reactor pressure vessel which is manufactured by "NEW BLUEMOON ENGINEERS" and make new design of some major parts of reactor pressure vessel and comparing the design through some experimental/analytical base modeling and thermal analysis of reactor pressure vessel by using advanced CAE tool. So it gives the best design which is feasible for reactor pressure vessel. This paper gives some of the important information, knowledge and analytical calculation and comparison of existing and new design reactor pressure vessels to empower the basic fundamentals to carry out work.***

Keywords: Reactor Pressure vessels, Design, Analytical calculation.

1. Introduction

A pressure vessel is a closed container designed to hold gases or liquids at a pressure substantially different from the ambient pressure.

The pressure differential is dangerous and many fatal accidents have occurred in the history of pressure vessel development and operation. Consequently, pressure vessel design, manufacture, and operation are regulated by engineering authorities backed by legislation. For these reasons, the definition of a pressure vessel varies from country to country, but involves parameters such as maximum safe operating pressure and temperature.

A Pressure Reactor, sometimes referred to as a pressure tube, or a sealed tube, is a chemical reaction vessel which can conduct a reaction under pressure. A pressure reactor is a special application of a pressure vessel. The pressure can be caused by the reaction itself or created by an external source, like hydrogen in catalytic transfer hydrogenation.

Shell, Heads, Nozzles are the main components of the reactor pressure vessel.

New Bluemoon Engineers manufacturing the following types of reactor pressure vessels in the present day and on the bases of that design, we will try to thermal analysis the reactor pressure vessel.

The schematic diagram of existing reactor pressure vessel is given below and on the bases of that diagram we are going for the design and analytical calculation.

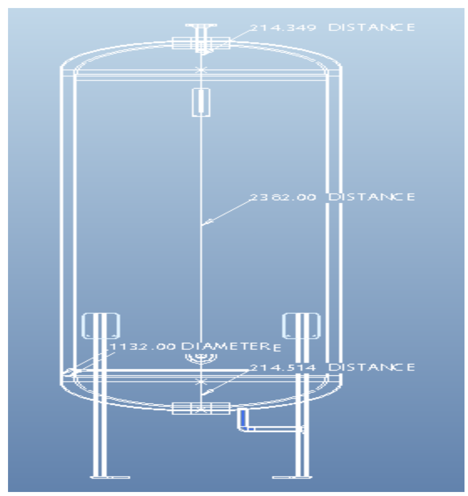

Figure 1: Reactor Pressure Vessel

2. Design of Pressure Vessels

The design of the pressure vessels begins with a selection of the design parameter such as:

1. Design pressure
2. Allowable stress
3. Corrosion allowance

1) DESIGN PRESSURE (Pi):

Design pressure is the pressure for which the pressure vessel is design.
Design pressure, Pi= 1.05 (Max. working pressure)
Hydrostatic test pressure= 1.3 (design pressure)

2) ALLOWABLE STRESS (σ_{all}):
As per IS and ASME Code, all allowable stress is based on

the ultimate tensile strength with a factor of safety of 3 and 4 respectively.

As per the DIN code, the allowable stress is based on the yield strength with a factor of safety of 1.5.

$$\sigma_{all} = \frac{S_{ut}}{Nf} ; \quad \sigma_{all} = \frac{S_{yt}}{1.5}$$

Where S_{ut}= UTS for pressure vessel materials, N/mm^2

S_{yt}= Yield strength for pressure vessel materials, N/mm^2

Nf = Factor of safety

3) CORROSION ALLOWANCE (C):

The wall of the pressure vessel is subjected to thinning due to corrosion which reduces the life of the pressure vessel.

2.1 Design of Pressure Vessel Shell

There are mainly two type's cylindrical and spherical pressure vessel shells.

The thickness of the cylindrical pressure vessel shells subjected to internal pressure is determined on the basis of theory of thin cylinders with suitable modification.

2.1.1Cylindrical Pressure Vessel Shell:

Let, σ_{all} = allowable tensile stress for cylindrical vessel shell, N/mm^2

Pi = Design Pressure (internal pressure), N/mm^2

di = inner diameter of the cylindrical vessel shell, mmd = mean diameter of the cylindrical vessel shell, (di + t), mm

t = thickness of the shell without corrosion allowance, mm

t_s = thickness of the shell with corrosion allowance, mm

l = length of the cylindrical vessel shell, m

η_l = efficiency of longitudinal joints, mm

C = corrosion allowance, mm

Therefore, the thickness of cylindrical vessel shell:

$$t = \frac{Pi \cdot di}{2 \sigma_{all} \eta_l - Pi} + C$$

2.2 Design of Pressure Vessel End Closures:

The cylindrical pressure vessels are closed at the ends by either:

1. Flat Heads
2. Formed Heads

In the existing and new design reactor pressure vessel, we are working with the semi – elliptical head so here we are discussing in details only about semi – elliptical head.

2.2.1 Semi-elliptical dished – head

The Thickness of pressure vessel semi-elliptical dished-head:

$$t_h = \frac{K_f Pi \cdot di}{2 \sigma_{all} \eta_l - 0.2Pi} + C$$

where K_f = stress intensification factor

$= 1/6 [2+K_1^2]$

; K_1=major axis/ minor axis=2 (taken)

S_f = 3 t_h or 20 mm which is larger

3. Analytical Calculation

As per the data provided by the company, we should try to get the necessary dimensions of the main parts of the reactor pressure vessel by analytical method.

3.1 Calculation of Circumferential Stresses

$$\sigma_t = \frac{Pi \cdot di}{2\,t} \text{ N/mm}^2$$

Table 1: Circumferential Stresses for Existing Core

Design pr. (kg/cm^2 g)	*Int. dia (mm)*	*Thk (mm)*	*Cirm. Stress (N/mm^2)*
11	1000	6	89.89×10^6
11.55	1000	6	94.38×10^6
12	1000	6	98.07×10^6
13	1000	6	106.24×10^6
14	1000	6	114.41×10^6
15	1000	6	122.58×10^6
16	1000	6	130.75×10^6
17	1000	6	138.92×10^6
18	1000	6	147.1×10^6
19	1000	6	155.27×10^6
20	1000	6	163.44×10^6
21	1000	6	171.61×10^6

3.1.1Comparison

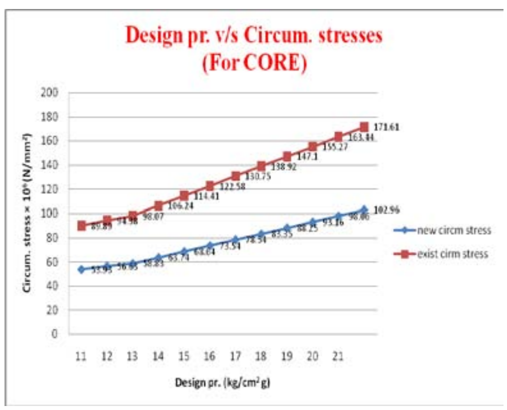

Figure 2: Design pr. Vs Circum. Stress (For Core)

Table 2: Circumferential Stresses For New Core

Design pr. (kg/cm² g)	*Int. dia (mm)*	*Thk (mm)*	*Cirm. Stress (N/mm²)*
11	1000	10	53.93×10^6
11.55	1000	10	56.63×10^6
12	1000	10	58.83×10^6
13	1000	10	63.74×10^6
14	1000	10	68.64×10^6
15	1000	10	73.54×10^6
16	1000	10	78.54×10^6
17	1000	10	83.35×10^6
18	1000	10	88.25×10^6
19	1000	10	93.16×10^6
20	1000	10	98.06×10^6
21	1000	10	102.96×10^6

3.2 Calculation of Longitudinal Stresses

$$\sigma_t = \frac{Pi \, . \, di}{4t} \text{ N/mm}^2$$

Design pr. (kg/cm² g)	*Int. dia (mm)*	*Thk (mm)*	*long. stress (N/mm²)*
11	1000	6	44.94×10^6
11.55	1000	6	47.19×10^6
12	1000	6	49.03×10^6
13	1000	6	53.12×10^6
14	1000	6	57.21×10^6
15	1000	6	61.29×10^6
16	1000	6	65.38×10^6
17	1000	6	69.46×10^6
18	1000	6	73.54×10^6
19	1000	6	77.63×10^6
20	1000	6	81.72×10^6
21	1000	6	85.81×10^6

Design pr. (kg/cm² g)	*Int. dia (mm)*	*Thk (mm)*	*long. stress (N/mm²)*
11	1000	10	26.96×10^6
11.55	1000	10	28.31×10^6
12	1000	10	29.41×10^6
13	1000	10	31.87×10^6
14	1000	10	34.32×10^6
15	1000	10	36.77×10^6
16	1000	10	39.22×10^6
17	1000	10	41.7×10^6
18	1000	10	44.12×10^6
19	1000	10	46.58×10^6
20	1000	10	49.03×10^6
21	1000	10	51.48×10^6

3.2.1Comparison

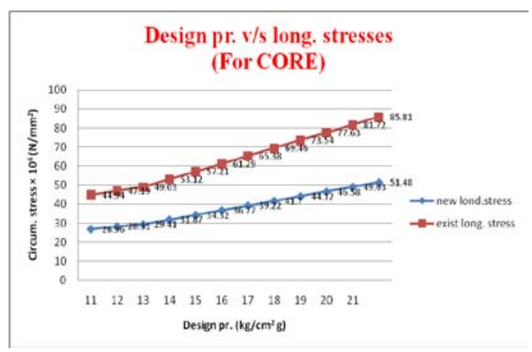

Table 3: Longitudinal Stresses for New Core

3.3 Summary of Design and Calculation Data

Table 4: Longitudinal Stresses for Existing Core

SR. NO	ANALYSIS OF DESIGN AND CALCULATION DATA				
		EXISTING RPV	NEW DESIGN RPV	SUMMARY	REMARKS
1	DESIGN PRESSURE	11.55 Kg/cm2 g	21 Kg/cm2 g	New design RPV has higher compare to existing RPV which is suitable	Feasible
2	OPERATING PRESSURE	11 Kg/cm2 g	11 Kg/cm2 g		
3	THICKNESS OF CORE SHELL	6 mm	10 mm	New design RPV has higher compare to existing RPV which is suitable	Feasible
4	THICKNESS OF JACKET SHELL	6 mm	6 mm	same as per the analytical calculation	
5	THICKNESS OF CORE DISHED HEAD	6 mm	10 mm		
6	THICKNESS OF JACKET DISHED HEAD	6 mm	6 mm	same as per the analytical calculation	
7	CIRCUMFERENTIAL STRESSES ON CORE	94.38 10^6 N/mm^2	53.93 × 10^6 N/mm^2	New design RPV has less compare to existing RPV which is suitable	Feasible
8	LONGITUDINAL STRESSES ON CORE	47.19 × 10^6 N/mm^2	26.96 × 10^6 N/mm^2	New design RPV has less compare to existing RPV which is suitable	Feasible
9	CIRCUMFERENTIAL STRESSES ON JACKET	9.17 × 10^6 N/mm^2	9.17 × 10^6 N/mm^2		
10	LONGITUDINAL STRESSES ON JACKET	4.58 × 10^6 N/mm^2	4.58 × 10^6 N/mm^2		ss

4. Conclusion

After analytical calculation, we have to conclude that the thickness and the design pressure of the new design reactor pressure vessel is increase compare to existing reactor pressure vessel but the circumferential stresses and the longitudinal stresses is decrease in new design reactor pressure vessel.

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