Presumptive Study of Temperature and Residual Strength of Desulfurization Tower Structure During and after Fire

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Abstract: Currently, the presumption of temperature and residual strength of structural components of desulfurization tower during and after fire has become one of the key difficulties in the analysis of structural safety of desulfurization tower. Taking the actual situation of a steel desulfurization tower after fire as the background, this study proposes a method to presume the maximum temperature of the structural members of desulfurization tower in fire and a method to presume the fire temperature of the residual strength of steel in desulfurization tower after fire. The results show that: in the fire, the maximum temperature of the sulfur tower structural components in the chimney area, the wet electric area and the mist removal area over the fire is greater than 700 ℃, and the lower part of the slurry area over the fire temperature is about 200 ℃. After the fire, the desulfurization tower anticorrosive materials burned out, the wall plate material strength has been reduced, and the chimney zone root safety reserve is low. Considering the phenomenon of “blue brittle” after high-temperature fire of steel, that is, the steel toughness is reduced, the chimney area and the combination of wet power area have the lowest safety reserve. Provide scientific basis for evaluating the safety appraisal of desulfurization tower structure after fire.

Keywords: Steel Structure Desulfurization Tower; Fire; Temperature Estimation; Residual Strength

1. Introduction

Desulfurization tower, as the core equipment in the modern industrial waste gas treatment process, bears the important mission of purifying the discharge gas and protecting the environment. Its working environment is extremely special, not only need long-term exposure to waste gas containing corrosive substances, but also may face high temperature, high pressure and other extreme conditions of the test. In this context, the risk of fire has become a non-negligible and highly destructive safety hazard in the operation of desulfurization tower.

The occurrence of fire accidents will not only pose a direct threat to the structural safety of the desulfurization tower, leading to deformation, fracture and even collapse of the structural components, but also have a far-reaching negative impact on its subsequent operational efficiency. After the fire desulfurization tower, its internal treatment system may fail due to uneven heating or structural damage, which in turn affects the purification effect and emission quality of the exhaust gas, posing a potential threat to the environment and public health.

Therefore, the temperature presumption and strength presumption of the structural components of desulfurization towers after fire has become an urgent and crucial topic for in-depth study.

In recent years, many engineers and experts and scholars have carried out extensive research on the related problems of desulfurization tower structure by various means. For example, through strength and modal analysis, they found that the dense manhole design on the desulfurization tower weakened the overall strength of the structure to a certain extent, and therefore suggested that appropriate strength reinforcing measures should be taken in the area of the openings [1]. In addition, the structural optimization of the desulfurization absorber tower is also one of the research focuses, including the installation of reinforcing members to improve the stress and deformation condition of the tower, as well as the optimization of the distribution of the flow field inside the tower by the addition of the tower ring geometric members [2,3].

In terms of numerical analysis, Li and Zhao et al. conducted an in-depth analysis of the dynamic characteristics of the flue box of a desulfurization tower with double large outlets by establishing a finite element model [4-6]. on the other hand, derived a simplified theoretical calculation formula for the desulfurization tower structure and established a one-dimensional simplified equivalent model through the equivalent model method, which provides a powerful tool for the rapid assessment of the desulfurization tower structure [7]. Song Bo et al. on the other hand, conducted a shaking table experimental study of a large-scale desulfurization tower structure of a power plant simulating earthquakes using a scaled-down scale model, which revealed the influence of the complexity of the desulfurization tower structure on the dynamic response and the important contribution of the weight of the top of the tower to the inhomogeneity of the peak distribution of the structural acceleration [8].

In recent years, Wei [9] et al. considered the degradation of material properties due to high temperatures and cyclic loading after fire, and developed a multistep finite element model to analyze the seismic performance of double-layered steel tubular concrete after exposure to fire. Han [10] used finite element simulation to investigate the seismic performance of SRCFST members under the action of non-uniform fire. It was found that as the number of fire-exposed surfaces decreases, the maximum overfire temperature at the center of the section decreases, the damage decreases, the stiffness degradation decreases, and the energy dissipation capacity increases. Yang et al [11] proposed a numerical model to simulate the structural behavior of steel tubular concrete in the path of a fire by considering the loading steps at ambient temperatures, the heating and cooling steps, and the loading steps after the fire. It was found that the constant load applied during the heating and cooling processes had a significant effect on the load carrying capacity after fire. Huo et al [12] investigated the seismic performance of the structure under the possible simultaneous occurrence of fire and earthquake by conducting cyclic performance tests of steel pipe concrete under the action of fire. Tseng [13] presented HRR and flame height correlations under horizontal seismic conditions using wood stacks as fuel.

However, although significant progress has been made in the study of the seismic performance of FGD tower structures, there is still a relative lack of research on the temperature presumption and residual strength presumption of FGD tower structures during and after fire. In order to fill this gap, this study is based on the actual situation after a fire in a steel desulfurization tower, which continued to burn for 53 minutes in the fire and then extinguished. Through on-site random sampling and experimental analysis of the structural components of the desulfurization tower after the fire, this study aims to propose an effective method to presume the maximum temperature of the structural components of the desulfurization tower in a fire, as well as a new method to presume the fire temperature based on the residual strength of the steel of the desulfurization tower after the fire. The results of this study not only help to improve the fire resistance and safety assessment of desulfurization tower structures, but also provide useful references and insights for the post-fire safety testing and identification of other industrial building structures.

2. Project Overview

This steel structure desulfurization tower was designed and constructed in 2017. The total height of the desulfurization tower is 60m, and the tower is divided into three functional areas from bottom to top, which are slurry area (main function is desulfurization and mist removal), wet electric area (main function is electrostatic dust removal), and chimney area. The fire was caused by the weldments falling on the PVC pipes in the mist removal area, and the fire lasted for about 53 minutes. After the fire, observing the whole FGD tower, the paint on the outer wall of the slurry area is basically intact, the paint in local area is bulging, the glass scale mastic on the inner wall is carbonized and turned black, but still attached to the inner wall; the spraying device is twisted and deformed. The structural status of the desulphurization tower after the fire is shown in Figure 1.

Figure 1. Current Status of Desulfurization Tower Structure

3. Presumed Maximum Temperature of Structural Elements of Sulfur Towers in a Fire

After experiencing a fire event, the change in state of the residual items becomes an important clue and a key basis for us to infer the temperature of the fire scene. This inference process not only relies on the actual temperature changes of the articles, such as the metamorphic temperature, the softening point temperature or the ignition point temperature, but also requires a careful comparison with the temperature values of these articles under standard conditions. This comparison enables a more accurate estimation of the temperature range in the area of the fire where the articles are located and provides strong data support for fire investigations.

In the temperature presumption process, the ignition point temperature of a fully burned item reveals the lowest possible lower temperature limit of the fire area, since the item will only be fully burned if the fire area temperature exceeds this ignition point. Similarly, the metamorphic or softening point temperatures of articles that have undergone morphological changes, such as metamorphosis or softening, provide us with clues to the lowest temperatures in the fireground. These changes indicate that the item has undergone a significant physical state transition by the time it reaches these temperature points.

Accordingly, the ignition temperatures of the unburned articles and the metamorphosis or softening point temperatures of the undeformed articles become important for the presumption of a maximum fireground temperature. It is likely that these items did not change because they were located in areas of the fireground that did not reach critical temperatures sufficient to initiate change.

Based on the methodology described above, the following temperature determinations were made: the chimney area was extremely hot, between 700°C and 750°C, and this area likely experienced the most intense fire; the wet electric and spray areas, although also affected by the fire, had slightly lower temperatures than the chimney area, but still exceeded the 700°C threshold; and the slurry area (excluding the spray area) had relatively low temperatures, lying in the range of 100°C to 300°C range, suggesting that this area may be at the edge of the fire or somewhat protected.

In addition, fire also has a significant effect on the properties of the steel in the desulphurization tower. In order to gain insight into the temperatures experienced by the steel during the fire, the mechanical properties of the material can be extrapolated with the help of the mechanical properties of the steel after cooling at high temperatures. Relevant experimental research shows that the steel in the experience of high temperature within 600 °C and natural cooling, its necking phenomenon is basically the same as the performance at room temperature, the modulus of elasticity also remains almost unchanged. This indicates that in this temperature range, the physical properties of steel did not change significantly.

However, when the steel experiences temperatures above 330°C and reaches 600°C, its yield strength changes significantly. This change follows a specific pattern that allows the maximum temperature experienced by the steel to be extrapolated by measuring its yield strength after cooling. Specific calculations may involve complex mathematical models and experimental data, but in any case, this method provides an effective means of assessing the extent to which fire affects the properties of steel. The calculations are as follows.

$$f_{yT} = f_y(1.1 - 3.0 \times 10^{-4} T_1) \qquad (1)$$

The yield strength of steel is unchanged at ≤38°C after overheating and cooling with water spray, and changes in the range of 38°C to 600°C according to the following formula:

$$f_{yT} = f_y(1.011 - 2.9 \times 10^{-4} T_1) \quad (2)$$

Where f_{yT} is the yield strength of the steel after cooling. f_y is the yield strength of steel at room temperature. T_1 is the highest temperature experienced by the steel.

A series of post-fire steel performance tests were conducted by carefully sampling the steel in the structural members of the desulfurization tower in situ and combining it with the residual strength data of the steel in the original structural members. These tests were designed to accurately determine the temperature range experienced by the structural members of the desulfurization tower during the fire, thereby providing a scientific basis for post-fire structural assessment and repair.

In the detailed determination process, advanced testing techniques and rigorous data analysis methods were used to compare the test results with the changing law of steel performance at different temperatures. This process not only takes into account the physical and chemical changes of steel at high temperatures, but also fully considers the degree of recovery of steel properties during the cooling process. All key data and information were systematically organized and presented in Table 1 for visual comparison and analysis.

Based on the results presented in Table 1, the following clear conclusions can be drawn: the judged temperatures in both the chimney zone and the wet power zone significantly exceeded 600°C, which indicates that these two zones experienced extremely high temperatures during the fire, and that the performance of the steel may have been severely affected. This finding is important for assessing the safety of the FGD tower structure and developing a rehabilitation program.

Meanwhile, the determined temperature in the lower part of the slurry zone was relatively low at 200°C. This result suggests that although the FGD tower as a whole was affected by the fire, the lower part of the slurry zone may have been exposed to less heat radiation for some reasons (e.g., farther away from the fire source, protected by insulation, etc.), and thus the performance of the steel may have been maintained relatively well.

In summary, this analysis not only provides valuable information on the heat exposure of the FGD tower during the fire, but also provides a solid foundation for subsequent structural rehabilitation and safety assessment work. By gaining an in-depth understanding of the changes in the properties of the steel after the fire, the overall safety of the FGD tower structure can be more accurately assessed and a more scientific and reasonable rehabilitation plan can be formulated.

Table 1. Desulfurization Tower Wall Plate Overfire Temperature Determination Process

number	level	position	Cooling method	Steel Strength(MPa)		presumed temperature(°C)	Judgment temperature(°C)
				f_{yT}	f_y		
1	+47.00	stack area	natural cooling	226	280	976.2	>600
2	+32.50	wet zone	natural cooling	298	339	736.5	>600
3	+1.50	slurry area	Water Jet Cooling	304	319	200.1	200

Combining the results of the detailed analyses and determinations of Method 1 (temperature presumptions based on changes in the state of the residuals) and Method 2 (fire temperature determinations based on steel performance tests) above, it was found that different areas of the structural components of the FGD tower experienced very different high temperatures during the catastrophic fire. Specifically, the maximum temperatures experienced in the three critical zones of the chimney, the wet electrical zone and the demisting zone all exceeded a staggering 700°C. This extremely high temperature range not only reveals that these zones were subjected to extremely intense fire impacts during the fire, but also indicates that the steel structures in these zones are likely to have suffered severe thermal damage, which may have seriously affected their mechanical properties and safety.

Meanwhile, the heat condition in the lower part of the slurry area is relatively mild. According to our comprehensive judgment, the overfire temperature in this area is around 200°C. This result suggests that although the

FGD tower as a whole was affected by the fire, the lower part of the slurry zone may have survived the relatively low temperature due to factors such as specific geographic location, effective thermal insulation or limitations of fire spread. This finding is important for the subsequent assessment of the extent of damage to the steel structures in this area and for the development of targeted repair strategies.

In summary, this comprehensive determination not only provides comprehensive and accurate information on the specific heat condition of the desulfurization tower during the fire, but also provides a valuable scientific basis for the subsequent assessment of structural safety, design of the repair program and development of fire prevention measures. Through in-depth analysis of the impact of fire on the structure of the desulfurization tower, it is possible to more accurately grasp the weak links of structural safety, so as to take more effective measures to ensure the safety and stability of the desulfurization tower in the future operation.

4. Conclusion

This study takes the actual situation after a fire in a steel desulfurization tower as the background, and proposes a method to presume the maximum temperature of the structural components of the desulfurization tower in a fire, as well as a method to presume the fire temperature of the residual strength of the steel of the desulfurization tower after a fire. Through the analysis, the following main conclusions are drawn:

(1) In the fire, the maximum temperature of the structural components of the sulfur tower overfire in the chimney area, the wet electric area and the demisting area is greater than 700°C, and the lower part of the slurry area overfires at a temperature of about 200°C. This part of the results lays the foundation for the following analysis of the seismic performance of the desulfurization tower structure.

(2) After the fire, the anticorrosive materials of the FGD tower were burned out, the strength of the wall plate materials was reduced, and the safety reserve of the root part of the chimney zone was low. Consider the phenomenon of “blue brittleness”, i.e., the reduction of steel toughness after high temperature fire.

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