Design And Analysis of Spherical Pressure Vessel As Per Manufacturing Aspect

Divyesh B. Asodariya
Dept of Mechanical Engineering
G.I.D.C. Degree Engineering College, Navsari, Gujarat, India

Abstract- *Pressure vessel are largely used in industries owing to its feature in storing liquid or gas. Method used for manufacturing spherical pressure vessel include explosive forming, Blow forming, Hydro-bulging process, Die forming and Hydroforming process. Spherical vessel for large thickness is difficult to fabricate from single piece die so Spherical vessel fabricated in forming industries are in from two piece of hemispherical shape and multiple pieces having shape of trapezoidal, hexagonal, rectangular petals, which are welded together. The complete procedure for designing is provided by ASME code, In Section 8 Div. 1. When spherical vessel with very large diameter is difficult to manufacturing in two piece. In present work the various literature surveys conducted on design and fabrication of spherical vessel also complete design procedure of spherical vessel and FE simulation of single piece hemispherical dish end is carried out validate with case study given in literature. Also, FE simulation spherical pressure vessel carried out, based on this thinning analysis, further analysis is carried out for different number of petal with and without consideration of crown. Furthermore, we derived the analytical equation for determining the parameter of the crown and petal, and we had done number of analysis for different number of petal and crown, By doing FE simulation we can predict the percentage of thinning for vessel which can extremely supportive for spherical vessel manufacturing industries at early stage in calculating thinning allowance of vessel and optimum value of petals for minimizing total cost is obtained.*

Keywords- Pressure Vessel, Petal, finite element simulation

I. INTRODUCTION

In manufacturing industries, a closed container which designed to use for hold gases and liquids at a pressure significantly dissimilar from gauge pressure is called as pressure vessel. The pressure may be obtained from exterior source, by the unintended or direct source of heat. Shell, head, nozzle support and fittings are the main components of pressure vessel

Large pressure vessels were developed during the industrial insurrection, predominantly in Great Britain, to be used as boilers for making steam to drive steam engines. Design and testing standards and a system of certification came about as the result of fatal boiler explosions.

In an early determination to approach a tank capable of bearing pressures up to 10,000 psi (69 MPa), a 6-inch (150 mm) diameter tank was industrialized in 1919 that was spirally-wound with two layers of high tensile strength steel wire to prevent sidewall rupture, and the end caps longitudinally reinforced with along high-tensile rods.

Pressure vessels are used in a multiplicity of applications in both industry and the private segment. They appear in these sectors as industrial compressed air receivers and domestic hot water storage reservoirs. Other examples of pressure vessels are diving cylinders, recompression chambers, refinement towers, autoclaves, and many other vessels in pulling out operations,

Theoretically almost any material with good tensile properties that is chemically stable in the chosen application could be employed. However, pressure vessel design codes and application standards (ASME BPVC Section II, EN 13445-2 etc.) contain long lists of approved materials with associated limitations in temperature range.

Specific mechanical properties of steel, accomplished by various manufacturing processes In addition to satisfactory mechanical strength, current standards dictate the use of steel with a high impact resistance, Spherical vessels have the benefit of good appearance, bulky volume and unvarying stress. At the existing phase they have initiate wide application in the oil, chemical, metallurgical, light and in water systems in buildings. By evaluation, the outmoded manufacturing method for spherical vessels is very multifaceted. The fabrication as well as welding are challenging; the production cost is comparatively high; and the production cycle is very long.

A designer always finds of great importance to make construction with minimum material cost satisfying exploitation requirements thereat. Since the material and energy–generating product prices are ever growing.

As well as market demands, the great designers' task is to optimize design Therefore constructions are, according to technical norms, arranged into more groups in respect of which according to different exploitation conditions matching different factors.

1.1 Types of Pressure Vessel:
1.2

Two types of pressure vessel are generally used.

- **Cylindrical Pressure Vessel:**

This type of pressure vessel widely used for storage due to their being less expensive. This type of pressure vessel are not as strong as spheres due to weak point at each end.

Fig. 1.1 Cylindrical Pressure Vessel

- **Spherical Pressure Vessel:**

For Storing of high-pressure liquids and air, this sort of pressure vessel is used. Cylindrical pressure vessel is less inflated than this type of pressure vessel. It has recompenses of less surface area per unit volume than any other profile of vessel. It means the heat transfer from adjoining to system of pressure vessel or inside the cylinder is having a smaller amount than associated to cylindrical pressure vessel.

Fig. 1.2 Spherical Pressure Vessel

1.2 Application of Spherical Pressure Vessel:

Application of Spherical Pressure Vessel in various field of industries are as follows.

- Storage of liquid and gases at high temperature and pressure.
- Oil refineries and petrochemical plants.
- Nuclear-powered reactor vessels.
- Chemical Industry.
- Refineries.
- Maritime and space ship environments
- Pneumatic reservoirs
- Hydraulic reservoirs under pressure
- Rail vehicle airbrake reservoirs
- Road vehicle airbrake reservoirs
- Storage vessels for liquefied gases
    - Ammonia
    - Chlorine
    - Propane
    - Butane
    - LPG

1.3 Materials of Spherical Pressure Vessel:

Ideally almost whichever material with virtuous tensile properties that is chemically constant in the preferred application could be employed. However, pressure vessel design codes and application standards (ASME BPVC Section II, EN 13445-2) contain long lists of approved materials with connected limitations in temperature range.

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 badly affected by welding, unless special safeguards are taken. In addition to acceptable mechanical strength, present standards dictate the use of steel by a high impact resistance, exclusively for vessels used in low temperatures. In applications where carbon steel would suffer corrosion, special corrosion resistant material should also be used.

Some pressure vessels are made of composite materials, such as filament wound composite using carbon fiber held in place with a polymer. Due to the very high tensile strength of carbon fiber these vessels can be very light, but are much more difficult to manufacture. The composite material may be wound around a metal liner, forming a composite overwrapped pressure vessel. Other very common materials include polymers Pressure vessels may be lined with various metals, ceramics, or polymers to prevent leaking and protect the structure of the vessel from the contained medium. This liner may also carry a significant portion of the pressure load.

II. OBJECTIVE AND RESEARCH GAP OF PRESENT WORK

From the research and literature survey, it can be seen that many analytical and numerical analysis is done on cylindrical vessel. Also lot of experimental investigations have been done on thinning variation in dished head during hot and cold forming using finite element analysis. But very less research is done on other forming process of Spherical vessel which are fabricated in forming industries are in from two piece of hemispherical shape and multiple piece having shape of trapezoidal, hexagonal, rectangular crown and petals, crown and petal type dish end.

Also very less work is noticed on numerical analysis, to study the effect of number of petal used in for thickness distribution.

Since the complete procedure for design of spherical pressure vessel is given in ASME with different allowances but when the very large dish end with large diameter are difficult to fabricate by single piece die.

Objective of present work is carry out FE simulation of spherical pressure vessel with different petal number and study effect on number of petal on percentage thinning.

III. DESIGN OF SPHERICAL PRESSURE VESSEL

3.1 Design Procedure:

Pressure vessels are designed to operate safely at a specific pressure and temperature, technically referred to as the "Design Pressure" and "Design Temperature". A vessel that is inadequately designed to handle a high pressure constitutes a very significant safety hazard.

The design and certification of pressure vessels is governed by design codes as the ASME Boiler and Pressure Vessel Code in North America, the Pressure Equipment Directive of the EU (PED), Japanese Industrial Standard (JIS), CSA B51 in Canada, Australian Standards in Australia and other international standards like Lloyd's, Germanischer Lloyd, Det Norske Veritas, Société Générale de Surveillance (SGS S.A.), Stoomwezen etc.

The input data for spherical pressure vessel is assume with the internal pressure of 10 MPa, Design temperature of 250°C, no external pressure effect, maximum corrosion allowance is 3 mm., diameter is 1 m. Design procedure followed ASME code section VIII Div. I

Analysis was carried out only on the petal of the pressure vessel. The material is to be taken as the SA 516 Gr 60 as per ASME section II, Part A.Simple design procedure for spherical pressure vessel is described as per ASME design code.

3.2 Formula For Thickness Of Spherical Pressure Vessel:

The required thickness at the thinnest point after forming of spherical pressure vessel under pressure shall be computed by the appropriate formulas are given in ASME code section VIII Div. I UG-32.

The symbols defined below are used in the formulas:
T = minimum required thickness of head after forming in (mm)
P = internal design pressure (UG-21), (MPa)
D = inside diameter of the head skirt (mm)
S = maximum allowable stress value in tension as given in the tables referenced in
U23. (MPa)
E = lowest efficiency of any joint in the vessel
L = inside spherical or crown radius, (mm)
C = corrosion allowances, (mm)

As per ASME SECTION VIII — DIVISION 1when the thickness of the shell of wholly spherical vessel does not exceed 0.356R, or P does not exceed 0.665SE, the following formulas shall apply: Minimum required thickness after forming can be determined using Eq.

t={$PL2SE$−0.2P}+C
t={10 X 5002(70X1)−0.2(5)}+3
t =38.79 ≅ $\mathbf{40\ mm}$

Once the vessel is formed, formed vessel meet the requirement which is describe in ASME code section VIII Div I UG- 81.

IV. FINITE ELEMENT ANALYSIS

For carry out our objective a numerical data for single piece hemispherical dish end taken from raval et al (2013) for which same data such as dimension of the dish end property of material etc. will utilized. The following geometry in Fig. 4.1 was considered

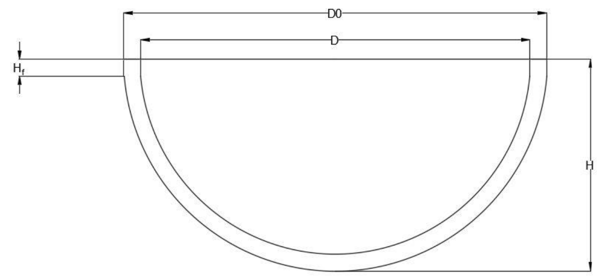

Fig. 4.1 Geometry of hemispherical dish end.

Where,
D = diameter of dish end.
H = Height of dish end
Hf= Flange height
T = minimum thickness of dish end

The mechanical property of material include Hardening exponent (n), strength coefficient (K), yield strength (YS), Ultimate tensile strength (TS) and modulus of elasticity (E), Poisson (ϑ) ratio for ferrous material grade SA-387 Gr22 and SA-516 Gr 60 are reported in following

Table- 4.1 Material Property

Material name	SA-516 Gr60
Young modulus, E (MPa)	210000
Poisson ratio, ϑ	0.3
Strength coefficient, K (Mpa)	704.27
Tensile strength, TS (Mpa)	498
Strain hardening exponent, n	0.25
YS (Mpa)	265
R0, R45, R90	1

Fig. 2 shows the sample IGES file of single piece hemispherical dish end (SPHDE) used for FE simulation for diameter (D), height (H) and thickness (T) combination of 490, 193 and 25 mm respectively.

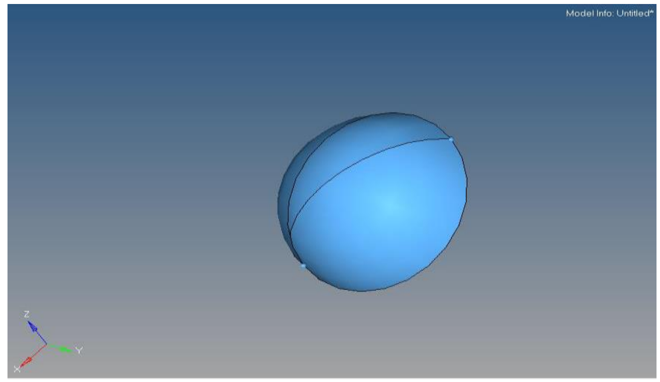

Fig. 4.2 Sample IGES file of Hemispherical

FE simulation software is use for thickness variations while forming of dish end with different number of petal. The output of FE simulation directly gives maximum and minimum percentage thinning.

4.1 The steps in setting up forming simulations:

- Import the IGES-geometry to simulation software.
- Mesh the dish end surfaces.
- Define material for the blank.
- Define the punch direction.
- Run the simulations, for 1 step stamping simulation.
- Evaluate the result.

Fig. 4.2 shows the simple 3D view of IGES of single hemispherical dish end with diameter; height and thickness are 490mm, 193 mm and 25 mm respectively. After import geometry meshing is generated on part.

Rigid mesh technique with the values of 0.5, 30, 0.1 and 15 as minimum edge length, maximum edge length, chordal deviation and fillet angle respectively. Value material property parameters for SA-387 Gr22 at average forming temperature of 900 °C and SA 516 Gr 60 are reported in Table 1 and used for FE analysis of single piece hemispherical dish end.

Power law plasticity material is used for material. At present work, autotipping of the dish end model for setting punch movement in Z direction and blank material is in XY plane constraints are applied to perform the complete simulation. Fig. 4.3 show the simple 3D view of IGES of two piece, three pieces without considering crown respectively.

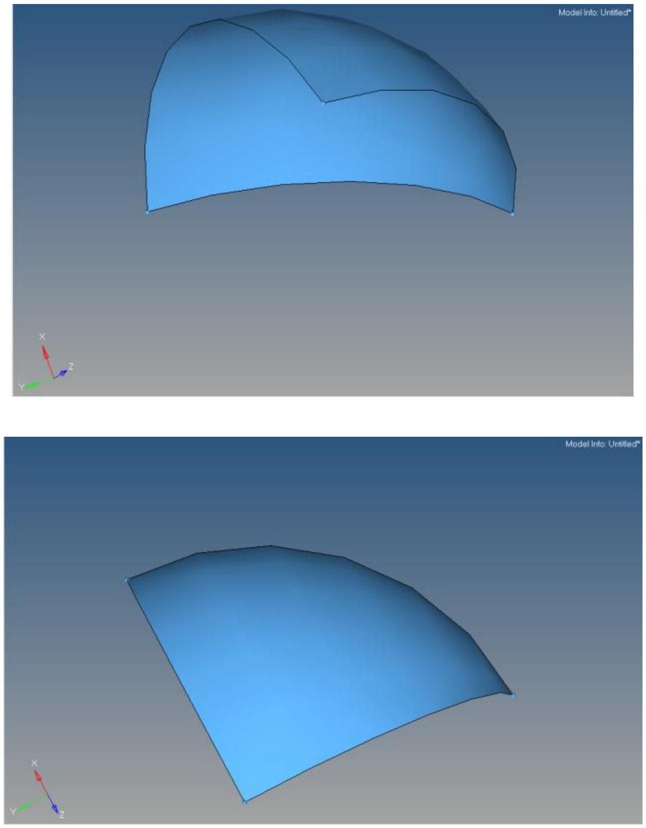

Fig. 4.3 Sample IGES file of pieces

V. RESULT AND DISCUSSION

5.1 Comparison between Literature & FE simulation data

Fig. 5.1 shows the sample FE simulation output plot of percentage thinning of SPHDE of ferrous material grade SA-516 Gr60 for diameter (D), Height (H) and thickness (T) combination of 490, 193 and 25mm respectively.

In provided simulation we can observed that in some of the area is covered by red color and some of the area of dished end is covered by yellow color in which Red color indicates the area of thinning and Yellow color indicates area of thickening.

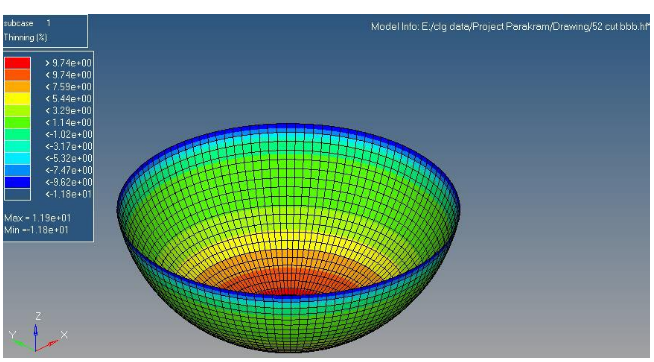

Fig. 5.1 FE simulation result of percentage thinning for SA 516 Gr60.

Table 5.1 Result Table of Hemispherical Dish End

Sr. No.	H (mm)	D (mm)	T (mm)	Percentage of Thinning		Percentage error
				Literature Result	FE simulation	
1	193	490	25	11.6	11.9	2.5

5.2 Result for percentage of thinning in vessel (Without crown)

The result of FE simulation of spherical pressure vessel with considering different petal number is presented. Figs 5.2-5.4 shows the FE simulation result for percentage thinning for different petal size without considering crown at top.

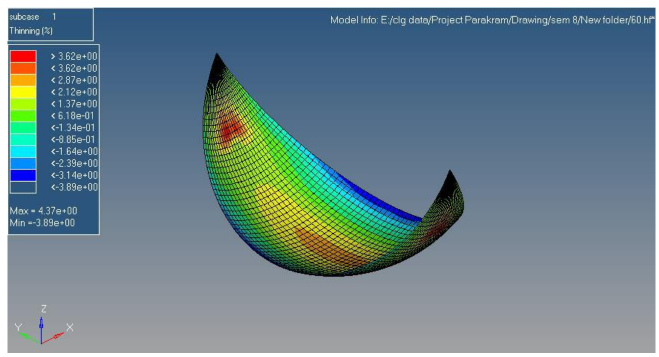

Fig. 5.2 FE simulation result with 6 pieces

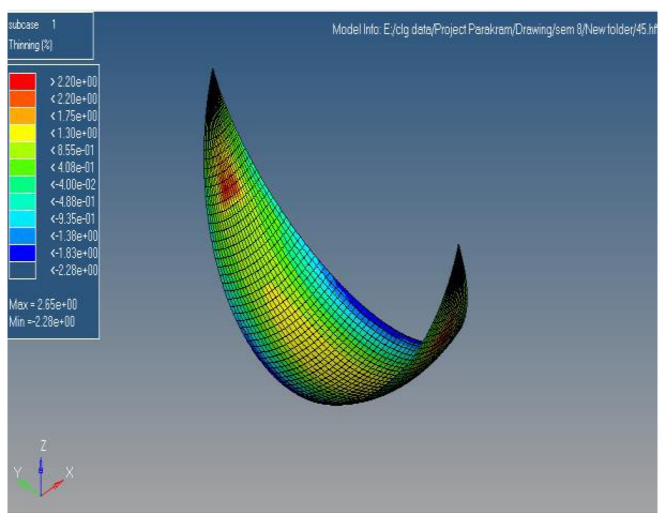

Fig. 5.3 FE simulation result With 8 pieces

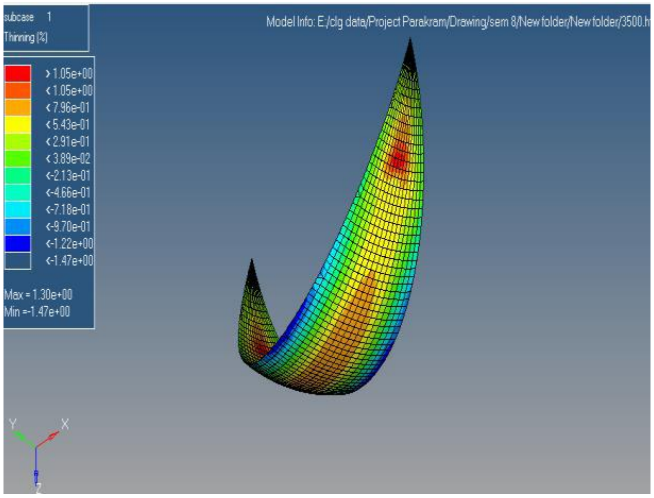

Fig. 5.4 FE simulation result with 10 pieces

FE simulations are performed for different cases (for different number of petal) and result obtain of percentage thinning is reported in Table 5.2

Table 5.2 Result Table of Pieces

Sr. No.	D (mm)	T (mm)	No. of Petals	Percentage of thinning
1	1000	40	2	16.8
2	1000	40	4	15.6
3	1000	40	6	4.37
4	1000	40	8	2.65
5	1000	40	10	1.30

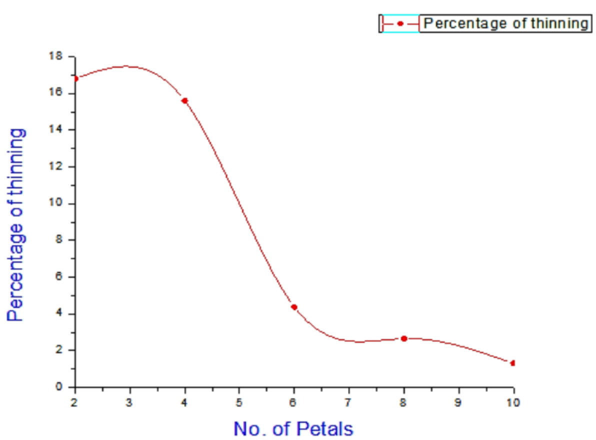

Fig. 5.5 Percentage thinning for different number of petal of SA 516 Gr 60For data reported in Table 5.2

5.3 Derivation of analytical equation

All the petal meet at single point and it create certain problem.so in figure 5.6 shows the simple 2D view of spherical pressure vessel with crown and 4 petal. It is noted from figure 5.6 that as the diameter of crown increases the length of petal decreases, so it can be concluded that crown diameter or height of crown is inversely proportional to height of petal.

So, it can be concluded that the ratio of height of crown (HC) to height of petal (HP) is important to decide crown diameter. The relation between different parameter of vessel to HC/HP ratio is derived below.

Where,

R = Radius of spherical pressure vessel (mm)
HC = Height of crown (mm)
HP = Height of petal (mm)
H = HC/HP

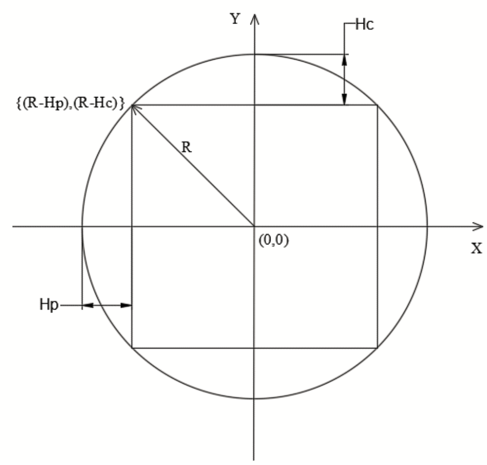

Fig. 5.6 Spherical vessel with petal and crown

From the geometry we can say that equation of line and equation of circle,

$$R^2 = x^2 + y^2$$

Where,
$(X\text{-}Y)=\{(R-H_P)^2,(R-H_C)^2\}$
SO,
$R^2=\{(R-H_P)^2,(R-H_C)^2\}$

Dividing whole equation with H_C

$$\frac{R^2}{H_C} = \left(\frac{R}{H_C} - \frac{H_P}{H_C}\right)^2 + \left(\frac{R}{H_C} - \frac{H_C}{H_C}\right)^2$$

Taking h= $\frac{H_C}{H_P}$

So equation becomes

$$R^2 + H_C^2 + h^2 H_C^2 - 2RH_C(h+1) = 0$$

5.4 Result for percentage of thinning in vessel (With H_C/H_P ratio)

We derived empirical equation for the calculating dimension of the petal and crown, based on that equation. Finite element simulation for the spherical pressure vessel considering different number of petals and ratio of height of crown (HC) to height of petal (HP).Empirical equation (1) for spherical pressure vessel which applicable to number of petal range 4 to 10,H_C/H_P ratio of 1.2 and diameter 1000 mm. By doing FE simulation we can predict the percentage of thinning for vessel thinning is reported.

Table 5.3 Result Table of Pieces with Hc/Hp ratio

Sr. No.	R	H_C/H_P	H_P	H_C	% of Thining	
					Petal	Crowa
1	500	0.2	272.85	54.57	7.08	1.36
2	500	0.3	241	72.3	5.28	1.9
3	500	0.4	217.93	87.17	5.08	2.08
4	500	0.5	200	100	4.93	2.31
5	500	0.6	185.5	111.3	4.77	2.98
6	500	0.8	163.14	130.51	4.49	3.53
7	500	1	146.45	146.45	4.26	3.99
8	500	1.2	133.36	160.03	4.05	4.39
9	500	1.4	122.75	171.85	3.87	4.74
10	500	1.6	113.93	182.28	3.72	5.07
11	500	1.8	1.6.44	191.6	3.58	5.33
12	500	2	100	200	3.45	5.59

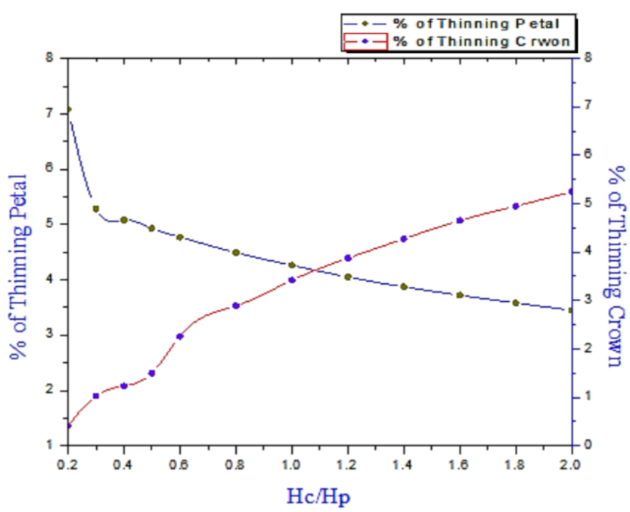

Fig. 5.6 Graph for the % of thinning vs Hc/Hp

From the above graph, Based on thinning percentage we can say that h=1.2 would me most feasible for crown as well as petal. For the h = 1.2, FE simulation for 4, 6, 8 and10 are described in the table 5.6.In which by doing FE simulation we can predict the percentage of thinning for vessel which can extremely helpful for spherical vessel manufacturing industries at early stage in calculating thinning allowance of vessel and leads to the huge amount cost benefit.

Table 5.4 Result Table of Pieces

Sr. No	Nos. of Petals	% of Thinning
1	4	4.05
2	6	2.43
3	8	1.13
4	10	0.783

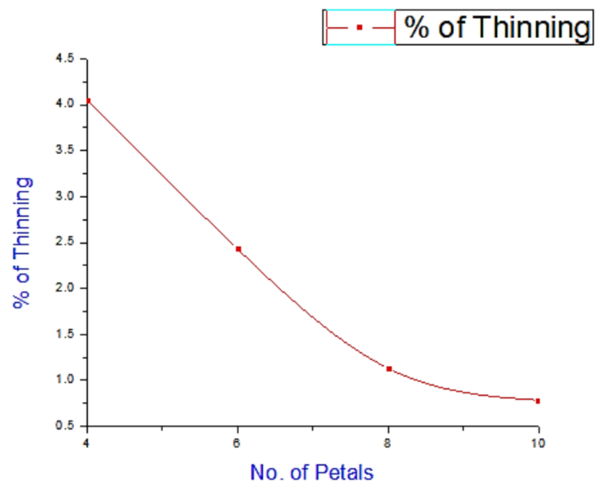

Figure: 5.6 % of Thinning vs Nos. of Petals

VI. CONCLUSION

It can be concluded from above result, between the numbers of petal four to six there is large decrease in percentage thinning also, if we are not adding crown then welding joints meet at one point which is not advisable.

For the spherical pressure vessel, we derived empirical equation for the calculating dimension of the petal and crown. In present work, finite element simulation for the spherical pressure vessel considering different number of petals and ratio of height of crown (HC) to height of petal (HP).Empirical equation for spherical pressure vessel which applicable to number of petal range 4 to 10, HC/HP ratio of 1.2 and diameter 1000 mm. By doing FE simulation we can predict the percentage of thinning for vessel which can extremely supportive for spherical vessel manufacturing industries at early stage in calculating thinning allowance of vessel.

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