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Study on Enhanced Heat Transfer of the Gas Hydrate Storage Tank in the Cool Storage Process

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Abstract

The object of this study is an internal heat transfer/external promote crystal small coil gas hydrate cool storage device. HCFC-141b hydrate is the cool storage medium, and water is secondary refrigerant. This paper studies on the influence of different structural parameters on storage tank heat transfer characteristics, such as the coil arrangement and coil spacing. This paper builds nine tubes model. And it uses fluent to simulate the temperature field variation of the model. In order to make the research easier, this paper fixes other variables and studies for a variety in the course of studying. An analysis of the temperature variation of the four points was carried out. By comparing aligned arrangement and staggered arrangement, we can draw some conclusions. (1) Coil spacing has great influence on the heat transfer efficiency of cool storage tank. (2) The temperature variation of aligned arrangement is faster than staggered arrangement. And within a certain time, the final temperature of aligned arrangement is lower than staggered arrangement.

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Keywords: Gas hydrate; Cool storage tank; Coil arrangement; Coil spacing

1. INTRODUCTION:

From the beginning of 1980’s, in order to relieve the pressure of peak power, reduce energy consumption and achieve the efficient and rational use of energy, people researching a new type of storage technology - gas hydrate cool storage[1]. Gas hydrate is an enveloping crystalline compound, which is composed of certain gases (or more volatile liquids) and water[3]. It can be crystallized in the freezing point above is its most important feature. It is also known as “warm ice”.

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The heat transfer performance of storage tank is directly related to the performance of the economic effect of the whole storage system, so it is important to study on the cool storage characteristics of the storage tank. Chinese Academy of Sciences, Guangzhou Institute of Energy Heat Pump and Air Conditioning, Refrigeration Technology Research Center of Bifen Shu, Kailhua Guo etc. proposed an internal heat transfer/external promote crystal small coil gas hydrate, cool storage device[3].

2. METHODS

This paper builds a three-dimensional model of the coil in cool storage and conduct reasonable mesh, and then use the fluent software fixed other variables studied only for a variable. Thereby provides the optimal coil arrangement and coil spacing thus enhances heat transfer, improving heat transfer efficiency.

The paper is used to have a theoretical study of heat transfer of the gas hydrate storage tank, uses numerical methods to establish the static and dynamic mathematical model of storage tank, researches the impact of storage media properties, flow conditions and geometry for the cold storage process. And master the variation of solid-liquid interface. It has great significance for the prediction of system performance, control mode and the entire system optimization[4,5].

The two processes, cool storage and cool discharge, is three-dimensional non-steady process. The general model is single-tube or double-tube. Single-tube model assumes each coil in infinite space, ignores the impact of heat transfer on the adjacent coil. Double-tube is more accurate than single-tube model. In fact, single tube or double tube has not fully considered the impact of heat transfer on the adjacent coil. Nine-tube model not only reflects the essence of heat transfer of storage tank simply and accurately, but also provides the basis for the design of the storage tank.

As can we seen from the above analysis, due to the heat transfer process is very complex in the storage tank, the model must be made appropriate assumptions. These assumptions are as follows[6]:
1) In calculating the heat transfer of each infinitesimal, the time interval is small. So we can consider at this time heat transfer is quasi-steady process;
2) Ignore the heat transfer of flow direction of secondary refrigerant and consider heat transfer only occurs in the radial direction;
3) Ignore the volume change during cool storage and cool discharge;
4) In cool discharge, consider solid hydrate is fixed, no float or deflection. The whole process is symmetrical;
5) The phase transition temperature is 8.4°C;
6) Ignore the heat loss of storage tank, that is, consider tank is insulation;
7) In the media each phase, physical parameters uniform distribution.

Using fluent software to calculate the temperature distribution, heat transfer characteristics of the model can be broadly analyzed. Select the same diameter, compared to four different tubes spacing, aligned arrangement and staggered arrangement.

This paper builds the nine-model, shown in Fig 1. In storage tank, water is secondary refrigerant, HCFC-141b hydrate is the cool storage medium. Automatic meshing, divided accuracy is 2, the calculation process is transient calculation, calculation time is 18000s, the time step is 30s, the minimum time step is 30s, the maximum time step is 100s, the initial temperature is 13.4°C. By observing the temperature change of the four points ABCD in each case, select the optimal solution.

The geometry of storage tank is a cube, which is 720×170×170mm. The diameter of the pipe is 10mm, coil spacing is 20mm, 25mm, 30mm, 35mm. In the analysis of simulation with fluent, setting physical parameters as follows: above 8.4°C is liquid hydrate, following 8.4°C and 8.4°C is solid hydrate. HCFC-141b hydrate physical parameters as shown in Table 1.
Table 1. Physical parameter table

<table>
<thead>
<tr>
<th>Density</th>
<th>Specific heat capacity</th>
<th>Thermal conductivity</th>
<th>Viscosity</th>
<th>Melting heat</th>
<th>Phase transition temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg · m⁻³</td>
<td>J / (kg · K)⁻¹</td>
<td>W / (m · K)⁻¹</td>
<td>kg · (m · s)⁻¹</td>
<td>J · kg⁻¹</td>
<td>K</td>
</tr>
<tr>
<td>1232</td>
<td>1160</td>
<td>0.39</td>
<td>0.00025</td>
<td>344000</td>
<td>281.4</td>
</tr>
</tbody>
</table>

The storage process of storage tank will go through two stages, that is sensible heat storage and latent heat storage. Single tube mathematical model as shown in Fig 2.

The performance of storage tank is complex and influenced by many factors. And among these factors are often coupled with each other. During the study, in order to make the study easier, each simulation fixed other variables, only studied for a variable. This paper focuses on the temperature field of the storage tank. Formula (2) and (8) describes the heat transfer process of storage tank in two stages, which are sensible heat storage and latent heat storage. Based on these two formulas, we can simulate coil internal melt on storage tank in the sensible heat storage process and latent heat storage.

1) Comparison of temperature field in a different coil spacing in aligned arrangement
The model is U-shaped tube bundle and aligned arrangement, the flowing water in the inner tube is 3.4 °C, velocity of flow is 5kg/s. Under the premise of ignoring the tube axial heat, we can directly set the tube boundary temperature is 3.4 °C. The diameter of the pipe is 10mm, coil spacing is 20mm, 25mm, 30mm, 35mm.
2) Comparison of temperature field in a different coil spacing in a staggered arrangement
The model is U-shaped tube bundle and staggered arrangement, its external conditions are similar to aligned arrangement.
3) Comparison of aligned arrangement and staggered arrangement

Liquid hydrate, which initial temperature is 13.4°C, becomes solid hydrate. According to temperature change, it obviously through three stages. The first stage is from 13.4°C to 8.4°C, in this stage, temperature drops the fastest. This is because in the initial stage, the temperature difference between liquid hydrate and secondary refrigerant is large, heat transfer coefficient is high. Thus, the temperature of liquid hydrate drops quickly; The second stage is from 8.4°C to 7.4°C, in this stage, temperature drops slowly, it is phase change process. Because latent heat of liquid hydrate is large and the heat transfer resistance is large. The temperature of liquid hydrate drops slowly; The third stage is from 7.4°C to 3.4°C. This stage is the heat conduction of solid hydrate. With the temperature of storage tank slowly approaching the temperature of secondary refrigerant, so descending speed of temperature gradually decreases.

(1) Sensible heat storage

Under the simplifying assumptions, the case of sensible heat storage is relatively simple. On the sensible heat storage stage, unified body with heat balance of each time step can be shown in the following:

\[ Q_{coil,i} = Q_{phm,i} \]  
\[ Q_{coil,i} = KF_{bare,i} \cdot (T_{phm,i} - T_{inlet,i}) \]

Formula (1) and (2) describe the heat transfer process of sensible heat in the storage tank.

(2) Latent heat storage

When the water around the coil of storage tank began to freeze, latent heat storage process begins. In the latent heat storage stage, heat balance of the united body at each time step can be expressed as followings:

\[ Q_{coil,i} = Q_{phm,t,i} + Q_{sol,i} + Q_{sc,i} \]

Names and units

- \( Q_{coil,i} \) — Capacity of heat transmission of the i-th coil unit body, W;
- \( Q_{phm,i} \) — Capacity of heat release of cool storing medium surrounding the i-th coil unit body, W;
- \( KF_{bare,i} \) — The product of heat transfer coefficient and heat transfer area, W/°C;
- \( T_{phm,i} \) — The temperature of cool storage medium outlet of the i-th coil unit body, °C;
\[ T_{\text{inlet},i} \] — The temperature of cool storage medium inlet of the i-th coil unit body, \(^\circ\text{C}\);

\[ Q_{\text{sol},i} \] — Latent heat released of liquid cool storage medium solidified into solid cool storage medium, \(\text{W}\);

\[ Q_{\text{sc},i} \] — Heat released of 8.4\(^\circ\text{C}\) solid cool storage medium is further cooled, \(\text{W}\).

3. RESULT

Heat transfer performance of cool storage is good or bad is directly related to the performance of the investment economic effect of the whole storage system, so it is important to study heat transfer characteristics of cool storage. In order to enhance heat transfer, this paper studies on the influence of different structural parameters on storage tank heat transfer characteristics, such as the coil arrangement and coil spacing.

By comparing the temperature variation of the four points (A, B, C, D) under various cases, this paper can obtain optimum scheme. Comparing Figure 3 to 10, we can conclude that at a certain time and a certain volume of the storage tank, U-shaped tubes with the same diameter, the bigger the coil spacing is, the better the heat transfer effect is. At the same time, the smaller the coil spacing is, the lower the central temperature is, the higher the surrounding temperature is, the greater the storage tank temperature gradient is; the bigger the coil spacing is, the more uniform the temperature distribution inside the storage tank is. Assuming HCFC-141b hydrate solidification at 8.4\(^\circ\text{C}\), so all of four cases freeze. Under four conditions, the minimum temperature of the storage tank is approximately same. It not applied in aligned arrangement but also in staggered arrangement. Comparing Figure 3 to 6 and Figure 7 to 10 (aligned arrangement and staggered arrangement), we can come to the following conclusions: 1) The temperature in the second stage has obvious differences between aligned arrangement and staggered arrangement. Comparing Figure 3 and Figure 7, we can conclude that the temperature change in aligned arrangement is faster than it in staggered arrangement. And within a certain time, the final temperature in aligned arrangement is lower than it in staggered arrangement. 2) Ignoring the impact of natural convection of water, temperature distribution of storage tank is completely symmetrical in aligned arrangement, while it is bilateral symmetry in staggered arrangement.

4. CONCLUSIONS

1) The smaller the coil spacing is, the lower the central temperature is, the higher the surrounding temperature is, the greater the storage tank temperature gradient is; 2) Assuming HCFC-141b hydrate solidification at 8.4\(^\circ\text{C}\), so all of four cases freeze. And the smaller the coil spacing is, the earlier the solidification phenomena exists; 3) The bigger the coil spacing is, the more uniform the temperature distribution inside the storage tank is; 4) In a certain time, a certain volume of the storage tank, U-shaped tubes with the same diameter, the bigger the coil spacing is, the better the heat transfer effect is; 5) Temperature distribution of storage tank is completely symmetrical in aligned arrangement. The temperature distribution of storage tank is more uniform. In short, aligned arrangement on the one hand simplified arrangement, on the other hand met the requirements of the temperature field uniformity. Therefore, aligned arrangement is more conducive to performance improvements of storage tank than staggered arrangement.

Acknowledgements

References