Wall Thickness Calculation

Vikesh G

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1 Introduction

There are many methods get the required minimum thickness for the bulkheads used in a rocket tank. In this paper, we will discuss how to find the minimum thickness required to withstand pressure of 1250 psia (upper limit) for a tank holding IPA (isopropyl alcohol) for a bipropellant rocket system.

2 Contextualizing

To calculate the required thickness of the bulkhead, we look at the standardized equations. The ASME (American Society of Mechanical Engineers) has a way to calculate the minimum thickness of "circular flat heads", which in other words, are bulkheads. In our case, our tanks are completely cylindrical, with pistons which are shaped as cylindrical disks inside the tanks. Pistons in this case don't need to be considered. In our case, the top bulkhead is in direct contact with the pressurizer N_2 gas and thus is considered bolted to the shell of the pressure vessel. The pressure taken for this calculation at 1250 psia is over the actual estimated pressure in the tank during operation, to add a margin of error and safety.

ASME UG-34 discusses the following equation for thickness calculation for circular flat heads:

$$t = d\sqrt{\frac{CP}{SE}} \tag{1}$$

d = inside diameter in inches
C = attachment factor
P = design pressure in psi
S = allowable stress of material in psi
E = joint efficiency

For our case, the diameter of the bulkhead is considered to be 12 inches.

The attachment factor C adjusts for how the circular flat head is attached to the shell of the pressure vessel, just directly affecting how much the plate can bend or flex. Since in our case the bulkhead is bolted directly into the pressure vessel, we can consider the the attachment factor to be around 0.3. This is an estimate.

The design pressure can be considered as 1250 psia, even though the target pressure inside the tank is around 1000 psia. ASME recommends to take 1.25*MEOP (maximum expected operating pressure) to add an in-built safety factor. PSIA to PSIG conversion is:

$$PSIG = PSIA - 14.7 \tag{2}$$

S here, the allowable stress of the material in psi. The ASME Boiler and Pressure Vessel code gives us a value of 42 ksi as the minimum tensile strength for 6061 T6 grade Aluminum. This, converted to maximum allowable stress in psi comes out to around 12,000 psi.

$$S_{allowable} = \frac{1}{3.5} \times \textbf{Maximum Tensile Strength} = 12,000 psi \tag{3}$$

Joint efficiency can be considered 1 for the purposes of this design, since it is a bolted circular plate.

Let's now calculate the thickness for our purposes:

$$t = 12 \times \sqrt{\frac{0.3 \times (1250 - 14.7)}{12000 \times 1}} \tag{4}$$

$$\boxed{\text{t = 2.108 inches}} \tag{5}$$

This however, uses an extremely conservative estimate for allowable stress. Taking $S_{allowable}$ to be 18000 psi,

$$t = 12 \times \sqrt{\frac{0.3 \times (1250 - 14.7)}{18000 \times 1}} \tag{6}$$

$$\boxed{\text{t = 1.721 inches}} \tag{7}$$

At C = 0.2 at $S_{allowable}$ = 12,000 psi (conservative):

$$t = 12 \times \sqrt{\frac{0.2 \times (1250 - 14.7)}{12000 \times 1}} \tag{8}$$

$$\boxed{\text{t = 1.721 inches}} \tag{9}$$

and at C = 0.1:

$$t = 12 \times \sqrt{\frac{0.1 \times (1250 - 14.7)}{12000 \times 1}} \tag{10}$$

$$\boxed{\text{t = 1.218 inches}} \tag{11}$$

Now C = 0.2, $S_{allowable}$ = 18,000 psi:

$$t = 12 \times \sqrt{\frac{0.2 \times (1250 - 14.7)}{18000 \times 1}} \tag{12}$$

$$\boxed{\text{t = 1.406 inches}} \tag{13}$$

and at C = 0.1:

$$t = 12 \times \sqrt{\frac{0.1 \times (1250 - 14.7)}{18000 \times 1}} \tag{14}$$

$$\boxed{\text{t = 0.994 inches}} \tag{15}$$

3 Conclusion

Advised to take higher estimates of thickness to add extra safety factor assuming mass of rocket is not too big of a concern. In initial stages of design, its recommended to take higher estimates and if needed, later when performing efficiency testing, shave mass off by taking riskier but lighter thickness values.

4 References

- https://fastcdn.pro/filegallery/fouladline.com/DOCUMENT-STANDARD/ASME
- https://www.cis-inspector.com/asme-code-calculation-flat-head-circular.html