

Stress calculation and strength verification of desulfurization and denitrification tower based on carbon-based catalytic multi-pollutant control technology

Gu Jiangong¹, Wu Linlin¹, Shi Lina², Zheng Xiangfeng¹, Xu Yun³, Liu Yining⁴,
Wu Jiayu⁵, Shi Honghui¹

¹ CHN energy Boiler and Pressure Vessel Inspection Co., Ltd., Beijing

² China Electricity Council ,Beijing

³ Key Laboratory of National Energy Group Science and Technology Research Institute
Co.Ltd., Nanjing China

⁴ GD Power Development Co. Ltd., Beijing

⁵ Dalian Development Zone Thermal Power Plant, Guodian Electric Power Development Co. ,
LTD. ,Dalian China

Abstract. The desulfurization and denitrification tower is the core equipment of the carbon-based catalytic multi-pollutant collaborative control technology. Its design strength ensures the pollutant removal effect and stable operation of the system. This paper used ANSYS finite element analysis software to establish a three-dimensional model of the tower and divided it into high-precision grids. Combined with actual load analysis, calculation and working condition combination, the deformation and stress distribution nephogram of the tower and the membrane stress and bending stress of each component were calculated. The strength check and stress assessment were carried out. When the calculation error is ignored, the overall design strength of the tower meets the requirements, but the stress of the local reinforced beams exceeds the limit. It is recommended to replace the steel with a higher allowable stress value.

Keywords: carbon-based catalytic method, desulfurization and denitrification tower, finite element, strength check, stress assessment

1. Introduction

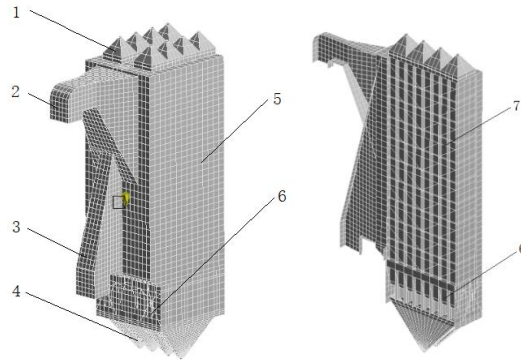
Carbon-based catalytic multi-pollutant collaborative control technology utilizes the excellent physical adsorption, chemical adsorption and catalytic properties of carbon-based catalysts (such as activated coke, activated carbon, etc.) to simultaneously remove sulfur dioxide, nitrogen oxides, dust, etc. from industrial flue gas. Heavy metals, dioxins, hydrogen sulfide and other pollutants, and realize high-value utilization of sulfur resources, are widely used in coal-fired power, steel, coking and other industries.[1]-[2] This technology is a dry pollutant removal technology. In order to achieve coordinated and efficient removal of multiple pollutants in one tower with large flue gas volume, the core equipment desulfurization and denitrification tower must be equipped with desulfurization first and then denitrification to ensure that the flue gas and carbon-based catalyst are in the tower. It has the functions of uniform flow inside and preventing the carbon-based catalyst from catching fire.[3]-[5]

As non-standard equipment, the desulfurization and denitrification tower has a large design size and complex structure. The verification of its design strength has important practical significance for the equipment safety of the desulfurization and denitrification tower and even the stable operation of the entire system. This article uses computer simulation and analysis technology and the finite element software ANSYS Workbench2020R1 to establish a three-dimensional beam shell model of the desulfurization and denitrification tower in engineering applications, analyze the load combination of the model under complex working conditions, and calculate the deformation distribution and stress distribution. and strength assessment and verification, providing technical solutions and method guidance for the strength verification and design work of the desulfurization

and denitrification tower, a key non-standard equipment of carbon-based catalytic multi-pollutant collaborative control technology.

2. Structural model of desulfurization and denitrification tower

The desulfurization and denitrification tower is designed using cross-flow technology and is divided into inlet and outlet flues and two symmetrical chambers on the left and right, such as wall panels, structural steel and reinforced steel. Each chamber is divided into four layers along the direction of flue gas flow. The flow direction of the carbon-based catalyst is divided into an upper funnel, a mobile unit, a lower frame and a lower funnel. The desulfurization and denitrification tower has a typical beam-shell structure, and the structural type after three-dimensional modeling is shown in Figure 1.



1-Upper funnel, 2-Outlet flue, 3-Intake flue, 4-Lower funnel, 5-Exterior wall panels, 6-Lower frame, 7-Mobile unit

Figure 1 Structural type of desulfurization and denitrification tower

The desulfurization and denitrification tower is meshed. SHELL181 units are used for the wall panels and BEAM188 units are used for the section steel. All beam and shell structures are topologically processed to achieve grid continuity of the structure. The grid model is shown in Figure 2. The total number of nodes is 681860 and the total number of units is 683642.

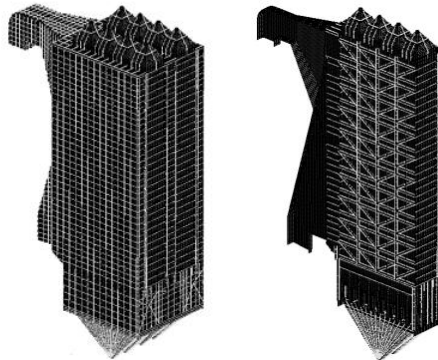


Figure 2 Grid model of desulfurization and denitrification tower

3. Load calculation and working condition combination

The wall plate material of the desulfurization and denitrification tower is Q235B, and the section steel material is Q345B and Q235B. Considering the actual operating conditions, the loads endured are mainly pressure, permanent load (self-weight), variable load (storage load, wind load, snow load) and temperature effect. Refer to GB50009-2019 "Load Code for Building Structures"[6] and GB50884- 2013 "Technical Specifications for Steel Silos"[7] calculates loads and performs load combinations.

3.1 Load calculation

The load is calculated according to "Technical Specifications for Steel Silos"[7].

(1) Pressure: After the flue gas enters the tower body, the inner wall of the flue, the top wall plate of the tower body, the side wall plate and the lower frame wall plate in contact with the flue gas bear the pressure of the flue gas. The design pressure is 0.006MPa, as shown in Figure (1) of Figure 3.

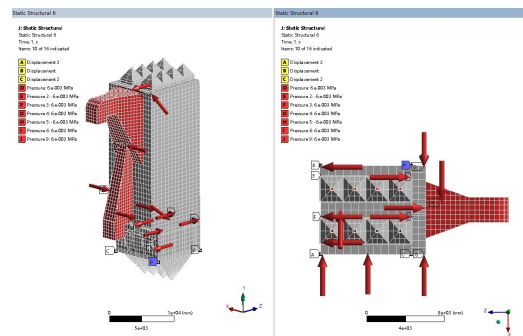
(2) Self-weight: Apply vertical downward gravity acceleration to the tower body. The weight of the insulation material is equivalent to the density of the tower material. As shown in Figure (2) of Figure 3.

(3) Storage load: the horizontal pressure and friction force of the carbon-based catalyst on the side wall plate of the mobile unit, The horizontal pressure and tangential pressure produced on the cone surface in the lower frame, the horizontal pressure and friction force on the vertical surface of the lower funnel, and the normal pressure and tangential pressure on the cone surface are shown in Figure (3) of Figure 3.

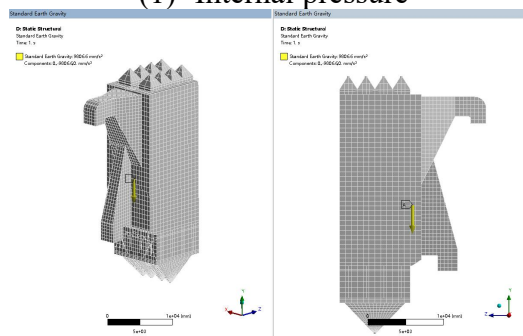
(4) Wind load: The standard value of wind load with a return period of 50 years in the place of use (Dalian City, Liaoning Province, China), as shown in Figure (4) of Figure 3.

(5) Snow load: The standard value of snow load with a return period of 50 years in the place of use (Dalian City, Liaoning Province, China) is shown in Figure (5) of Figure 3.

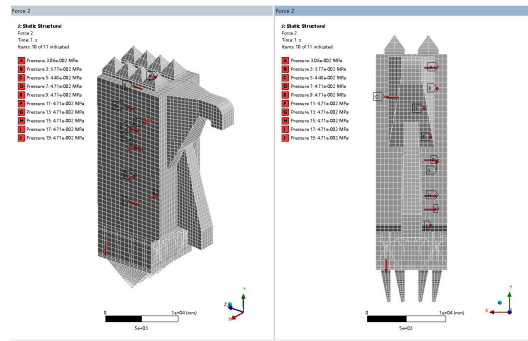
(6) Temperature load: Considering the actual working conditions, the temperature of the desulfurization and denitrification tower body is divided into three intervals. The tower body in contact with the carbon-based catalyst (upper funnel + mobile unit) is 160°C, and the temperature of the tower body in contact with the flue gas is 160°C. (Flue) Take 150°C. Since the desulfurization and denitrification tower is insulated, the temperature of other parts of the tower is calculated based on the principle of heat conduction. The final temperature field of the entire tower is used as the temperature load condition for stress calculation, as shown in Figure (6) of Figure 3.



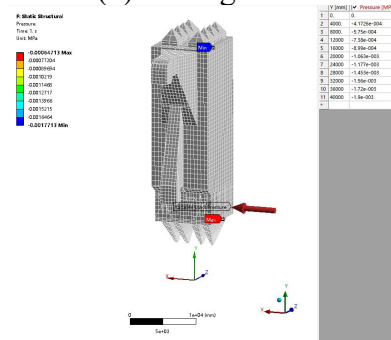
(1) Internal pressure



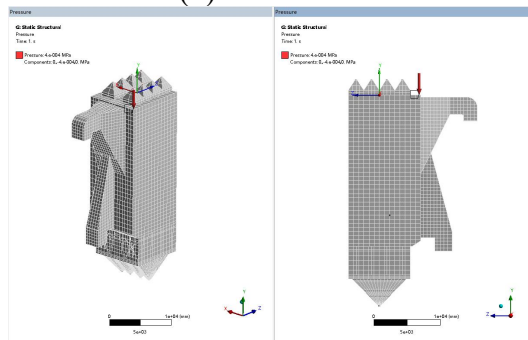
(2) Structural self-weight and insulation load



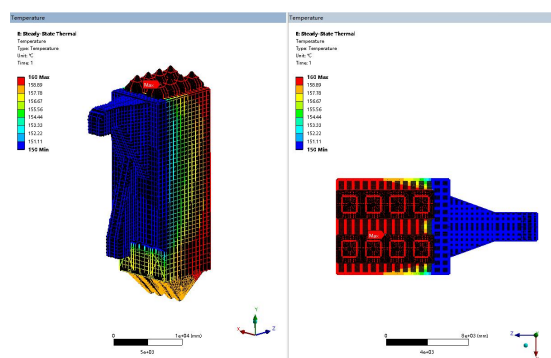
(3) Storage load



(4) Wind load



(5) Snow load



(6) Temperature load

Figure 3 Schematic diagrams of tower load boundary Conditions
Table 1 Load Partial Factors

| Load category | Self weight | Temperature | Design pressure | Wind load | Snow load | Storage load (dominant variable load) |
|-------------------|-------------|-------------|-----------------|-----------|-----------|--|
| Partial factor | 1.2 | 1.4 | 1.4 | 1.4 | 1.4 | 1.3 |
| Adjustment factor | / | 0.6 | 0.6 | / | 0.5 | 0.9 |

3.2 Displacement boundary conditions

The support of the tower body relies on 4 movable bearings connected to the bracket (located at the four corners of the contact surface between the lower frame and the lower funnel). There are 4 constraint points, one of which constrains all degrees of freedom in all directions, and the two points on both sides of it. Two points constrain one degree of freedom in the main axis direction, and one point on its diagonal is designed for universal sliding, which only constrains its vertical degree of freedom.

2.3 Combination of load conditions

The desulfurization and denitrification tower is subjected to pressure, self-weight, storage load, wind load, snow load and temperature effect at the same time. According to "Load Code for Building Structures"[6], the combination of load conditions are calculated according to the following formula, and the partial coefficients of various loads are shown in Table 1.

$$S_d = \sum_{j=1}^m Y_{Gj} S_{Gjk} + Y_{Q1} Y_{L1} S_{Q1k} + \sum_{i=2}^n Y_{Qi} Y_{Li} \Psi_{ci} S_{Qik}$$

4. Stress calculation and verification

Attach the load combination to the model, combined with the displacement boundary conditions, and perform deformation and stress analysis calculations on the model. The results are shown below.

The deformation distribution cloud graph of the tower body is shown in Figure 4. Due to the influence of the outlet flue and inlet flue, the deformation of the upper part of the tower body is relatively large. Due to the carbon based catalyst filling the entire interior of the tower body, the maximum deformation of the tower body is located in the lower frame. As shown in the stress distribution cloud graph in Figure 5 and Figure 6, most of the stress intensities of the bearing components in the tower body under this combination of working conditions are less than the allowable value, and some parts exceeding the allowable value also have stress concentration only in small local areas, mainly at the connection between the flue and the front wall panel, or at the connection between the mobile unit and the lower frame. This small range of stress concentration does not affect the overall strength of the bearing parts.

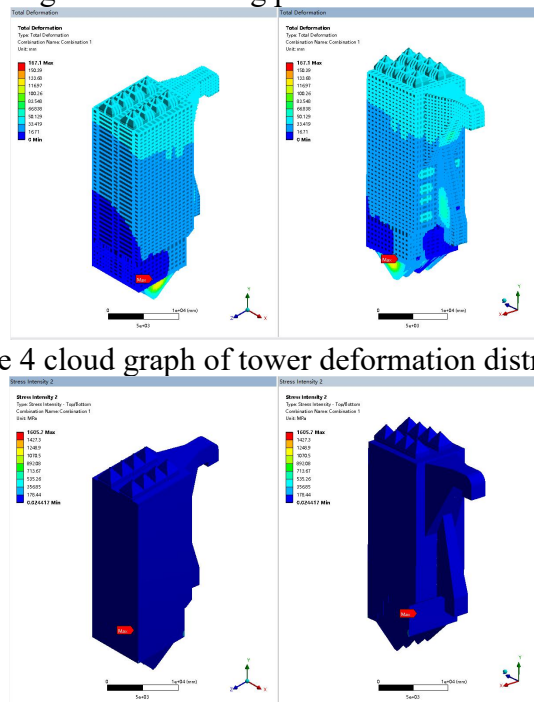
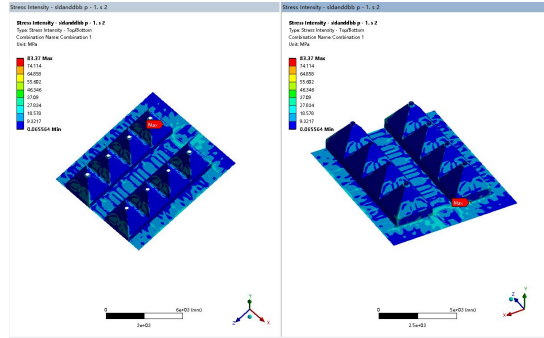
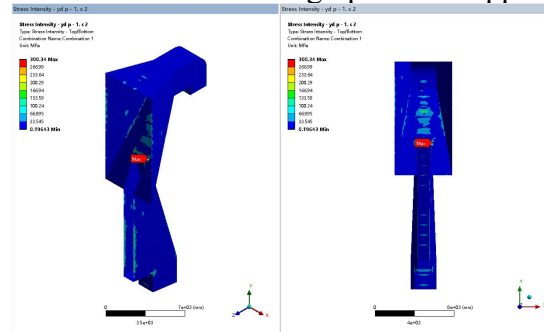


Figure 4 cloud graph of tower deformation distribution

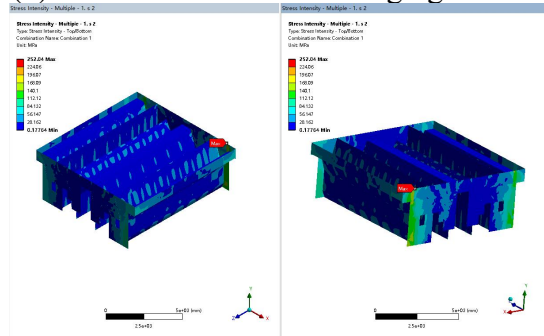
(1) Cloud graph of stress intensity distribution of tower body



(2) Stress distribution cloud graph of the upper funnel



(3) Stress distribution cloud graph of flue



(4) Stress distribution cloud graph of the bearing surface of the lower frame
Figure 5 Surface stress for individual structures

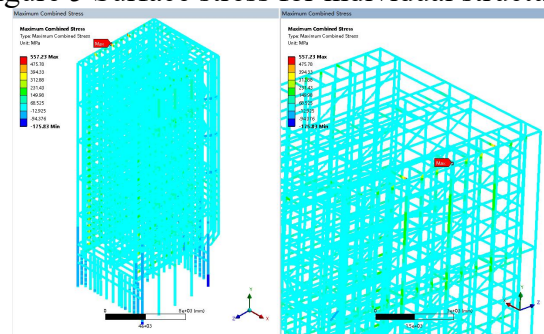


Figure 6 The cloud graph of Combined Stress Distribution of Main Beam and Column Structures of the Tower

Organize the film and bending stress of each component, and evaluate them according to the relevant requirements of JB4732-1995. The results are shown in Table 2.

Table 2 Stress Evaluation Table for Desulfurization and Denitration Tower Body (Unit: MPa)

| Position | PL+Pb | |
|----------------|------------------|-----------------------|
| | Calculated value | Allowable value (3Sm) |
| Top wall panel | 83.37 | 318.6 |

| | | |
|-----------------------------|-----------|-------|
| Side wall panel | 236.82 | 318.6 |
| Rear wall panel | 83.61 | 318.6 |
| Front wall panel | 328.45(注) | 318.6 |
| Flue | 300.34 | 318.6 |
| Mobile unit side wall panel | 244.41 | 318.6 |
| Lower frame bearing surface | 252.04 | 318.6 |

Note: Although the maximum stress exceeds the allowable value, the result cloud graph shows units below the allowable value. It can be seen that the area exceeding the allowable value is only a small area, which does not affect the overall strength of the pressure bearing components.

Taking Figure (3) of Figure 5 as an example, the maximum stress exists in the right angle area where the flue and front wall panel are vertically connected, which is only a small area and quickly decays to within the allowable value. In actual structures, due to the reinforced structure of bolted connections, the strength at this location does not affect the overall strength of the structure.

The other cases where the strength value exceeds the allowable value are all the same. The maximum stress generally occurs at the edge of the structure, only in a small area at the connection with the accessory components, and will not affect the overall strength of the pressure bearing components.

As can be seen from the combined stress cloud graph of the main beam-column structure of the frame in Figure 14, the combined stress of most beams and columns is below 200MPa. The beam material is Q235B, and the allowable tensile and compressive strength is 215MPa; the column material is Q235B and Q345B, and the allowable tensile and compressive strength is 215MPa and 305MPa. Therefore, the tensile and compressive strength of most beams and columns can meet the requirements. It should be noted that the beam between the moving units has a steel type of L63X6, and it can be seen from the combined stress cloud map that the combined stress of the beam exceeds the allowable stress value of 215MPa. It is recommended to replace the steel type and increase the cross-sectional area and modulus of bending section to improve the stress situation here.

5. Conclusions

By establishing an overall model of the desulfurization and denitrification tower, the actual load calculation and working condition combination are carried out to obtain the overall deformation and stress distribution of the tower body. For the pressure bearing components of the tower body, according to JB4732-1995 and the relevant requirements of ASMEVIII-2, the stress results are classified and various types of stresses are checked separately. The stress intensity and membrane+bending stress of most pressure bearing surfaces meet the requirements of the specifications. Although the stress of a small number of components exceeds the allowable value, due to the steel structure type of this tower structure, the stress concentration in a small local area will not affect the overall strength and safety of the structure.

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