Stress analysis of 48 kg LPG cylinder

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Abstract. Objective of this research was to analyze the stress of a 48 kg LPG cylinder designed under Thai Industrial Standard TIS 27-254. The design was employed by using test pressure of 3.3 MPa and the tank wall thickness of 2.65 mm which provided the maximum tensile strength of 429.3 MPa, yield strength of 286.2 MPa and burst pressure of 5.99 MPa. The material used to produce the gas cylinder was SG295 grade steel with a yield strength of 300 MPa and a maximum tensile strength of 440 MPa, which covered the design requirements. The research results were found that at the 85 percent of cylinder volume, gas density of 0.54 kg / l, liquid height of 0.9367 m and gauge pressure of 0.073 psi gave circumferential and longitudinal stresses of 0.0357 MPa and 0.0178 MPa, respectively. According to analysis results of finite element method revealed that the stress concentration area was the circumference at the center position of the tank with the highest value at the welding joint.

1. Introduction
The LPG tank as shown in figure 1 is a product with industry mandatory standard, TIS number 27-2543 because it is a pressure container directly affecting the safety of the users. LPG (cooking gas) is composed of propane and butane gases mixing in different ratios which may sometimes be propane or butane only. However, LPG in Thailand is used by mixing 70 parts of propane and 30 parts of butane, mostly from natural gas and crude oil separation in oil refineries. Just like NGV, LPG is utilized by being compressed into tanks for ease of transportation. LPG is in a liquid state and changed to a vapor state as heated. Then the volume expansion will be 250 times greater than that of the liquid state and therefore, the tank contains only 85% of its total capacity for safety. The selection of LPG tank material must be considered for maximum tensile strength, elongation ability and the strength of welding wires for making tank. Normally, the maximum operating pressure of a gas cylinder is 1.65 MPa and the test pressure is 2 times of the maximum operating pressure [1, 2] Thus, this research was conducted to determine the trend of stress on the designed gas cylinder wall when the pressure was applied.
2. Methodology and materials

2.1. Method study
Study the necessary data for analysis, including type of steel used for forming a gas cylinder, maximum tensile strength and elongation, test pressure according to TIS 27-2543 industry standard, diameter, shape and wall thickness of the gas cylinder.

The results of this study indicated that the steel used for forming gas cylinder wall was SG 295 grade steel according to JIS G 3116 standard with chemical composition and mechanical properties as shown in table 1 and table 2 respectively.

**Table 1. Chemical composition of SG295 grade steel.**

| Chemical composition (%) | C max | Si max | Mn max | P max | S max |
|--------------------------|-------|--------|--------|-------|-------|
| SG295                    | 0.20  | 0.35   | 1.00   | 0.040 | 0.040 |

**Table 2. Mechanical properties of SG295 grade steel.**

| Yield strength (MPa) | Tensile strength (MPa) | Elongation (%) |
|----------------------|------------------------|----------------|
| SG295                | 300                    | 440            | 26             |

The maximum operating pressure of the gas cylinder is 1.65 MPa. Industrial product standard requires that the test pressure must be twice the maximum operating pressure. Hence, the test pressure required 3.3 MPa, the measured inner diameter was 369.7 mm, the tank wall thickness was 2.65 mm.

2.2. Analysis of the strength of the 48 kg LPG tank
The maximum strength can be obtained from equation (1). The result is 429 MPa.

\[
\sigma_u = \frac{P_s (D - t)}{0.6 \times 2000 \times J \times t}
\]

The yield strength can be obtained from equation (2). The result is 286.2 MPa.

\[
\sigma_y = \frac{P_s (D - t)}{0.9 \times 2000 \times J \times t}
\]

The explosive pressure (burst test) can be obtained from equation (3). The result is 5.99 MPa.

\[
P_b = \frac{f_b \times 2t}{d}
\]

Define

\[
\sigma_u = \text{Maximum tensile strength (MPa)} \quad \sigma_y = \text{Yield strength (MPa)}
\]

\[
d = \text{Inner diameter (millimeter)} \quad t = \text{Tank wall thickness (millimeter)}
\]
\[ P_h = \text{Test pressure (kPa)} \quad P_e = \text{Explosive pressure (kPa)} \]
\[ D = \text{Outer diameter (millimeter)} \quad J = \text{Joint factor 0.9 for 3pcs cylinder} \]

2.3. Verification
Verification of results using finite element software (Solidworks Simulation Program) that has been accepted in engineering analysis [3-6] consists of 5 main steps.

Step 1. Drawing a gas tank by specifying the material used to make the tank
Step 2. Determine the end boundary conditions
Step 3. Determine the test load
Step 4. Define the mesh and resolution as appropriate
Step 5. Command the program to analyze the results

3. Result and discussion
As the body material was defined as steel grade SG295 and the test load was determined based on the results of the gauge pressure of 0.073 psi. Fixed free boundary condition of the entire tank was determined and analyzed using standard elements pyramid type, triangular base, 4-face Jacobian, 4-point, element size = 32.4255 mm, number of nodes = 15,622 nodes. This induced circumferential stress = 0.0357 MPa and longitudinal stress = 0.0178 MPa, and both axial stresses were different insignificantly as shown in figure 2. Furthermore, the effect of gas pressure when expanding under the design using stress of yield criteria as a specification provides the stress concentration zone along the circumference of the gas cylinder, near the top and bottom position of the tank as shown in figure 3. If there is a welding joint in the center of the tank, the stress concentration is positioned in the center of the tank as shown in figure 4.

![figure 1](image1.png)

Figure 1. 48 kg LPG tank.
Figure 2. Stress result (normal).

Figure 3. Stress result (expand under yield criteria design).

Figure 4. Stress concentration area (when it have welding joint at circumference center).
4. Conclusion

From the design analysis, it was found that the gas cylinder designed for maximum strength, yield strength and explosive pressure was 429.3 MPa, 286.2 MPa and 5.99 MPa respectively at tank wall thickness 2.65 mm. As the tank was filled with LPG, the maximum stress at normal operation analyzed by finite element method was 0.0357 MPa along the circumference. If there was a circumferential weld, the stress accumulation area would be at the center of the tank. Further studies should be examined on the minimum wall thickness of the gas cylinder that can withstand the designed pressure and predict the service life of the gas cylinder, which is necessary to know the corrosion rate of the LPG tank wall and weld quality of gas tanks.

References

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