Ilmenite-Sulphuric Acid Digestion Pressure Vessel: Design and Analysis

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***Abstract* — Pressure vessels are containers used for containment of Gases, Liquids at substantially higher pressure. This paper deals with the sizing and mechanical design of a chemical reactor used for the Digestion of Ilmenite and Sulphuric Acid. The mechanical design of the components of the Pressure vessel has been achieved using the ASME code and engineering design formula. The maximum principal stress theory has been used as the yield criteria for designing the components of the vessel. The stress variations across the length of the shell has been found using analysis in Ansys and stiffening rings of suitable dimensions have been provided to prevent buckling of the vessel. Hydrostatic pressure has been found within the allowable limit which proves that the vessel can withstand the applied pressure. The results obtained in ANSYS has been optimized by varying the element size, shape of elements and number of elements in ANSYS.**

Keywords* — *Ilmenite- Sulphuric acid, ASME, ANSYS, Mesh sensitivity, Boundary Condition.

I. INTRODUCTION

A pressure vessel is to be designed for Ilmenite- Sulphuric acid digestion process. The process involves digestion of Ground Ilmenite with 93-98% H_2SO_4 for 3 hours. Mechanical agitation is given at the initial stage of the reaction and the mixture thickens and a dough like mass is formed. After allowing the mass to cool and on adding 4.5 cubic meters of dilute sulphuric acid having acidity of 6-7 N is added to the reacted mass. The slurry having a density of 1.5 g/cc is pumped to a settling tank and allowed to settle for about 8 hours and the clear liquor is collected.

II. PROBLEM DEFINITION

A pressure vessel is to be designed for Ilmenite- Sulphuric acid digestion process. The process involves digestion of Ground Ilmenite with 93-98 % H_2SO_4 for 3 hours. Mechanical agitation is given at the initial stage of the reaction and the mixture thickens and a dough like mass is formed. After allowing the mass to cool and on adding 4.5 cubic meters of dilute sulphuric acid having acidity of 6-7N is added to the reacted mass. The slurry having a density of 1.5 g/cc is pumped to a settling tank and allowed to settle for about 8 hours and the clear liquor is collected.

The operational requirements of Pressure vessel for Ilmenite-Sulphuric acid digestion process is

Table 1: Operational requirement of pressure vessel

Sr. No.	Parameters	Values
1	Maximum Temperature	300°C
2	Operating Pressure	1.01 bar
3	Bulk Density	1800 kg/cm^3
4	Heat Supply	Steam

III. LITERATURE REVIEW

B. S. Thakkar, S. A. Thakkar [1] conducted a series of hydrostatic tests to determine the performance of pressure vessel under pressure to examine the ability of the structure to withstand various pressures. The pressure vessel was designed using ASME codes & standards. FEA analysis was done to verify the above design procedure. This aspect of design greatly reduces the development time of new pressure vessel, allows the designer to keep free from multiple prototypes for pressure vessel before finalizing the design.

Dinesh U Parmar, Ashwin D Patel [2] developed a double walled tank of SS304 material using ANSYS. The analysis was carried out on ANSYS all the parts of storage tank where stresses were induced. The storage tank thus designed was found to be fit for use in Industries.

Qayssar Saeed Masikh, Dr. Mohammad Tariq [3] analysed thin and thick-walled pressure vessel for different material. The optimization of the thickness of pressure vessels on the basis of its thickness variation has been applied and the results obtained are verified using Maximum normal stress theory and Maximum shear stress theory.

Merlin J. Thattil, Chitaranjan Pany [4] designed a pressure vessel with different end domes (tori spherical and hemispherical) subjected to internal pressure and for a volume of 1000 litres which will be useful for space applications. The analysis has been carried out on ANSYS software to estimate the stress in dome and cylindrical shell of pressure vessel. Stresses at the junction of tori spherical head to cylindrical shell were found to be lower than hemispherical domes.

Sourabh Lawate, B. B. Deshmukh [5] compared the different types of heads; a finite element method software ANSYS was used to observe the stresses in these heads. Axis-symmetric behaviour of elements was used to reduce the modelling & also analysis time. On comparing the stresses, tori spherical head was found better than elliptical head & hemispherical heads.

Muhammad Adil Khattak, Amer Farhan Rafique [6] discussed the technical specifications and numerous other requirements for designing a Reactor Pressure vessel. It was found that most of the pressure vessels are made of steel especially A516 and are manufactured by welding the rolled and forged parts. During welding, material undergoes complex temperature changes that the pressure vessel is constructed using material Carbon steel (ASTM A516 Gr70) cladded with Alloy 20 (ASTM B463) plate.

IV. CONSTRUCTION AND WORKING OF SETUP

The pressure vessel is constructed using material Carbon steel (ASTM A516 Gr70) cladded with Alloy 20 (ASTM B463) plate.

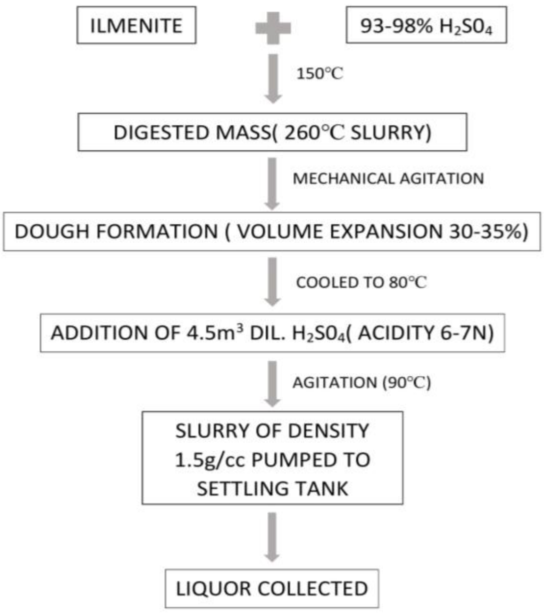

Fig. 1: Ilmenite Sulphuric Digestion process

The setup consists of a pressure vessel in which Ilmenite-sulphuric acid digestion process is carried out. Ground Ilmenite and sulphuric acid is fed to the reactor through the manhole and digested for 3 hours at a temperature of about 1500. During digestion the core temperature of the mass goes up to 2600. Average temperature of the mass remains at 210 to 2200. Mechanical agitation is given at the initial stage of the reaction to prevent any lump formation. The mixture thickens and a dough like mass is formed. An anchor type agitator is used for handling both slurry and dough like mass. A 60 hp motor provides the torque to the agitator. The speed reduction is done by gear box (gear ratio=1:140). A gland sealing (Stuffing box) is used to prevent the gases produced during the process from escaping the reactor. The volume expansion after the reaction is about 30-35%. The reacted mass is allowed to cool to at least 80°C with the help of jacket. Nozzles are provided to the jacket for admission of water. 4.5 cubic meters of dilute sulphuric acid having acidity of 6-7 N is added to the reacted mass (per t of Ilmenite processed) Nozzles are provided for admission of acid. Mechanical agitation is provided to dissolve the sulphates of titanium, ferrous, ferric, and other cations. During this process, the temperature of the mass rises to 90°C. The slurry having a density of 1.5g/cc is pumped to a settling tank and allowed to settle for about 8hours and the clear liquor is collected. A suction system is provided for removal of exhaust gas from the reactor and a scrubbing system for removal of polluting particles from the exhaust gas.

V. SIZING OF PRESSURE VESSEL

The sizing of pressure vessel is the first step of designing. Result obtained are as follows.

Table 2: Operational requirement of pressure vessel

Sr. No.	Parameter	Description
1	Volume of Ilmenite	0.2202 m^3
2	Volume of sulphuric acid	0.88 m^3
3	Volume of (93-98% w/w) of H_2SO_4	4.5 m^3
4	Volume of tori spherical head	0.6 m^3
5	Volume of cylinder	5.1 m^3
6	Diameter of tank	1.9 m
7	Length of cylindrical portion	1.79 m
8	Freeboard length	0.55 m
9	Total height of cylindrical tank (freeboard included)	2.34 m
10	Total volume of cylinder (freeboard included)	6.6 m^3

VI. FINITE ELEMENT ANALYSIS

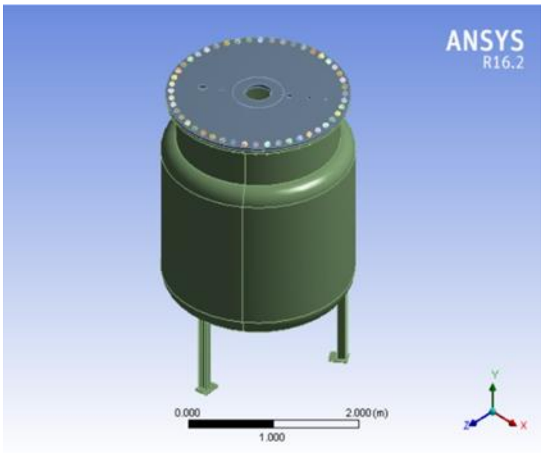

Fig. 2: FEA Model of Pressure Vessel

Figure shows the complete solid model of the pressure vessel and leg support. The pressure vessel is filled with liquid and is subjected to the operating weight. Meshing is done to the complete solid model. The scope of analysis is limited to study the stresses and deformation. Boundary conditions: Fixed Support at base, Internal Pressure: 0.1 MPa, External Pressure: 0.85 MPa.

A. *Mesh sensitivity Analysis*

A mesh sensitivity analysis is performed on the FEA model of pressure vessel, to ensure the optimum mesh size for proper convergence and accurate numerical results. The value of maximum principal stress and deformation occurring in the structure is used as a convergence criterion.

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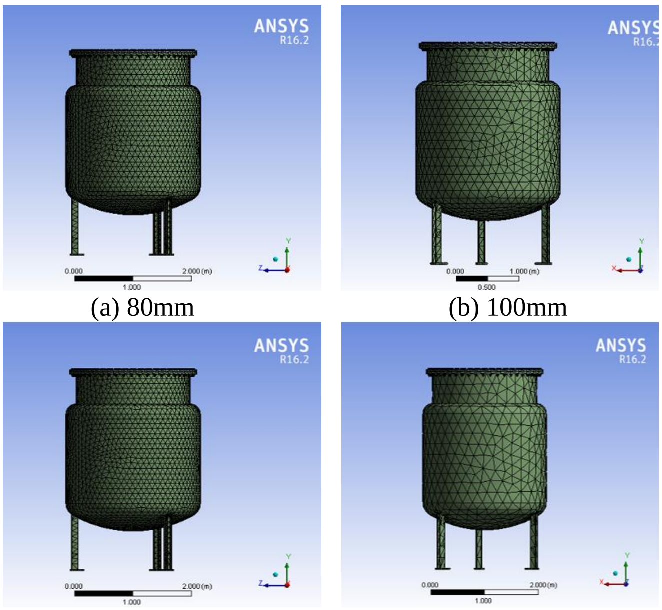


(a) 80mm (b) 100mm

(c) 150mm (d) 200mm

Fig. 3: Mesh of Element size

B. *Convergence Criterion- Maximum Principal Stress*

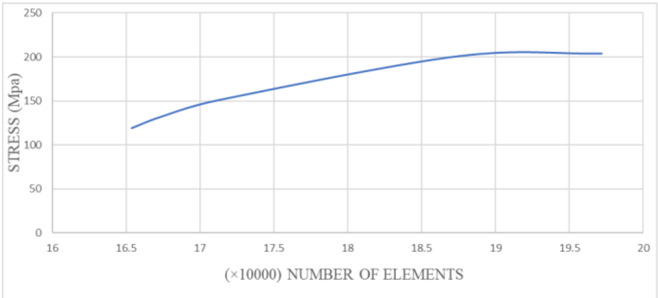


Fig. 4: Graph of Mesh Sensitivity Analysis

From the element number 167000 the mesh become precise. It also shows that as the number of elements reaches 196500, the meshing in the model of pressure vessel receives enough sensitivity.

C. *Analysis on complete vessel*

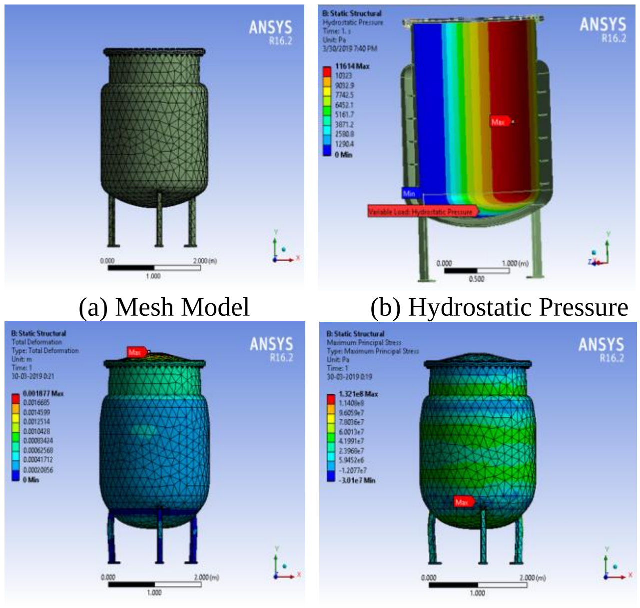
- Type of analysis: Static Analysis
- Properties of Material: Structural steel
- Poisson's ratio: 0.3
- Density: 7850 kg/m^3

D. *Meshing Detail*

- Method: Tetrahedron
- Attribute: Volume
- Meshing size: 0.18m
- Number of elements: 167432

E. *Boundary Condition*

- Fixed Support at base
- Internal Pressure: 0.1 MPa
- External Pressure: 0.85 MPa



(a) Mesh Model (b) Hydrostatic Pressure

(c) Deformation (d) Stress pattern

Fig. 5: Vessel Simulation

VII. RESULTS

The results gave a detailed distribution of local Stresses, Deformation and Hydrostatic Pressure in the pressure vessel. It is seen that the maximum deformation is located on top cover and maximum stress is near leg joint on the jacket.

Table 3: Result of Analysis on complete Pressure Vessel

Parameter	Maximum	Minimum
Stress (Pa)	1.32e8	-3.01e7
Deformation (mm)	1.877	0
Strain (m/m)	0.66e-3	-3.5e-5
Hydrostatic Pressure (Pa)	11614	0

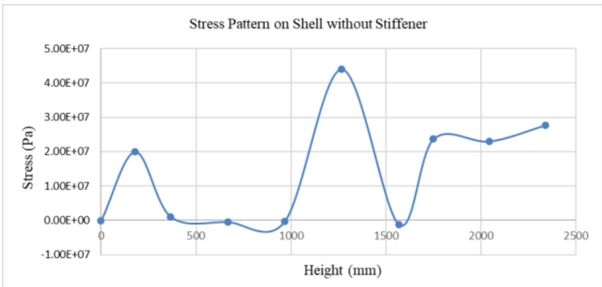


Fig. 6: Graph of Stress pattern on Shell without Stiffener

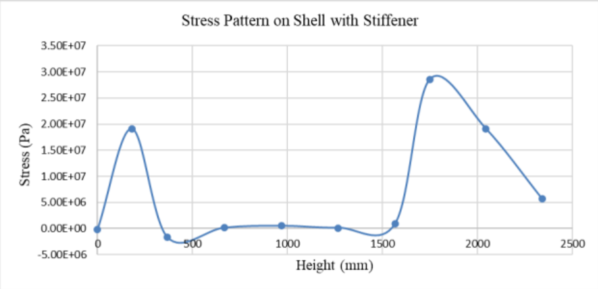


Fig. 7: Graph of Stress pattern on Shell with Stiffener

In figure 6 it can be seen stress is abruptly changing when stiffener in not attached. While in figure 7 stiffener rings are added to reduce the compressive stress induced in the shell due to external pressure. Here, on addition of stiffener, stress in stiffener region is reduced and varies moderately.

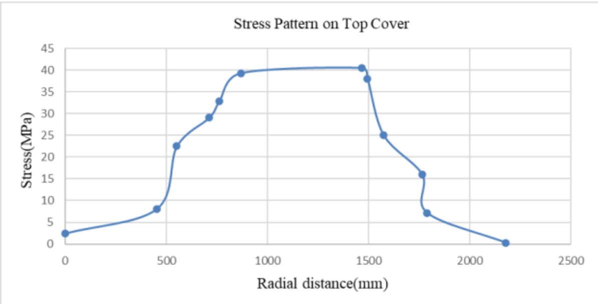


Fig. 8: Graph of Stress pattern on Top cover

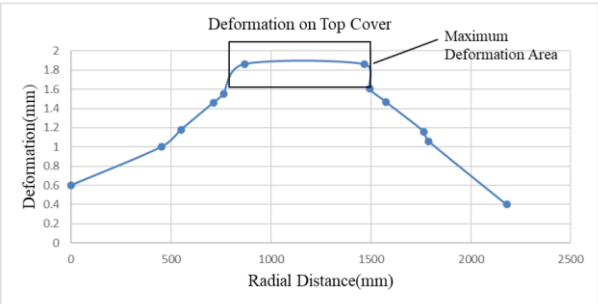


Fig. 9: Graph of Deformation on Top cover

From figure 8 and 9 it is observed that stress Pattern increases radially over the top cover till 40MPa and then decreases. Deformation on the top cover increases radially till 1.8mm and then decreases. Maximum Deformation i.e. 1.8mm is seen around the opening for the shaft.

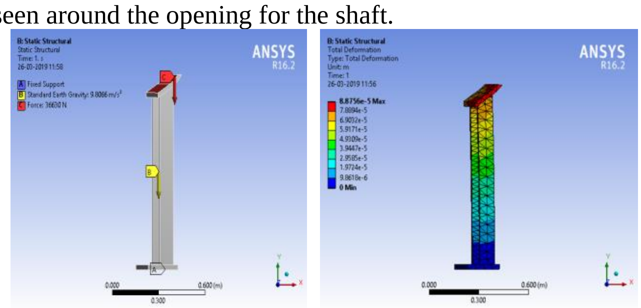


Fig. 10: Boundary Condition and Deformation of Leg Support

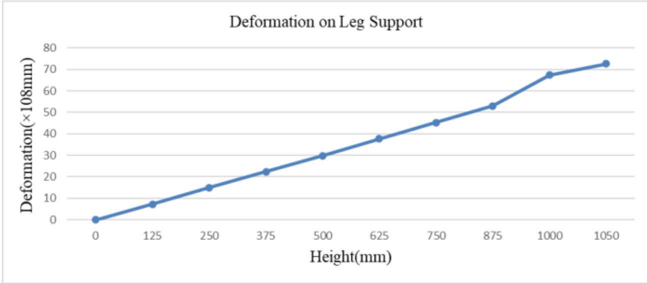


Fig. 11: Graph of Stress on Leg support

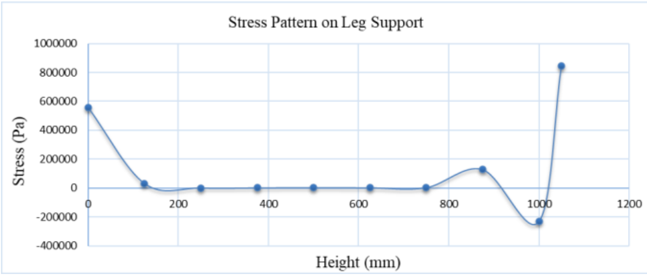


Fig. 12: Graph of Deformation on Leg support

From figure 11 and 12, the results give a detailed distribution of local stresses and deformation on the leg support. It is seen that the maximum deformation and maximum stress is near leg joint.

Table 4: Result of Analysis on Leg Support

Parameter	Maximum	Minimum
Stress (Pa)	7.45e6	-5.34e6
Deformation (mm)	0.0887	0

VIII. CONCLUSION

Using the ASME code Section VIII Div. 1 design by rule, the Pressure vessel design for Chemical reactor carrying out the Ilmentite Sulphuric acid digestion process has been achieved. The Theories of Failure play an important role in the design of Pressure vessels. In the design of pressure vessels, FEA tool can be used effectively as it helps to understand the structural behaviour of pressure vessel.

The pressure vessel was analysed for various operating conditions using ANSYS for internal pressure 1 bar and external pressure of 8.5 bar. The various forces analysed are pressure exerted by internal fluid on the shell, weight of the fluid, pressure exerted by steam in Jacket. The stresses and deformation produced in each member were found within allowable range. It is seen that the maximum deformation and maximum stress is near leg joint. The stresses and deformation produced in each member are within the maximum allowable range.

Using the mesh sensitivity analysis in FEA, the optimum number of elements for enough mesh sensitivity was found out. The mesh became precise for element number 167000.

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REFERENCES

[1] B. S. Thakkar, S. A. Thakkar," Design of Pressure Vessel using ASME code, Section VIII, division 1", International Journal of Advanced Engineering Research and Studies, Vol. I, Issue II, January-March 2012

[2] Dinesh U. Parmar, Ashwin D. Patel, "Design and Validation of Storage Tank", International Journal for Scientific Research & Development, Vol. 3, Issue 12, 2016

[3] Qayssar Saeed Masikh, Mohammad Tariq, Prabhat Kumar Sinha, "Analysis of thin and thick walled pressure vessel for different materials", International journal of mechanical engineering and technology, Volume 5, Issue 10, 2014

[4] Merlin J. Thattil, Chitaranjan Pany, "Design and Analysis of Pressure Vessel with different end domes", International Journal of Science, Engineering and Technology Research, Volume 06, Issue 08, August 2017

[5] Sourabh Lawate, B. B. Deshmukh, "Analysis of Heads of Pressure Vessel", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, Issue 2, February 2015

[6] Muhammad Adil Khattak, A Mukhtar, Amer Farhan Rafique, N Zareen, "Reactor Pressure Vessel (RPV) Design and Fabrication: A Literature Review", Journal of Advanced Research in Applied Mechanics, Volume 22, Issue 1, 2016

[7] Mr. Uday V. Aswalekar, "Pressure Vessel Optimization a Fuzzy Approach", International Journal of Engineering Research and Applications, Volume 5, Issue 5, May 2015

[8] Apurva Pendbhaje, Mahesh Gaikwad, Nitin Deshmukh ,Rajkumar Patil, "Design and analysis of pressure vessel" - International Journal of Innovative Research in Technology & Science, Volume 2, Issue 3, 2012

[9] Prof. Vishal V. Saidpatil, Prof. Arun S. Thakare "Design and Weight Optimization of Pressure Vessel Due to Thickness Using Finite Element Analysis" International Journal of Emerging Engineering Research and Technology Volume 2, Issue 3, June 2014

[10] ASME Boiler and Pressure Vessel Code 2007 Sec VIII Division 1 (2007)

[11] Sandeep Gond, Akhilesh, Anoop Singh, Vinod Sharma," Design and analysis of Pressure Vessel", International Journal of Scientific & Engineering Research, Volume 5, Issue 4, April,2014.

[12] Dennis Moss, "Pressure vessel design manual".

[13] Dr. M. M. Patil, Dr. Lokesh Bajpai, "Design, Analysis and Experimental Verification of Torispherical Head and Toriconical Bottom Pressure Vessel", International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 10, December 2014

[14] Arun Kumar. M, H. S. Manjunath, Amith Kumar. S. N, Design of pressure vessel using ASME codes and a comparative Analysis using FEA", International Research Journal of Engineering and Technology, Volume 04, Issue 11, Nov -2017.