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# Fatigue Life Prediction of Reactor Vessel with Limpet Coil as per ASME SEC. VIII Div-1

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**ABSTRACT:**The pressure vessels are the leakage proof canisters. The name suggests its main purpose that is to maintain a given substance under desired pressure and temperature. The pressure vessels are used in the industrial application for carrying the substances which are in liquid phase or gaseous phase under the required pressure and temperature limits. The required pressure and temperature limits are supplied externally or with the help of direct and indirect sources or using both the ways together. This project is mainly focusing on the design and analysis of reactor pressure vessel and its fatigue life prediction. The failure of limpet coil-also known as half pipe jacket; is studied on the basis of thermal analysis which is carried out with the help of designing methods for the pressure vessel as per the ASME sec VIII Div. 1 for given designing conditions and for various parameters. Its validation is done with the help of PV Elite (2019) software. The design model is prepared in solid works using dimensions obtained in the analytical design. The ANSYS software is used for Finite Element Analysis. It is done for shell of the vessel and limpet coil by implementing suitable conditions and the resemblance of results for sec. VIII div 1 are studied. The thermal Analysis for limpet coil for heating is done at design temperature of 260 °C and on pressure of 8 kg/cm<sup>2</sup>. The result of thermal analysis is utilized for material selection of limpet coil. The study of various induced stresses is utilized for fatigue life prediction of pressure vessel.

**KEYWORDS:-** Pressure Vessel, ASME Sec. VIII Div.1, Fatigue life, Limpet coil, PV Elite (2019), ANSYS.

## I. INTRODUCTION

A pressure vessel may be defined as a closed container designed to store fluids i.e. gases or liquids at a pressure substantially higher or lower than the ambient pressure. Generally, the ambient pressure is lower than the inside temperature. For Example, glassware, autoclaves, compressed gas cylinders, compressors (including refrigeration), vacuum chambers and custom designed laboratory vessels. The pressure vessel containers or tanks are useful in petrochemical industry, petroleum, nuclear industry and chemical industry. These components fall in the category of the equipment that include reacting elements, separation and storage of the raw material fluid required for the further reaction or for processes. Likewise, the pressurized vessels have wide application in the industrial plant for storage and manufacturing purpose. [1]

Pressure vessels may differ greatly, but their name specifies that these vessels are under pressure with an addition of chemicals or temperature. When the steam boilers are holding the fluid inside, it may change its state. The storage of harmful chemicals in pressure vessels is an important segment in every chemical industry because of its safety. So, in case of the chemical reactor pressure vessel, the fluid may have chemical reaction with the other reagent. Generally, the pressure vessels are seen with the combination of high pressure and high temperature along with highly radioactive material and the fluids having high flammability. Hence pressure vessels are considered to be dangerous. For any pressure vessel design, a primary consideration is its safety. They have history of fatal accidents over their development and operation. So it should be keenly seen that no leakage of the fluid from vessel should occur that may lead to the hazardous accident. Code is a standard that has been adopted by one or more governmental bodies and has the force of law, or when it has been incorporated into a business contract. Codes specify requirements of design, fabrication, inspection and testing of pressure vessels. A detailed study of various parts of pressure vessels like shell, head support, flanges, nozzles etc. is carried out according to rules of ASME code section VIII, Division I. Based on company point of view, the design should achieve with adequate standards, safety and at low cost. [1]



Fig.1 Reactor Pressure Vessel with Limpet Coil [1]

## II. LITERATURE SURVEY

Zahiruddin Mohammed Farooque Khateeb, Dr. Dhanraj P. Tambuskar. [1]

In the year 2016, have designed and analyzed Acetic acid pressure vessel as per the ASME section VIII, division 1 for pharm industry. And studied the failure of half pipe jacket (limpet coil) on basis of thermal analysis. The PV-ELLITE software was used for the validation of the same aspects. The design model was prepared using CREO. FEA analysis was done for the vessel shell and limpet coil in Ansys 15. Results were compared with the section VIII, division 1, Thermal analysis for external limpet coil for heating at design temperature at 275 °C and on pressure 20 kg/cm<sup>2</sup> was done. Material for limpet coil was suggested depending upon the result of thermal analysis.

M. A. Khattak, A. Mukhtar, A. F. Rafique and N. Zareen [2]

In year 2016 have given an overview which addresses the unique features of pressure vessels, such as material used for their preparation, design and construction along with various other relevant aspects of pressure vessel, selection of Pressure vessel components on the basis of available ASME standards.

Sumit V. Dubal, Dr.S. Y. Gajjal [3]

In the year 2015, have analyzed the pressure vessel of SA- 516 Gr. 70 for internal pressure. The analysis was carried for nine different loading cases. They calculated total deformation and maximum Von Misses stress by experimental method and by FEA and concluded that it is required to reduce stress by increasing thickness of shell and nozzle. The comparison of experimental and FE Analysis gave minimum error and hence provided quite acceptable results.

Merlin J. Thattil, Chitaranjan Pany [4]

In the year 2017, have designed pressure vessel with configurations of tori spherical and hemispherical end domes made of 15CDV6 subjected to internal pressure for a volume of 1000 liters which would be useful for space application. The material non-linearity performed in ANSYS software. Also estimated the stress in dome and cylindrical shell of pressure vessel. They concluded that stresses at the junction of tori spherical head to cylindrical shell were lower than hemispherical domes. And hence the fabrication of tori spherical pressure vessel is much easier as compared to spherical dome pressure vessel

V. V. Kharchenko, S. V. Kobel'skii, V. I. Kravchenko, A. Yu. Chirkov, A. A. Zvyagintse [5]

In the year 2007, have compared the results of calculated KI values for a longitudinal semielliptical surface crack in the WWER-1000 RPV obtained by engineering and numerical procedures. The three-dimensional KI computations were performed with the SPACE software. The reliable service of nuclear power plant equipment is based on the reactor pressure vessel (RPV) integrity both in normal operation and in an emergency. Stress intensity factors of RPV are calculated for testing resistivity to brittle fracture.

V. P. Gawade, Prof. M. U. Gaikwad [6]

In the year 2016, have designed a pressure vessel using ASME Code Sec. VIII Div.-I. The analysis for the same is done with the help of ANSYS. They found that the analysis results were so close to the analytical design, and hence



concluded that both the data validates. The result showed that there was less the induced stress than the maximum allowable stress. The analysis result proved that the design procedure adopted was appropriate. The FEA also helped to study the actual stress distributions in pressure vessel components.

Prof. Mr. Amol Mali, Mr. Hemant Bhosale, Mr. Dilpreet Singh Bedi, Mr. Akash Modasar [7]

In the 2017, have presented the approach of design of pressure vessel using PV Elite software. The code selection is done as per ASME standards. The required materials were selected and modeling of Pressure vessel was done in PV elite for different calculations. Arrived at the conclusion that the design was done in less time with adequate accuracy and designed vessel was safe for internal pressure and all the elements were in safe condition.

Binesh P Vyas, R.M. Tayade, Ankit D Kumbhani [8]

In the year 2013, have done the design of a pressure vessel using PV Elite software and concluded that design of pressure vessel by using PV Elite has given accurate analysis result and also reduced time. Due to mathematical calculation designing of pressure vessel becomes tedious but by using software like PV Elite designing of pressure vessel can be done easily.

A. Devaraju, K. Pazhanivel [9]

In the year 2015, has designed the standard cylindrical pressure vessel and calculated the stresses induced in the various part of the vessel like vessel walls and top of the dish manually and compared these results with the ANSYS Results. The maximum stress occurred at the joining of hemispherical part and main flange whereas the minimum stress occurred at top of the nozzle. Hence they concluded that safe design was achieved.

K Vijaya Lakshmi & Y V Mohan Reddy. [10]

In the year 2015 have selected a pressure vessel and designated it according to ASME codes and standards. ASME codes of unfired pressure vessel rules and standards were used to construct this pressure vessel. The drafting design of pressure vessel was done using Auto CAD software. As the mathematical calculation of pressure vessel becomes tedious, graphical based software PV Elite for the analysis on shell, head, nozzle and saddle supports makes the work easier and hence the safety parameters of pressure vessel were analysed using PV Elite software.

### III. PROPOSED METHODOLOGY AND DISCUSSION

The design Methodology includes following steps for the pressure vessel design:

#### A. Selection of Code.

For the design of the pressure vessel along with its fittings, many engineering standards are available which give detailed information related to it. In India, we follow ASME in general but other national and international standards may also be used. The pressure vessels are designed using ASME Section VIII Division-I. The analytical method is followed for determining thickness and stress of components of pressure vessel. Here the component of pressure vessel refers to shell, head and nozzles, skirt support. There are various factors [13] which must be considered while selection and designing of the pressure vessel such as

1. Dimensions and geometry thickness diameter, length, and their limitations.
2. Operating condition
3. Functions and location, corrosive nature, Nature of fluids,
4. Materials, its physical properties and cost.
5. Type of failure
6. Fabrication techniques
7. Theories and type of failure
8. Economic consideration

#### B. Selection of Material

The variety of materials have been in use for the fabrication of pressure vessel. The material is selected depending upon the appropriateness of the design requirement. The materials used in the manufacturing of the receivers shall comply with the requirements of the relevant design code, and be identifiable with mill sheets. The selection of materials for the shell should check the suitability of the materials with the maximum working pressure and fabrication process. For this kind of pressure vessel, the selection of material use is based on Appendix B.

#### C. Design Pressure

The pressure used in the design of a vessel component together with coincident design metal temperature is called design pressure. The vessel and its components are should be designed for a higher pressure than the operating pressure. A design pressure higher than the operating pressure with 10 percent, whichever is the greater, will satisfy the requirement. The pressure of the inner fluid will also be considering. The maximum allowable working pressure (MAWP) for a vessel is the permissible pressure at the top of the vessel in its normal operating position at a specific temperature. This pressure is based on calculations for every element of the vessel using nominal thicknesses exclusive of corrosion allowance. It is the basis for

establishing the set pressures of any pressure-relieving devices protecting the vessel. If the MAWP is not calculated; the design pressure may be substituted (UG22, ASME VIII.) [9]

**D. Design Temperature**

Design temperature is the temperature that will be maintained in the metal part of the vessel which is being considered for the specified operation of the vessel. In many cases, for vessels, the design temperature is the temperature that corresponds to the design pressure. There are mainly two temperatures related to the vessel and should be taken into consideration which are maximum design temperature and a minimum design temperature (MDMT). The MDMT shall be the lowest temperature expected in service or the lowest allowable temperature as calculated for the individual parts. Design temperature for vessels under external pressure shall not exceed the maximum temperatures. [1]

**E. Corrosion Allowance**

Corrosion allowance describes an extra measurement added to the thickness of the wall of the pressure vessel. This helps to estimate the expected metal loss throughout the lifespan of the vessel. The corrosion allowance is useful in taking care of corrosion occurring over the life of a vessel. Since the depth of penetration may vary from case to case, corrosion allowance has a safety factor equivalent to 2. By knowing the expected rate of corrosion and the expected service life of parts, it is possible to compute the additional thickness needed for corrosion resistance of equipment in the design process. As stainless steel is used for design of pressure vessel there is no need of addition of corrosion allowance. [1]

Corrosion allowance must be determined once the wall thickness has been identified. The wall thickness should comply with various requirements such as temperature, pressure and weight. A design criterion of corrosion allowance is 2 mm for a pressure vessel.

Factors that affect the rate of corrosion include: -

1. Temperature
2. Humidity
3. Wind
4. Rain
5. Impurities

**F. Design of Shell**

The “shell” of a pressure vessel refers to its wall, which is typically cylindrical. The shell is composed of metal plates with a thickness carefully calculated to sufficiently contain the pressure of the vessel's contents. [1]

The minimum thickness for shell or maximum allowable working pressure for cylindrical shells is given by (1) or (2) below.

When  $t \geq r/2$ , or  $P$  does not exceed  $0.385SE$ , the following formulas shall apply.

1. Circumferential stress -----UG-27(c) (1)
2. Longitudinal stress -----UG-27(c) (2)

Figure 2 shows the pressure vessel shell and details

$P$  = internal pressure

ID, OD, = inside/outside diameter

$S$  = allowable or calculated stress

$E$  = joint efficiency

$L$  = crown radius

$t$  = thickness of shell

$r$  = knuckle radius

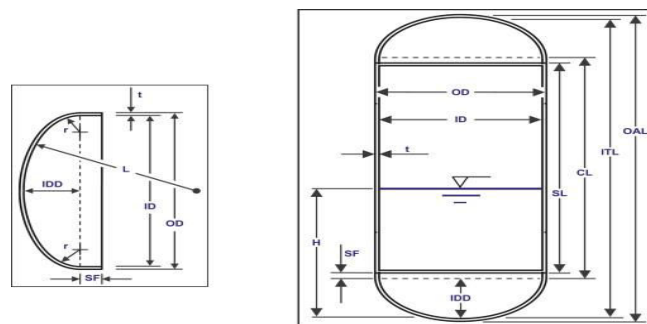


Fig.2 Shell of a Pressure Vessel [1]

### G. End closure Design [9]

The head thickness is calculated by (UG-16). And other, loading is taken in account by UG-22.

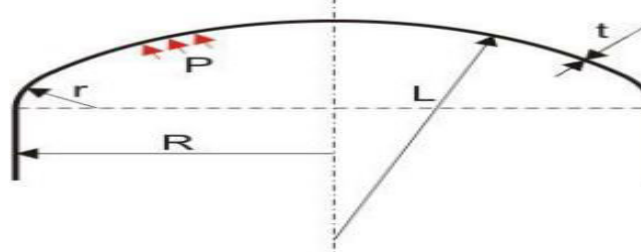


Fig.3 End Closure [1]

L -crown radius  
r -knuckle radius  
R- Mean radius of a shell  
h -depth of head  
P -internal pressure

### H. Nozzles, Openings and Reinforcements [11]

A pressure vessel nozzle is an opening in the pressure vessel through which fluid enters or exits the pressure vessel. The Nozzle, in general, projects from the pressure vessel's surface and ends with a means of joining (flanged or welded) piping or equipment. Openings in cylindrical or conical portions of vessels, or in formedheads, shall preferably be circular, elliptical. When the long dimension of an elliptical opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment.

### I. Various Supports-

Support is used to bear all the load of pressure vessel, earthquake and wind loads. It is considered to be the non-pressurized part of the vessel. There are different types of supports which are used depending upon the size and orientation of the pressure vessel.

**1. Saddle Support** – 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. [15]

**2. Leg Support**– Small vertical drums are typically supported on legs that are welded to the lower portion of the shell. The max. ratio of support leg length to drum diameter is typically 2: 1. Reinforcing pads are welded to the shell first to provide additional local reinforcement and load distribution. The number of legs depends on the drum size and loads to be carried. Support legs are also used for Spherical pressurized storage vessels. Cross bracing between the legs is used to absorb wind or earth quake loads. [4]

**3. Skirt Support**-Tall vertical cylindrical pressure vessels are typically supported by skirts. A support skirt is a cylindrical shell section that is welded either to the lower portion of the vessel shell or to the bottom head (for cylindrical vessels). The skirt is normally long enough to provide enough flexibility so that radial thermal expansion of the shell does not cause high thermal stresses at its junction with the skirt. [9]

**4. Lug Support**- 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 [4]

### J. Loads On Pressure Vessels

A pressure vessel has to withstand various types of loading individually and in various possible combinations. Pressure vessels may be subjected to stresses arising from a variety of loading conditions including internal pressure and multiple external loads from attached piping systems. [10]

Following types of loadings should be considered while designing a vessel-

#### 1. Loads due to pressure-

It includes internal pressure loads, external pressure loads, design pressure loads and operating pressure loads.



**2.Loads due to moments-**

It includes winds load, seismic load, transportation load, thermal load, dead weight load.

**K. ANSYS-ANSYS** is a software which is used for various analysis such a dynamic analysis, structural analysis, heat transfer analysis, fluid analysis etc. [11]. A certain geometric shape and size also called as basic-size of a pressure vessel is required to analyse the pressure vessel in ANSYS. The ANSYS analysis allows the designer to make some fine adjustments and, to identify and approach other design issues which could otherwise remain hidden or neglected. All the above clearly shows that the optimal design (by ANSYS software) is having more advantages than conventional design (by human force).

**IV. EXPERIMENTAL RESULTS**

Table 1: Design Result for Pressure Vessel with Nozzle

Sr. no	Component	Minimum design requirement value as per ASME design (mm)	Finished thickness (mm)	Validation Software- PV Elite. Result	Remark
1.	CylindricalShell	t = 7.7 mm	t = 10 mm	Passed	Validated
2.	Ellipsoidal head-Top dish End	t = 7.5 mm	t = 12 mm	Passed	Validated
3.	Ellipsoidal head-Bottom dish End	t = 7.8 mm	t = 12 mm	Passed	Validated
4.	Limpet coil	t = 3.22mm	t = 4 mm	Passed	Validated
5.	N1	t =5.78 mm	t= 6.22mm	Passed	Validated
6.	N2	t = 5.1 mm	t = 8.4 mm	Passed	Validated
7.	N3	t =4.257 mm	t=5.267mm	Passed	Validated
8.	N4	t = 10.5 mm	t =12 mm	Passed	Validated
9.	N5	t = 10.5 mm	t= 12 mm	Passed	Validated
10.	N6	t = 10.5 mm	t =12 mm	Passed	Validated
11.	N7	t =1.5 mm	t = 3.4mm	Passed	Validated
12.	N8	t =1.5mm	t =3.4mm	Passed	Validated
13.	N9	t =1.5 mm	t= 3.4mm	Passed	Validated
14.	N10	t =1.5 mm	t = 3.4mm	Passed	Validated
15.	N11	t = 3.22 mm	t = 4 mm	Passed	Validated
16.	N12	t =3.22 mm	t = 4 mm	Passed	Validated
17.	N13	t = 3.5 mm	t = 4 mm	Passed	Validated
18.	N14	t =2.9 mm	t = 4 mm	Passed	Validated
19.	N15	t = 3.22 mm	t = 4 mm	Passed	Validated
20.	N18	t = 2.9 mm	t = 4 mm	Passed	Validated
21.	N19	t = 3.4 mm	t = 4 mm	Passed	Validated
22.	N20	t = 10.5 mm	t = 12 mm	Passed	Validated
23.	N21	t = 2.9 mm	t = 4 mm	Passed	Validated
24.	N22	t = 2.9 mm	t = 4 mm	Passed	Validated
25.	M1	t =10.5 mm	t = 12 mm	Passed	Validated

Table 2: Design Result for loadsat Supports and moments

Sr.no.	Type of Loads at supports	Calculated value (kg.f)	Moments (kg.m)
1.	Wind loads	582.976	2974.35
2.	Seismic loads	1175.26	5985.62

Table 3: Design Result for Induced Stresses at Reinforcing pad

Sr.no.	Type	Maximum Induced Stress as per ASME design (N/mm <sup>2</sup> )	Allowable Induced Stress(N/mm <sup>2</sup> )	Result	Remark
1.	Circumferential stress at Vessel's Reinforcing pad	46.76	137.90	Passed	Validated
2.	Longitudinal stress at Vessel's Reinforcing pad	85.28	248.22	Passed	Validated
3.	Shear stress at Vessel's Reinforcing pad	255.31	413.70	Passed	Validated

Table 4: Thermal Analysis result on Limpet Coil for SA/ IS 2062 Gr B

Material– SA 2062 Gr B	Allowable parameter (N/mm <sup>2</sup> )	Deformation	Safety Factor	Result from ANSYS (N/mm <sup>2</sup> )	Remark
Equivalent stresses	Tensile yield stress -117.2	Elastic	At shell side -1	At shell side-137.9	Safe
		Elastic	At bottom side-1	At bottom side - 186	Safe

Table 5: Thermal Analysis result on Limpet Coil for SA 285 GR C

Material – SA 106 Gr B	Allowable parameter (N/mm <sup>2</sup> )	Deformation	Safety Factor	Result from ANSYS	Remark
Equivalent stresses	Tensile yield stress - 206	Elastic	At shell side 0.48	At shell side -353	Safe
		Plastic	At bottom side -0.85	At bottom side -457	Failed

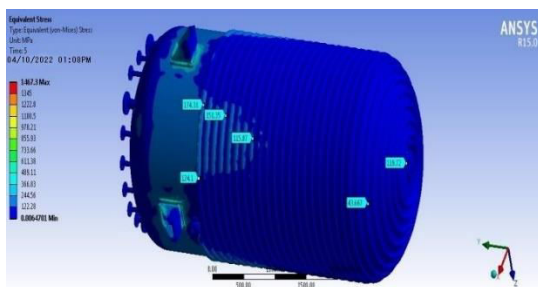


Fig.4 Thermal Analysis result on Limpet Coil for 285 GR C

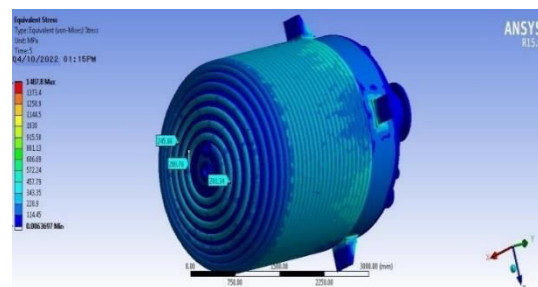


Fig.5 Thermal Analysis result on Limpet Coil SA for SA/ IS 2062 Gr B

### V. CONCLUSION

10 kl hydrogenated pressure vessel is designed using ASME Code Sec. VIII Div.1. The vessel was tested for various cyclic loadings for prediction of fatigue life. The thermal analysis was done in ANSYS. The analysis results are so close to the analytical design; hence both the data validates. The result obtained is summarized as follows  
 A. Design of 10 kl hydrogenated pressure vessel satisfies the standard set by ASME section VIII division 1.





B. The different stresses at different components on the vessels like head, shell, dish ends, nozzles and limpet coil help to predict the fatigue life of those components and hence of vessel. The analytical result obtained is that the induced stress is less than the maximum allowable stress. The analysis result proved that the design procedure adopted is appropriate.

C. As hydrogenated mixture is non-hazardous lethal service as per UW -2 is not required.

D. Fibre elongation as per UG-79 & UHA-44 is 3.38%.

E. PWHT and PFHT is not mandatory as per the UW-2, UCS-56, UCS-68 and UCS 79

F. The FEA helped to study the actual stress distributions in pressure vessel components. This analysis on limpet coil is done in Ansys 15 and it is found that limpet coil with IS 2062 Gr. B is having equivalent stresses within the tensile yield limit with safety factor 1 at shell side and 1 at the bottom side and deformation is elastic.

G. Analysis on limpet coil is done in Ansys 15 and it is found that limpet coil with SA 285 GR C is having equivalent stresses more than the tensile yield limit with safety factor 0.48 at shell side and 0.85 at the bottom side and deformation is plastic.

H. Based on Ansys 15 report IS 2062 Gr B is suitable material for construction.

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