Research Status on Dust Removal Technology for High Temperature Gas

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Abstract: High-temperature dust removal technology has a wide range of industrial application, and is an important research direction for the dust removal. The research status, characteristics and application range of several high-temperature dust removal technologies were summarized in this paper, such as high-temperature cyclone dust removal technology, high-temperature filter dust removal technology and high-temperature electrostatic dust removal technology. It is concluded that improving the fine particles collecting efficiency of cyclone dust collector may be an important research direction.

1. Introduction

With the continuous development of economy, the efficient utilization of energy and environmental protection has attracted more and more social attention. Petroleum, chemical, electric power and other industries produce a large number of fine particles every year. For example, in the coal classification conversion clean power generation process, tar is easy to mix with particles, resulting in quality degradation. In order to improve the quality of tar, gas-solid separation of tar in gaseous state is required, and the temperature is usually above 673K[1]. In the integrated coal gasification combined cycle power generation (IGCC) system, the gas entering the gas turbine requires particle removal in the range of 370-595℃ to reduce the wear of gas turbine blades[2]. Before SCR denitrification facility, dust removal at high temperature can prolong the service life of the catalyst and improve the efficiency of denitrification efficiency in general coal-fired power plants. In the process of catalytic cracking unit of refinery, the catalyst running loss is the main source of particulate matter in the high temperature flue gas. It will not only cause the scaling of waste heat recovery equipment, but also combines with other solid wastes to form hazardous wastes in the follow-up. High-temperature dust removal technology is very important to improve the overall economy and reduce environmental pollution. How to improve the efficiency of high temperature dust removal and realize the continuous economic operation of high-temperature dust removal equipment are the research direction of high temperature dust removal.

High temperature dust removal technology can be divided into high temperature cyclone dust removal technology, high temperature filter dust removal technology and high temperature electrostatic dust removal technology according to different gas-solid separation mechanism. In this paper, research status, characteristics and application range were summarized in detail, and the development direction of high temperature dust removal technology is proposed according to my own views.

2. High temperature cyclone dust removal technology

Cyclone dust collector is one of the dust removal equipment that is widely used dust removal at high
temperature at present. Its principle is to make the dusty gas flow through the cyclone dust collector rotating motion, so that the particles hit the wall of the cylinder due to the centrifugal force and then fall into the ash hopper or ash discharge pipe rely on the gravity.

By selecting materials with high heat resistance, good wear resistance and non-corrosion resistance, the dust removal temperature of the cyclone separator can reach 1273K\(^3\)-\(^4\). The key points of cyclone dust collector are how to improve the dust removal efficiency and reduce the pressure drop. S G Mohamed-Swaray et al. established a new semi-empirical model to simulate the dust removal performance of cyclone dust collector at different operating temperatures, and conducted experimental verification on different dusty gas rates, geometric parameters and particle concentrations within the range of 293K-873K\(^5\). H M Ei-Batsh et al. studied the influence of inlet pipe size on dust removal efficiency and pressure drop of cyclone dust collector\(^6\). They concluded that the decrease of the diameter of external pipe increased the dust removal efficiency, but also increased the pressure drop, while the change of length of external pipe had no significant influence on dust removal efficiency and pressure drop. H S Kim et al. studied the dust removal efficiency of cyclone dust collector at high temperature(673K) and high pressure(6bar) through simulation calculation and experiment, and concluded that temperature and pressure had a great influence on particles with particle size below 10μm, and the efficiency of dust collection decreased significantly with the increase of temperature and the decrease of pressure\(^7\).

A Kepa simulated the diameter and different positions of the inverted cone in the large cyclone barrel, and concluded that the dust removal efficiency was slightly higher when the inverted cone position was lower\(^8\). S Demir studied the relationship between the operating pressure drop and size of cyclone collector. And they obtained the conclusion that the operating pressure drop decreased with the increase of the height of the inverted cone and the height of the cylinder, and increased with the increase of the height of the vortex\(^9\). W W Wang et al. proposed a new type of circulating cyclone dust collector. By adding concentric internal parts to the traditional cyclone, the dust-containing airflow can be separated in the inner parts and the vertebral body respectively for primary and secondary separation, which not only improves the dust removal efficiency, but also reduces the pressure drop and velocity gradient\(^10\). G J Wan et al. used the RSM turbulence model to simulate the movement of dust-containing airflow in the cyclone dust collector within the temperature range of 293K-1273K and they concluded that temperature had a great influence on tangential velocity, and pressure drop and separation efficiency decreased with the increase of temperature\(^11\).

Cyclone dust collector has the advantages of simple structure, easy to manufacture, low operating cost, high temperature resistance, moderate pressure drop and can deal with a large number of dust-containing gases. However, the dust removal efficiency is not high for small particles of 5μm and below due to the limitation of its structure and action mechanism. Therefore, cyclones often work in combination with other technologies.

3. Filter type dust removal technology
The filter type dust collector is based on the principle of physical interception. Its dust removal efficiency is very high. Its function principle is that the particles in the gas are captured by the filter element when the dusty gas flows through the filter element. As the filter element catches the particles continuously, the filter element surface will form a filter cake composed of particles. The filter cake can also play a good role in intercepting the particles to improve the dust removal efficiency\(^12\).

3.1 Porous ceramic and metal filters
The filter element is the core part of the filter type dust collector. Its structure is mostly porous structure. The pores can intercept the particles in the dusty gas, and the dust removal efficiency can reach 99%. At present, porous ceramic filter and porous metal filter are studied more. Porous ceramic filter elements are generally candle-shaped, tubular and cross-flow shaped\(^13\). Porous ceramic filter elements can work under harsh conditions such as high temperature, high pressure and corrosive dusty gas, and their heat transfer and brittleness can be improved by composite use with metal materials or fiber
materials[14]. When the particles are collected continuously, the pressure drop of the filter element increases rapidly. Then the filter element can be regenerated by means of high-pressure gas back blowing or liquid backwashing. J D Chung et al. conducted experiments with ceramic candle-type filters at high temperatures, and the results showed that the dust removal efficiency was very high, but the pressure drop decreased linearly with time[15]. H Kamiy et al. also reached similar conclusions through experiments at different temperatures. Porous metal filter elements make use of the plasticity of metal materials to form different structures, mainly in the form of metal sintered screen, metal fiber mat and sintered metal[16]. Its advantages lie in good mechanical properties, high temperature resistance, and processing and welding easily[17]. The disadvantage is that the strength will decrease with the increase of temperature. Moreover, when the temperature is too high, oxidation, corrosion and sintering will occur and plug the pores, so the maximum operating temperature limit exists[18].

3.2 Granular bed filter
Granular bed filter is a kind of dusty gas purifying by using particle layer composed of stable particles[19]. According to its operation mode, the granular bed filter can be divided into three categories: fixed bed, fluidized bed and moving bed.

In the filtration process of the fixed bed granular filter, the granular layer does not move, but it cannot run continuously. After a time, it needs to be regenerated by back blowing. G H Yang put forward a kind of double granular bed operation mode of small granular bed in the lower and larger granular bed in the upper. Dusty gas flows from the top downward, the upper large granular bed increased the dust capacity and extended the counter blowing cycles. The lower level of small granular bed ensured the particle capture efficiency and reduced the bed thickness of small particles[20].

The granular layer is in fluidized state in fluidized bed dust collector. The particles in the dust gas collide with the particles in the fluidized state to achieve the effect of collecting particles. However, the filter layer in the fluidized state is relatively loose and the flow field needs to be evenly distributed. It not only makes the collecting efficiency of small particles poor, but also makes it easy to make the filter particles and some of the captured small particles enter the outlet air flow, so that the overall dust removal efficiency is not good. B C Chiang et al. studied the effect of temperature on dust removal through experiments[21]. High temperature increased the particle diffusion, intensified the friction between particles and improved the dust removal efficiency. Some researchers have increased the efficiency of dust removal by using acoustic waves or different filtration media[22-23].

Moving bed granular filter takes into account the characteristics of fixed bed granular filter and fluidized bed granular filter. Under the general structure, the dusty gas flows from the left side, through the middle granular layer, and flows out from the right side. The particles in the middle granular layer flow from the top to the bottom, thus forming moving filter layer. The continuous flow of particles in the middle granular layer is very important for the removal efficiency of moving bed. In order to make the flow field uniform and the filter medium flow continuously, the researchers made different changes to the moving bed form. S S Haiau et al. proposed the method of adding a guide element inside and they added a louver inside to improve the flow of the filter medium[24-26].

Each type of granular bed filter has its own advantages and disadvantages, summarized in the following table1.

| Granular bed filter | Advantage | Disadvantage |
|---------------------|-----------|--------------|
| Fixed bed           | High dust removal efficiency | High pressure drop and regular back blowing |
| Fluidized bed       | Low pressure drop          | Low dust removal efficiency   |
| Moving bed          | High dust removal efficiency and continuous operation | High energy consumption       |
4. High temperature electrostatic dust removal technology

Electrostatic precipitator (ESP) is a kind of equipment that uses static electricity to remove dust. High temperature electrostatic precipitator is generally used to purify the flue gas above 300℃. It has a wide application prospect in IGCC and power stations, etc. However, it has not been applied in industries on a large scale and is still under further study.

In order to find out the influence of temperature on the performance of high temperature electrostatic precipitator, researchers have carried out many experiments at high temperature. W Z Zhu et al. tested the influence of operating parameters such as temperature (363K-763K), working voltage, dusty gas flow rate and initial concentration of particles on dust removal efficiency through experiments. The results show that under the same voltage, the dust removal efficiency increased with the increase of temperature [27]. While under the same current, the dust removal efficiency decreased with the increase of temperature, and the dust removal efficiency increased with the increase of voltage, dusty gas flow rate and initial concentration of particles. G Xiao et al. conducted experiment in the range of 623K-973K with the wire-tube dust collector, and evaluated the performance of ESP at high temperature through dust removal efficiency, energy consumption index and outlet mass concentration. The energy consumption index increased rapidly with the increase of temperature [28]. P Yan et al. studied the effects of temperature (373-1073K) and pressure (30-100kPa) on negative DC corona discharge with a wire plate precipitator. The results showed that the corona current density increased with the increase of temperature and decreased with the increase of gas pressure. The analysis showed that the high temperature can caused the extra corona current composed of the extra ion current and the extra electron current [29-30].

Y Li et al. concluded that ionic wind had a more significant influence on gas secondary flow, gas viscosity was higher and field charge was weakened at high temperature [31]. The high temperature increased the ratio of the average resistance to the average electrostatic force acting on the particles. Therefore, the dust removal efficiency decreased. X Xu et al. studied the particle collection efficiency and particle migration speed of high-temperature electrostatic precipitator through experiments [32]. They concluded that the decrease of applied voltage at high temperature led to the reduction of particle charging electric field force of the particle, and thus reduced the particle migration speed and collection efficiency. Z Y Shen et al. conducted pilot scale test to better study the actual situation of the dust removal efficiency. The results showed that the dust removal efficiency reduced rapidly with the temperature from 563K to 1020K and temperature had a great influence on discharge. High temperature limited the maximum operating voltage, and small particles was difficult to capture at high temperature [33].

![Figure 1. The effect of temperature on voltage](image)

High temperature affects the corona discharge and the increase of temperature will increase the discharge current under the same voltage, which is conducive to improving the dust removal efficiency. However, the high temperature reduces the maximum applied voltage, resulting in the decrease of charged particles and electric field intensity, which reduces the dust removal efficiency. The overall results show that high temperature reduces the dust removal efficiency. In addition, the adjustable voltage range becomes smaller at high temperature as shown in Figure 1. It is difficult to control the
5. Conclusion
High-temperature dust removal technology has a broad application prospect. However, dust removal equipment has higher requirements for the heat resistance, operation stability and operation economy due to the high temperature environment. Although the research on these high temperature dust removal technologies has made great progress, there are still some shortcomings. Compared with the other two kinds of high-temperature dust removal technologies, high-temperature cyclone dust removal technology has the advantage of wide temperature application range and is a mature technology. And cyclone dust collector is the most widely used high temperature dust collector in industry at present. Therefore, it is an important direction of future research to improve the collecting efficiency of small particles by reforming structure or using pre-agglomeration technology.

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