Design of on line detection system for static evaporation rate of LNG vehicle cylinders

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Abstract. In order to solve the problems existing in the regular inspection of LNG vehicle cylinders, the static evaporation rate on line detection system of LNG cylinders is discussed in this paper. A non-disassembling, short-term and high-efficiency on line detection system for LNG vehicle cylinders is proposed, which can meet the requirement of evaporation rate test under different media and different test pressures. And then test methods under the experimental conditions, atmospheric pressure and pressure are given respectively. This online detection system designed in this paper can effectively solve the technical problems during the inspection of the cylinder.

1 Introduction
Liquefied natural gas (LNG), the main component is methane, is recognized as one of the world's most clean energy. LNG vehicle cylinder is a kind of Cryo insulation pressure vessel, which is designed with double layer (vacuum) structure. The cylinder liner for the storage of liquefied natural gas, the outer wall wrapped with multilayer insulation material, has superior insulation performance, at the same time the jacket (the space between two layers) is highly evacuated, together form a good thermal insulation system. The cylinder internal cooling performance in the event of failure, the internal liquefied gas will quickly evaporate and the formation of high pressure in the cylinder, resulting in cylinder safety valve frequent take-off, waste of resources and environmental pollution, and even lead to explosion. Therefore, the periodic inspection of LNG cylinders, especially the detection and evaluation of its thermal insulation properties, can effectively ensure the safety and economic operation of cylinders.

At present, inspection technology, testing methods and test standard system of LNG cylinder is not perfect. Therefore, many research institutions carried out LNG vehicle cylinder detection technology research\cite{1-5}.

In Shanghai Jiao Tong University, the performance of the static evaporation rate of the low temperature thermal insulation cylinders was studied, and the influence of the pressure on the daily evaporation rate was summarized\cite{4}.

In order to study the law of liquid evaporation in LNG vehicle cylinder, in Xi'an Jiao Tong University, a series of daily evaporation rate tests were carried out, and the relationship between evaporation rate and filling rate was fitted. The influence of ambient temperature and pressure on evaporation rate was analyzed\cite{7}.
The application of self boosting method in vehicle welded insulated cylinders periodic inspection is carried out in Shandong Institute of Special Equipment Inspection. In the case of non disassembly, the heat insulation performance of the bottle is judged by the increasing value of the pressure in the 24h, but this method is not suitable for short time detection\cite{6}.

In Fujian Special Equipment Inspection and Research Institute, with liquid nitrogen as working substance, the vaporization rate test of high vacuum low temperature insulated container was carried out using weighing method. The grey prediction method was applied to this method, and the detection time was reduced from 3D to 1D, which can effectively improve the detection efficiency, and reduce the amount of the cryogenic liquid consumption. In addition, the evaporation rate test device for vehicle welded insulated cylinders was developed in this institute, which lays the foundation for the development of the periodic inspection of the LNG welded insulated cylinders\cite{2,3}.

In order to solve the problems existing in the regular inspection of LNG vehicle cylinders, the static evaporation rate on line detection system of LNG cylinders is discussed in this paper. A non-disassembling, short-term and high-efficiency on line detection system for LNG vehicle cylinders is proposed, which can meet the requirement of evaporation rate test under different media and different test pressures. And the test methods under the experimental conditions, atmospheric pressure and pressure are given respectively. This online detection system designed in this paper can effectively solve the technical problems during the inspection of the cylinder.

2 Necessity

2.1 Long detection time
The test method of static evaporation rate is mostly in accordance with the provisions of the national standard GB18443.5. According to the test requirements and the structural characteristics of the vehicle cylinders, the cylinder is required to be disassembled. But the disassembly process of the cylinder is time-consuming and laborious, and it is easy to damage the shell of the cylinder, causing unnecessary inspection damage. In addition, after the disassembly, according to the standard requirements, cylinder media need to be replaced by liquid nitrogen, static balance of 48 hours, and then the static evaporation rate test needs at least another 48 hours. Thus, for a vehicle cylinder test, the period of time is generally 5 to 7 days.

2.2 Medium replacement
According to the national standard GB18443.5, in the test of the static evaporation rate, the medium in cylinder must be replaced with liquid nitrogen. However, how to replace and recycle is the inspection agencies must consider.
2.3 No relevant testing standards

Low temperature vessels have the corresponding inspection requirements. The inspection items, inspection methods and assessment criteria have detailed data base and strict assessment requirements. However, LNG cylinders without the state, industry, enterprise inspection standards, only a few provinces and cities have local inspection standards. In comparison, part of the assessment indicators in local standards vary widely, and the implementation also needs to be further verified.

3 Design of on line detection device

3.1 Performance analysis

First, on-line test. In order to avoid the replacement of the storage medium and the venting of cylinder during the test, it is necessary to test the cylinder directly under normal operating conditions. At this time, since the cylinder has a certain evaporation rate, the internal pressure of the cylinder always rises. The on-line inspection system must ensure that the cylinder maintains normal operating pressure. Then, the evaporation rate can be obtained at a certain pressure.

Second, real-time detection. Since the pressure boost of the cylinder is continuous, in order to ensure that the pressure in the cylinder is maintained at the set test pressure, the cylinder must always be opened during the test, and on line testing system needs to achieve that the opening of cylinder to ensure the evaporation gas flows out from the cylinder. This process requires the precise regulation of the pressure regulating valve, and then the real-time measurement of the cylinder evaporation rate under pressure can be realized.

Third, static evaporation rate calculation formula under pressure. The calculation formula of the static evaporation rate in the national standard GB18443.5, is shown in the following:

\[ \alpha_{20} = \alpha_0 + \frac{h}{h_{fg}} \left( 0.7 \times \frac{T_1 - T_2}{T_1 - T_3} + 0.3 \times \frac{293.15^4 - T_3^4}{T_1^4 - T_3^4} \right) \]  

Taking into account the environmental temperature, pressure and other factors, the theoretical calculation formula under pressure should be revised. Through the multi group experiments under pressure, the correction term of pressure can be added, and the calculation formula of the static evaporation rate under pressure state can be finally established.

3.2 Device construction

(1) Pressure setting range: 0-1.6MPa, the test pressure must be adjusted continuously to meet the requirements of different stress tests. During each stress test, the reference pressure must be stable. During the test, the cylinder pressure fluctuation must be maintained at the KPa level.

![Device construction diagram](image-url)
2) High precision pressure regulating valve: This valve can stable control the cylinder internal pressure. According to the cylinder pressure, the valve can accurately adjust its opening. when the pressure is stable, the valve opening is stable, and the flow is steady. Minimum operating temperature is 168℃, open and close pressure ±2Kpa.

3) Mass flow meter: This meter can be used to record the gas flow from the high precision pressure regulator valve. The flow rate can be recorded in real time, and can be cumulative calculated. The accuracy is 1%; the range is 10L/min.

4) Temperature: Used to test the inlet temperature of mass flow meter.

5) Pressure gauge: Used to test atmospheric pressure.

4 Test method

4.1 Experimental program
Comparison test of static evaporation rate between different medium: LNG and LN were used for comparative testing. By comparing the test results between this two media, the theoretical conversion formula for the evaporation rate of LNG under pressure can be modified. Then, the test can be carried out using LNG, and avoid the media replacement.

Cylinder pressure and ambient temperature are the main parameters affecting the static evaporation rate of the cylinders. In experiment condition, different pressure and different ambient temperature tests are carried out according to the working conditions of the vehicle LNG cylinders. And the real-time test data of the static evaporation rate of the cylinders under different conditions are obtained.

4.2 Atmospheric pressure test
(1) Cylinder filling rate of 90%, open the cylinder vent valve, close the cylinder, to maintain at least 48h;

(2) When the cylinder pressure is stable to normal pressure, and the cylinder gauge pressure is close to zero, connect the hose to the cylinder vent valve and connect the mass flow meter. After the flow rate is stable, the recording will start; the recording time is 48h;

4.3 Under pressure test
(1) Close the vent valve, disconnect the hose from the vent valve and connect the pressure regulating valve to the vent valve;

(2) Open the cylinder booster valve, when the pressure is slightly higher than the set working pressure (regulating valve opening pressure), close the booster valve;

(3) Adjust the pressure regulating valve opening pressure to the set pressure value;

(4) After stabilization, connect the hose to the pressure regulator and connect the mass flow meter, then start recording.

5 Conclusion
In this paper, on line test device for the evaporation rate test of the LNG vehicle cylinders is developed, which can meet the requirements of the evaporation rate test under different medium and different test pressures. This online detection system designed in this paper can effectively solve the technical problems during the inspection of the cylinder.

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