Research Status of Dust Reduction Technology in Coal Handling System of Thermal Power Plant

Xia Xing-ding1,a*, Yang Yong1,b, Sun Yu-nong2,c, Zhang Yi-dan2,d
1Zhejiang Wenzhou Power Generation Co., Ltd, Wenzhou, Zhejiang, China
2Harbin Hengyu Electric Power Engineering co., Ltd, Harbin, Heilongjiang, China
*aemail: xiaxingding@zjenergy.com.cn, bemail: yangyong@zjenergy.com.cn,
cemail:1228260400@qq.com, demail: hrbhygs@126.com

Abstract. Aiming at the dust control of coal handling system in thermal power plant, the research status of dust reduction related theory and technology was summarized. This paper introduced the research progress of dust and air separation mechanism and multiphase flow simulation technology in dust removal and suppression, as well as the features and application of dust removal technologies such as wet dust suppression, bag type dust removal, high voltage electrostatic dust removal, unpowered dust reduction and others. The technical route of dust reduction in coal handling system of thermal power plant was advised, which provides reference for dust control in coal handling system

1. Introduction
Thermal power generation has always been the major source of power supply in China, while the thermal power plants still face a series of environmental problems. For example, the dust in their coal handling system exceeded the standard level, and a large amount of dust is produced in the coal unloading, coal handling, coal loading and other processes [1]. Since the falling coal dust cannot be cleaned in time during continuous work, the coal dust is suspended in the air for a long time, which not only affects the function and life of the equipment, but also directly endangers the health of the operators and the surrounding air quality. At the same time, as a combustible material, pulverized coal is actively prone to safety accidents such as deflagration [2]. Therefore, the dust control and reduction technology of coal-fired power plants has always been valued by people.

2. Research status of dust reduction technology at home and abroad
At present, the major dust reduction methods at home and abroad include high-voltage electrostatic dust removal, Wet dust suppression, bag type dust removal, and unpowered dust reduction. The following analyzes the technical features and application of dust reduction facilities often used in coal handling system of thermal power plants.

2.1. Theory on dust reduction

2.1.1. Research on dust particles flow and separation mechanism. The application effect of ventilation and dust removal technology mainly depends on the understanding of the flow characteristics of dust particles in the chute. Therefore, the flow and separation mechanism of dust is heavily weighted in dust removal research. The flow characteristics of dust particles in chute are
relatively complex, which are not only related to dust characteristics and Reynolds number, but also related to the size of chute section, roughness of chute wall and layout of pipe network. Dust particles will produce various states such as vortex, suspension and sedimentation in the process of moving with the airflow.

To understand the movement characteristics of dust in a horizontal chute, the relationship between its suspension force and gravity is generally analyzed. The dust particle suspension force can be expressed as \[ F = \frac{k A^2 v^2}{2} \] (1)

Where: \( F \) is the dust suspension force, \( k \) is the suspension coefficient of dust particles, and \( A \) is the projected area of dust particles in chute. When dust particles are spherical with diameter \( D \), \( A = \frac{\pi}{4} d^2 \), \( \rho \) is air density, and \( v \) is the speed of dust particles' horizontal movement. When the dust particles are considered spherical, the weight is

\[ G = \frac{\pi}{6} d^3 \rho g \] (2)

Where: \( \rho_g \) is the dust density. When the dust suspension force is equal to gravity, that is \( F = G \), dust particles can be suspended. At this time, the corresponding velocity of airflow boundary layer is:

\[ v_c = \sqrt{\frac{4g}{3k\rho} d \rho g} \] (3)

The force of dust particles in vertical and inclined chutes can be converted with reference to the calculated values of horizontal chutes. When the dust-containing airflow flows into the separation zone at a speed greater than the boundary layer, the dust particles will gradually deviate to the separation interface and adhere to it, the adhered dust particles will be gradually removed, and new dust particles will continue to adhere to it.

The Wet dust suppression method is often used in coal handling systems, which is mainly concerned with the mechanism of droplets catching in wet spray to trap dust, mainly including inertial collision mechanism, diffusion mechanism, gravity sedimentation mechanism, and adhesion mechanism, etc.

Among them, the inertial collision mechanism refers to the dust particles with larger size or heavier weight, which will deviate from the dust-containing gas under the influence of relatively large inertial force in the flow, and finally hit the water mist, droplets and other wet objects to be separated. The Stokes number describing the effect of inertial collision, the empirical formula for calculating this value is \[ K_s = \tau \frac{2v_0}{D_c} \frac{\rho_d d_f^2 v_0}{\mu_d D_c} \] (4)

Where: \( \tau \) is the relaxation time, \( v_0 \) is the gas flow rate, \( D_c \) is the cylinder diameter, \( \rho_f \) is the dust density, \( d_f \) is the dust diameter, \( \mu_9 \) is the aerodynamic viscosity.

In addition, some dust is trapped and restrained by diffusion mechanism. When dust particles collide with atmospheric molecules and perform a Brownian diffusion-like movement, they can fully contact with liquid droplets and separate from them. The calculation formula for the diffusion, separation and capture efficiency of spherical dust particles is as follows:

\[ \alpha = \frac{4.18 \sigma}{S_c} \frac{S_c}{S_c} \frac{v}{v_{\infty} d} = \frac{4.18 \sigma}{S_c} \frac{S_c}{S_c} \frac{v}{v_{\infty} d} \] (5)

Where: \( \sigma \) is the contact coefficient, \( S_c \) is the Schmidt number, \( v \) is the gas kinematic viscosity coefficient, \( v_{\infty} \) is the velocity of dust particles at infinity, \( d \) is the dust particle diameter, and \( Re \) is the Reynolds number.

In addition, the dust can be collected by gravity sedimentation, adhesion, coalescence, and interception. In fact, the movement trajectory of dust particles and droplets is related to the speed of the dust-containing gas, the resistance of the airflow, the shape, size and quality of the dust particles, and the adhesion of the dust to the droplets. Gas-solid two-phase flow is much more complicated than
theoretical analysis, so the research on dust flow theory and the improvement of relevant empirical formulas are still important directions and contents of subsequent research.

2.1.2. Study on coupling mechanism of multiphase flow in spray dust fall. With the rapid development of computational fluid dynamics technology, numerical simulation has become a low-cost, high-efficient analysis method for fluid dynamics. In the study of dust removal theory, in addition to the basic theory of kinematics, a dedicated gas-liquid-solid multiphase flow model can be established for the coupling process of coal dust movement and dust mist by special simulation software. The internal fluid environment can be simulated and analyzed to explore the influence of structural parameters and operating environmental parameters of coal handling device on dust suppression.

Currently, in the numerical simulation methods of multiphase flow, the mechanical models for multiphase continuum flow mainly include Euler - Lagrangian model and Euler - Euler model [3].

The Euler - Lagrangian model is mainly used to solve the problem of dispersed multiphase flow. Its basic idea is to treat the fluid phase as a continuous phase, and obtain its flow information by directly solving the Navier-Stokes equation, while the motion of the discrete phase is independent and is controlled by the momentum equation, allowing the exchange of momentum, mass and energy between the two. The single particle dynamic model and particle trajectory model are widely used in this type of model. The Euler - Euler model is mainly used to solve the problem of multiphase flow with high concentration of the dispersed phase. It regards the particle phase and the fluid phase both as the continuous phase and calculates in the Euler coordinate system. By calculating the element changes of each space point in the flow field at different times, the movement of the whole flow field is obtained. For the multiphase flow with small particle concentration, the prediction results of this method have large errors.

When using multiphase flow to simulate the internal flow of dust removal system, it involves air, droplets and solid particles, which belongs to the typical gas-liquid-solid three-phase flow. For this kind of multiphase flow model, due to the uneven distribution of dispersed phase and the existence of slip velocity and velocity gradient between phases, the dispersed phase is in an unstable state, and the flow situation is very complex. Compared with single-phase flow analysis, the velocity, concentration, and physical properties of the various phases of the multiphase flow field have a larger interaction range. It is necessary to construct a suitable geometric model and solution to describe the basic control equations for more complicated multiphase flow. At the same time, the physical properties of the fluid are quite different at the boundary between phases, and the distribution of physical properties in the region is extremely uneven. How to accurately describe the position of the phase boundary and its change is also a difficulty in numerical simulation technology of multiphase flow.

Therefore, when the multiphase flow is used for the simulation evaluation of the dust removal effect, a series of issues such as the parameter setting of the interaction between the phases and the simulation convergence still need to be further studied to improve the accuracy of the simulation results.

2.2. Application status of dust reduction technology

2.2.1. Wet dust suppression technology. Wet dust suppression technology is a method in which water and dust-containing gas are fully contacted to wash off the dust particles, thereby purifying the gas. For coal handling systems in thermal power plants, the dust is mainly pulverized coal with a diameter of less than 10μm. Wet dust suppression technology is to produce a large amount of the mist droplets by atomization of magnetized water, absorb and gather with pulverized coal, and settle gradually in a sealed trough and a guide chute to achieve the effect of dust control, as shown in Figure 1.
The key of Wet dust suppression is how to improve the combined effect of water and dust. Cheng Weimin and others proposed high-pressure atomization through nozzles to improve dust removal efficiency [5]; Jiang Haibo and others added surfactants to the water to enhance the wettability of water to improve dust removal efficiency [6]; Liu Zhichao and others studied the dust removal effect of magnetized water. Magnetized water was prepared by magnetization device, which changed the wettability and surface tension of water, and then magnetized water was sprayed out by atomization device. The experimental results show that the dust removal effect of magnetized water is significantly higher than that of tap water [7].

Wet dust suppression technology has high dust removal efficiency and relatively simple operation. However, its disadvantage is that it consumes a lot of water during operation. It is not suitable to be promoted in areas with scarce water resources or relatively arid areas, and the workload of equipment maintenance is relatively heavy. As the water content increases, coal consumption for power generation increases, and the economy of power generation units decreases.

Wet dust suppression uses direct spray for dust removal, as well as dry mist dust removal and multi-tube flushing dust removal. Wet dust suppression technology has a significant effect on dust suppression in closed and semi-closed environments with unorganized emissions. Among them, dry mist suppression technology has a significant effect, but the equipment using this technology requires large investment in equipment, continuous power supply, and high operating costs. It also causes secondary pollution and has heavy maintenance workload.

2.2.2. **Bag type dust removal technology.** Bag type dust remover is a kind of equipment which filters the dust air flow by fiber woven material to achieve the purpose of dust suppression [8,9]. When the dust-containing gas enters the bag filter, the dust is adsorbed and trapped on the filter bag. The dust content of the filtered gas will be significantly reduced, and it can be discharged through the air outlet. The efficiency of the bag filter can theoretically reach 99%, but the air leakage and resistance changes during the operation of the dust remover will affect its actual dust removal effect. Some scholars have achieved the purpose of reducing the airflow resistance of the dust remover by studying the internal airflow distribution. Haiming Fu and others proposed to expand the area of the inlet duct and disposed bluff body refinement by a computer simulation of the flow field, which effectively reduces the resistance of airflow [9]. Furthermore, the quality of filter bag is also key to the efficiency of the dust removal, especially the permeability and density of the filter cloth will directly affect the dust removal effect. Jinhuai Zhao and others have achieved good dust removal effect by using pleated filter bag technology, but the cleaning and price of pleated filter bag still need to be improved [10]. Moreover, in recent years, with the mature of manufacturing technology of large bag filter, its safety and stability have been improved, so that the application scale and quantity of rotary back blowing and pulse back blowing bag filter equipment have increased. However, in the coal handling occasion, because it will
be sprayed in the processes of coal storage and transportation, and the dust suppression and
temperature prevention, the humidity will be too large. Long time operation makes the droplets which
combines dust with water remain on the surface of the filter bag, forming a certain thickness of
"slime" to block the filter cloth, which significantly reduces the efficiency of dust removal.

2.2.3. Unpowered automatic dust reduction technology. Unpowered automatic dust reduction
technology mainly applies the principles of aerodynamics, pressure balance, etc. \cite{11}, adopts a closed-
loop flow balance device to realize the control of material flow, so that the induced wind pressure
inside the guide chute and the external space pressure are approximately balanced; The dust-air
automatic whirl system and the automatic monitoring system are installed to jointly control the air
pressure in the coal chute, to realize the closed-loop and effective circulation of the internal air, and to
carry out decentralized control of the dust generation point, which effectively overcomes the
disadvantages of the traditional dust removal method. Since unpowered dust removal technology is an
emerging technology that has only been developed in recent years, the research and design of
unpowered dust removers at home and abroad are still in a stage of continuous development and
exploration. Wang Hongsheng and others established a gas-solid two-phase flow model of air and dust
by studying the transfer point and the dust movement law at the guide trough of the belt transportation
system, and based on the simulation results, designed a closed ventilation and dust removal system \cite{12}. Based on Euler simulation, soft ball collision simulation and discrete element simulation (DEM),
Zhang Jiangshi and others carried out numerical simulations on the movement law of coal falling
materials, analyzed and studied the causes of dust generation, and modified the dust removal system
on this basis \cite{13}. Nordell, Cleary \cite{14, 15} and others used discrete elements to simulate the flow
distribution of materials in the transfer station, and pointed out that the curved transfer chute can better
control the flow pattern and flow speed of bulk materials, and reduce impact and dust. Comprehensive
and multi-level considerations starting from the coal chute to the guide trough, from the coal falling
speed, angle, force, pressure, direction, etc., and from the mechanism of coal dust generation, this
paper analyzes and seeks effective dust control methods.

![Diagram of unpowered automatic dust reduction equipment](image)

1. Irregular section coal chute, 2. Dust condensation and dust depression by mist, 3. Sealed tail box, 4. Tail pulley 5. Idler sets,
6. Add a pallet between the idler sets to reduce belt sag, Prevent airflow and dust from escaping, 7. Return tank pressure
relief, 8. Conventional guide trough, 9. Flexible dust-preventing curtain, 10. Multiple damping plates reduce air velocity, A
variety of dust-preventing curtains prevent different particles from escaping, 11. Expansion of fully enclosed guide trough,
12. Double-layer anti-overflow apron on both sides of the guide trough.

Fig.2 Schematic diagram of unpowered automatic dust reduction equipment

A typical unpowered automatic dust reduction equipment usually consists of a curved coal chute, a
fully enclosed expansion guide trough, a pressure relief bin, and an airflow damping adjustment
system, as shown in Figure 2. The coal chute with special-shaped cross-section can "bundle" the coal
flow, reduce the cross-sectional area of the diffuse flow, reduce the compression and disturbance of
the coal flow on the airflow in the coal chute, reduce the induced air volume and reduce the induced
wind speed. The improved fully enclosed guide trough can confine the coal dust-containing airflow in a relatively closed space and prevent the coal dust airflow from escaping. There is an airflow pressure difference between the return box and the chute, which can realize the autonomous diffusion and pressure relief of the airflow. The multi-layer damping plate arranged in the guide trough can consume the kinetic energy of the high-speed airflow and reduce the speed of the airflow. At the same time, the damping plate is equipped with a filter to filter out the dust of different particle sizes step by step. A water mist spray system is set at an appropriate position in the guide trough. The airflow of speed reduction and primary filtration is mixed with the highly atomized water mist particles sprayed by the water mist spray system. The water mist particles and dust particles are fully collided and agglomerated into clusters, and then settle down under the influence of gravity, so as to achieve further dust suppression and dust reduction effects.

The unpowered dust reduction technology has the advantages of short construction period, low investment, no manual operation, low operation and maintenance cost, good dust reduction effect, no secondary pollution, safe and reliable use, and novel and reasonable technology. Unpowered dust reduction technology is in line with the direction of energy conservation today and is an important direction for the development of dust reduction in coal handling systems in thermal power plants in the future. However, engineering problems are complex and changeable. The theoretical support of unpowered dust reduction needs to be improved, and the structure needs to be optimized. The rationality of dust gas flow needs to be adjusted flexibly according to the actual situation of the project to improve technical reliability and versatility.

2.2.4. High-voltage electrostatic dust removal technology. The high-voltage electrostatic dust collector is a kind of dust removal equipment that charges the dust through a high-voltage electric field, and then makes the charged dust particles deposit on the electrode under the force of the electric field, and finally achieves the purpose of dust removal. The electrostatic collector has the advantages of stability, reliability, safety, high dust removal efficiency, high degree of automation, small size, light weight, high efficiency, and energy saving. In the high-voltage electrostatic collector of the coal handling system, it needs to be led to the outdoors through the air duct to eliminate the risk of internal combustion of the high-voltage electrostatic dust remover.

Because of its high efficiency and low resistance, electrostatic dust removal can be used in high-temperature environment and in the dust removal of non-conductive dust, corrosive gases, non-hazardous dust containing gas blast. It can be able to better remove micro small dust particles, have a high collection efficiency, good stability, low power consumption, shock free cathode, less maintenance, anti-condensation, low noise, continuous and stable operation, etc., so it has achieved rapid development. However, when the electrostatic dust remover is running for a long time, more and more dust will adhere to the electrode, which will reduce the efficiency of negative ion emission and directly affect the efficiency of electrostatic dust remover. Moreover, relative to other types of dust removal devices, its relatively high cost, high requirements of manufacturing and installation, complex maintenance and others limit its wider applications [16, 17].

3. Examples of dust reduction
In a coal handling system currently used by our company, 900mm×900mm square straight-through coal chutes are adopted on the tail of the belt conveyor below the screen and crusher. Many dust particles and induced wind will be generated during work, resulting in high dust concentration at the tail of the belt conveyor and the entire belt, easy coal blockage of coal chute and heavy maintenance workload. To solve this problem, based on the multiphase flow simulation analysis of the on-site handling system, we optimized the coal handling system from the following aspects: (1) design curve coal chutes, expand the sealed guide trough, increase the return air buffer bin to reduce the induced wind during the process. (2) by adding double sealed spill-preventing plates, belt pallet and multiple heavy damping curtains to enhance sealing during handling. (3) wet dust suppression + lipophilic
chemicals. Through the combined application of several dust suppression and dust removal measures, the dust on site has been effectively reduction.

4. Conclusion
At present, the common dust suppression and dust reduction methods have their own limitations. Considering the limitations of the dust reduction system transformation conditions, research and innovation should be carried out through equipment maintenance and technical transformation, thus ensuring the effect of dust on the premise, as far as possible to reduce operation and maintenance cost. Combined with practical engineering applications needs, the combined dust reduction technology can be optimized and innovated by absorbing the characteristics of various dust removal devices and coal transfer mode. In particular, simulation analysis techniques such as discrete element and multiphase flow should be used to provide a theoretical reference for the design of dust reduction devices, reduce test costs, and better meet the needs of dust control in thermal power plants.

References
[1] Yang Yongping, Yang Zhiping, Xu Gang, Wang Ningling. Energy consumption status and outlook of thermal power generation in China[J]. Proceedings of the Chinese Society for Electrical Engineering, 2013, 33(23):1-11+15.
[2] Liang Haimin. Application of automatic unpowered dust collector in dust control of coal handling system[J]. Science and Technology Innovation and Application, 2013, (25): 44 - 44,45.
[3] Wan Yiliang. High-efficiency wet dust collector fluid characteristics and application research [D]. Jiangxi University of Science and Technology, 2016.
[4] Cleary, P.W., and Sawley, M.L. DEM modelling of industrial granular flows:3D case studies and the effect of particle shape on hopper discharge[J]. App.Math. Modelling,2002,26:89-111.
[5] Cheng Weimin, Nie Wen, Zhou Gang, Zuo Qianming. Study on dust suppression performance of high pressure spray atomization particle size in coal mine [J]. Journal of China University of Mining and Technology, 2011, 40(02): 185-189+206.
[6] Jiang Haibo, Xiao Yuelong, Zhao Wu. Research on the wettability of coal dust with new surfactant solutions[J]. China Safety Production Science and Technology, 2013, 9(06): 11-15
[7] Liu Zhichao, Ma Sai, Song Wenya. Study on the efficiency of magnetized water spray dust removal[J]. Mining Safety and Environmental Protection, 2016, 43(02): 19-21.
[8] Ji Jing Wen, Angie Chen flue dust bag technology [M] Beijing: China Electric Power Press, 2006: 26 - 26. [12] An Analysis of characteristics and equipment manufacturing technology of bag type dust remover [J]. China Powder Industry,2017(05):16-19.
[9] Fu Haiming, Zhao Youjun. Dynamic testing and optimization of the flow field of the bag type dust remover [J]. Journal of Central South University (Natural Science Edition), 2010, 41(02): 799-806.
[10] Zhao Jinhua, Qian Lei. Application of pleated filter bag technology in ultra-low emission transformation of iron and steel[J]. Industrial Safety and Environmental Protection, 2019, 45(12): 85-87.
[11] Chen Hui. Application of unpowered dust removal in thermal power plants [D]. Southwest Jiaotong University, 2017.
[12] Wang Hongsheng, Wu Bing, Ding Xiaowen. Simulation study on dust movement rules and control technology of belt handling system[J]. Mining Safety and Environmental Protection, 2017, 44(03): 10-15.
[13] Zhang Jiangshi, Liu Jinfeng, Wang Xuesong, Zhu Yingying, Chen Zhanguo. Research and application of unpowered dust removal technology for belt coal handling system in alpine area[J]. Mining Safety and Environmental Protection, 2018, 45(04): 84- 88
[14] Lawrence K. Nordell. Particle flow modeling: transfer chutes & other applications[C]. Beltcong,
Johannesburg Republic of South Africa, 1997.

[15] Cleary, P.W., and Sawley, M.L. DEM modelling of industrial granular flows: 3D case studies and the effect of particle shape on hopper discharge [J]. App. Math. Modelling, 2002, 26: 89-111.

[16] Yan Keping, Li Shuran, Zheng Qinzhen, Zhou Jingxin, Huang Yifan, Liu Zhen. Development and application of electrostatic dust removing technology [J]. High Voltage Technology, 2017, 43(02): 476-486.

[17] Wang Shilong, Chen Ying, Han Ping, Zhang Guoqing, Zheng Qinzhen, Shen Xinjun, Li Shuran, Yan Keping. Emission control of PM 10 and PM 2.5 for electric dust removal in coal-fired power plants I: Selection of electric dust removal and industrial application [J]. Science and Technology Review. 2014.