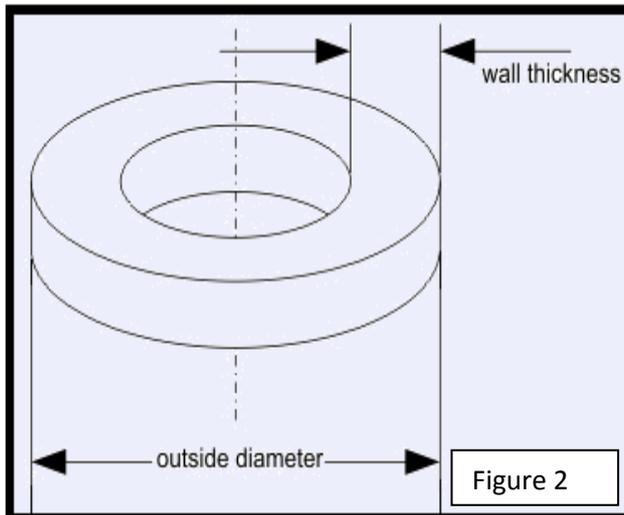
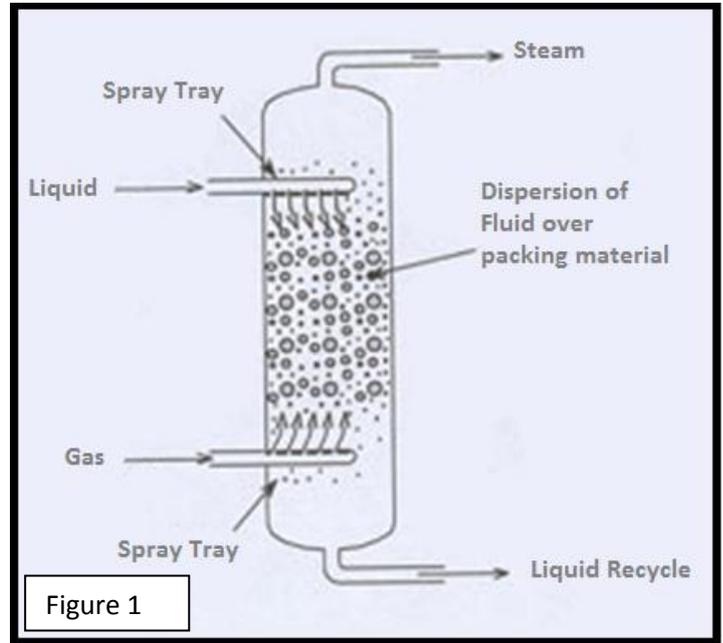


Using Stresses to Determine the Wall Thickness of a Natural Gas Saturator

Ceres Power Ltd is a leading fuel cell business, committed to providing alternative energy solutions to address the global challenges of reducing emissions and increasing fuel efficiency by developing the company's patented solid oxide fuel cell (SOFC) technology for use in small scale combined heat and power products for the residential sector and in energy security applications.

TASK

I currently work within the systems engineering team and was tasked to carry out a design study to find a more energy and cost efficient alternative process for steam generation, than compared to the design currently in use. After a comprehensive literature review, my proposed solution was to design a natural gas saturator, modelled as an absorber column. The process occurs where de-ionised water is sprayed into the column over packing material and the natural gas is distributed from the bottom of the column (Figure 1). Dispersion of the two fluids over ceramic packing increases greater surface area and causes the de-ionised water to saturate the natural gas particles. The generated steam can be extracted from the top of the column and any remaining water collects at the bottom of the column where it is then recycled.



SOLUTION

One of the many calculations carried out was to determine the wall thickness of the cylindrical shell required for internal pressure resistance.

The following equations describe the stresses on the column wall:

$$\sigma_1 = \frac{P_i D}{2e} \quad (1)$$

$$\sigma_2 = \frac{P_i D}{4e} \quad (2)$$

Where,

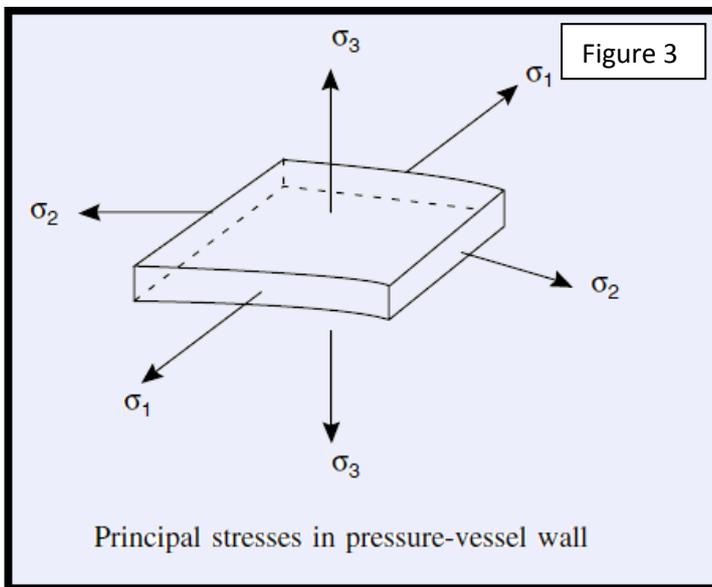
σ_1 = Longitudinal stress acting vertically on the column [N/mm]

σ_2 = Circumferential/tangential stress acting across the column [N/mm]

P_i = Internal column pressure [N/mm²]

e = Wall thickness [mm]

D = Outer column diameter [m]



For the purposes of design and analysis, pressure vessels are sub-divided into two classes depending on the ratio of the vessel diameter to the wall thickness: thin-walled vessels, with a thickness ratio of less than 1 : 25; and thick-walled above this ratio.

The principal stresses (Figure 3) acting at a point in the wall of a vessel, due to a pressure load, are shown in Figure 3. If the wall is thin, the radial stress σ_3 will be small and can be neglected in comparison with the other stresses, and the longitudinal and circumferential stresses σ_1 and σ_2 can be taken as constant over the wall thickness. (Sinnot R.K, 2007)

The column material used shall be; stainless steel 304 at 298K, $\sigma_1=165\text{N/mm}$ (Sinnot R.K, 2007)

$$\text{Now, } D = D_i + e \quad (3)$$

This is because the outer diameter, D is equivalent to the inner diameter, D_i plus the wall thickness, e .

Substitute equation (3) into equation (1)

$$\sigma_1 = \frac{P_i(D_i + e)}{2e} \quad (4)$$

Rearranging to make e the subject:

$$e = \frac{P_i D_i}{2\sigma_1 - P_i} \quad (5)$$

Given that,

$$P_i = 70 \text{ bars}$$

Conversion of units for consistency;

$$P_i = 70 \text{ bars} = 70 \times \frac{10^5 \text{ N}}{\text{m}^2} = \frac{70 \times 10^5 \text{ N}}{\text{m}^2} \times \frac{1 \text{ m}^2}{10^6 \text{ mm}^2} = 7 \frac{\text{N}}{\text{mm}^2}$$

Given that,

$$D_i = 1.89 \text{ m}$$

Substitute all known values into equation (5)

$$\therefore e = \frac{7 \frac{\text{N}}{\text{mm}^2} \times 1.89 \text{ m}}{2 \times 165 \frac{\text{N}}{\text{mm}} - 7 \frac{\text{N}}{\text{mm}}} = 0.041 \text{ m} \cdot \frac{1000 \text{ mm}}{1 \text{ m}} = 41 \text{ mm}$$

Corrosion allowance is generally in the range of 2mm – 4mm. So 3.5 mm will be added to the wall thickness, as a safety margin.

$$\therefore e = (41 + 3.5) \text{ mm} = 44.5 \text{ mm}$$

Thus the calculation confirmed that the vessel diameter to wall thickness is well within the ratio limit.