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Numerical analysis of thermal insulation performance of horizontal LNG cylinder

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Numerical analysis of thermal insulation performance of horizontal LNG cylinder

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Abstract. Low temperature insulation performance is an important index for evaluating the performance of LNG cylinders. In this paper, a horizontal LNG cylinder was used as the research object, a numerical analysis model for the heat transfer performance of horizontal LNG cylinder was established, the main factors that affect the insulation performance of horizontal cylinders were analyzed, and the structural optimization method was given. At the same time, the influence of different filling rates on the insulation performance of horizontal cylinders was analyzed.

1. Introduction

Liquefied natural gas (LNG), which is mainly composed of methane, is a cleaner energy source. As an important storage and transportation equipment of LNG, LNG cylinder is a kind of low temperature adiabatic pressure vessel. Its low temperature adiabatic performance is an important index to evaluate the performance of LNG cylinder. Therefore, the periodic inspection of LNG cylinder, especially the inspection and evaluation of its adiabatic performance, is an important link to ensure the safe operation of LNG cylinder.

Because of the complex internal structure of cryogenic cylinders, there are many factors affecting the thermal insulation performance, the research on the thermal insulation performance of cryogenic cylinders is the focus in recent years [1, 2]. Shanghai Jiaotong University has carried out a series of studies on the static evaporation rate of cryogenic adiabatic cylinders, and studied the influence of pressure, temperature and filling rate on the daily evaporation rate [3,4]. Based on the experimental data, Li Yang and other scholars established the finite element model to calculate the temperature field and local leakage heat of cryogenic vessels, and put forward some suggestions for structural design [5]. Tian Hongxin and other scholars have carried out the research on the heat transfer performance of the bottom support of LNG cylinder, and given the optimal design method of the bottom support [6]. Nie Yuhong and other scholars have carried out the numerical simulation research on the heat transfer performance of LNG cylinder, and given the optimization design method of the neck structure of vertical LNG cylinder [7].

The above research mainly focuses on the heat transfer performance of vertical LNG cylinder, but because the horizontal cylinder is different from the vertical cylinder in structure, its heat transfer

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performance is different, so the law that affects its adiabatic performance needs further study. In this paper, a horizontal LNG cylinder was used as the research object, a numerical analysis model for the heat transfer performance of horizontal LNG cylinder was established, the main factors that affect the insulation performance of horizontal cylinders were analyzed, and the structural optimization method was given. At the same time, the influence of different filling rates on the insulation performance of horizontal cylinders was analyzed.

2. Numerical analysis model

2.1. Heat transfer mathematical model

The reason for the evaporation of liquid in cylinders is the absorption of heat from the outside. For horizontal LNG cylinder heat transfer, it is necessary to study the relationship between the total heat flow through the cylinder and the evaporation of liquid in the cylinder. The total heat flux of the cylinder is mainly introduced into the liquid through thermal insulation material and mechanical components. According to the heat balance relationship:

$$\mathrm{K} \cdot \mathrm{S} \cdot \frac{\Delta T}{\delta} = M\gamma \tag{1}$$

When the finite element model is established, the steady state heat balance calculation model is adopted. The differential equation of heat balance is:

$$\frac{\partial}{\partial \mathrm{x}}\left(\mathrm{k_{xx}}\frac{\partial \mathrm{T}}{\partial \mathrm{x}}\right) + \frac{\partial}{\partial_{\mathrm{y}}}\left(\mathrm{k_{yy}}\frac{\partial \mathrm{T}}{\partial \mathrm{y}}\right) + \frac{\partial}{\partial \mathrm{z}}\left(\mathrm{k_{zz}}\frac{\partial \mathrm{T}}{\partial \mathrm{z}}\right) + \ddot{\mathrm{q}}=0 \tag{2}$$

Because the thermal properties of materials vary with temperature, it is necessary to establish the heat balance matrix equation for nonlinear thermal analysis when the finite element model is established, as follows:

$$\mathrm{C(T)\dot{T} + K(T)T = Q(T)} \tag{3}$$

2.2. Finite element model

In this paper, a horizontal LNG insulating cylinder with a volume of 375 L was studied. The cylinder diameter is 660 mm, the length is 1663 mm, and the inner and outer cylinder wall thickness is 3 mm. The main material is 06Cr19Ni10 (304).

Considering the symmetry of the cylinder structure, one half of the three-dimensional finite element model was established in the calculation process, as shown in Fig.1.

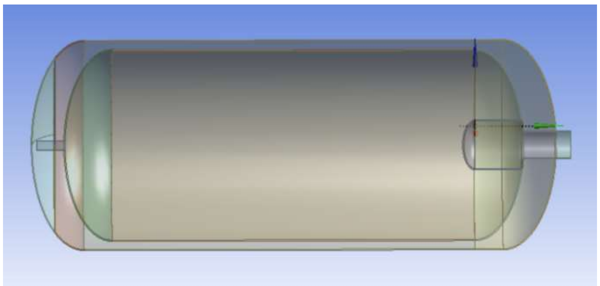

Figure 1. Three dimensional finite element model of gas cylinder.

The shell, neck tube and support structure of the model were mainly divided by mapping mesh, and the vacuum part between the inner and outer cylinders was divided by free mesh because of the

IOP Conf. Series: Materials Science and Engineering **452** (2018) 022084
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complicated boundary structure. In the calculation process of the model, the mesh was refined and the mesh independence was adopted. The mesh generation is shown in Fig.2.

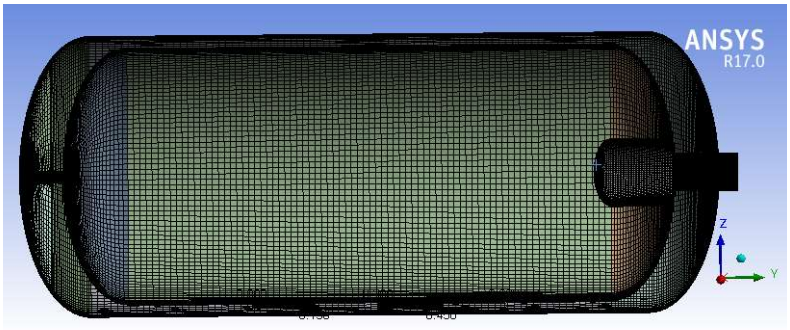


Figure 2. Finite element mesh

The horizontal LNG cylinder studied in this paper is insulated by high vacuum multi-layer winding. The vacuum part is regarded as a whole, and the heat transfer process is assumed as follows:

The multilayer thermal insulation material contains 30 layers of insulation, and its apparent thermal conductivity is 7.86 x 10-5W/m K.

When the cylinder is in a stationary state, the gas space can be assumed to be in a stable state, that is, the convective heat transfer and radiative heat transfer inside the gas can be ignored. Under certain conditions, the ambient temperature is constant and does not vary with time.

The container is filled with cryogenic liquids. The temperature at the interface between the liquid and the cylinder or gas is 77K. The natural convection coefficient of air on the outer surface of the insulation layer and the outer surface of the collector head is 5W / (m2. K), and the ambient temperature is 293K.

3. Results and analysis

3.1. Insulation performance analysis of gas cylinders

Taking the gas cylinder with a filling rate of 90% as an example, the numerical analysis of the heat transfer performance of horizontal cylinders is carried out. The heat leakage of the cylinder is mainly composed of the heat leakage of the vacuum insulation layer, the heat leakage of the neck and the heat leakage of the bottom support. The temperature distribution of the cylinder is shown in Fig.3. As can be seen from the figure, the heat transfer of the cylinder is mainly concentrated on the neck and bottom support. Figures 4 and 5 show the temperature distribution at the neck and bottom support respectively. The heat conduction of the neck and bottom support plays an important role in the heat leakage of the cylinder. The results show that the heat leakage of the neck and bottom supports is 12.47W and 7.65W respectively. Therefore, under the condition of good vacuum insulation, the optimization design of neck and support structure plays an important role in the insulation performance of the cylinder.

Fig.4 shows that the temperature gradient of the neck structure is mainly along the axial direction. Fig.5 shows that the temperature gradient of the bottom support is mainly along the radial direction. Because of the small wall thickness, the temperature gradient along the wall thickness can be neglected.

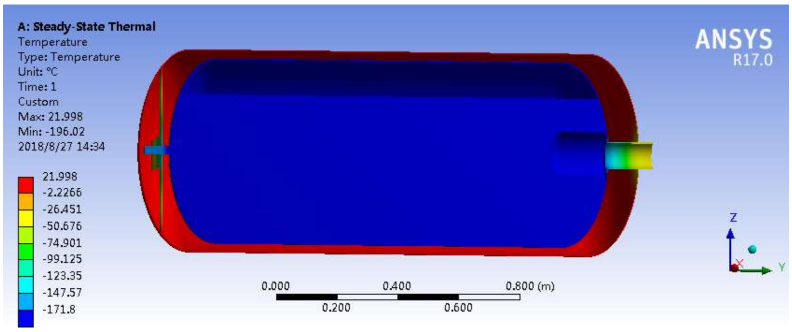


Figure 3. Temperature distribution of gas cylinders.

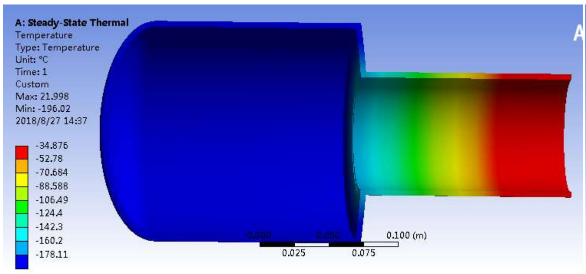


Figure 4. Temperature distribution of neck

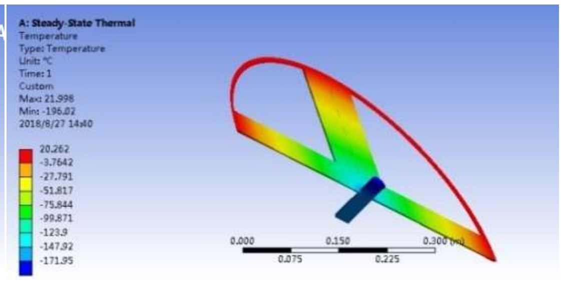


Figure 5. Temperature distribution of support

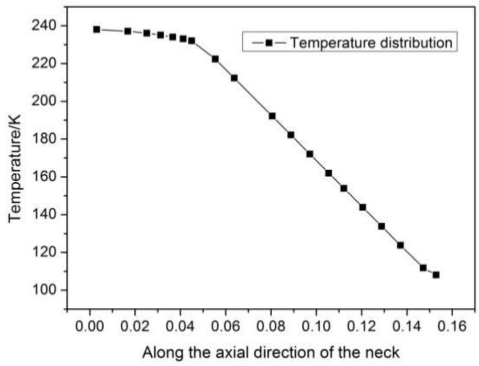


Figure 6. Temperature distribution along the axial direction of the neck

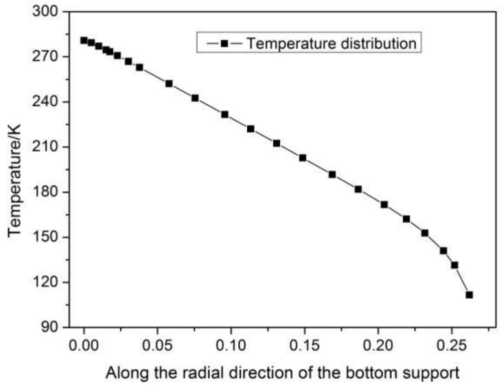
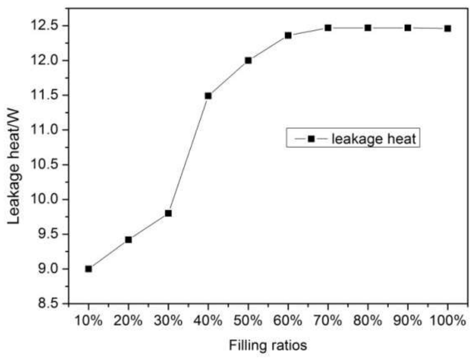


Figure 7. Temperature distribution along the radial direction of the bottom support

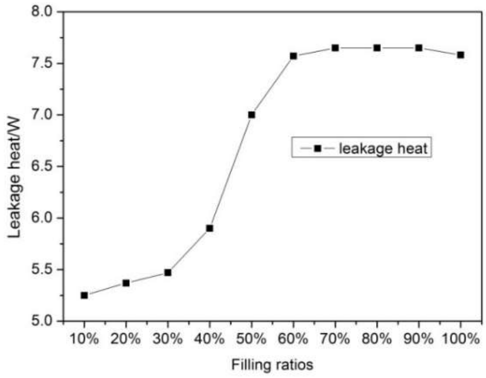
Fig.6 shows the temperature distribution along the axial direction of the neck. Fig.7 shows the temperature distribution along the radial direction of the bottom support. The temperature gradient of the neck is linearly distributed in the cylinder, and the change of temperature is slowed down at the position of the neck near the mouth of the cylinder, and the temperature gradient is obviously reduced. The support pin at the bottom support is the main leakage spot. The temperature gradient near the support pin is larger and the rest positions are linear in the radial direction. Therefore, in the design of the bottom supporting structure, the heat transfer can be reduced by increasing the length of the supporting pin and reducing the cross-sectional area of the supporting pin under the premise of sufficient strength.

3.2. Influence of filling rate on heat leakage

Because LNG cylinder is sealed storage, in order to ensure safety and compensate for thermal expansion, the upper part of the cylinder liner needs to leave 5%-10% gas space. During the use of the cylinder, the filling rate will gradually decrease, and the static evaporation rate of the cylinder with different filling rate is also different. Therefore, it is necessary to study the influence of filling rate on the insulation performance of gas cylinders. In this paper, the cylinders with different filling rates are selected for numerical simulation. According to the actual situation, the filling rates are selected as 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10% respectively. Fig.8 and Fig.9 show the leakage heat of the neck and bottom supports at different filling ratios, respectively. As can be seen from the figure, the heat leakage of the neck and bottom support increases with the filling rate, but there is a sharp increase in the filling rate between 40% and 60%. This is mainly due to the horizontal structure of the cylinder, when the liquefied gas in the cylinder begins to contact the support and neck to fully submerged support and neck, the cylinder filling rate is just 40%-60%, which results in a large fluctuation of heat leakage in this stage. This is the difference between the horizontal cylinder and the vertical cylinder. Therefore, the influence of the filling rate should be fully considered in the static evaporation rate test of the horizontal cylinder.



Figures 8. Leakage heat of the neck at different filling ratios



Figures 9. Leakage heat of the bottom support at different filling ratios.

4. Conclusion

In this paper, a horizontal LNG cylinder was used as the research object, a numerical analysis model for the heat transfer performance of horizontal LNG cylinder was established, the main factors that affect the insulation performance of horizontal cylinders were analyzed, and the structural optimization method was given. At the same time, the influence of different filling rates on the insulation performance of horizontal cylinders was analyzed.

(1)The heat conduction of the neck and bottom support plays an important role in the heat leakage of the cylinder. The temperature gradient is larger at the neck closer to the bottle mouth. The support pin at the bottom support is the main leakage spot. Therefore, in the design of the bottom supporting structure, the heat transfer can be reduced by increasing the length of the supporting pin and reducing the cross-sectional area of the supporting pin under the premise of sufficient strength.

(2)The heat leakage of the neck and bottom support increases with the filling rate, but there is a sharp increase in the filling rate between 40% and 60%. Therefore, the influence of the filling rate should be fully considered in the static evaporation rate test of the horizontal cylinder.

Acknowledgments

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