Development of Pollution Treatment Technologies for Coal Storage Yards in Thermal Power Plants and Case Study

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Abstract. The coal storage yard of thermal power plants are exposed to the air, causing problems like polluting the environment, falling short of requirements of eco-protection and undermining safe production. It causes threats in three forms: coal dust, coal pile explosion, and coal pile spontaneous combustion. Wind and dust suppression walls, dry coal sheds, fully enclosed coal sheds and other measures can be used in these yards to prevent pollution in the yard. Pollution treatment in these yards can avoid static dusting of coal and reduce the spread of dynamic dusting. This study interpreted the necessity of environmental treatment of coal storage yards and the development of three main technologies, and conducted detailed analysis and discussion of various environmental treatment solutions for coal storage yards of thermal power plants. This study intends to provide experience and lessons for environmental treatment of coal storage yards.

1. Introduction

The coal storage yard of thermal power plants are exposed to the air, causing problems like polluting the environment, falling short of requirements of eco-protection and undermining safe production. It causes threats in three forms: coal dust, coal pile explosion, and coal pile spontaneous combustion. With rapid economic growth, the storage and transportation of coal, mineral powder, sand and dust and other bulk materials are increasing, and the dust pollution caused thereby are gaining more attention; meanwhile, as the laws and regulations for energy saving and environment protection become more strict, dust pollution control and energy consumption in coal storage yards have become the key to management of thermal power plants [1]. As the standards for environmental protection in heat thermal plants become higher, environmental treatment technologies develop more advanced, it is more difficult to implement closed management, and the engineering technologies are improving. As stipulated in Article 31 of the “Law of the People’s Republic of China on the Prevention and Control of Atmospheric Pollution”, for storage of coal, coal gangue, coal slag, coal, sand, lime and other materials in areas with concentrated population, fire prevention and dust prevention measures must be taken to prevent air pollution [2]. Wind and dust suppression walls, dry coal sheds, fully enclosed coal sheds and other measures can be taken in the yards to prevent pollution. According to the “Beijing-Tianjin-Hebei and Surrounding Areas 2017-2018 Comprehensive Air Pollution Control Action” (Environmental Air Pollution Control [2017] No. 110) issued jointly by 16 national ministries
and commissions, cities in the Beijing-Tianjin-Hebei air pollution transmission channel should take the lead in completing the closure of the coal storage yards. The coal storage yard of thermal power plants should actively improve the environment, which is in line with the economic interests of enterprises, the industry standards and the national laws and regulations, and it will increase the enterprises' sense of social responsibility.

2. Necessity of pollution control and treatment in coal storage yards

When stacked and loaded, the coal moves against the air, causing dust and thus pollution [3]. Coal yard dusting is divided into two categories: one is static dusting on the surface of the coal yard, and the other is dynamic dusting in the process of stacking and reclaiming. Static dusting is mainly caused by wind turbulence, and dynamic dusting mainly refers to dusting during loading and unloading operations, which are normal operations condition in thermal power plants. Under the action of the wind, the small coal particles have three motion states: rising, drifting and cloud-like flying [4]. The operation gap in the coal storage process is necessary for coal storage and transportation. To control the amount of dust, we can increase the moisture content of the coal or conduct the operation in windless conditions. Environmental treatment of coal storage yards is necessary because of the following three reasons: 1) it meets the requirements of environmental protection; 2) it meets the industry standards, laws and regulations; 3) it is conducive to reducing smoke exhaust losses; 4) it facilitates safe operation of the system; 5) it can effectively reduce coal combustion losses.

3. Development of pollution treatment technologies in coal storage yards

The development of pollution treatment technologies in coal storage yards in thermal power plants has the following three stages:

State 1: installing wind and dust suppression wall. The US Environmental Protection Agency proposed a series of design parameters and standards for the windbreak network in 1986 for the design department [5]. The Europe, the United States, and Japan have studied and used wind and dust suppression technologies for a long time. The wind and dust suppression walls were initially used in port yards. Foreign countries have developed many methods to prevent dust from scattering for outdoor yard equipment, but studies in China in this regard were ten years later than those abroad. Constructing wind and dust suppression walls in thermal power plants in China entailed much work in the early stage in China. Representative cases include: Inner Mongolia Daihai Power Generation Co., Ltd. Phase I and II coal storage windshield and dust suppression wall (total circumference 1,678 m, height 17.62m), Huaneng Shangdu Power Plant Phase I, II and III coal storage windshield Dust suppression wall (total circumference 2,500 m, height 15 m), etc.

Stage 2: Using dry coal sheds. At the end of 1960, some coal-fired power plants in southern China constructed dry coal sheds. In the early 1970s, dry coal sheds were quickly adopted in most provinces south of the Yangtze River and were included in the “Design Regulations” as design standards [6]. In the early 1990s, the dry coal shed was introduced into the “Technical Specifications for the Design of Thermal Power Plants” and widely implemented. The dry coal sheds were generally set up in the coal storage yards in heat power plants. The dry coal shed span is generally not large and is slightly longer than the stacking and feeding machine. Representative cases include: dry coal shed project of Huaneng Nantong Power Plant (span 102.6m, length 90m), dry coal shed project of Jiaxing Power Plant (span 103.5m, length 80m), etc.

Stage 3: using fully enclosed coal sheds. The fully enclosed treatment technology can create a “clean pollution zone”, which can meet the requirements of environmental protection, and the dust suppression effect can reach 100%. The main production area of the power plant is separated from the coal storage yard, making the coal storage area clean, and it is helpful to improve the air quality of thermal power plants.

There are three main engineering cases of fully enclosed coal sheds: coal sheds with a three-center cylindrical grid structure, coal sheds with a pre-stressed tube truss structure, and gas-membrane fully enclosed coal sheds. The three-centered cylindrical grid structure is a high-order statically
indeterminate space structure composed of many rods regularly from two or more directions. It changes the general planar truss stress system and can withstand loads from all aspects, including a curved grid structure [7]. The representative cases are Dalian Xizhongdao North District Heating Project closed coal shed project (span 110m, length 198m), Guodian Longhua Power Plant closed coal shed project (span 115m, length 207m), Changzhi City Ruida Industrial Park Coking Project closure Coal shed project (span 145m, length 200m) [8], etc.

The string structure is a combination of the upper string rigid compression member through the brace and the lower string cable to form a self-balanced force system. It is a large-span prestressed spatial structure. The prestressed tube truss coal shed closed span can reach more than 200 m. Representative cases include Guodian Fangjiazhuang Power Plant Coal Yard Closed Coal Shed Project (span 229 m, length 254 m, the world's largest span of similar buildings), Inner Mongolia Huadian Tuyou Power Plant Coal Yard Closed Coal Shed Project (span 192 m, length 242 m), etc.

In the 1960s, the world’s first gas film building was built in North America. Currently, thousands of gas film buildings have been built around the world. The gas film is a new type of building of advanced technologies in the new era, and the domestic gas film building is being vigorously developed. The representative cases of gas-membrane fully enclosed coal shed projects are: Shenhua Bayannaoer Coal Preparation Plant gas-membrane fully enclosed coal shed (at the time of completion, it is the largest in Asia, with a total of 3 sheds), the dimension parameters are: length 550 m, span 110 m; length 400 m, span 110 m; length 232 m, span 100 m. Wangqu Power Plant's gas-membrane fully enclosed coal shed (currently the largest span in Asia), the enclosed dimensions are: length 198 m, span 180 m, etc.

4. Engineering cases of pollution treatment of coal storage yards

4.1. Wind and dust suppression walls
The wind and dust suppression wall is used for pollution control in coal storage yards. The aperture ratio, geometric shape and different shapes of holes are processed to develop the wall, with the upper and lower interference airflow inside the wall to reach an effect of weak interior wind, strong exterior wind, or no wind inside and small wind outside the wall, thus to prevent dust. The wind and dust suppression wall can suppress 85% of the dust. The wind and dust suppression wall is the most cost-efficient solution for pollution control, with a unit construction price at 285~752 yuan/m². The height of the wind and dust suppression wall can be calculated by referring to the following calculation formula, and the maximum value is selected: A, 2m≤ (the height of the wind and dust suppression wall-coal pile height) ≤ 5m; B, the effective shelter range of the wind and dust suppression wall = height of wind and dust suppression wall × 16; C, (height of wind and dust suppression wall ÷ coal design pile height) ≥ 1.1~1.2. The recommended length of the wind and dust suppression wall panel is 3 ~ 4m, the recommended width is 250mm ~ 300mm, and the recommended opening rate of the wind and dust suppression wall panel is 30% ~ 36%. With the large-scale development of the coal yard closure work, the current use of wind and dust suppression walls for coal storage yards has gradually decreased. Most thermal power companies are dismantling the wind and dust suppression walls, and the coal yard is fully closed.

4.2. Coal shed with a three-center cylindrical surface grid structure
There are many cases of coal sheds with a three-core cylindrical grid structure, and it enjoys a long history. The dozens of thermal power plants under the jurisdiction of Huaneng North Company adopted coal sheds with a three-core cylindrical grid structure for the early coal yard closure. They have accumulated much experience in operation and engineering practice, and have released the “Northern Company Coal Yard Closed Renovation Project Management Method”. According to the “Method”, the closed coal yard engineering work includes: all civil engineering, electrical, lighting, fire protection, ventilation, dust, roads, underground facilities and anti-spontaneous combustion systems, dynamic inventory management, intelligent blending burning system and Subsequent work.
such as a digital coal yard interface[9].

The features of the grid structure are: strong adaptability, mature technology, convenient processing, easy installation, practicability and economic efficiency, and architectural aesthetics. The horizontal thrust of the grid structure is large, the column distance is small (generally 6-8m or smaller), the basic engineering volume is large, the cost is high, and the requirements for the basic site are high. In particular, in poor geological conditions or severe surrounding building restrictions, the adverse effect of the large grid frame reaction force on the structural safety and economy is more obvious. The grid structure is mostly installed by high-altitude loose fitting, the high-altitude operation time is long, and the quality of the labor team is relatively low. Because of the weak safety awareness, construction accidents are likely to occur. At present, the high-altitude scattered fight is the main method for the grid frame. Due to the large span and long length of the coal shed, cumulative errors are likely to occur. The grid nodes are connected by bolts and balls, and there are many nodes. The connection between bolts and rods is prone to electrochemical reactions with corrosive media. The corrosion of coal sheds in the past is mainly internal corrosion of ball nodes, which is not easy to be observed and remedied.

4.3. coal shed with a prestressed tube truss structure

The prestressed tube truss structure is a combination of the upper string rigid compression member through the brace and the lower string cable to form a self-balanced stress system. It is also known as the string chord truss structure, which is a large-span prestressed spatial system and a creative invention of hybrid structures[10]. The features of the structure are as follows: the material performance can be fully exerted in the plane, the self-weight is reduced, and a large space can be crossed. The prestressed tube truss structure can inflict the cable proper initial tension by exerting a certain pretension on the cable, give full play to the tensile capacity of the cable, and make the internal force of the truss evenly distributed. Compared with the same span three-cylindrical grid structure, the horizontal thrust of this structure is reduced, and the base column distance can be 13~16m, which can save nearly half of the amount of basic engineering work compared with traditional grid structures. It can cut the cost by 40%, and the advantage is more obvious in regions with poor geological conditions. The prestressed tube truss structure is provided with horizontal tension strings, which can simultaneously reduce the arch foot thrust and resist wind load. The introduction of truss with compression and bending resistance has greatly enhanced the rigidity and stability of the system. The prestressed tube truss has a simple structure and a small number of rods. Generally, the steel truss installation technique of “ground assembly, section lifting, and high-altitude closing” is adopted. The basic welding work is all completed on the ground, and the installation is upgraded in sections. The construction is highly safe. Since the node welding work is basically performed on the ground, it is also convenient for the owner and the supervisor to monitor the construction quality. At the same time, all the nodes of the prestressed tube truss are welded with intersecting lines, which has good sealing performance, is resistant to corrosion, and is convenient for later maintenance and has a low maintenance cost. The larger the span and the larger the projected area, the more obvious the economics of the prestressed structure.

4.4. Gas film fully enclosed coal shed

The gas-membrane fully-enclosed coal shed is made into a closed space with membrane materials, anchored, inflated, and equipped with an appropriate steel cable system to form a closed-type coal, ore and other raw materials storage structure that can resist wind, frost, rain, and snow. The air-membrane fully enclosed coal shed is inflated without beams and columns, and the space is excellent. After inflation, it stands on the ground and can be folded and stored after deflation. The installation, withdrawal and handling of this kind of gas film building are very convenient. The gas-membrane fully enclosed yard has seen wide adoption abroad, and its fully-enclosed structure and safety performance has made it the only structure that meets the eco-protection standards of scenic spots in North America. The features of the structure are: large space without beams and columns, flexible and
diverse shapes; pollution-free, maintenance-free and long service life. The flexible membrane is light in weight and has a low cost: the overall cost is much lower than the grid structure and prestressed pipe truss structure. Moreover, the construction period is short, the construction is not restricted by natural conditions and can be implemented even in winter. It has excellent light transmittance, low energy consumption, reusability, strong corrosion resistance, and is featured by convenience for move and transform. However, the external equipment of the gas film coal shed is highly dependent, and it requires continuous air supply during operation. The air pressure automatic adjustment system is installed indoors to continuously adjust the indoor air pressure to adapt to the external load changes. The indoor-outdoor pressure difference is around 250 Pa, which is equivalent to the atmospheric pressure difference between the 1st and 9th floors of a residential building, which cannot be felt by the human body in general. The inflatable membrane structure with stiffening cables can be used for permanent structures. The gas film coal shed outperforms over other closed coal sheds in terms of environmental protection and the cost, but its adaptability to the environment in terms of wind pressure resistance and snow pressure resistance needs to be further tested and perfected in actual operations [11].

5. Other cases of environmental treatment in coal storage yards
In addition to the above-mentioned cases, there are circular coal yards, silo-shaped coal storage yards and wedge-shaped coal storage yards for pollution treatment. Compared with the silo-shaped yard, the circular yard has a longer construction period, higher investment, more difficulty in reconstruction. It has advanced technologies, high process control level, eco-friendliness, large storage capacity and occupies a small area of land. However, the circular coal yard has the following disadvantages: low coal pressure, loose coal piles, poor coal pile formability; poor prevention of coal pile spontaneous combustion, high technical standards for coal yard design, construction, equipment manufacturing, and installation. The silo-shaped yard is an upright container for storing bulk materials, which maximizes the use of space and occupies a small area. It can completely solve the pollution of dust. The stacking and reclaiming of materials adopts the top-in and bottom-out method, which can realize the first-in first-out and accurate ratio of coal storage, thus achieving the purpose of improving economic efficiency. The wedge-shaped coal storage yard with a falling coal tower has low energy consumption, low operating cost, good thermal insulation effect, outstanding environmental protection performance, and can avoid the impact of severe weather on the safe operation of the yard. However, it covers a large area, the underground part is deep, and the excavation volume is large; in subsequent operations, the uneven settlement of the foundation is very destructive to the coal storage site, and it is easy to produce cracks, leading the groundwater to entering the coal and undermining the coal quality [12]. The investment estimates of the three solutions show that the cost of the bar-shaped coal storage yard is much lower than that of the circular coal storage yard and the wedge-shaped coal storage yard. The characteristics of the circular coal yard and the bar-shaped coal yard are compared in terms of system reliability, environmental protection, floor area, economy, etc. The results show that the two coal yards are reliable and meet the standards of environmental protection. The bar-shaped coal yard occupies a larger area than the circular coal yard, but its cost is relatively low [13].

A more representative case is the honeycomb cluster coal storage yard of Huaneng Changxing Power Plant. The honeycomb cluster coal storage yard is a new solution, which is better than traditional bar-shaped coal yard and the circular coal yard, more environmentally friendly, has higher accuracy in coal blending and the highest cost.

The various types of pollution control solutions in coal storage yards of thermal power plants are shown the following figures.
Figure 1. Wind and dust suppression wall

Figure 2. Dry coal shed

Figure 3. Coal shed with a three-center cylindrical surface grid structure

Figure 4. Coal shed with a prestressed tube truss structure
Figure 5. Gas film structure coal shed

Figure 6. Honeycomb cluster coal storage yard

Figure 7. Double-span structure coal storage shed

Figure 8. Circular coal storage shed
6. Conclusion
Currently, wind and dust suppression walls are less used, and the dry coal sheds are gradually being rebuilt and converted into closed coal sheds. The pollution control of coal storage yards will eventually enter the stage of fully enclosed coal sheds. The prestressed pipe truss solution is more suitable for super large span projects with a span of more than 120 m. For coal yards with large coal storage spans, three-span cylindrical grid double-span structure coal sheds are also widely used. The three-center cylindrical grid is more suitable for small-span projects with a span of less than 150 m. Gas-membrane coal sheds are seeing wider adoption in small-span projects, and have also been used in projects of a span of 180 m. With the overall improvement of environmental awareness, more and more attention has been paid to pollution control of coal storage yards in thermal power plants, the control technology is advancing, and more suitable solutions are adopted in light of the actual conditions of the coal storage yards of thermal power plants. The coal storage yard of thermal power plants should improve pollution control. Through analysis and discussions, this study aims to provide guidance for similar engineering work and provide experience for pollution control in coal storage yards.

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