Design and Analysis of Pressurevessel with Counter Flow Limpetsystem for Variable Thermal Loads

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Abstract:- Pressure vessels play a crucial role in the process industry, serving diverse functions. Their design is tailored to operational factors like fluid type, quantity, volume, temperature, and pressure. The objective of this project is to meticulously design and analyze pressure vessels using ANSYS software, aiming to determine the optimal thickness. Various components, including the Shell, Heads, Nozzles, Supports, and Lifting Lugs, are compared against standard thicknesses. The aim is to optimize allowable stress for the chosen Material of Construction (MOC) and assess the pressure vessel's thickness under different load cases. This optimization enhances component thickness, leading toreduced weight and cost without compromising safety. The resulting optimized pressure vessel is engineered to withstand all conditions with the same safety factor as the existing model but with lower weight, effectively achieving cost-efficient performance.

Keywords:- *ANSYS (Software), MOC(Material of Construction).*

I. INTRODUCTION

- *In many Sectors of an Engineering, Pressure Containers are useful. The following are some of the varieties of pressure vessels that are frequently used in most of the industries and areaccessible on the market, according to the pressure vesselmaker.*

- *Spherical Pressure Vessel,*
- *Cylindrical Pressure Vessel and*
- *Conical Pressure Vessel*

Helix

The Greek word "eliks" (which means spiral) is the origin of the term "helix." Helix is the term used to describe a spiral or anything like a spiral Helix can also refer to the shape created by a screw thread. Screws, helical gears, and worm gears are examples of typical mechanical parts. Helixes can be seen in everyday objects like suspensions in automobiles, the springs in clickable ballpoint pens, and weighing scales. Helix axes, helix radius, helix pitch, and helix fitting-where the diameter is the biggest lateral dimension of the helix-are the four geometric characteristics needed to define a finite helical.

A helix angle connects a helix with a pivotal axis on its rightside, a cone, or a circular chamber. The range of helix points decreases from 5° to 45°. The range for single and double helices is 5° to 20° and 20° to 45°, respectively.

In order to convert between rotational and linear movementor force, a screw thread is a helical shape. A ridge is wrapped in the shape of a helix around a cone or cylinder to create a screw thread; the former is referred to as a direct thread and thelatter as a tapered thread.

Types of Helices

The three different types of helices are 310, pi, and alpha helices. Both right-handed and left• handed helices are possible. A right-handed helix is one that is moved farther away from the viewer by a clockwise screwing motion, whereas a left-handed helix is one that is moved in the same direction as the observer.The band curvature and torsion of a circular helix (i.e., one with a constant radius) are both constant. The funnel-shaped helix is not a geodesic of the cone, but rather a helix followed bya cone of upset (i.e., a bend forming a stable point regarding thehub of the cone). In concrete words, an upward-inclining cone is followed by a tapering helix.

It is referred to as a broad or round-shaped helix if the bend's deviation forms a consistent point with a reasonable line in space. As long as the ratio between the arch and the twist doesn't change, a bend is an overall helix. The inclination helix is the steady point that the bend essence creates when there is a fixed axis present in space.

How to get Length and Pitch of the Helix

The height of one full helix tum, which is thought to correspond to the helix's line, is known as the pitch of a helix.The magnitude of R prime of T integrated from A to B is equivalentto the definite integral of the length of a helix.

- The -helix is really little. Each full turn contains 3.6 amino corrosive deposits, and each deposit advances by 1.5 angstrom units (1 angstrom unit equals 10 to 1 nm, 10 to 4 m, or 10 to 7 nun) along with the helix's pivot.
- The dimensions of each helix of B-form DNA are around 12 angstroms in diameter, 12 angstroms in width, and 6 to 8 angstroms deep from the primary groove.
- Alpha-helices have 3.6 amino acid residues per turn, thus ifa helix is 36 amino acids long, there are 10 turns in it.

- The pitch/helix turns are 3.37 nm (33.7 angstrom units), compared to its character period. Ten bases make up one strand for each pitch, and they are spaced roughly 0.34 nm (3.4 angstrom units) apart.
- A circle, square that is solid or full, etc., is a 2D object that has the least lateral dimension. A line literally signifies something that is long but not also wide or tall.
- For a helix of a given length, a helix point of 40 degrees hastwice as many turns as a helix point of 20 degrees.
- Calculate the number of turns needed to build a helix 6000 mm long if the pitch of the helical structure is 220 mm in relation to length.
- Length ::: 6000 nun,Pitch ::: 220 mm,
- Since, Length ::: Pitch X nos. of Tums, Therefore, Nos. of Turns ::: Length/Pitch,Nos. of turns ::: 27,
- Thus the Nos. of Tums on 6000 mm Long shell is "27".

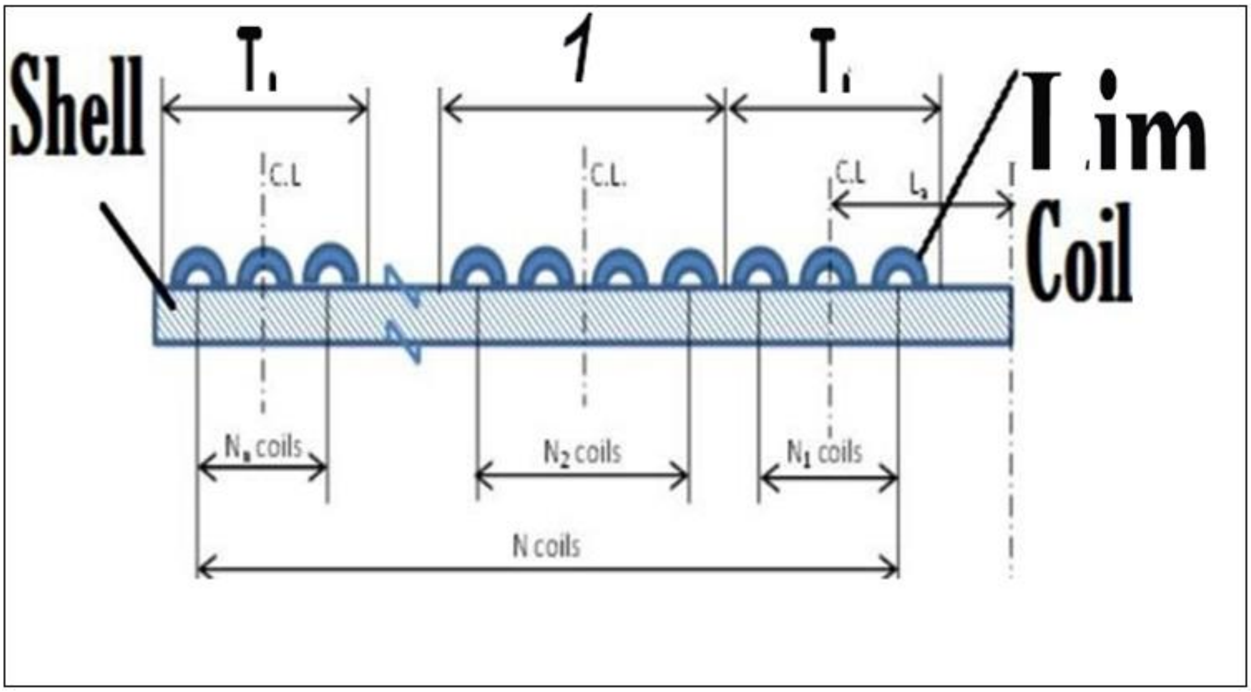


Fig 1 Shell with Numbers of Tums for Limped Coil

II. PROBLEM DEFINITION

Reactor type Pressure vessels are used as an alternative solution to handle pressurised fluids with various range of operating fluid temperature, as this vessel will be design as per peak thermal loading cases where, chances of disaster and explosionsare more. In order to maintain the safe conditions, the PV with Limpet system will be designed and analysed using ANSYS and the results will be provided to the industry for fabrication. Meanwhile the thickness of PV will be also optimized. Along with the thermal stresses, maximum allowable workingpressure (MAWP) and keeping the corrosive nature of the handling fluid in mind the analysis has been done. The PV hasbeen designed as per the ASME section VIII Division I and the data for the same being carried out by the industry. We are considering the primary design of the pressure vessel as a Single-layer and then correspondingly the analysis for Limpet system will be done for the same. From the perspective of saving the fluid against improper thermal conditions, like too fast cooling or overheating due to fluctuating thermal loading, high pressure conditions and corrosion due to internal fluid, thedesign of Limpet system is done using PV-Elite software. This eventually helps to save the cost and in turn provides resistanceagainst high temperature conditions. The approach for the design is design by analysis method and optimization of certainparameters.

III. THEORETICAL CALCULATION OF REACTOR PRESSUREVESSEL WITH LIMPET

➢ *Design Data from Industry*

This is an industrial project and hence the following basic engineering package will be taken from the industry, they are as follows,

- *Operating Temperature and Pressure.*

- ✓ Operating Volume Capacity.
- ✓ Percent Filling.
- ✓ Water Capacity.
- ✓ Nature of Service Fluid-Corrosive//Hazardous// abrasive/ lethal
- ✓ Required MOC.
- ✓ Type of Ends.
- ✓ Nozzle Schedule.
- ✓ Preference on Corrosion allowance, if not, will have to be calculated.
- ✓ Design Code, preferred/specified by Client / Process Department. If not, will have to select.

- *Design of PV by Process Engineer*

A Process Engineer/Process Designer is the one who lays the foundation of design code, ASME calculations and all the appropriate parameters that are usually required for the process. For our study all the data pertaining to the process is taken from the Process Designer for carrying out the further analysis.

- *Design of PV as per the ASME Code*

The Pressure Vessels are mostly designed as per followingcodes:

- *American Code : ASME Sec VIII Div.-1*
- *Indian Code : IS: 2825*
- *British Code : PD: 5500*
- *German Code: AD-MerkBlatter*

- *Design Basis/ Input Data from Process Department:*

During start of the Project or the design of the pressure vessel, following data is required from the Process Department / Personal / Client.

- ✓ Shape of Vessel.
- ✓ Position: Horizontal or Vertical.
- ✓ Process Fluid.
- ✓ Design Temperature.
- ✓ Design Pressure.

Table 1 Design Codes

Sr. No.	Country	Name of Design Code	F.O.S on	
			Tensile Stress	Yield Stress
1.	American Code	ASME Sec VIII Div.-I	3.5	1.5
2.	Indian Code	IS:2825	3	1.5
3.	British Code	PD:5500	2.35	1.5
4.	German Code	AD-Merkblatter	-	1.5

- *Basics for Selection of Design Code*

The code which gives optimum thicknesses, more safety (Factor of Safety) and more life to the equipment's shall be selected. The decision for selecting the code may be broadly based on Factor of safety, but this may not yield optimum or lesser thicknesses. Hence the final decision will be primarily designer's preview.

From the above table, it is observed that the F.O.S on yield stress of all the codes are same i.e., 1.5. Whereas on tensile stress, it is Maximum in ASME Sec VIII Div.-I & Lowest in PD:5500.Hence, it is inferred that, using PD: 5500 will result in lower thicknesses, lesser safety and ASME Sec VIII Div.-I will result in higher thicknesses & more safety. Use ASME pressurevessel code as design code for pressure vessels if not specified /preferred by Client.

- *Design Pressure*

The design pressure is the difference between internal and external pressures used to determine the minimum thickness required for each vessel component. It has a sufficient safety buffer above the operational pressure. (Design pressure = 1.1 times the Operating pressure or add more lOpsi in same) plus the static head of the operating fluid.

Design Pressure = 1.1 x Operating Pressure + Static Head due to service liquid Minimum design pressure for a Code non-vacuum vessel is 15 Psig

Negative gauge working pressure vessels are often intended forFull Vacuum.

- *Maximum Allowable Working (Operating) Pressure*

At the required temperature, it is the maximum gauge pressure allowable at the top of the completed vessel in its operational configuration. It is computed using the nominal vessel thickness, excluding corrosion allowance and thickness required for non- pressure loads. In most circumstances, it will be equal to or extremely close to the pressure vessel or component's design pressure.

- *Design Temperature*

The style is unique. Temperature is the working fluid's maximum temperature +50°F as a safety margin, or the operating fluid's minimum temperature if the vessel is built for low temperature service (below -20°F) It has a sufficient safety buffer above the operational temperature (50 to 100 percent of operating Temperature)

Design Temperature = 1.5 x Operating Temperature Design Temperature = 2.0 x Operating Temperature

IV. CAD MODEL AND FEA ANALYSIS INTRODUCTION

- *2D Model in Auto CAD*

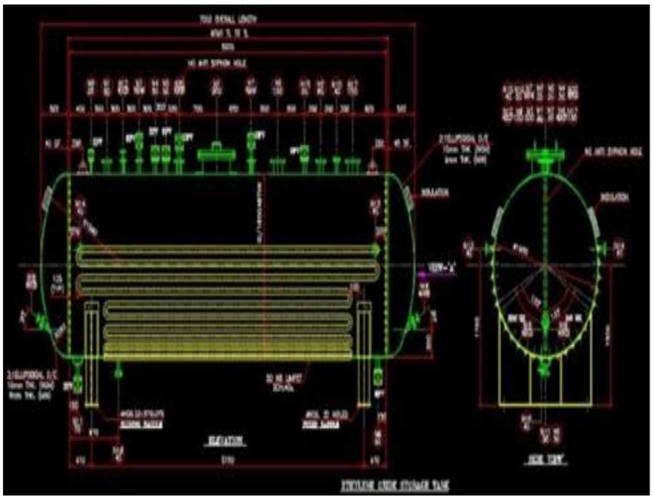


Fig 2 Auto CAD Drawing

➢ *3D Model in Solid Works*

Fig 3 3D-Model

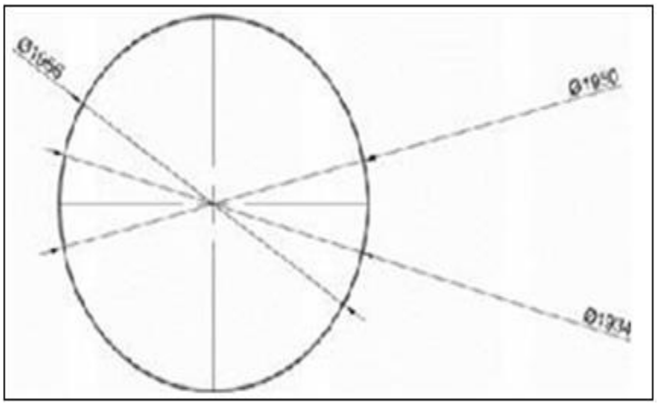


Fig 4 Thickness of Shell

➢ *FEA Analysis in ANSYS*

- The Finite Element Analysis process involves following steps:
- Create a mesh by breaking down the structure into smaller components.
- Assemble the elements at the nodes and implement the boundary conditions and needed contacts to arrive at the set of equations.
- Solve the system of equations.
- Calculate the desired amounts using the results after they've been post-processed (e.g., stress, displacement, temperature).

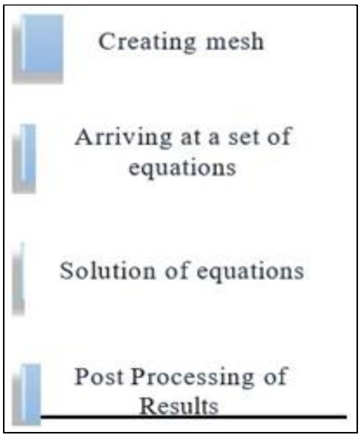


Fig 5 Steps in FEA

- *Advantages of FEA*

✓ Gives comprehensive results.
✓ It is feasible to simulate potentially unsafe or unworkable load circumstances and failure scenarios in a safe manner.
✓ Allows rapid analysis of performance as various parameters can be calculated simultaneously.
✓ Low investment and rapid calculation time.

Before answering the above question, given below is the brief about the design by formula approach used prior to FEA.

Formula-based design The ASME Code's Section VIII, Division I, takes a different approach. Previously, vessel design and engineering were done using predetermined codes, which specialists dubbed the "design by formula" technique. It includes specific rules for determining wall thickness and other details of vessel components, as well as separate procedures for dealing with component discontinuities.

➢ *Shortcomings of the Approach*

The regulations didn't account for everything a designer might wish to consider, Thermal gradients, piping loads, nozzle loads, quickly varying loads, seismic loads, wind, and so on are all factors to consider. The stress was computed using the average membrane stress and did not include any other types of stressessuch as thermal loads.

- *Design by Analysis Approach:*

Design by Analysis with Section III and Section VIII, Division 1of the code addressed the flaws of the Design by Formula approach. The designers can estimate stresses anywhere in the vessel, not simply the membrane stresses in regular sections, according to Section III and Section VIII, Division I of the regulation. Finite Element Analysis is used in this Design by Analysis method.

- *Fabrication:*

Following the completion of the FEA study, the results are compared to theoretical calculations, and the Pressure Vessel isthen sent for fabrication.

V. RESULTS ANALYSIS

A. *Single Layer Pressure Vessel Analysis*

➢ *Material Data*

SA240 GR304 (Base Material)

Density	7.2e-006 kg mm"-3
Thermal Conductivity	1.62e-002 W mm"-1 C"-1

Young's ModulusMPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa	Temperature C
2.e+005	0.3	1.6667e+005	76923	

Tensile Yield Strength MPa
170

Compressive Yield Strength MPa
170

Tensile Ultimate Strength MPa
285

B. Material Data- For Multi-Layering:

SA240 GR304 (Base Material): Stainless Steel Gr.

Density	7.2e-009 kg rnrnA-3
Thermal Conductivity	1.62e-002 W rnrnA-1 CA-1

Young's Modulus MPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
2.e+005	0.3	1.6667e+005	76923

Tensile Yield Strength MPa
170

Compressive Yield Strength MPa
170

Tensile Ultimate Strength MPa
285

- *Liner Material*

Density	7.8e-009 kg rnrnA-3
Thermal Conductivity	2.e-002 W rnrn/\-1 CA-1

Young's ModulusMPa	Poisson's Ratio	Bulk Modulus MPa	Shear Modulus MPa
1.9e+005	0.27	1.3768e+005	74803

Tensile Yield Strength MPa
267.6

C. Steady State Thermal Analysis

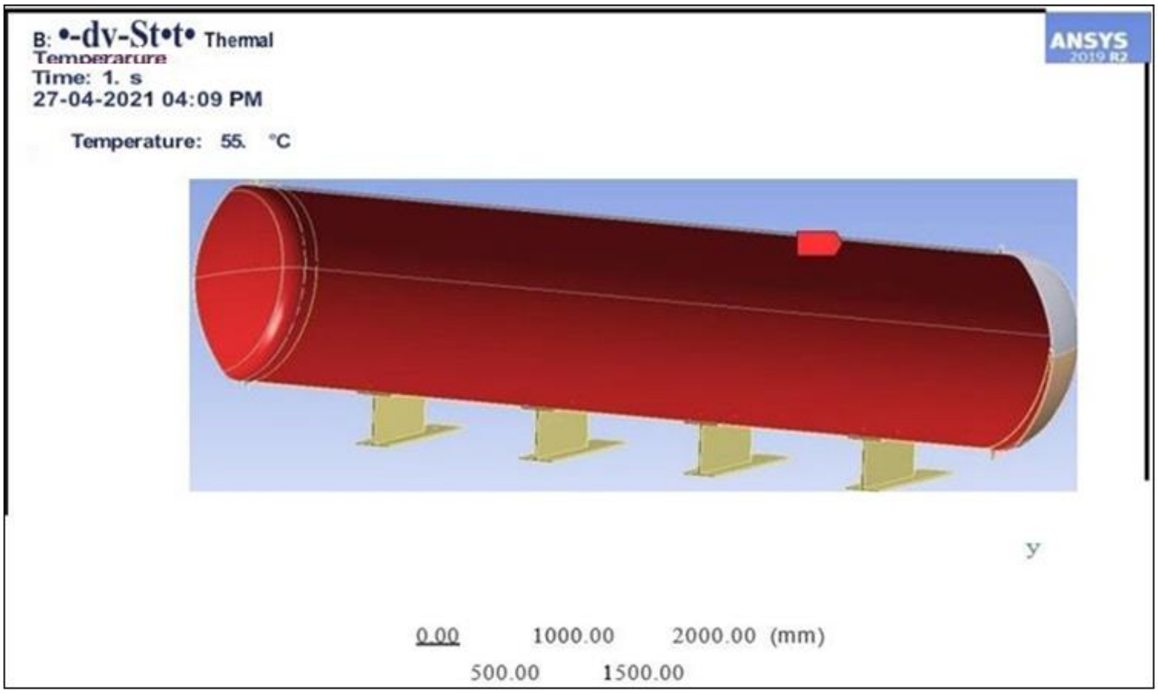


Fig 6 Temperature 55 Degree Celsius

- *Stress Constraints*

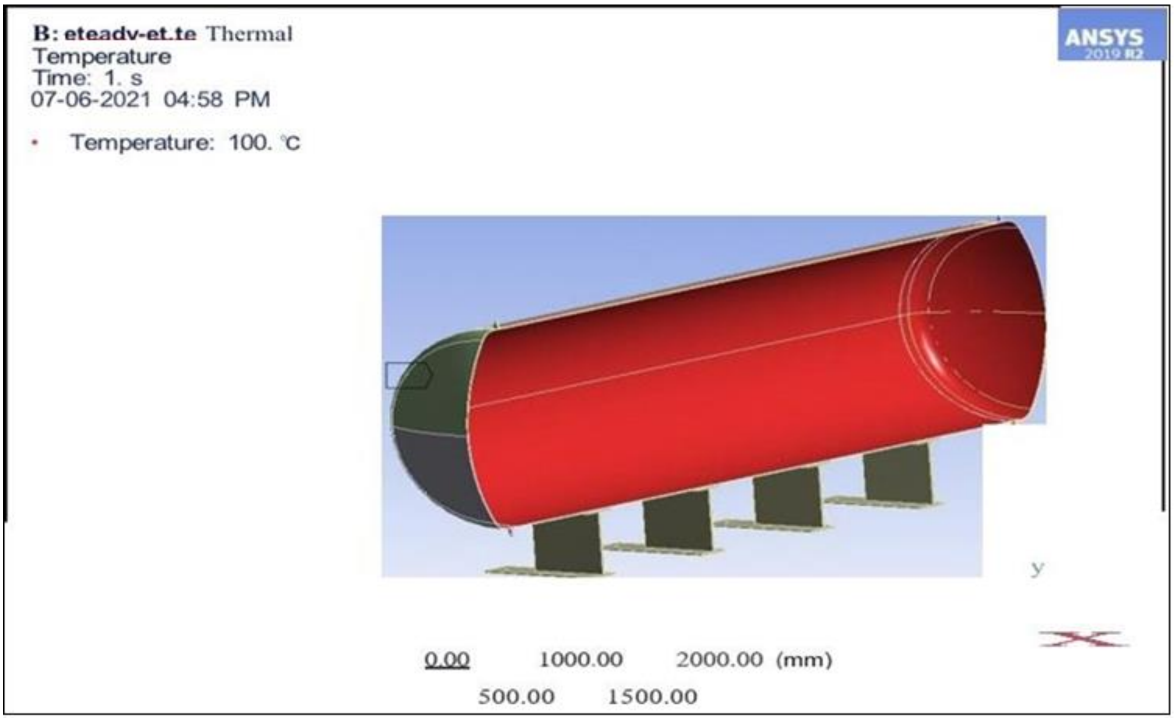


Fig 7 Temperature 100 Degree Celsius

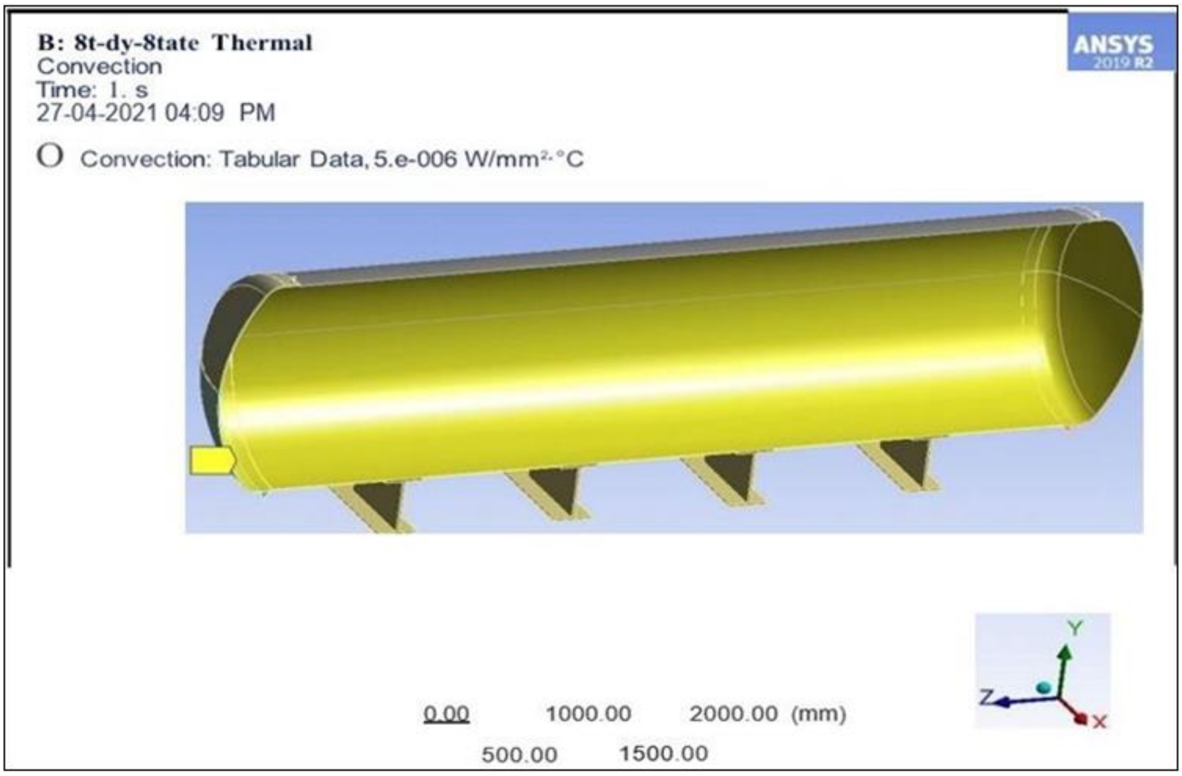


Fig 8 Convection

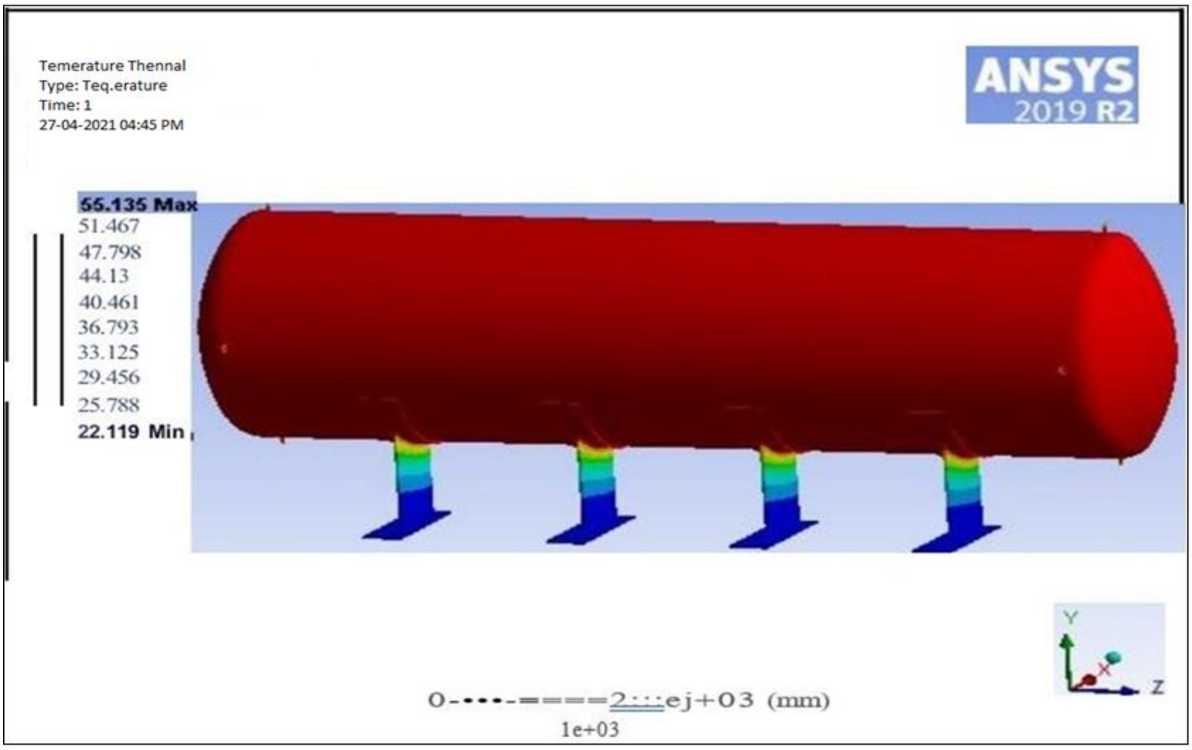


Fig 9 Temperature Distribution 55 Degree Celsius

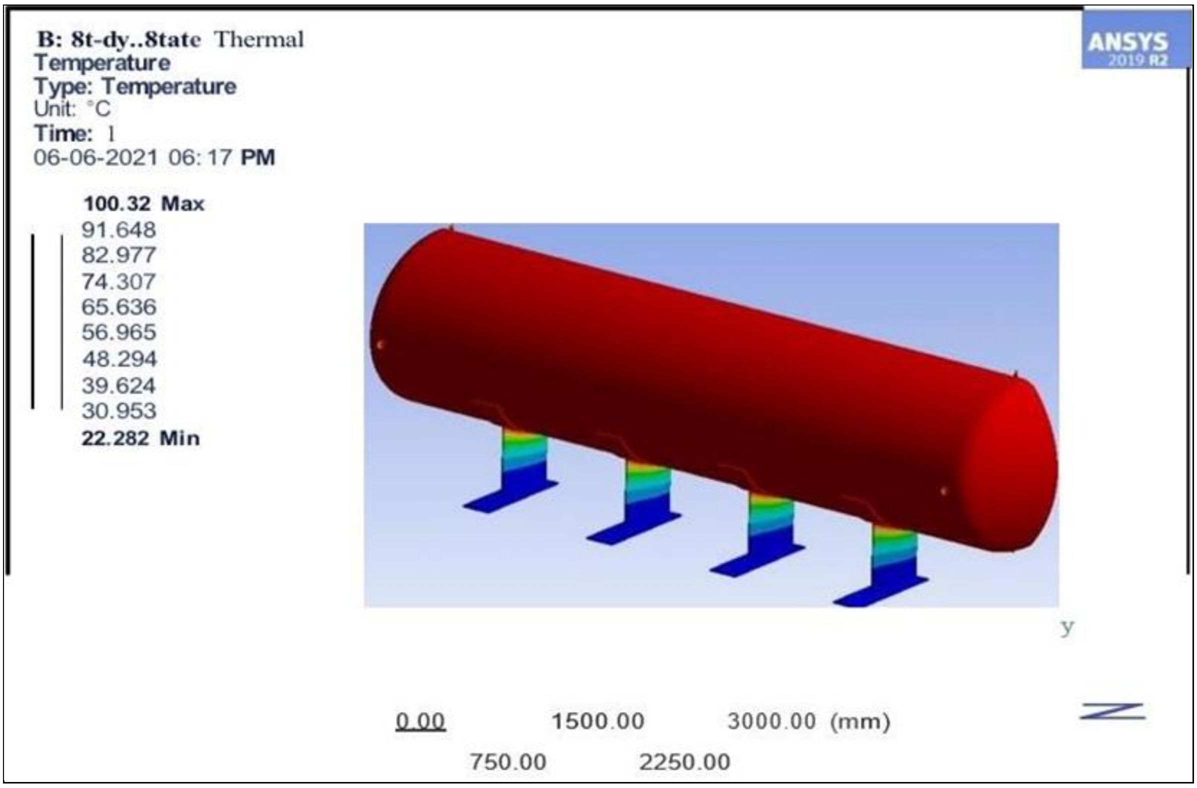


Fig 10 Temperature Distribution 100 Degree Celsius

A Gradual Steady-State Thermal Analysis is been carried out and a gradual temperature distribution is been shown, as one can see there is a gradual increase in temperature from 22.119 degree Celsius to 55.135 degree Celsius.

➢ *Total Heat Flux*

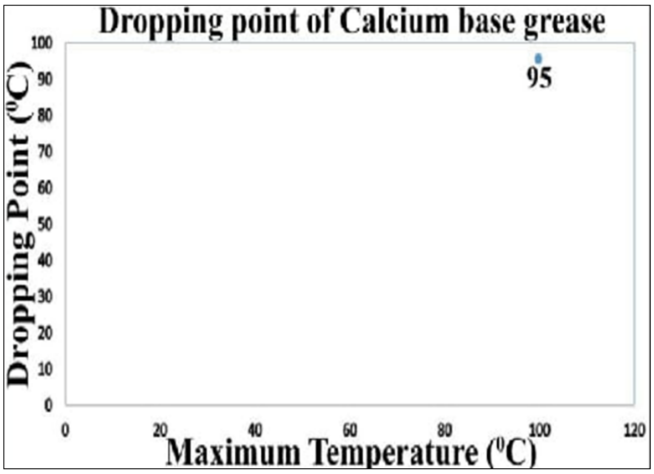


Fig 11 Temperature Distribution Graph for 100 Degree Celsius

A Temperature Distribution is shown Above as seen there is a linear rise in the temperature profile.

D. *Static Structural Analysis*

The displacements, stresses, strains, and forces caused in structures or components by loads that do not cause significant inertia or damping effects are determined using a static structural analysis. The loading and reaction conditions are assumed to stay stable, implying that the loads and structure's response will change slowly over time. Use the ANSYS, Samcef, or ABAQUS solvers to calculate a static structural load on a structure. In a static analysis, the following forms of loading can be used:

- External Pressure and force been employed.
- Forces of inertia in a steady state (such as gravity or rotational velocity).
- Small displacements is imposed (Value more than zero).
- Strain caused to due Temperature.

To put it another way, these skills are used in circumstances where the loading is more static and does not change with time or location.

One of the best instances of static structural difficulties is the reactions on a chair when someone sits in it, as well as the strains caused by a bolt-nut pair on a fork connection.

➢ *Load Constraints*

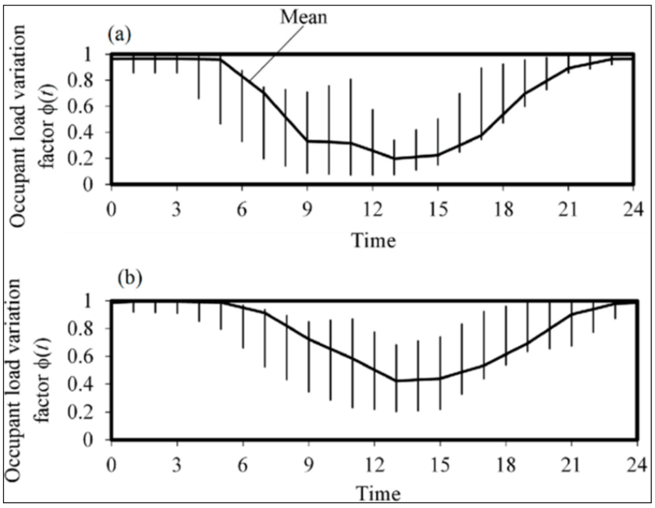
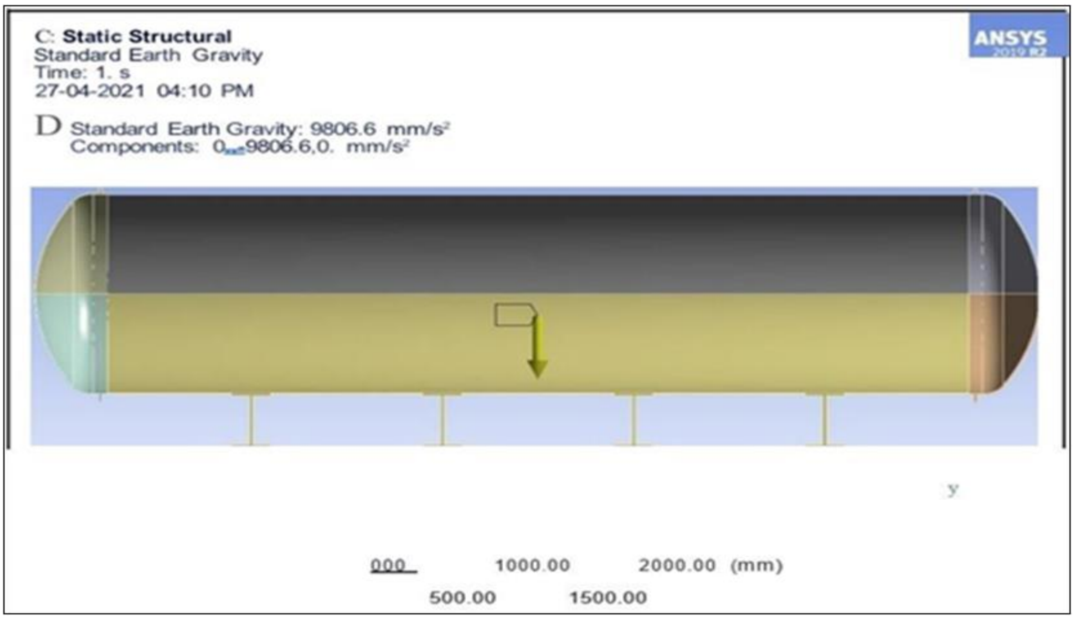


Fig 12 Load Variation SEG


C: **Static Structural**
Standard Earth Gravity
Time: 1. s
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D Standard Earth Gravity: 9806.6 mm/s²
Components: 0,-9806.6,0. mm/s²

Fig 13 Standard Earth Gravity

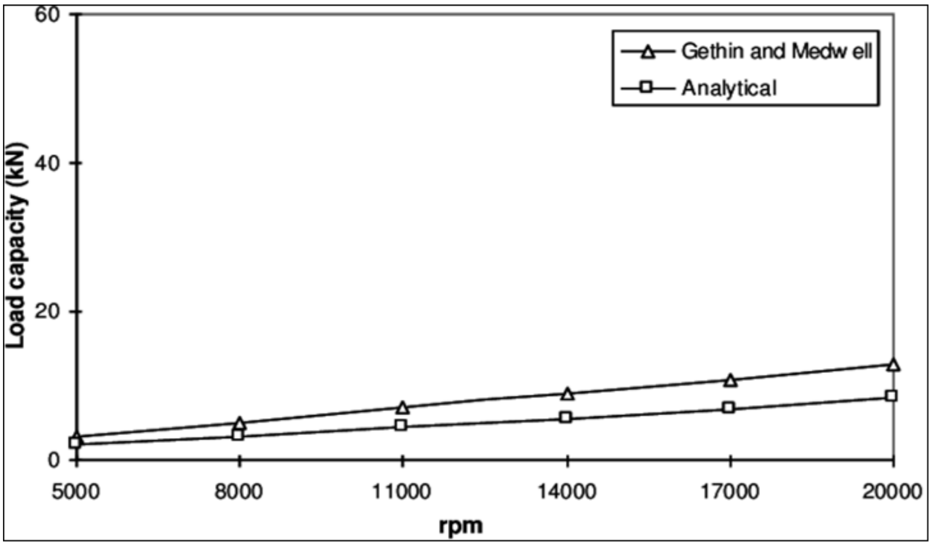


Fig 14 Load Variation Pressure 0.7 Mpa

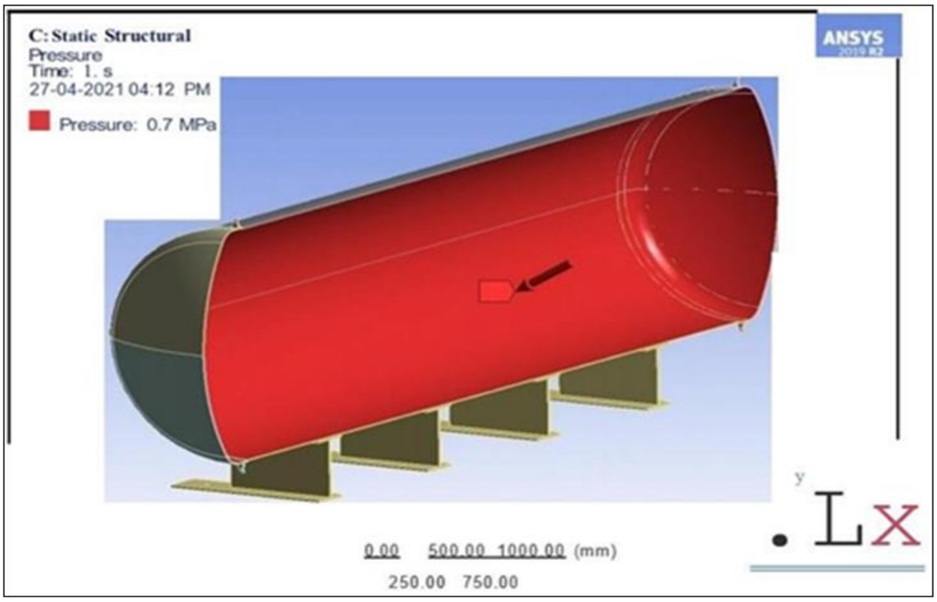
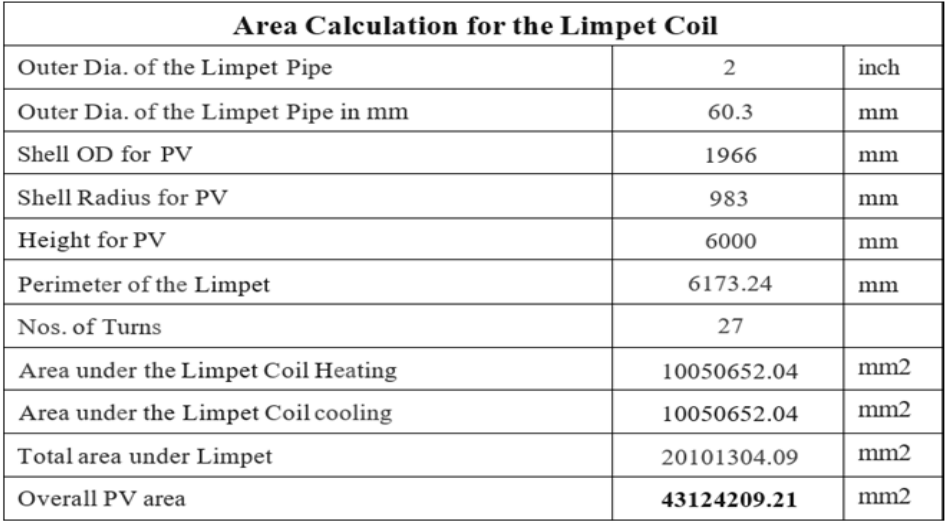


Fig 15 Pressure 0.7 Mpa

E. Area Calculations for Limpet Coil

Table 2 Area Calculation for the Limpet Coil



Area Calculation for the Limpet Coil		
Outer Dia. of the Limpet Pipe	2	inch
Outer Dia. of the Limpet Pipe in mm	60.3	mm
Shell OD for PV	1966	mm
Shell Radius for PV	983	mm
Height for PV	6000	mm
Perimeter of the Limpet	6173.24	mm
Nos. of Turns	27	
Area under the Limpet Coil Heating	10050652.04	mm2
Area under the Limpet Coil cooling	10050652.04	mm2
Total area under Limpet	20101304.09	mm2
Overall PV area	**43124209.21**	mm2

Table 3 Time Taken in Min. Sec for Limpet system with Natural cooling and Counter flow system

Sr. no.	**Range**	**Graph of Cooling temperature-drop taken by Reactor against the Time with Natural Cooling**	**Graph of Cooling temperature-drop taken by Reactor against the Time with Counter flow Cooling systems**
Readings	**Temp in Deg oc**	**Time Taken in Min.Sec**	**Time Taken in Min.Sec**
1	125 to 115	42.3696	28.3212
2	115 to 105	36.2536	26.3254
3	105 to 95	33.1956	24.2135
4	95 to 85	31.9965	21.3698
5	85 to 75	29.9674	20.3625
6	75 to 70	17.2315	16.9458
7	70 to 65	16.3325	14.2354
8	65 to 60	15.9625	12.3256
9	60 to 55	14.6854	10.235
10	55 to 50	14.3326	8.0321

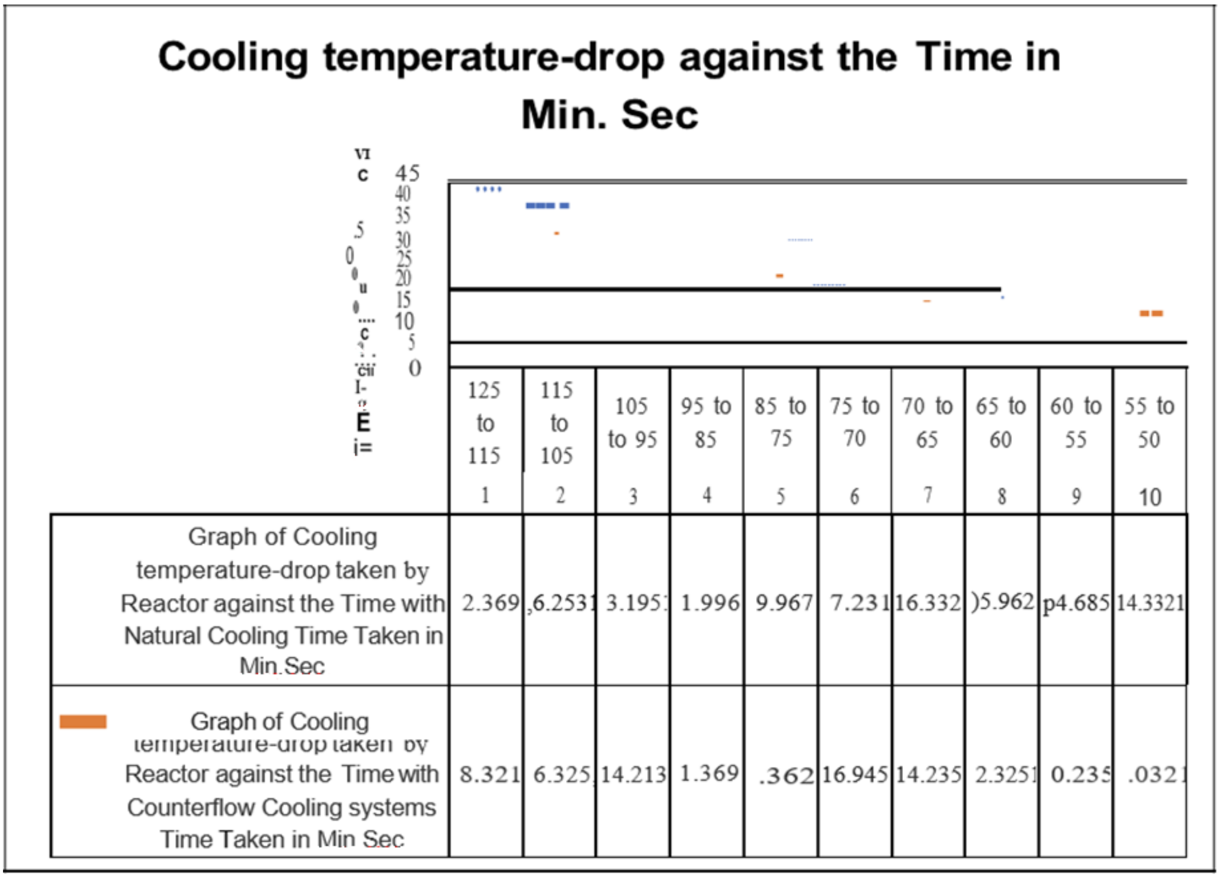


Fig 16 Graph Representing Cooling Temperature Drop Against the Time in Min. sec

Fig 17 Glimpses of the Servotex Engineer's Workshop

VI. EXPECTED OUTCOME

The pressure vessel has been analysed for the operating fluid of Ethylene oxide with Limpet system. The analysis has been performed for both Mono-layer pressure vessel. The stress, strain and deformation values have been compared for both the cases. Along with variable thermal loading and performance of Limpet will be analysed.

In high-pressure applications, multi-layering of pressure vessels is quite beneficial. In comparison, it has been discovered that increasing the number of layers in a pressure vessel reduces the Hoop stresses. A uniform stress distribution has been observed which is the indication of a suitable and optimal analysis.

Thus, this concept has provided the process designer a new way to enhance the various process parameters and provides fine extension for thickness optimization, weight and cost of production. Hence based on the design analysis and the economic benefits of Multi- layered pressure vessels over traditional Mono block pressure vessels, it has been concluded that Multi- layered pressure vessels are superior for high pressure and high temperature working circumstances.

VII. CONCLUSION

- The pressure vessel first been analysed for the operating conditions, handling fluid as Ethylene oxide with Limpet system.
- The analysis has been performed for pressure vessel. The stress, strain and deformation values have been compared for both the cases. Also the Limpet been tested for Mechanical & thermal loading and performance of Limpet will be analysed over Time period.
- The systems performance will be checked and in case of failure necessarily changes will be done in design and again analysis will be performed.
- The system will be having the More efficiency compared to the previous proposed system.
- As the Rate of Cooling is faster, so the New system been recommended to Client which can be incorporated in existing system.
- As the overall cycle time for Cooling down the Reactor pressure vessel is reduced, it will help in Rate of production with great efficiency.

REFERENCES

[1]. Ameya Palekar, Prasad Kompelli, Nikhil Mayekar, Aniruddha Shembekar, Ravindra Kurane, Ravi Mahatale, Sagar Bharadwaj, "Study and Design of Shell of Multi Wall Pressure Vessel". International Journal of Technical Research and Applications,2016.

[2]. AT Poojary, S Jaganath, R Nayak, "Modelling and equivalent stress analysis of flat dish and pressure vessel."2015

[3]. Chaoming He, Rong Yu, Haoran Sun, Zilong Chen, "Lightweight multilayer composite structure for hydrogen storage tank".

[4]. International Journal of Hydrogen energy2016

[5]. Chaudhari Riddhish, Damale Rahul, Bhujbal Anurag, borage Prashant, Rutukesh Bhosale. "Design and Analysis of Pressure Vessel Using Software". International Research Journal of Engineering and Technology (IRJET),2019

[6]. Christopher J. Evans, Timothy F. Miller, "Failure Prediction of Pressure Vessels Using Finite Element Analysis." Journal of Pressure Vessel Technology,2015

[7]. I Satyanarayana, K Praveena, "Design and analysis of Pressure Vessel by using FEM." International Journal of Innovative Science, Engineering and Technology, 2016.

[8]. M. Madhavi, K.V.J. Rao, K. Narayana Rao, "Design and analysis of filament wound pressure vessel with integrated-end domes."

[9]. Defence Science Journal, 2009

[10]. Niranjan Kumar, Sanjib Kumar Acharya, Dulal Krishna Mandal, Samar Chandra Monda} "Optimization of Shell- Thickness in Multilayer Pressure Vessel and Study on Effect of Number of Shells on Maximum Hoop Stress".lnternational Journal of Engineering Science and Technology (IJEST), 2011

[11]. Rayapuri Ashok, R Ranjith Kumar, Tirumala Rao. "Design and Analysis of CFRP (Composite Multilayer High-Pressure Vessels and Burst Pressure Analysis for Various Fiber Orientation Angles." International Journal of Advanced Trends in Computer Science and Engineering, 2013

[12]. Sandeep Gond, Akhilesh, Anoop Singh, Vinod Sharma, Shyamal Bihari Lal. "Design and Analysis of the Pressure Vessel." International Journal of Scientific & Engineering Research, 2014.

[13]. Shildip D Urade, Bhope DV and Khamankar SD. "Stress Analysis of Multi-Layer Pressure vessel." Journal of Applied Mechanical Engineering, 2015.

[14]. Siva Krishna Raparla, T. Seshaiah. "Design and Analysis of Multilayer High-Pressure Vessels." International Journal of Engineering, 2012

[15]. Surnit V. Dubai, Dr. S. Y. Gaijal, "Finite Element Analysis of Reactor Pressure Vessel under Different Loading Conditions." International Conference on Computing Communication Control and Automation, 2015

[16]. V. V. Wadkar, Jadhav Surnit S, Jadhav Tejasvi D, Chougule Amit A, SheteSuchita S, "Design and Analysis of Multi-Layer Pressure Vessel." International Journal of Advanced Technology in Engineering and Science, 2016

[17]. V. V. Wadkar, S.S. Malgave, D.D. Patil, H.S. Bhore, P. P. Gavade. "Design and Analysis of Pressure Vessel Using Ansys." Journal of Mechanical Engineering and Technology (JMET), 2015

[18]. Yeddula Suvarna, B. Ravi Sekhar, "Modelling and Analysis of Multi-layer High Pressure Vessel". International Journal of Science Technology and Management, 2016.