

# Mechanical Design of Air Oil Separator Tank using PV-Elite Software

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**Abstract** – The use of compressed air is an integral feature of every industrial firm. The safety factor of Air-oil separator tank is related to both the tensile stress and yield strength for material allowance. ASME Code Section VIII has fully covered these two on the construction code for pressure vessel. This code section addressed mandatory requirement, specific prohibition, and non-mandatory guidance for pressure vessel materials, design, fabrication, examination, inspection, testing, certification, and pressure relief. Mechanical design of a vertical pressure vessel for two phase separator based on this standard has been done using PV Elite software. Analyses were carried out on skirt, shell, nozzle, dish end and flanges. The input parameters are material, pressure, temperature, and diameter and corrosion allowance. Analysis was performed to calculate thicknesses of all the parts for the design conditions.

**Key Words:** Air-oil separator tank, Pressure vessel, Mechanical design, PV Elite Software.

## 1. INTRODUCTION

Pressure vessels are containers for the containment of pressure either internal or external. This pressure comes from an external source or by the application of heat from a direct or indirect source or any combination of them. The pressure vessels are used to store fluid that may undergo a change of state inside as in case of boiler or it may combine with other reagent as in a chemical plant. In our application air-oil separator tank is used after air end assembly in screw compressor. Pressure vessels are commonly used in industry to carry both liquid and gases under pressure. The material comprising the vessel is subjected to pressure loading and hence stresses from all direction. The normal stress resulting from this pressure is functions of radius of the element under consideration, the shape of the pressure vessel as well as the applied pressure (ASME, 2007).

Separate is used to separate a mixture of immiscible fluids of different density. Based on the number of fluid involved, separator is classified into two phase separator and three phase separator refers to the number of streams leaving the vessel and not the inlet fluid stream.

Although most separators are two-phase in design, separating the gas and total liquids, three - phase separator mainly needed in natural gas processing. It separates gas, oil or other liquid hydrocarbons, and free water. Most platforms have a series of production separators, starting with a high-pressure separator, which separates the (HP) gas from the liquids. Liquids are then piped to a medium pressure (MP)

separator, which removes more gas and then passes the liquids to a low pressure (LP) separator that removes even more gas and then separates water from the oil (Arnold and Stewart, 1999).

Separators are built in various designs, such as horizontal, vertical or spherical. Vertical separator is commonly used in offshore due to limitation of space. Meanwhile horizontal separator is installed in a plant that space is not considered as barrier. This research reported the design of vertical two phase separator as shown in the Figure 1.

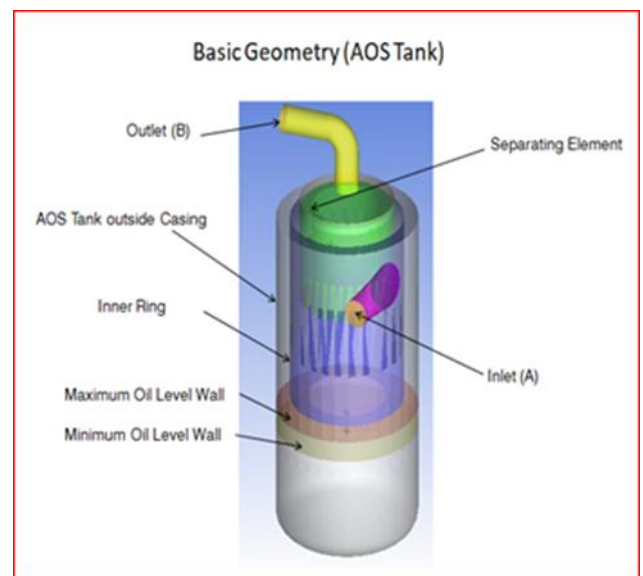


Figure1. Two Phase Separator

Process design of two phase separator follows API (American Petroleum Institute) standard criteria. Mathematical model and thermodynamic analysis had been studied extensively by Taylor and Lucia, 1995, Dionne, 1998. Whilst this research merely analyzed mechanical design of two and three phase separator that basically a pressure vessel. There for it is focused on the pressure vessel design. The pressure vessels must design thoroughly because rupture of pressure vessels causes an explosion that may result in loss of life and property. Research on modeling of leakage of a pressure vessel that contain two phase of fluid has been done. The simultaneous equation were solved using MATALAB by Cokorda 2004.

Investigation on the potential of over pressurization of a pressure vessel maintaining chemical material was done

by Adkins, 1994. However the first stage to prevent rupture of pressure vessel is designing the pressure vessel with great care. Implementation of software for designing mechanical equipment facilitate engineer with a comprehensive analysis either structure analysis or dynamic simulation.

Design and analysis of pressure vessel for static loading and its assessment by Ansys was done by Jimit and Mahavir, 2008. The main feature is to check the behavior of pressure vessel under fluctuating load including various aspects such as selecting the material based on ASME codes.

This research implements PV Elite software to analyze elements of vertical pressure vessel for two phase separator. This graphical based software has GUI (Graphical User Interface) that collect model description and the interactive analysis displayed intermediate result conveniently on the same screen.

## 2. RESEARCH METHOD

The input design for pressure vessel refers to the data from Kirloskar Pneumatic Co Ltd Pune, one of compressor manufacturer located in India. This order-based company had a project from one of oil and gas industry to manufacture a screw compressor and for separation of oil and gas pressure vessel for two phase separator, with the material of SA- 36, design pressure of 14 bar, design temperature of 132°C and maximum corrosion allowance of 0 mm. Shell diameter is 398 mm, Dish end diameter is 398 mm elliptical. and length of vessel is 790 mm.

Design procedure followed ASME Code Section VIII. Analysis was carried out only on the following elements of pressure vessel: skirt, shell, dish end, body flange and blind flange. The step of analysis is illustrated on flow chart as shown on Figure 8. Material is selected according to purchase order. Design, Input parameter is given for every part. All the mathematical equation refers from ASME section VIII. For example for calculation, thickness is calculated using Equation 1

$$t = P.R / (2SE - 0.2P) + CA \quad \dots\dots\dots 1$$

Where:

t= head thickness, mm

P = pressure, bar

R = radius of head, mm

S = stress of material, bar

E = joint efficiency

CA = corrosion allowance, mm

Maximum Allowable Working Pressure can be determined using Equation 2.

$$MAWP = \frac{2SEt_a}{R + 0.2t_a} \quad \dots\dots\dots 2$$

Where: ta = allowable thickness, mm.

Allowable thickness depends on the nominal thickness, corrosion allowance, head diameter and shell diameter.

The same equation would appear in the output screen whenever analysis menu was run. The similar step was conducted on different elements such as on shell, nozzle, dish end, skirt, flange and also nozzle.

Saddle is only available on horizontal type of pressure vessel and for vertical one the term is leg. Weight of each element and the total weight of pressure vessel had also calculated.

The output of analysis can be presented in many features. It can be in the form of table, or export to word processor in the form of final report. Since this research have not completed yet, the output would be presented as they are generated.

## 3. RESULT

Vertical pressure vessel is drawn per elements and the icon for each element can be found easily. The input parameter for each element also type in the suitable bar as can be seen on Figure 2 to figure 6. Once all the elements were connected, the pressure vessel would be as shown on Figure 5.

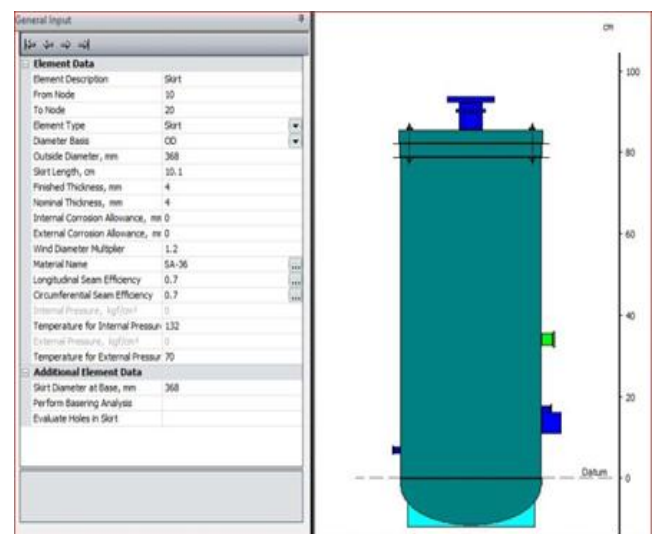


Figure2. Skirt of vessel and the input data screen

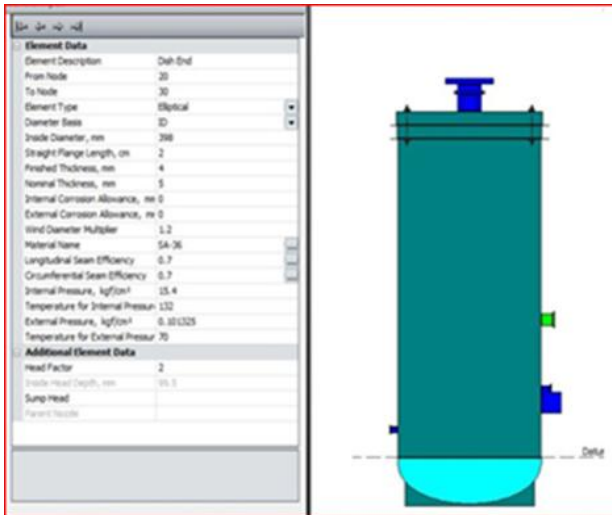


Figure3. Dish End of vessel and the input data.

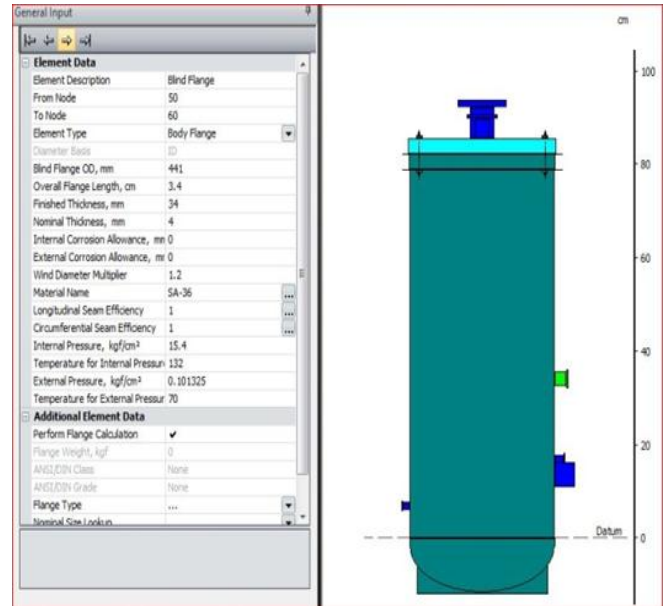


Figure6. Blind flange and the input screen.

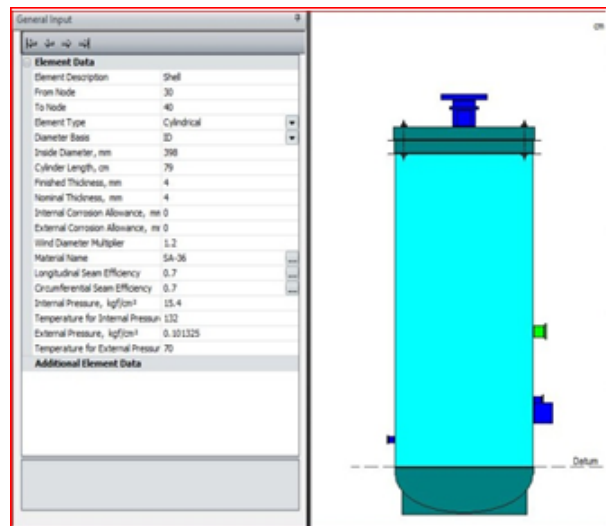


Figure4. Shell and the input screen.

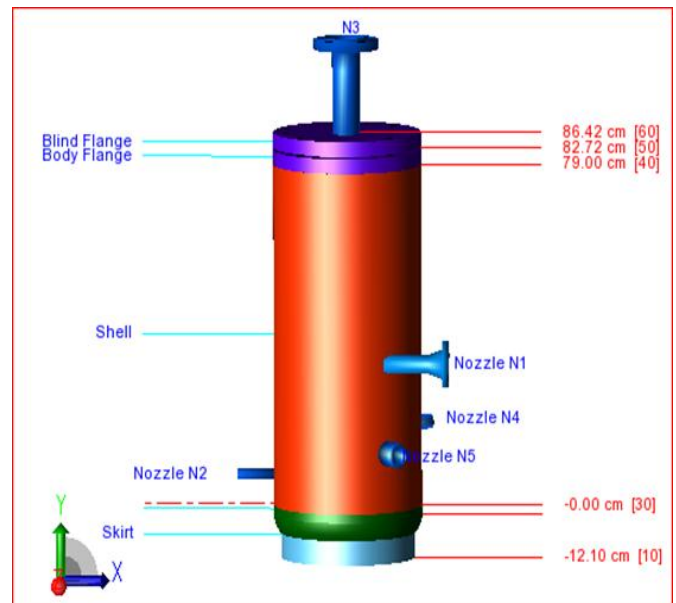


Figure7. Geometry in PV-Elite

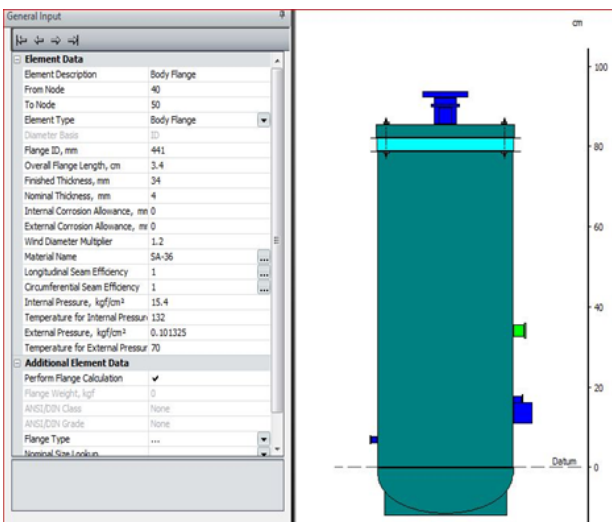


Figure5. Body flange and the input screen

### 3.1 Results of Dish End analyzes

1. Required Thickness due to Internal Pressure [tr]:

$$= (P \cdot D \cdot K_{cor}) / (2 \cdot S \cdot E - 0.2 \cdot P)$$

$$= (15.400 \cdot 398.0000 \cdot 1.000) / (2 \cdot 1167.10 \cdot 0.70 - 0.2 \cdot 15.400)$$

$$= 3.7583 + 0.0000 = 3.7583 \text{ mm}$$

2. Max. Allowable Working Pressure at given Thickness, Corroded [MAWP]:

$$= (2 \cdot S \cdot E \cdot t) / (K_{cor} \cdot D + 0.2 \cdot t)$$

$$= (2 * 1167.10 * 0.70 * 4.0000) / (1.000 * 398.0000 + 0.2 * 4.0000)$$

$$= 16.389 \text{ kgf/cm}^2$$

3. Maximum Allowable Pressure, New and Cold [MAPNC]:

$$= (2 * S * E * t) / (K * D + 0.2 * t)$$

$$= (2 * 1167.10 * 0.70 * 4.0000) / (1.000 * 398.0000 + 0.2 * 4.0000)$$

$$= 16.389 \text{ kgf/cm}^2$$

4. Actual stress at given pressure and thickness, corroded [Sact]:

$$= (P * (K_{cor} * D + 0.2 * t)) / (2 * E * t)$$

$$= (15.400 * (1.000 * 398.0000 + 0.2 * 4.0000)) / (2 * 0.70 * 4.0000)$$

$$= 1096.700 \text{ kgf/cm}^2.$$

5. Straight Flange Required Thickness:

$$= (P * R) / (S * E - 0.6 * P) + c$$

$$= (15.400 * 199.0000) / (1167.10 * 0.70 - 0.6 * 15.400) + 0.000$$

$$= 3.794 \text{ mm.}$$

6. Straight Flange Maximum Allowable Working Pressure:

$$= (S * E * t) / (R + 0.6 * t) \text{ per UG-27}$$

$$= (1167.10 * 0.70 * 5.0000) / (199.0000 + 0.6 * 5.0000)$$

$$= 20.222 \text{ kgf/cm}^2.$$

7. Required Thickness due to Internal Pressure [tr]:

$$= (P * D * K_{cor}) / (2 * S * E - 0.2 * P) - 4(c)$$

$$= (0.169 * 398.0000 * 1.000) / (2 * 1167.10 * 1.00 - 0.2 * 0.169)$$

$$= 0.0289 + 0.0000$$

$$= 0.0289 \text{ mm.}$$

8. Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:

$$= ((2 * S * E * t) / (K_{cor} * D + 0.2 * t)) / 1.67$$

$$= ((2 * 1167.10 * 1.00 * 4.0000) / (1.000 * 398.0000 + 0.2 * 4.0000)) / 1.67$$

$$= 14.019 \text{ kgf/cm}^2$$

9. Maximum Allowable External Pressure [MAEP]:

$$= \min(\text{MAEP}, \text{MAWP})$$

$$= \min(10.53, 14.0193)$$

$$= 10.533 \text{ kgf/cm}^2$$

### 3.2 Results of shell analyzes

1. Required Thickness due to Internal Pressure [tr]:

$$= (P * R) / (S * E - 0.6 * P) \text{ per UG-27 (c)(1)}$$

$$= (15.400 * 199.0000) / (1167.10 * 0.70 - 0.6 * 15.400)$$

$$= 3.7941 + 0.0000 = 3.7941 \text{ mm}$$

2. Max. Allowable Working Pressure at given Thickness, corroded [MAWP]:

$$= (S * E * t) / (R + 0.6 * t) \text{ per UG-27 (c)(1)}$$

$$= (1167.10 * 0.70 * 4.0000) / (199.0000 + 0.6 * 4.0000)$$

$$= 16.226 \text{ kgf/cm}^2$$

3. Maximum Allowable Pressure, New and Cold [MAPNC]:

$$= (S * E * t) / (R + 0.6 * t) \text{ per UG-27 (c)(1)}$$

$$= (1167.10 * 0.70 * 4.0000) / (199.0000 + 0.6 * 4.0000)$$

$$= 16.226 \text{ kgf/cm}^2$$

4. Actual stress at given pressure and thickness, corroded [Sact]:

$$= (P * (R + 0.6 * t)) / (E * t)$$

$$= (15.400 * (199.0000 + 0.6 * 4.0000)) / (0.70 * 4.0000)$$

$$= 1107.700 \text{ kgf/cm}^2$$

### 3.3 Result of Reinforcement calculation,

#### Description: Nozzle N1

1. Reqd thk (a) of Cylindrical Shell, Tr [Int. Press]

$$= (P * R) / (S * E - 0.6 * P) \text{ per UG-27 (c)(1)}$$

$$= (15.40 * 199.0000) / (1167 * 1.00 - 0.6 * 15.40)$$

$$= 2.6468 \text{ mm}$$

2. Reqd thk per UG-37(a) of Nozzle Wall, Trn [Int. Press]

$$= (P * R) / (S * E - 0.6 * P) \text{ per UG-27 (c)(1)}$$

$$= (15.40 * 17.53) / (1202 * 1.00 - 0.6 * 15.40)$$

$$= 0.2262 \text{ mm}$$

3. Area Required [A]:

$$= (d * t_r * F + 2 * t_n * t_r * F * (1 - f_r))$$

$$=(41.3159*2.6468*0.5+2*3.5560*2.6468*0.5*(1-1.00))$$

$$=0.547 \text{ cm}^2$$

4. Area Available in Shell [A1]:

$$= d(E1*t - F*tr) - 2 * tn(E1*t - F*tr) * (1 - fr1)$$

$$=41.316(1.00*4.0000-0.5*2.647) -2*3.556(1.00*4.0000-0.5*2.6468)*(1 - 1.000)$$

$$= 1.106 \text{ cm}^2$$

5. Area Available in Nozzle Projecting Outward [A2]:

$$= (2* tlnp)*(tn -trn)*fr2/sin(alpha3)$$

$$= (2*8.89)*(3.56-0.23)*1.0000/sin(64.5)$$

$$= 0.656 \text{ cm}^2$$

Nozzle Calculation Summary:						
Description	MAWP kgf/cm <sup>2</sup>	Ext	MAPNC kgf/cm <sup>2</sup>	UG45 [tr]	Weld Path	Areas or Stresses
Nozzle N1	16.23	OK	...	OK 2.65	OK	Passed
Nozzle N1	16.23	OK	...	OK 2.65	OK	Passed
Nozzle N4	16.23	OK	...	OK 2.65	OK	Passed
Nozzle N2	16.23	OK	...	OK 2.51	OK	Passed
Nozzle N5	16.23	OK	...	OK 2.65	OK	Passed
N3	15.40	OK	...	OK 4.52	OK	Passed
N7	19.92	OK	...	OK 3.22	OK	Passed
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Min. - Nozzles	15.40	N3				
Min. Shell&Flgs	16.23	30	40	16.23		
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Computed Vessel M.A.W.P.	15.40		kgf/cm <sup>2</sup>			

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#### 4. DISCUSSION

Design of pressure vessel can be finished quickly by applying numerous calculations in software. The drawing process was simpler associated to other software.

This research only investigated a part of parameter design. There are other parameters that are not considered such as thermal loads, wind loads, earthquake, transportation, erection, fabrication methods, etc. However this insufficiency can be overcome by mastering software.

Table -2 Comparative Analysis

Sr. No	Parameter	Required (mm)	Experimental (mm)	PV-Elite (mm)
1	Shell Thickness	3.6	8	4
2	Dish End Thickness	4.35	8	5
3	Skirt Thickness	3.2	4	4
4	Body Flange Thickness	33	30	34
5	Blind Flange Thickness	27	30	28

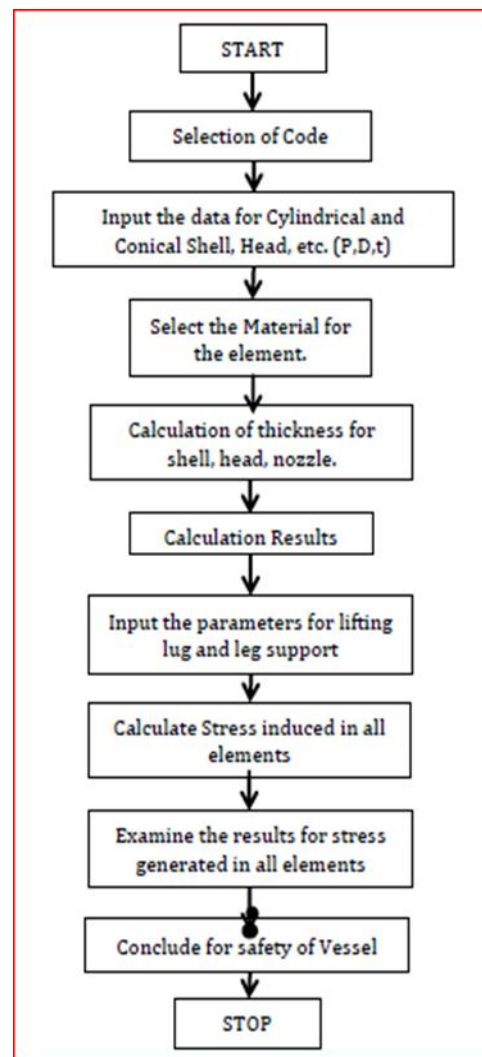


Figure8. Process Flow chart

#### 5. CONCLUSION

Mechanical design of air-oil separator tank (pressure vessel) has been done using graphical based software. Drawing process was very easy and input parameter can be entered in the same screen. Results from the software fully comply with the Standards and also experimental results.

Research can be explored to take into account other parameters. The behaviors of pressure vessels in case of fluctuating load could be a challenging matter for future research.

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