Research on Air Pressure Cycle Test of Liquefied Petroleum Gas Cylinder

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Abstract. Air pressure cycle tests were performed on liquefied petroleum gas (LPG) high-density polyethylene liner glass fiber fully wound cylinders. During the repeated filling and discharging of the gas cylinder, the changes of the internal and external surface temperature and internal pressure of the gas cylinder with time were obtained. Through experimental analysis and numerical simulation, the characteristics of the flow field in the cylinder during the pressure cycle test at different pressure cycle rates were studied. The results show that the temperature in the gas cylinder rose steadily during the test. The temperature rise trend of the gas cylinder in Fluent simulation was the same as that in the test. In the air pressure cycle test, the temperature change of the cylinder was larger than that of the cylinder when it was filled with LPG, and the structure and material properties of the cylinder were unchanged. This test can check whether the LPG high-density polyethylene liner glass fiber fully wound cylinders are safe.

1. Introduction

Liquefied petroleum gas (LPG), as a clean energy, has been in a steady growth stage in China [1]. With the laying of domestic natural gas pipelines, the modernization of cities and the increase in natural gas imports, civilian LPG consumption has been impacted. However, due to the decline in international oil prices at the end of 2014 and the strict implementation of safety and environmental protection requirements, dimethyl ether, an alternative to LPG, has gradually lost its original market, instead promoting the recovery of LPG in the civilian sector. In the first-tier and second-tier cities in China, the floating population is relatively large, and LPG cylinders have a rigid demand. The demand for liquefied petroleum gas in the field of civil combustion has maintained a good trend. With the development of ethylene production and processes such as aromatization, alkylation, methyl tert-butyl ether (MTBE) and propane dehydrogenation (PDH), LPG has developed rapidly in the field of industrial raw materials, and LPG consumption space has ushered in huge increase.

There is a good prospect for LPG high-density polyethylene liner glass fiber fully wound cylinder. Since the supply of carbon fiber in 1998 increased [2], its price has started to fall, making the cost of manufacturing carbon fiber composite cylinders even more attractive. Compared with LPG steel cylinders, these new gas cylinders have the following advantages [3]: (1) Light weight. The specific strength of the fiber material is very high, which is about 50% to 75% of the titanium alloy cylinder.
And at the same time, the bearing capacity of the cylinder is improved. (2) Long working life under load. (3) High safety, fatigue failure mode with leakage before blasting. (4) Low production cost and short cycle. The cylinder is wound with a winding machine, which has high precision, high production efficiency and low labor intensity.

Gas cylinder pressure cycle test [4] is of great significance for verifying the reliability of repeated filling of gas cylinders. And it is an important means for testing the safety margin, structural rationality and reliability of composite gas cylinders. During the air pressure cycle test, effective control of pressure and temperature should be implemented. However, there is little research on the law of pressure increase and temperature change of composite gas cylinders during the air pressure cycle test. There is currently no method to accurately control the boost rate and the temperature of the cylinders [5]. Therefore, it is necessary to study the flow field characteristics in the air pressure cycle test of LPG cylinders.

2. Experiment methods

The test cylinders are LPG high-density polyethylene liner glass fiber fully wound cylinders. The outer diameter of the cylinder is 545 mm and the volume is 27.5 L. The temperature measurement uses a Pt100 temperature sensor with a temperature measurement range of -60 to 200 °C and an accuracy of 0.1 °C. The pressure measurement uses a pressure sensor with a range of 5 MPa and a level of accuracy of 2. The tested temperature and pressure were recorded and saved by a paperless recorder, and the relevant temperature and pressure were recorded every 1 s. The armored thermocouple model is WZP 231, which is used to measure the internal temperature of the gas cylinder. The position of the internal temperature measurement points of the gas cylinder is shown in Figure 1. The cylinder port uses a three-way valve.

The cylinder is placed horizontally. Adhesive Pt100 platinum thermal resistance measures the temperature of three measuring points on the outer wall surface. The measurement points are in the middle of the bottle, near the mouth of the bottle, and at the flat bottom of the bottle, as shown in Figure 2.

Pressure cycling tests require repeated filling of the cylinder. During the pressure cycle test, the internal pressure of the gas cylinder first rose to the upper limit of the specified cycle pressure to maintain the pressure, and then decreased to the lower limit of the specified cycle pressure to continue the pressure retention until the end of the test. The pressure cycling rate was changed to do two sets of experiments to explore the effect of the pressure cycling rate on the performance of the gas cylinders to ensure that the structure and material properties of the gas cylinders remained unchanged after the test.

According to the above test process, after the test data is collected, the collected data needs to be sorted by relevant software, and the pressure cycle test is numerically analyzed using Fluent. The heat transfer coefficient of each interface in Fluent is 0.1 W/m² · K; the environment and initial temperature are 295 K; the total filling process takes 108 s, and the termination pressure is 3.2 MPa. The gas inlet takes the pressure inlet conditions. The relationship between pressure and time is shown in the following formula (1):

\[ P = 0.0288 \times t^4 - 8.0815 \times t^3 + 807.18 \times t^2 + 1018.4 \times t + 2613.7 \]

(1)
The changes of inlet pressure with time are consistent in the test and simulation, as shown in Figure 3. In Figure 3, $P_{\text{test}}$ is the cylinder inlet pressure during the test, MPa; $P_{\text{Si}}$ is the cylinder inlet pressure during the simulation, MPa.

3. Test results and discussion

The data collected in the test has been completed, and the collected data was organized using the origin software. The temperature rise during air filling is shown in Figure 4. During the test air filling process, the measured temperature change in the bottom of the cylinder is only 2 °C, because the flow field was hindered by the penetration of the armored thermocouple into the metal rod in the cylinder. In Figure 4, $T_{\text{M1.S}}$, $T_{\text{M2.S}}$, and $T_{\text{B.S}}$ are respectively the temperature of the mouth, middle and bottom of the cylinder during simulation; $K$; $T_{\text{M1.T}}$, $T_{\text{M2.T}}$, $T_{\text{B.T}}$ are respectively the temperature of the mouth, middle and bottom of the cylinder during the test, K; $P$ is the cylinder inlet pressure during the test and simulation, MPa.

Before Fluent numerically simulated the pressure cycle test, the correctness of the model was verified. The temperature rise trend of the air filling process simulated by Fluent basically accords with the actual filling process (see Figure 4), and this model could be used. In the air filling process simulation, the temperature changes of the three measurement positions at the bottom, middle and mouth of the cylinder with time is consistent with that during the test and the maximum temperature difference is 8.63 °C. Due to the lagging thermal response of platinum resistance, there is an error between the variation trends of temperature in simulation and test. The temperature rise trend at the bottom of the bottle is very different from the test.

![Figure 3. Changes in inlet pressure over time in test and simulation.](image)

![Figure 4. Changes in temperature of cylinder over time in test and simulation.](image)

The pressure cycle test data obtained by changing the pressure cycle rate is shown in Figure 5. In Figure 5, $T_{\text{M1}}$, $T_{\text{M2}}$, and $T_{\text{B}}$ are respectively the temperature of the mouth, middle and bottom of the cylinder during the test, K; $P$ is the cylinder inlet pressure during the test, MPa.

The throttling expansion of the filled air produces the Joule-Thomson effect. The temperature will decrease and the cooling effect will occur. Therefore, the temperature of the cylinder started to fall within 15 seconds. After the air entered the cylinder from the pipe, the speed decreased, and the kinetic energy changed to internal energy, which caused the temperature of the gas in the cylinder to rise. During the filling process, the gas in the bottle was compressed to do work, which caused the gas temperature to rise. A metal rod with a thermocouple in the gas cylinder hinders the flow of air in the bottle, making it turbulent and unable to flow to the bottom of the gas cylinder. After the pressure was released, the gas in the container and the container wall, and the container wall and the environment performed heat transfer, so that the temperature of the gas in the container decreased.
4. Conclusion

An air pressure cycle test was performed on a 27.5 L LPG high-density polyethylene liner glass fiber fully wound cylinder, and the safety margin, structural design, and reliability of the cylinder were tested. During the test, the temperature variation in the cylinder was 17 °C, which was greater than the temperature variation of the cylinder when it was filled with LPG, and the structure and material properties of the cylinder were unchanged. Therefore, this test can test the safety performance of this cylinder. In Fluent simulation, the temperature rise trend of the cylinder was the same as that in the test, and the maximum temperature difference was within the acceptable range. This model can be used to simulate the internal flow field of a gas cylinder in an air pressure cycle test, which is helpful to explore the method of controlling the pressure increase rate and temperature of a composite material cylinder in the test.

Acknowledgments

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