International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 04 | Apr 2019 www.irjet.net p-ISSN: 2395-0072

Design and Analysis of Pressure Vessel used in CNG Package

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Abstract – *The main objective of this paper is to design and analysis of Pressure vessel .An air receiver is an integral part of any compressed air system. The main purpose is for storing compressed air and avoiding pressure fluctuations in the system. The significance of air receiver is to damp the pulsations from the discharge line of a reciprocating compressor, resulting in an essentially steady flow of air in the system. The main objective is to design components of air receiver using ASME code, to determine stresses and deformation on ANSYS and to validate analytical approach with ANSYS at the specified parameters. The aim of the study is to analyse the stress concentration at a particular temperature for future calculation.*

Key Words: **Air Reciever, CNG, CNG package, Blow Down Vessel, Radiogrphy.**

1. INTRODUCTION

An air receiver is an integral part of any compressed system. The main purpose of this is to act as temporary storage of compressed air and handle pressure fluctuations in the system. It also optimizes running efficiency of system. Advantages include small size and weight; do not require separate cooling systems, simple maintenance procedures. The main disadvantage is relatively high noise. The importance of air receiver is it damps pulsations from discharge line of reciprocating compressor, resulting in an essentially steady flow of air in the system. It serves as a reservoir to take care of sudden or unusually heavy demands for air in excess of the compressor's designed capacity. It knocks out solid dirt and particulate matter that may have passed through the compressor inlet filter or may be formed by compressed wear. Applications of air receiver are painting, vehicles in an auto body shop, providing dental and medical services, sandblasting in a machine shop and manufacturing facilities.

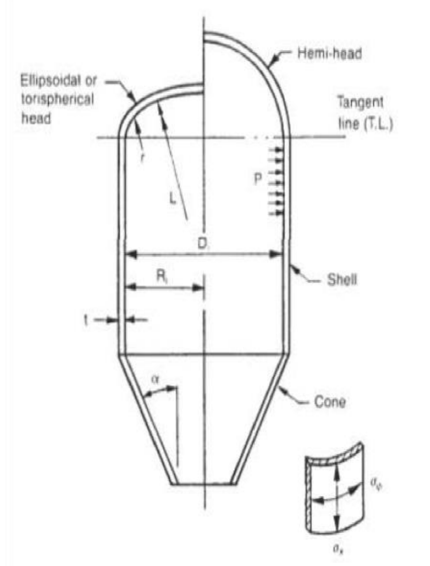

Fig1.1 General configuration and dimensional data for vessel shells and heads[1]

In most countries, vessels over a certain size and pressure must be built to a formal code. In the United States that code is the ASME Boiler and Pressure Vessel Code***(***BPVC***)***. These vessels also require an authorized inspector to sign off on every new vessel constructed and each vessel has a nameplate with pertinent information about the vessel, such as maximum allowable working pressure, maximum temperature, minimum design metal temperature, what company manufactured it, the date, its registration number (through the National Board), and ASME's official stamp for pressure vessels (U-stamp). The nameplate makes the vessel traceable and officially an ASME Code vessel.

Many pressure vessels are made of steel. To manufacture a cylindrical or spherical pressure vessel, rolled and possibly forged parts would have to be welded together. Some mechanical properties of steel, achieved by rolling or forging, could be adversely affected by welding, unless special precautions are taken. In addition to adequate mechanical strength, current standards dictate the use of steel with a high impact resistance, especially for vessels used in low temperatures. In applications where carbon steel would suffer corrosion, special corrosion resistant material should also be used.

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Pressure vessels can be dangerous, and fatal accidents have occurred in the history of their 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.

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Types Illustrated

Fig 1.2. Horizontal Drum on Saddle support[2]

Saddle supports are used for horizontally mounted pressure vessels.The load acting on the support is uniformly distributed over the support. A vessel supported in a horizontal position will have concentrated loads imposed on shell where the supports are attached. Calculations to resist the forces involved are not given here because the involve so many variables depending upon the size and weight of the vessel.

Fig 1.3 Vertical Pressure vessel with lug support[3]

Lug supports are generally used for vertical pressure vessel. The load acting on such support is very high. It is limited to small and medium diameter in the range of 2:1 to 5:1. The lugs are typically bolted to horizontal structural members in order to provide stability against overturning loads.

There are four factors of consideration before selection of air receiver-minimizing pressure fluctuations/drops, meeting short term peak air demands, energy considerations, and safety considerations.

- **Minimizing pressure fluctuations/drops:-**

  An air receiver can be used to minimize pressure fluctuations that could have an impact on the production process and quality of end product. Selection depends on compressor's output pressure and application. Note that the compressed air stored in air receiver is only useful as long as its pressure is sufficient for process which uses it.

- **Meeting short term peak air demands:-**

  If the demand for compressed air changes drastically, it is important to account for the spikes in the demand to ensure the system pressure does not drop below an acceptable level. An air receiver provides storage to meet short term peak air demands that the compressor cannot meet.

- **Energy considerations:-**

  Using an air receiver can help reduce energy consumption of compressed air system by enabling load/unload compressors to operate on a longer cycle with tighter pressure bands. This will also prevent pressure fluctuation and frequent motor starts, while providing steady pressure and extending life of the compressor.

- **Safety considerations:**

If needed, an air receiver will provide a supply of air to enable production processes and systems to be safely shutdown in an emergency situation.

Role of air receiver in air supply system is to remove the dirt and oil content in the air supply. The air receiver tank acts as a reservoir of compressed air for peak demands. It will help to remove water from the system by allowing the air a chance to cool and minimizes pulsation in the system caused by a reciprocating compressor or a cyclic process downstream. It allows lowering the pressure on compressor because of stored energy. The stored air approaches the dryer at a lower temperature, thus increasing the efficiency of the dryer.

Components of Pressure Vessel:

1. **Shell**

The Shell contains the pressure and consists of plates that have been welded together with an axis. Horizontal drums use shells with a cylindrical shape.

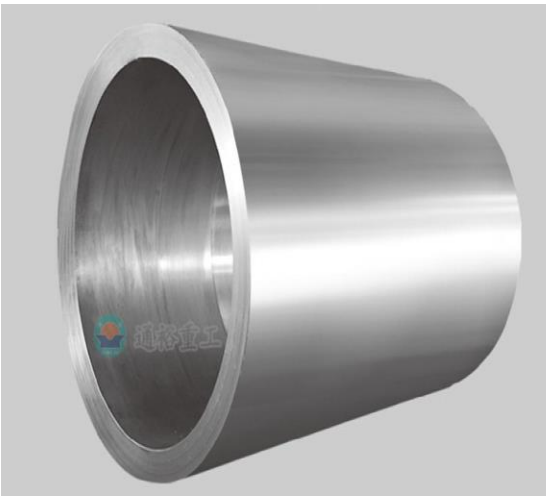


Fig.1.4 Shell of vessel [4]

It is the primary component that contains the pressure. Pressure vessel shells in the form of different plates are welded together to form a structure that has a common rotational axis. Horizontal drums have cylindrical shells and are constructed in a wide range of diameter and length. The shell sections of a tall tower may be constructed of different materials, thickness and diameters due to process and phase change of process fluid. Shell of a spherical pressure vessel is spherical as well

2. The Head

This is what closes off the end of a pressure vessel. Curved heads results in less losses and less stress concentration.

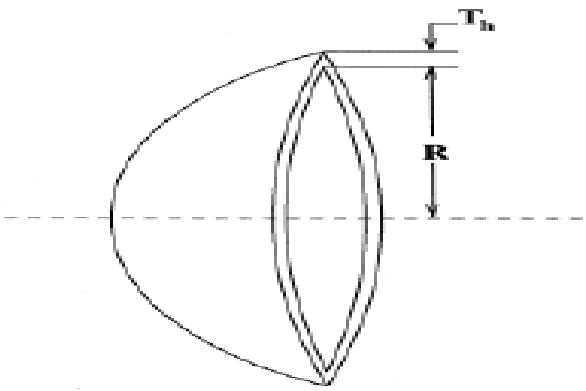


Fig 1.5 Head of vessel [5]

All the pressure vessels must be closed at the ends by heads (or another shell section). Heads are typically curved rather than flat. The reason is that curved configurations are stronger and allow the heads to be thinner, lighter and less expensive than flat heads. Heads can also be used inside a vessel and are known as intermediate heads. These intermediate heads are separate sections of the pressure vessels to permit different design conditions

3. **The Nozzle Head**: This is a cylindrically shaped component used for penetration of the shell. A nozzle is a cylindrical component that penetrates into the shell or head of pressure vessel.

Fig1.6 Different nozzles of pressure vessel[6]

It is responsible for the intake of the fluid at lower pressure and discharge the fluid at higher pressure as per the specification given by the client.

The velocity of the fluid getting discharged is very high.

4. **The Supports:** These take the weight off the pressure vessel. There are numerous types of supports including Saddle and Lug.

Fig1.7 Saddle support for horizontal[7]

Horizontal drums are typically supported at two locations by saddle support. It spreads over a large area of the shell to prevent an excessive local stress in the shell at support point. One saddle support is anchored whereas the other is free to permit unstrained longitudinal thermal expansion of the drum.

Fig1.8 Lug support for vertical[8]

Vertical pressure vessels may also be supported by lugs. The use of lugs is typically limited to pressure vessels of small and medium diameter (1 to 10 ft) Also moderate height to diameter ratios in the range of 2:1 to 5:1. The lugs are typically bolted to horizontal structural members in order to provide stability against overturning loads.

2. OBJECTIVES

i) To design components of air receiver using ASME code.

ii) To determine stresses and deformation on ANSYS.

iii) To validate analytical approach with ANSYS.

iv)

3. SCOPE

Air Supply System requires air receiver as a major constituent. Design of air receiver requires compliance to specific international standards. Hence, development of skill to design and manufacturing such equipment is need of industry. In modern era, use of new software technique made it much simpler to design air receiver. However, need of understanding basic from Code still remains important aspect.

4. EXPERIMENTAL VALIDATION:

3.2Thickness calculations for shell:-

Selected material for shell- SA 516 Gr.70

Allowable Stress at design temperature for selected material (S) = 20000 psi

Joint Efficiency (E) = 0.70

Thickness for circumferential shell (t) = PR/(SE-0.6P)

= 128.52*685.615/ (20000*0.70-0.6*128.52)

= 6.32mm

Thickness for longitudinal shell (t) = PR/(2SE+0.4P)

= 128.52*685.615/ (2*20000*0.70+0.4*128.52)

f = 3.14mm

Selecting the larger value of thickness i.e. 6.32mm

Adding corrosion allowance of 3mm, t = 6.32+3 = 9.32mm

Adding mill tolerance of 6% on (t+CA), t= 9.32+0.55 =9.8792mm

Joint Efficiency (E) = 1

Thickness for circumferential shell (t) = PR/(SE-0.6P)

= 128.52*685.615/ (20000*1-0.6*128.52)

= 4.4228mm

Thickness for longitudinal shell (t) = PR/(2SE+0.4P)

= 128.52*685.615/ (2*20000*1+0.4*128.52)

= 2.20mm

Selecting the larger value of thickness i.e. 4.4228mm

Adding corrosion allowance of 3mm, t = 4.422+3 = 7.422mm

Adding mill tolerance of 6% on (t+CA), t= 7.4222+0.445mm =7.867

Thickness calculations for dish end:-

Selected material for dish end- SA516 Gr.70

Allowable Stress at design temperature for selected material (S) = 20000 psi

Joint Efficiency (E) = 0.70

Thickness calculations for ellipsoidal dish end (t) = PD/(2SE-0.2P)

= 128.52*1371/ (2*20000*0.70-0.2*128.52)

= 6.292mm

Adding corrosion allowance of 3mm, t = 6.292+3 = 9.292mm

Adding 15% forming tolerance, t = 9.292+1.3938 = 10.6858mm

Joint Effeciency (E)=1

Thickness calculations for ellipsoidal dish end (t) =PD/(2SE-0.2P)

=128.52*1371/(2*20000*1-0.2*128.52)

= 4.407

Adding corrosion allowance of 3mm, t = 4.407+3 = 7.407mm

Adding 15% forming tolerance, t = 7.407+1.111 = 8.518mm

Material for flange- SA 105

Nozzle flange rating from design temperature and design pressure- CL 150 (ASME B16.5 Table 2-1.1)

Nozzle thickness calculations

Selected material for nozzles- SA 106 Gr.B

Allowable Stress for nozzles (S)= 17100 psi

Joint Efficiency, E = 1

For inlet/outlet nozzle:-

t_a = PR/SE-0.6P

= 0.886*84.5/118*1-0.6*0.886

=0.637mm

Adding corrosion allowance of 3mm

t_a =3.637mm

t_{b1}= PR/SE- 0.6P

= 0.886*84.5/138*1-0.6*0.886

= 0.544mm

Adding corrosion allowance of 3mm

t_{b1}= 3.544mm

t_{b2}=0 [external pressure=0]

t_{b3}= 6.22mm [from table UG 45]

t_b= min(tb3, max(tb1,tb2))

=min(6.22, 3.544)

t_b= 3.544mm

= 3.544+3= 6.544mm [corrosion allowance]

t_{ug45}=max(ta,tb)

= max(3.637,6.544)

t_{ug45}=6.544mm + 12.5% of 6.544 (milling tolerance)

t_{ug45}= 7.362mm

For Manhole :-

t_a= PR/SE-0.6P

= 0.886*300/118*1-0.6*0.886

= 2.262mm

Adding corrosion allowance of 3mm

t_a= 2.262+3=5.262mm

t_{b1}=0.886*300/138*1-0.6*0.886

=1.933m

Adding corrosion allowance of 3mm

t_{b1}= 4.933mm

t_{b2}=0

t_{b3}= 8.34mm [from table ug45]

t_b3= 11.34mm [corrosion allowance of 3mm]

t_b=min (tb3 , max (tb1,tb2))

= min(11.34, 4.933)

t_b=4.933mm

=4.933+3=7.933mm [corrosion allowance]

t_{ug45} = max (5.262,7.933)

= 7.933mm

t_{ug45}= 7.933+12.5% of 7.933

= 8.924mm

For drain / vent : -

Ta=PR/SE-0.6P

=0.886*30/118*1-0.6*0.886

=0.226mm

Ta=3.226mm (corrosion allowance =3mm)

Tb1=PD/2SE-0.2P

=0.886*60/2*138*1-0.2*0.886

=0.1927mm

Tb1= 3.19227mm(corrosion allowance =3mm)

Tb2=0 (neglecting external pressure)

Tb3=3.42mm (from table UG45)

Tb3=6.42mm (corrosion allowance =3mm)

Tb=min[tb3,max(tb1,tb2)]

=min(6.42,3.1927)

Tb=3.1927mm

= 3.1927+3 = 6.1927mm

Tug45= max(ta , tb)

= max(3.266, 6.1927)

= 6.1927mm

Tug45= 6.1927+0.774 [milling tolerance]

=6.966mm

For Pressure Gauge:-

Ta=PR/SE-0.6P

=0.886*16.7/118*1-0.6*0.886

=0.1259mm

Ta=3.1259mm (corrosion allowance =3mm)

Tb1=PD/2SE-0 .2P

=0.886*33.44/2*118*1-0.2*0.886

=0.125mm

Tb1= 3.125mm(corrosion allowance =3mm)

Tb2=0 (neglecting external pressure)

Tb3=2.96mm (from table UG45)

Tb3=5.96mm (corrosion allowance =3mm)

Tb=min[tb3,max(tb1,tb2)]

=min(5.96, 3.125)

Tb=3.125mm

= 3.125+3 = 6.125mm

Tug45= max(ta , tb)

= max(3.1259, 6.125)

= 6.125mm

Tug45= 6.125+0.765 [milling tolerance]

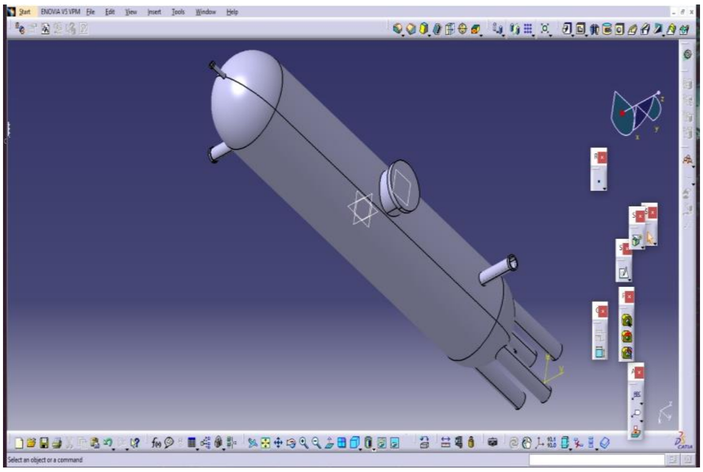
=6.89mm

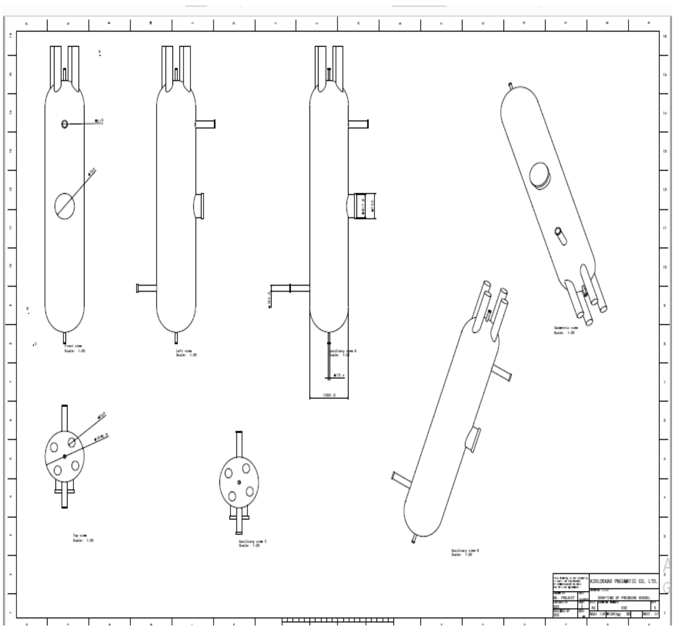
5. MODELLING OF PRESSURE VESSEL:

After calculating the values for the required dimensions for the design of the pressure vessel, the design of above said model has been done upon following the certain criteria.

We upon research found that CATIA would be the best suited software for modeling of vessel as it leads to be very smooth process for the import of model file(IGS File) to the software for analysis.

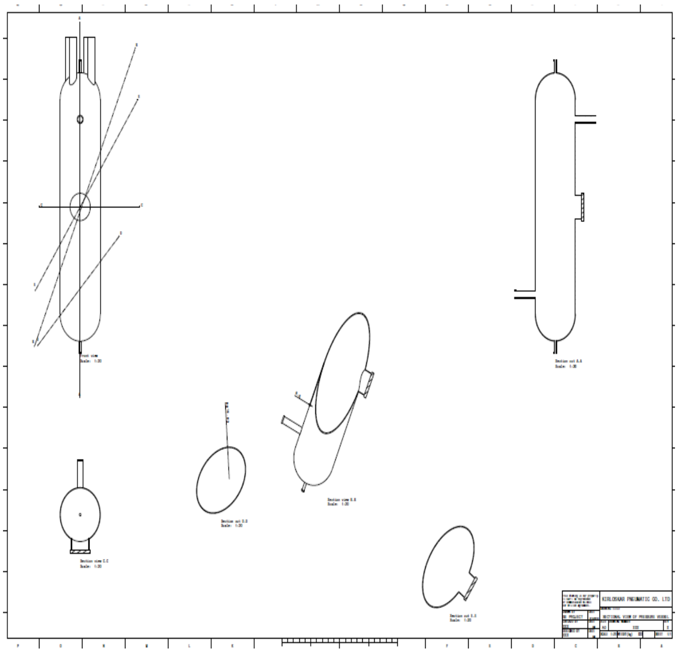
Thereafter modeling has been started by defining the geometric parameters of vessel in 2D, then 2D sketch was converted into 3D model by extruding it accordingly.





Sectional view of the Vessel:-

This view helps in observing the thickness of the material used in the assembly. It also gives the overview of the interior of model.



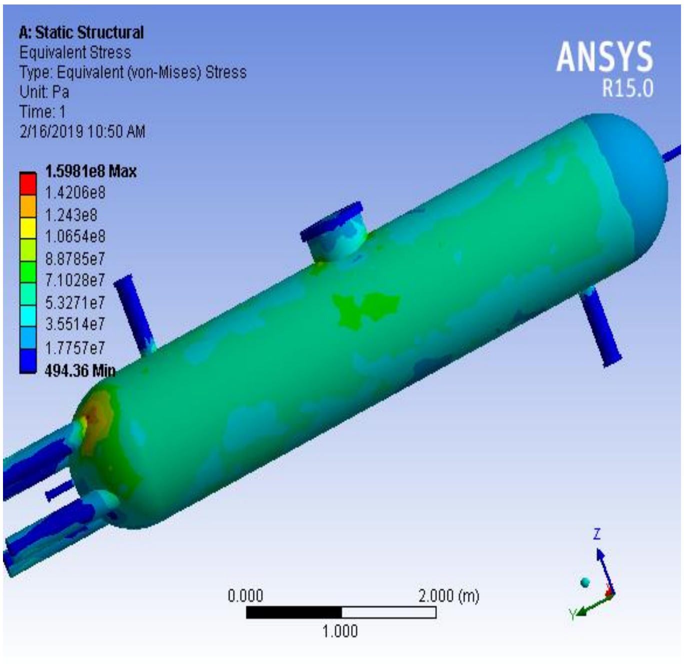
5. ANALYSIS OF THE PRESSURE VESSEL:

The analysis of the model was carried out in order to observe whether the model would operate properly in the given conditions. The analysis was carried out using ANSYS WORKBENCH software which creates a virtual environment as per the given criteria and helps to analyze if any failure occurs.

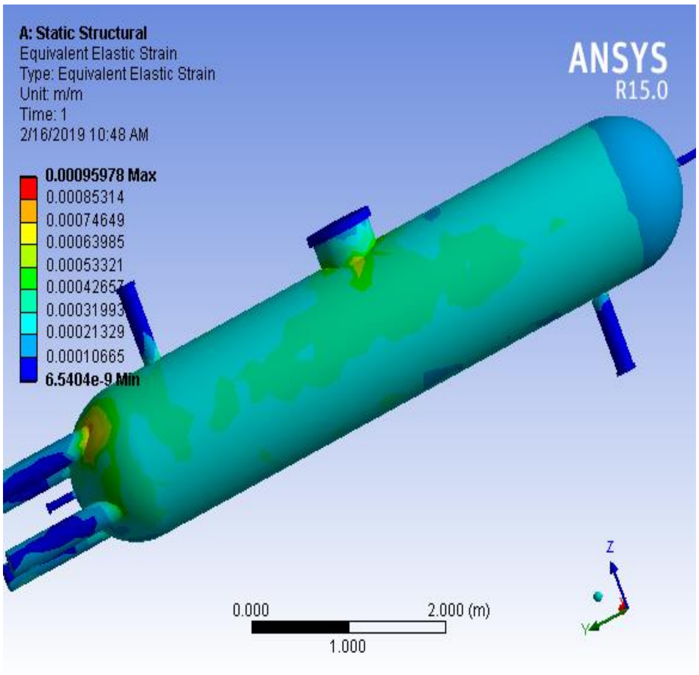
The analysis process started with meshing of the model which create uniformity in the model. After meshing the supports were fixed and material properties were added and the operating internal pressure was applied and observed.

The stress, deformation and elastic strain were under the limit after observation.

STRESS DISTRIBUTION IN THE VESSEL:



ELASTIC STRAIN IN THE VESSEL:



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