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DESIGN AND ANALYSIS OF HORIZONTAL PRESSURE VESSEL FOR VACUUM SYSTEM DRAIN COLLECTION RECEIVER

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Abstract: The knowledge of process equipment design or Pressure Vessel design is an important prerequisite for the development of any processing industries, such as oil & gas, Chemical Processing Industries, Pharmaceutical, since it governs the shape and size of the plant.in this project work emphasis is given on mechanical aspect of process equipment design i.e. strength and rigidity consideration, for the smooth functioning and operation of equipment. In a refinery or in process industry for some process purpose vacuum is required to remove the air inside the piping and main vessel. That air may contain moisture, chemical vapors and steams etc. It is also a very corrosive environment. All of this corrosive air will get condensed and that condensate need to store in an ancillary pressure vessel as a collection receiver for an oil refinery or process industry. The proposed work focuses on design and analysis of horizontal pressure vessel for Vacuum system drain collection receiver based on (ASME) Boiler and Pressure Vessel Code, Section VIII, Division 1. As per the customer requirement, the pressure vessel will be designed for a capacity of 0.5 m^3. The vessel is required to contain an internal working pressure of 0.815 kg/cm^2 with Temperature is 51.6 ^0C. In order to make this pressure vessel safe, the vessel is designed for Maximum pressure is 1.54 kg/cm^2, with design temperature of the fluid is 102^0C. The Theoretical results are validating with the PV elite software result as per ASME Section –VIII and Division.1.

Keywords: Vacuum system, ASME, Pressure vessel, and condensate etc….

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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. In a refinery or in process industry for some process purpose vacuum is required to remove the air inside the piping and main vessel. That air may contain moisture, chemical vapors and steams etc. It is also a very corrosive environment. All of this corrosive air will get condensed and that condensate need to store in an ancillary pressure vessel as a collection receiver for an oil refinery or process industry as shown in fig-1

The proposed work focuses on design and analysis of horizontal pressure vessel for Vacuum system drain collection receiver based on (ASME) Boiler and Pressure Vessel Code, Section VIII, Division 1. As per the customer requirement, the pressure vessel will be designed for a capacity of 0.5 m^3. The vessel is required to contain an internal working pressure of 0.815 kg/cm^2 with Temperature is 51.6 ^{0}C. In order to make this pressure vessel safe, the vessel is designed for Maximum pressure is 1.54 kg/cm^2, with design temperature of the fluid is 102^{0}C.

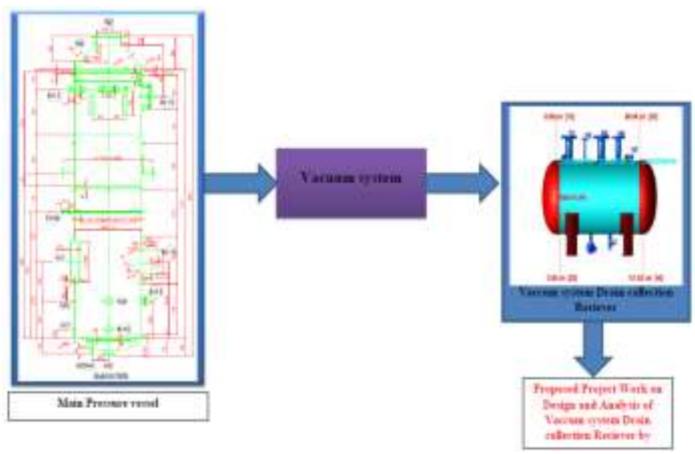

Fig -1: Layout of project work

1.1 Basic Considerations in Process Equipment Design

(a) Selection of type of vessel and its capacity required gives the service in the most satisfactory manner. Here the basic parameters under consideration are function of the vessel, nature of fluid and process, and storage or processing capacity of equipment.

(b) Optimum Processing Condition: Optimum condition such as temperature, pressure etc. Under which equipment is expected to perform are governed by the process requirements.

(c) Appropriate Material of Construction: For the construction of equipment, appropriate material must be recommended which should be suitable for the process conditions with sufficient strength and low cost. Another important requirement of the material selected is the ability to resist the corrosion.

(d) Sufficient Strength and Rigidity of Components and Equipment: While designing equipment, various loads are to be considered; like load due to self-weight, loads from supported equipment and piping, wind and earthquakes load, impact and cyclic load which ultimately affect the strength and rigidity of equipment.

(e)Performance of Mechanism: Satisfactory performance of mechanism for smooth and reliable functioning of equipment is required.

(f) Ease of maintenance and repair: selection and positioning of the proper openings and connections gives ease in maintenance and repair or replacement.

(g) Ease of Operation and control: Equipment should be designed ergonomically for easy operation and control. The controls should be easily accessible and logically positioned.

(h) Fabrication Methods: Each fabrication method has certain advantages for particular types of equipment. The size, shape, service, and material properties of the equipment influence the selection of the reliable fabrication method.

(i) Economic Considerations: Obviously it is a major constraint on any engineering design: plant must make profit within its constraints; the cost of material, mechanism and fabrication must be as low as possible.

(j) Safety Requirements: all safety measures must be taken while designing equipment.

1.2 Materials of Construction for Processing Equipment's

The most important criteria to be considered when selecting a material of construction are various properties of material. Properties of material can be easily divided into three groups as physical, chemical and mechanical properties. Specific weight, thermal conductivity etc. are the physical properties of material. Whereas chemical composition which affects the corrosion resistance is major chemical property of the material, Strength, stiffness, toughness, hardness and resistance to wear, creep and fatigue etc,Are the important mechanical properties under consideration Apart from this machinability, weld ability etc. are important from fabrication point of view.

The materials commonly used in process vessel construction can be grouped as follows:

1. Ferrous Materials: carbon, low alloy, high alloy and stainless steels etc.

2. Non-Ferrous Materials: Aluminum, copper, nickel and their alloy etc.

3. Non-Metallic Materials: Plastics, rubber, glass, graphite etc.

1.3 Limitations of Pressure Vessel

Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, persistent slip bands (PSBs), and grain interfaces. Round holes and smooth transitions or fillets will therefore increase the fatigue strength of the structure. Pressure vessels are held together against the gas pressure due to tensile forces within the walls of the container. The normal (tensile) stress in the walls of the container is proportional to the pressure and radius of the vessel and inversely proportional to the thickness of the walls. Therefore, pressure vessels are designed to have a thickness proportional to the radius of tank and the pressure of the tank and inversely proportional to the maximum allowed normal stress of the particular material used in the walls of the container.

A fracture is the separation of an object or material into two or more pieces under the action of stress. The fracture of a solid usually occurs due to the development of certain displacement discontinuity surfaces within the solid. If a displacement develops perpendicular to the surface of displacement, it is called a normal tensile crack or simply a crack; if a displacement develops tangentially to the surface of displacement, it is called a shear crack, slip band, or dislocation. Fracture strength or breaking strength is the stress when a specimen fails or fractures.

2. Aim and objectives behind present research work

Aim of proposed work is to design new horizontal pressure vessel For Vacuum system Drain Collection Receiver as per ASME div VIII section1 and analyzing with PV elite software results.
The main objectives of proposed work is to analyze the design of a horizontal pressure vessel For Vacuum system Drain Collection Receiver as per customer requirement based on ASME code section VIII Divison.1. According to that following are the objectives to be discussed.

- To understand the industrial operating parameters by industrial visit.
- To understand construction and working of design of a horizontal pressure vessel In Vacuum system Drain Collection Receiver.

- To understand the reasons behind the defect occurred in the horizontal pressure vessel.
- To plan for design of horizontal pressure vessel In Vacuum system Drain Collection Receiver based on ASME code section VIII Divison.1.
- To prepare a model for analysis purpose using PV Elite Software techniques.
- To prepare design calculation to overcome possible defects in horizontal pressure vessel.
- To compare theoretical results with the results of PV elite software.
- To check design consistency and suggest final design for fabrication based on the analysis carried out.

2.1 Definition of the problem:

- In a refinery or in industry for some process purpose vacuum is required to remove the air inside the piping and main vessel. This vacuum is created with the help of vacuum system. That air may contain moisture, chemical vapors and steams etc. It is also a very corrosive environment. As per the client's requirement, all of this corrosive air will get condense and that condensate need to store in an ancillary pressure vessel as a collection receiver for an oil refinery or process industry.
- In order to make horizontal pressure vessel For Vacuum system Drain Collection Receiver we are using the ASME code section VIII Div.1 and analyzing the same with the results we are getting with the help of PV Ellite software. Also tackling various defect arising in the pressure vessel.
- Thus problem can be defined as **"Design of horizontal pressure vessel For Vacuum system Drain Collection Receiver as per customer requirement and overcoming defects arising in horizontal pressure vessel"**

3. Manual Calculations

Design pressure including static head:

$$\text{Static Head} = \frac{(Desnsity\ of\ contents)*H}{1000}$$

$$= \frac{683*635}{1000}$$

$=433.705$ Kg/$m3$

$= 0.043$ Kg/cm²

Therefore,

Design pressure including static head = (Design pressure) + (Static Head)

= 1.54 +0.043

= 1.583 Kgf/cm²

3.1 Cylindrical Shell Thickness for Internal Design Pressure as Per UG-27(c)

Fig -2: Cylindrical shell

1] Circumferential Stress (Longitudinal Joints) as per UG 27 (c):

Minimum required thickness $t = \frac{PR}{(SE - 0.6P)}$

= $0.155 * 320.500/[(138 * 1) - (0.6 * 0.155)$

= 0.361 mm

2] Longitudinal Stress (Circumferential Joints) as per UG 27 (c):

Minimum required thickness $t = \frac{PR}{(2SE + 0.4P)}$

$= \frac{0.155 * 320.500}{[(2 * 138 * 1) - (0.4 * 0.155)]}$

=0.212 mm

But, As per UG-16(b), Minimum required thickness shall be>3/32 inch

i.e., t = 0.094 inch

=2.500mm

Therefore

Cylindrical Shell Thickness =Governing thickness + corrosion allowance

=2.500+3

=5.500~6mm

3.2 Cylindrical Shell Thickness for External Design Pressure as Per UG-28(c):

Fig -3: Cylindrical shell

From Fig. G Subpart 3 of section II part D,

Factor A= 0.0002272

From Fig. CS-2 Subpart 3 of section II part D,

Factor B= 22.71

- Maximum Allowable external working Pressure (Pa):

Pa= 4B/3(D0/t)

=4*22.71/3*(215.6667)

=0.140402 MPa

AS Pa > P Hence Thickness Is Adequate. Design is Safe for External Pressure

3.3 Ellipsoidal Head Thickness for internal design pressure, as Per UG-32 (d)

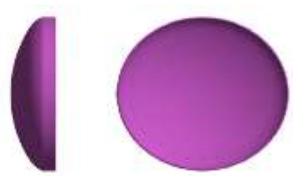

Fig -4: Ellipsoidal head

Minimum Required Thickness of Head as Per UG-32(d)

$$t = \frac{PD}{(2SE - 0.2P)}$$

$$t = \frac{0.155*641}{(2*138*1)-(0.2*0.155}$$

t = 0.36mm

t = 0.36mm

But, As per UG-16(b), Minimum required thickness shall be>3/32 inch

i.e. , t = 0.094 inch

=2.500mm

Therefore,

Ellipsoidal Head Thickness = Governing thickness + corrosion allowance

= 2.500+3

=5.500~6mm

Provided Head Thickness is Adequate.

3.4 Ellipsoidal Head Thickness for External design pressure, as Per UG-33(d)

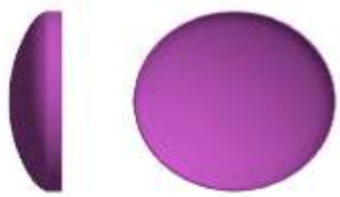

Fig -5: Ellipsoidal head

Spherical Radius Factor (K_O) =0.90

Therefore,

Outside Radius of Ellipsoid Head

(R_O) = (K_O*D_O)

(R_O) =0.90*647

(R_O) =582.300 mm

Factor A = $\frac{0.125}{\frac{R_O}{t}}$

$=\frac{0.125}{582.300*3}$

= 0.000644

From fig CS-2, Factor

B=64.380Mpa

=656.483 Kg/Cm2

Maximum Allowable external working Pressure (P_a)

$(P_a) = \frac{B}{\frac{RO}{t}}$

$P_a = \frac{64.380}{582.300/3}$

P_a = 0.332 MPa

P_a = 3.38 Kg/Cm2

Hence Pa > P Hence Thickness Is Adequate.

3.5 Checking for Heat Treatment of Shell (As Per UCS-79 &UG 79):

all vessel shell sections, heads, and other pressure parts fabricated by cold forming shall be heat treated subsequently when the resulting extreme fiber elongation exceeds 5% from the supplied condition.

The extreme fiber elongation:

$$\%\text{Elongation} = \frac{(50\times t)}{R_f} \times \left(1 - \frac{R_f}{R_O}\right)$$

$$= \frac{(50\times 6)}{320.500} \times \left(1 - \frac{320.500}{infinity}\right)$$

=0.936

% Elongation is 0.936(less than 5%) therefore heat treatment check is not required for shell.

3.6 Checking for Heat Treatment of Dish end (As per UCS-79 &UG 79):

The extreme fiber elongation:

$\%\text{Elongation} = \frac{(75\times t)}{R_f} \times \left(1 - \frac{R_f}{R_O}\right)$

Where,

Inside spherical radius of dish = $K_0 \times D_i$

=0.9×635

=571.500mm

Inside knuckle radius of dish =0.17× D_i

=0.17×635

=107.950mm

Governing radius = min ($K_o \times D_i$, 0.17× D_i)

=107.950mm

Final Centerline mean Radius= (governing thickness + t/2)

R_f=107.950+6/2

R_f=111.950mm

Material designation=SA516 Gr 70

% Elongation= $\frac{(75\times 8)}{111.950} \times \left(1 - \frac{111.950}{infinity}\right)$

=5.36

% Elongation is 5.36(exceed than 5%) therefore heat treatment check is required for Dish end.

4. PV-Ellite software Calculations

4.1 Inputs for Ellipsoid Head:

In element screen different type of head are available.

Head available are:

• Hemispherical • Torispherical • 2:1 Ellipsoidal • Conical Flat Head • Flanged Head.

Select the required head from it.Then put the following inputs • Dimensions • Material of construction • Straight face dimension • Finished Thickness • Nominal Thickness • Corrosion allowance • Material of construction • Condition of Material (Normalized / Not Normalized) • Design Parameters .Once we put all the values dish end will appear in screen as shown below:

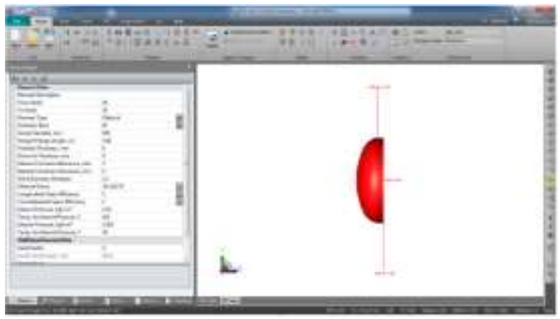

Fig -6: Ellipsoid Head 3D Model

4.2 Inputs for Cylindrical Shell:

In element screen select a shell. Then put the following inputs

• Diameter
• Shell Length
• Material of construction
• Finished Thickness
• Nominal Thickness
• Corrosion allowance
• Material of construction
• Condition of Material (Normalized / Not Normalized)
• Design Parameters

Once we put all the values dish end will appears in screen as shown below:

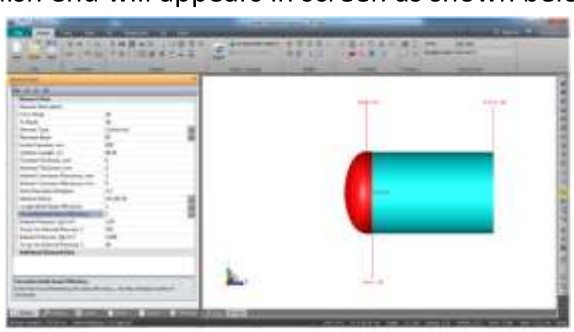

Fig -7: Cylindrical Shell 3D Model

4.3 Inputs for Nozzles:

Select the element on which you want to provide nozzle. Then click on the Nozzle Symbol indicated in "Detail Screen". Once you click on nozzle symbol, below screen will appear. First select the required type of Nozzle. To select type click on the correct image of below screen. These images are of

- Set in Nozzle with RF Pad
- Set in Nozzle without RF Pad
- Set out Nozzle with RF Pad
- Set out Nozzle without RF Pad
- SRN (Self Reinforced Nozzle)

Once we select required type of nozzle then we have to put following parameters of Nozzles

- Nozzle Description
- Nozzle Material
- Nozzle Size
- Nozzle thickness (Nozzle Schedule)
- Corrosion allowance
- Nozzle elevation / Distance from Node (Weld Line)
- For Inclined Nozzle, Nozzle inclination angle.
- If not inclined the click on radial nozzle.
- Nozzle inside Projection
- Nozzle outside Projection

If Reinforcement element is required then put

- Pad Material
- Pad outside Diameter
- Pad Thickness
- Welding Details of Nozzles

Nozzle Flange Details

- Flange Type (Like WNRF/SORF etc)
- Flange Rating
- Flange Grade

Similarly add inputs for all nozzles, after you complete input for all nozzle then vessel will appear as indicated below,

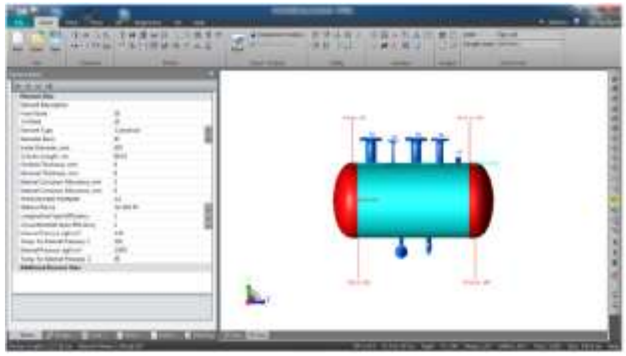

Fig -8: Nozzles 3D Model

Then click on the analyze symbol which is in “Analyze” screen. Then you will get complete vessel calculations Reports.

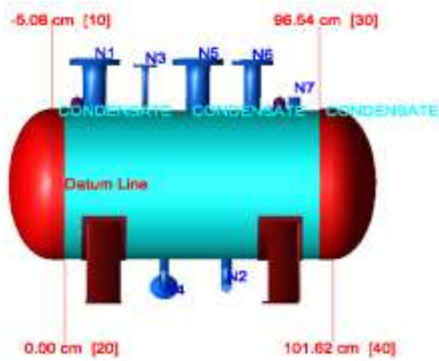

Fig -9: Vacuum system drain collection receiver (3D-Model)

5. RESULTS AND DISCUSSION

5.1 Cylindrical Shell Design for internal Pressure:

Table -1: Cylindrical Shell Thickness for internal Pressure

	Required Thk for internal pressure	UG 16 Requirements	Final Required Thickness + Corrosion allowance	Unit	Variation in %	Remark
PV Elite Result	0.361	2.5	5.5	mm	0.0	Accepted
Theoretical Result	0.361	2.5	5.5	mm	0.0	Accepted

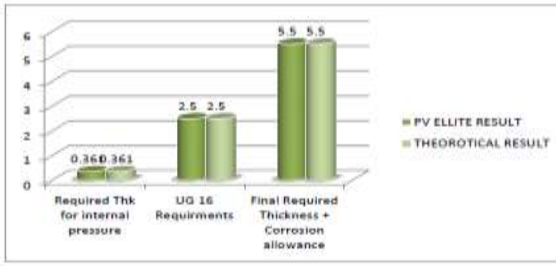

Chart -1: Cylindrical Shell Thickness for internal Pressure

5.2 Cylindrical Shell Design for External Pressure:

Table -2 Maximum allowable working Pressure

	Maximum allowable working Pressure	Unit	Variation in %	Remark
PV Ellite Result	1.4315	Kgf/cm^2	-0.174642	Accepted
Theoretical Result	1.434	Kgf/cm^2		

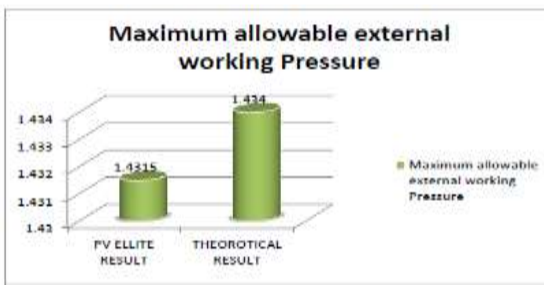

Chart -2: Maximum allowable working Pressure

5.3 Shell Design for External Pressure:

Table -3 Factors A and Factor B Results

	Factor A	Factor B	Unit	Remark
PV Ellite Result	0.0002271	231.54		Accepted
Theoretical Result	0.0002271	231.57	Kgf/cm^2	
Variation in %	0	-0.01		

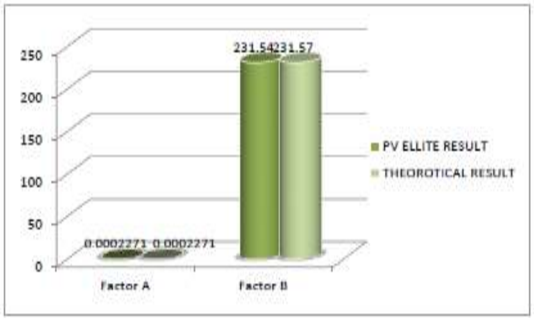

Chart -3: Factors A and Factor B Results

5.4 Ellipsoid head Design for internal Pressure:

Table -4 Ellipsoid head thickness for internal Pressure

	Required Thk for internal pressure	UG 16 Requirement	Final Required Thickness + Corrosion allowance	Unit	Remark
PV Ellite Result	0.356	2.5	5.5	mm	Accepted
Theoretical Result	0.36	2.5	5.5	mm	
Variation in %	-1.12	0	0	%	

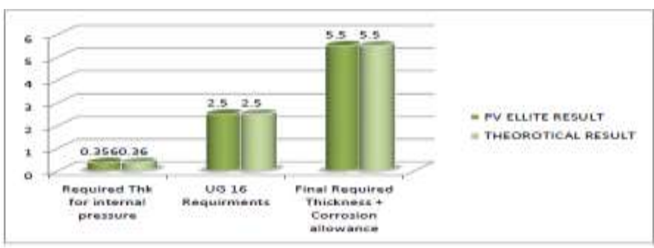

Chart -4: Ellipsoid head thickness for internal Pressure

5.5 Ellipsoid head Design for External Pressure:

Table -5 Factors A and Factor B Results

	Factor A	Factor B	Unit	Remark
PV Ellite Result	0.000644	656.52	-	Accepted
Theoretical Result	0.000644	656.483	-	
Variation in %	0	0.0056	%	

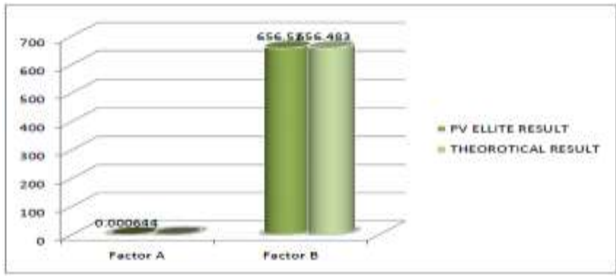

Chart -5: Factors A and Factor B Results

5.6 Ellipsoid head Design for External Pressure:

Table -6 Maximum allowable working Pressure

	Maximum allowable external working Pressure	Unit	Remark
PV Ellite Result	3.3824	Kgf/cm^2	Accepted
Theoretical Result	3.3822	Kgf/cm^2	
Variation in %	0.0059	%	

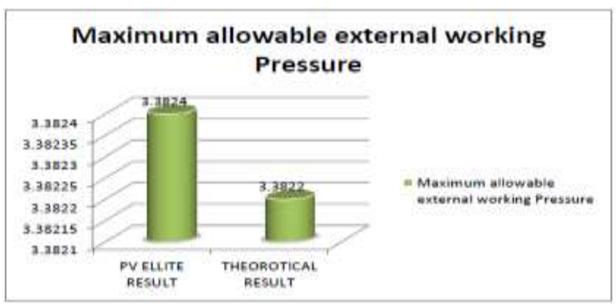

Chart -6: Maximum allowable working Pressure

5.7 Ellipsoid head Design for External Pressure Results:

Table -7 Ellipsoid head Thickness

	Required Thickness	Unit	Remark
PV Ellite Result	3.3967	mm	Accepted
Theoretical Result	3.3976	mm	
Variation in %	0.026	%	

Chart -7: Ellipsoid head Thickness

5.8 Extreme Fiber Elongation Results:

Table -8 Extreme Fiber Elongation

	Fiber Elongation for shell	Fiber Elongation for Dish End	Unit	Remark
PV Ellite Result	0.936	5.36	%	Accepted
Theoretical Result	0.936	5.36	%	
Variation in %	0	0	%	

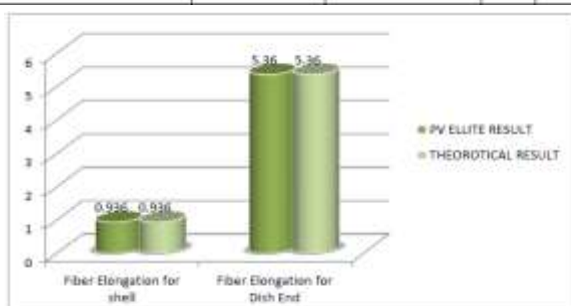

Chart -8: Extreme Fiber Elongation

5.9 Hydrostatic test pressure Results:

Table -9 Hydrostatic test pressure

	Design Pressure + Static Head	Hydrotest Pressure	Unit	Remark
PV Ellite Result	2.002	1.583	Kgf/cm²	Accepted
Theoretical Result	2.002	1.583	Kgf/cm²	
Variation in %	0	0	%	

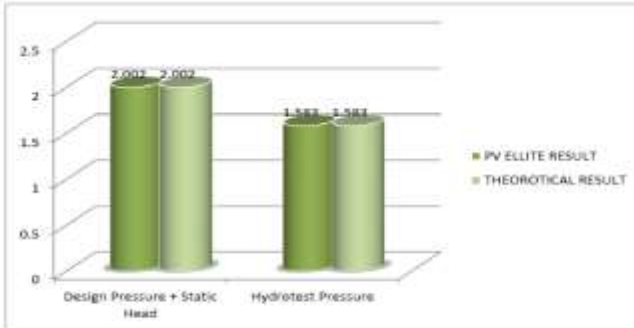

Chart -9: Hydrostatic test pressure

3. CONCLUSIONS

A numerical design study was performed to examine the structural failure of pressure vessels exposed to internal pressure As per ASME section VIII Div.1.Also it is analyzed by PV-Ellite software the result fully complied with standard code and had been employed on practical design of pressure vessel.

The design of pressure vessel is more of a selection procedure, selection of its component rather than designing each and every component, for storage of fluid the pressure vessel is mostly used because of its simplicity, high reliability, lower maintenance and compactness. The main parameter towards the design of pressure vessel is its high pressure fluid storage. The selection of pressure vessel component is very critical, slight change in selection will lead to different pressure vessel altogether from what is aimed to be designed. It is observed that all the manufactures of pressure vessels follow the ASME design codes for designing of pressure vessel so that leaves the designer free from designing the component. This aspect of design greatly reduces the development time for a new pressure vessel. It also allows the designer the freedom to play with multiple prototypes for the pressure vessel before finalizing the decision. Selection of pressure vessel should be according to standards rather than customizing the design additional conclusion were made from project study are Low overall cost, Less time.

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