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Thermal Stress FE Analysis of Large-scale Gas Holder
Under Sunshine Temperature Field

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Abstract. The temperature field and thermal stress of Man type gas holder is simulated by using the theory of sunshine temperature field based on ASHRAE clear-sky model and the finite element method. The distribution of surface temperature and thermal stress of gas holder under the given sunshine condition is obtained. The results show that the thermal stress caused by sunshine can be identified as one of the important factors for the failure of local cracked oil leakage which happens on the sunny side before on the shady side. Therefore, it is of great importance to consider the sunshine thermal load in the stress analysis, design and operation of large-scale steel structures such as the gas holder.

1. Introduction
Gas holder is an important large-scale steel structure pressure vessel for stabilizing the pressure of the gas pipe network, which is widely used in petrochemical and iron and steel enterprises. The thin oil sealing type Man dry gas holder in a steel plant, which can store 165000m³ blast furnace gas, is a positive 24 polygon gas holder and its each side plate height is 810mm. In 2007, the sealing oil leakage began to happen in the twelfth stand column area of the gas holder and the phenomenon was slight at first. After a while, the seal oil was leaking badly and other columns leaked seal oil as well. Repair welding cannot improve the situation. By the scene investigation, it was found that the sealing oil leakage on the sunny side of the gas holder was more serious than that on the shady side, indicating that this phenomenon was closely related to sunshine.

Zhaoxiong Zhang[1], based on the access method as a theoretical basis, discussed the analysis method of temperature field under sunshine on the basis of Ecotect and pointed out the factors affecting the temperature field under sunshine. Based on the ASHRAE model, Shutang Liu et al. simulated the temperature field of the box type steel structure during the summer solstice day. Based on the ASHRAE model, the sunshine temperature field of gas
holder is calculated according to the coefficient of continuous variation with annual solar radiation intensity in China, and the thermal stress of the gas holder under the sunshine temperature field and operating conditions is further calculated by ANSYS. It is analyzed whether the thermal stress under sunshine is the main factor leading to the oil leakage.

2. Theory of sunshine temperature field

According to the ASHRAE clear-sky model recommended by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) [3], the instantaneous solar radiation intensity is calculated using the coefficient of continuous variation with annual solar radiation intensity in China [4]. The solar radiation received by building consists of direct radiation, sky scattering radiation and reflected radiation from the ground and buildings [5].

The total solar radiation intensity on a non-vertical surface:

\[ G_t = \max(\cos \theta, 0) + C F_{ws} + \rho_g F_{wg}(\sin \beta + C) G_{ND} \]  \hfill (1)

where \( \theta \) is the angle of incidence (if \( \cos \theta \) is less than 0, there is no direct light to the surface and the surface is in shadow, so the surface direct radiation intensity will not be considered); \( C \) is the ratio of scattered radiation to vertical incidence in the plane; \( F_{ws} \) is the surface angular coefficient of the sky; \( \rho_g \) is the reflectivity of the ground or horizontal surface; \( F_{wg} \) is the angular coefficient of the surface to the ground; \( \beta \) is the solar elevation angles; \( G_{ND} \) is the direct radiation intensity of the sun, W/m\(^2\).

Convective heat transfer on the surface of steel components can be calculated by the formula of Newton's cooling:

\[ q_h = h(T_0 - T) \]  \hfill (2)

where \( h \) is the surface coefficient of heat transfer; \( T_0 \) is outdoor temperature; \( T \) is external surface temperature for steel components.

The long wave radiation from the surface of steel components can be expressed as

\[ q_c = \varepsilon \sigma (F_{wg}(T_g^4 - T^4) + F_{ws}(T_{sky}^4 - T^4)) \]  \hfill (3)

where \( \varepsilon \) is the long wave emissivity of the surface; \( \sigma \) is the Stefan-Boltzmann Constant, \( 5.67 \times 10^{-8} \text{W/(m}^2 \cdot \text{K}^4) \); \( T_g \) is the surface temperature; \( T_{sky} \) is effective sky temperature.

3. Finite element model of gas holder’s thermal analysis

The main components of gas holder are its head and its body. The body of gas holder is a regular polygonal prismy reinforced shell made up of wind-pressure ribs, side shells, stand columns and stairway, which bears the weight of gas holder and the vertical load transmitted through the gas holder head, the internal gas pressure, the wind load, the snow load, and temperature load. In order to simplify the model, the secondary structures such as stair corridors are ignored [4].

The side shell is orthogonal anisotropy and the ability carried circumferential load is much greater than that carried vertical load. For the convenience of modeling, the I-shaped type beam which has equal cross-sectional area, bending rigidity and section modulus is used to be equivalent to the stiffener [5]. In the actual structure, the column and the guide plate are welded together first, and the guide plate and the side plate are welded to the whole during the installation of the gas holder from the bottom up. The guide plate and column can be modeled as a whole structure because of the same force they bear, and their effective cross-section can
be equivalent by I-shaped section beam which can be simulated by the BEAM189 space beam element in ANSYS. The element SHELL181 is adopted in the side shell of the gas holder. Finite element model is shown in Fig. 1 (Total model) and Fig. 2 (The connecting part of the column and the side plate).

![Figure 1. Finite element model(Total) Figure 2. Finite element model(Local)](image)

In the calculation, the most dangerous condition is selected, that is, the time when the summer air temperature is the hottest is selected for calculation. The parameters in the simulation analysis are as follows: the geographical latitude is 30°N; the solar declination Angle for 16°; the convective heat transfer coefficient is $10\, \text{W/(m}^2 \cdot \text{°C})$; when the atmospheric temperature is $32.5\, \text{°C}$ (uniform temperature field) before sunrise, about 6:00 in the morning, the component is not affected by sunshine; the sunshine duration is about 12h; the solar radiation intensity is about $1370\, \text{W/m}^2$; the atmospheric extinction coefficient is 0.42; atmospheric cleanliness is 1.0; the surface solar radiation absorption coefficient is 0.55.

The indirect method is used to analyze the thermal stress of the gas holder, that is, the node temperature of the temperature field, which select the temperature of the surface of the gas holder at 15:00, is applied to the structural stress analysis as the body load. Other boundary conditions and major loads are as follows: The maximum gas pressure is $800\, \text{mmH}_2\text{O}$; the top of the gas holder is symmetrically equipped with two $15\, \text{kN}$ erecting crane; The body load of itself; the basic snow pressure is $0.4\, \text{kN/m}^2$. Full freedoms constraint is applied at the bottom of the gas holder in modeling.

### 4. Results & Discussion

From 6 am to 5 pm, six time points as shown in Fig. 3 are selected to analyze and compare the circumferential temperature change curve at the position of gas holder which is $30\times810\, \text{mm}$ high. It can be seen that the variation of time and sun position will cause the change of position where the temperature is highest, and highest temperature appears at 3 pm. The temperature of the gas holder on the sunny side changes parabolically. Because of direct solar radiation, the accepted air temperature heat conduction and ground radiation on the shady side is not affected by surface angle, so the temperature is almost the same, which verifies the accuracy of the model from the aspects of temperature.
The circumferential Tresca stress at the side plate with a height of 35m is shown in Figure 4, and the stress varies from 78.5MPa to 84MPa. Due to the lack of direct solar radiation, the surface temperature and thermal stress of the position between the columns 7# and 19# basically unchanged as Fig. 4 and 5 show. In other parts of the gas holder, the variation trend of thermal stress is consistent with variation of temperature as well, so the temperature effect is obvious.

Since the wind-pressure ribs restrain the radial displacement of side plate, the pressure on the side plate connected with the wind-pressure ribs suddenly increases. In order to minimize the impact of the wind-pressure ribs, the Tresca stress distribution of upper and lower side plates far away from the position of the wind-pressure ribs between the second and third wind-pressure ribs shown in Fig. 6. It can be observed that the maximum stress of the local structure distribute in the strip domain at the junction of the upper and lower side plates and of the side plate and column, while the minimum stress point appears in the small area near the junction of the side plate and the column. The stress distribution at the connection between the side plate and the column is very uneven, which varies from 17.0MPa to 99.3

Figure 3. The Circumferential temperature curve at different time period

Figure 4. The circumferential Tresca stress along side plate

Figure 5. The Circumferential temperature curve at 15:00 period
MPa. The stress is within the allowable range of the Q235 which is the material of the side plate, and it cannot cause failure under normal circumstances.

![Figure 6. The Tresca stress of the side plate](image)

It shows the variations of the temperature stress along the axial path at the side plate and the vertical column in Fig. 7 and Fig. 8. The two curves have great similarities except that their amplitudes are different. There are two peaks in the curves, which are located respectively in the wind-pressure ribs and the side plate ribs, and the stress curve of the column varies more obviously.

![Figure 7. The axial thermal stress along side plate](image)

![Figure 8. The axial thermal stress along column](image)

5. **Conclusion**

The distribution of surface temperature and thermal stress of gas holder is obtained by using the theory of sunshine temperature field based on ASHRAE clear-sky model and the finite element method. The result shows that the variation trend of the thermal stress in all parts of the gas holder is consistent with that of the surface temperature, and the temperature effect is obvious. Although the structure of the gas holder is complicated, it is obvious that the thermal stress of the connection between the column and the side plate, which is also the heat affected
zone of the weld seam, is larger than that of other locations, and it weakened the local bearing capacity of the gas holder, so the thermal stress of sunshine temperature can be used as one of the important factors of the local cracking failure of the gas holder which happen on the sunny side before on the shady side.

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