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# Synergistic Humidification and Chemical Agglomeration to Improve Capturing the Fine Particulate Matter by Electrostatic Precipitator

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**Abstract:** The wet electrostatic precipitator (WESP) overcomes the shortcomings of traditional electrostatic precipitators, such as dust re-entrainment and back corona. It can effectively remove high-specific-resistivity dust, with a good removal effect on $PM_{2.5}$. It is proposed to adopt chemical agglomeration and humidification agglomeration technology in the wet electrostatic precipitators to achieve ultra-low dust emissions from coal-fired power plants. The results show that the addition of chemical agglomerates, surfactants, and water vapor all affect the dust diameter of coal-fired power plants. After adding sesbania gum (SG), the $D_{50}$ of dust particles increases from 28.29 μm to 48.22 μm. And the $D_{50}$ of dust particles is 36.46 μm when spraying 3.6 kg/h water vapor only. With the cooperation of chemical agglomeration agents and water vapor, the dust agglomeration effect and removal efficiency can be further improved. When 10 mg/L SG is synergistically combined with 2.9 kg/h water vapor, the $D_{50}$ is 64.75 μm, and the dust removal efficiency reaches 97.88%. On this basis, by adding 5 mg/L of Hexadecyltrimethylammonium bromide (CTAB), the $D_{50}$ is 83.06 μm, and the dust removal efficiency increases to 98.62%. The synergistic effect of chemical agglomeration and humidification agglomeration promotes the aggregation of dust from coal-fired power plants. It can improve the removal efficiency of WESP for fine particulate matter but has little impact on the operation of existing equipment. The synergistic effects of multiple agglomeration technologies are also the direction for future research on the removal efficiency of fine particulate matter.

**Keywords:** fine particles wet electrostatic precipitator; humidification coagulation; chemical coagulation; dust removal efficiency

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**Citation:** Chen, H.; Li, H.; Wang, S.; Han, Y.; Zhai, X.; Xiao, L. Synergistic Humidification and Chemical Agglomeration to Improve Capturing the Fine Particulate Matter by Electrostatic Precipitator. *Coatings* **2024**, *14*, 420. https://doi.org/10.3390/coatings14040420

Academic Editor: Maria Vittoria Diamanti

Received: 7 March 2024
Revised: 26 March 2024
Accepted: 28 March 2024
Published: 31 March 2024

## 1. Introduction

As the world's largest coal producer and consumer, China's primary energy and power generation fuel structure has long been dominated by coal. In 2022, China's coal industry achieved new economic and technological indicators, and the raw coal production of enterprises above the designated size reached 4.09 billion tons [1]. It is expected that the proportion of coal-fired power generation will still reach about 50% by 2030 [2,3]. Coal-fired power plants are one of the main sources of atmospheric pollutants. Coal can produce atmospheric pollutants such as smoke, sulfur dioxide, nitrogen oxides, and mercury compounds during combustion [4,5], of which $PM_{2.5}$ is an important factor in environmental problems such as low atmospheric visibility and haze weather. More research shows that air pollution caused by high concentrations of $PM_{2.5}$ is an important factor in inducing chronic respiratory and circulatory diseases [6–9]. Therefore, it is necessary to improve the fine particle removal efficiency of dust collectors to achieve the goal of controlling $PM_{2.5}$ emissions and reducing pollution. This study uses a wet electrostatic precipitation system as the experimental platform and adopts chemical agglomeration and humidification agglomeration technology to improve the collection efficiency of fine particles. It provides new ideas for agglomeration technology to remove fine particles.

Among the existing agglomeration technologies, chemical agglomeration has received widespread attention from researchers due to its advantages of simple operation, obvious effect on fine particles, and low energy consumption. It has broad development prospects. In 1999, Durham et al. [10] conducted a study on the removal efficiency of particulate matter affected by the chemical agglomeration injection into flue gas. After injecting a chemical agglomerant with a mass fraction of 0.05%, the removal efficiency of particulate matter by electrostatic precipitators increased from 73% to 83%. In 2001, Torben [11] conducted research on the mechanism of chemical agglomeration and tested the influence of various factors on the coalescence and growth of particulate matter during each agglomeration process. He found that fine particulate matter agglomerates under the simultaneous action of coalescence and shear forces. In 2003, Zhang J et al. [12] proposed using chemical agglomeration to improve the removal efficiency of dust removal equipment in power plants and cement plants. By spraying the agglomeration promoter solution into the flue gas at the front end of the dust removal device, the fine particles can be agglomerated, grown and captured by the dust collector. In 2007, Zhao Y et al. [13] studied the influence of factors such as flow rate and concentration of the agglomerant solution on the agglomeration effect. In 2008, Sarah et al. [14] found that aggregates with larger diameters have lower water content. As the gas flow rate increases, the aggregates will break. When the solution viscosity increases to a certain extent, the aggregates become more stable. In 2009, Dong Y et al. [15] found that adding chemical agglomeration promoters to a fluidized bed desulfurization tower can improve the removal efficiency of fine particles. Li H et al. [16,17] selected four polymer compounds to prepare agglomeration promoter solutions and analyzed the particle size before and after agglomeration by using a laser particle size analyzer. In 2012, the experimental results of Leiviskä et al. [18] showed that kaolin can significantly improve the agglomeration and sedimentation of particulate matter. In 2015, Balakin et al. [19] conducted multiphase flow agglomeration experiments and explored the mechanism and collision efficiency of liquid bridge agglomeration by using numerical simulation methods. In 2017, Guo et al. [20] added different chemical agglomeration agents and explored their agglomeration effects from the perspectives of solution concentration, temperature, pH, etc. In 2018, Sun et al. [21,22] compared the results of single turbulence agglomeration experiments with those of turbulence-coupled chemical agglomeration experiments and found that chemical agglomeration was more conducive to the agglomeration and removal of larger particles. In 2022, Zhou et al. [23] found through experiments that when styrene butadiene lotion (SBE) and Triton X-100 were added together, fine particles could be agglomerated into large particle agglomerates whose diameter is greater than 10 μm.

The above studies indicate that chemical agglomeration technology can effectively promote the coarsening of fine particles, which is beneficial for the capture and removal of fine particles. In practical industrial applications, the simultaneous action of humidification and chemical agglomeration in wet electrostatic precipitation is not implemented, and the addition of chemical agglomeration agents requires the installation of separate devices, which increases operating costs. Through the action of chemical agglomeration agents, whose long polymer chains with polar groups connect multiple fine particles in a “bridging” manner, they agglomerate fine particles into large-sized particles. Surfactants can enhance the wettability of solutions and reduce the surface tension of solutions. Spraying water vapor can change the humidity of flue gas, promote fine particles to become condensation nuclei and increase the collision probability between particles. This study combines humidification with chemical agglomeration without changing the structure of the electrostatic precipitator; it will form dust-laden droplets with fine particles as condensation nuclei to improve the adhesion of particles. This further improves the capture efficiency of fine particles and it provides a direction for ultra-clean emissions from coal-fired power plants.

## 2. Materials and Methods

### *2.1. Experimental Facility*

### 2.1.1. Wet Electrostatic Precipitation System

The wet electrostatic precipitation system required for this experiment is shown in Figure 1. The main components are the feeding system, low-voltage control system, high-voltage power supply system, fan system, and spray system. The gas flow of the electrostatic precipitator system is 10,000 $m^3/h$, and the size of the electrostatic precipitator (length × width × height) is 2.8 m × 1.4 m × 5.8 m. The inlet dust content in this experiment is 110 $mg/m^3$. While adding the dust into the screw feeder, it is stirred by a stirring blade, and the power supply frequency for the drive motor is changed by a variable frequency controller at the same time, enabling the dust to enter the removal system evenly at a given speed. The chemical agglomeration agent is added to a water tank with dimensions (length × width × height) of 1.5 m × 1.2 m × 1.2 m. One side of the water tank has a corresponding volume of water filling scale. During the experiment, the water volume in the tank was 1.5 $m^3$. The mass of chemical agglomeration agent added is determined according to the desired solution concentration. The water vapor generation device is used to humidify the flue gas. It consists of a pressure controller, pressure gauge, water tank, dial gauge, outlet valve, safety valve, inlet valve, drain valve, and exhaust pipe. During testing, record the dial gauge before and after the experiment, and calculate the spray rate of water vapor sprayed out.

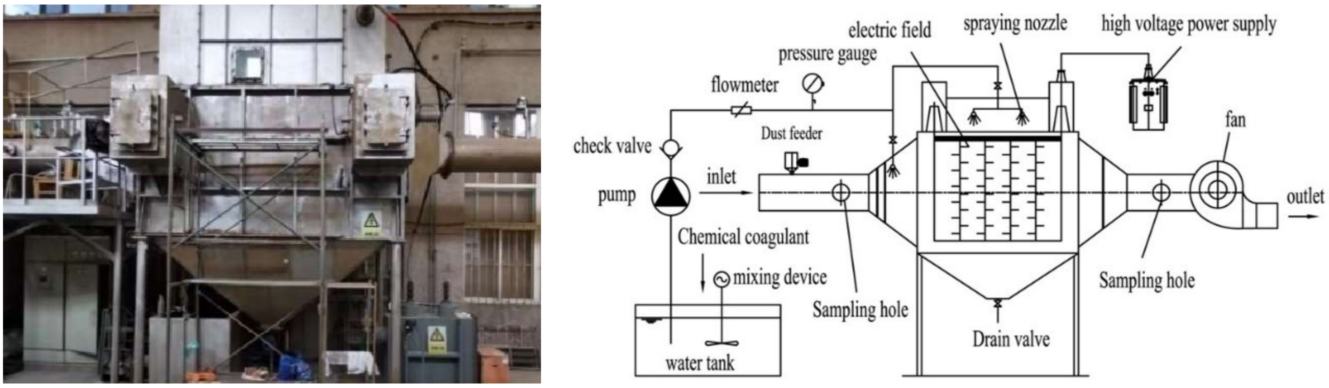


**Figure 1.** Wet electrostatic precipitator system.

### 2.1.2. Sampling System

This experiment uses the isokinetic sampling method to sample dust content, which has the advantages of high analytical accuracy, easy operation, and wide applicability. The sampling system mainly includes a sampling pipe, a regulating valve, a drying bottle, a vacuum pump, a buffer bottle, and a wet-type flowmeter. The filter cartridge is installed inside the sampling pipe and can be quickly disassembled. It is made of high-purity fiberglass, which has minor weightlessness when dried in an oven before and after the experiment. The total measurement error of the sampling system is less than 0.1 $mg/m^3$. The dust content sampling system is shown in Figure 2.

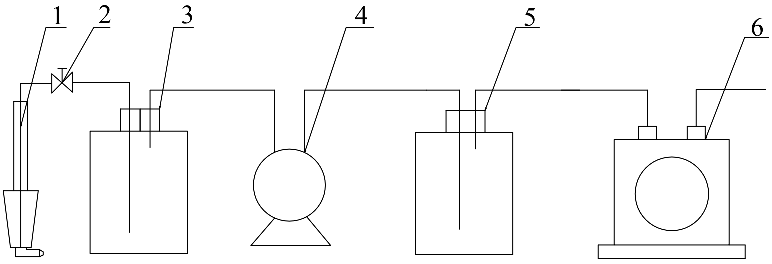


**Figure 2.** Sampling system: 1. Sampling pipe. 2. Regulating valve. 3. Drying bottle. 4. Vacuum pump. 5. Buffer bottle. 6. Wet type flowmeter.

#### 2.1.3. Measurement and Observation Technology

The device for determining the particle size distribution of dust is a BT-9300H laser particle size analyzer, which consists of a laser particle size analyzer and a circulating disperser, and is used to obtain the particle size distribution of the test sample. The scanning electron microscope model is S4800-II, which is produced by Japan for observing the morphology and elemental composition of dust from coal-fired power plants.

### *2.2. Experimental Materials*

The dust used in the experiment was from the dust collector ash hopper of the Qinhuangdao Chenlong coal-fired power plant. The shell pressure resistance of the wet electrostatic precipitator was 0.5 MPa, the operating voltage was 40 kV, the wind speed of the electric field was 1 m/s, the flue gas temperature was 18 °C~25 °C, and the relative humidity was 20%~50%. The chemical agglomeration agents and surfactants shown in Table 1 are used to improve collection efficiency under the additive effect of humidification.

**Table 1.** Experimental materials.

| Species | Name | Molecular Weight | Characteristics | Manufacturer |
|---|---|---|---|---|
| Chemical agglomerates | XTG (xanthan gum) | $1 \times 10^6$~$3 \times 10^6$ [24] | Natural polymer polysaccharides | Tianjin Guangfu Fine Chemical Research Institute, Tianjin, China |
| | SG (sesbania gum) | $2.3 \times 10^5$~$3.4 \times 10^5$ [25] | Natural polymer polysaccharides | Guangdong Xinrui Biotechnology Co., Ltd., China |
| | KGM (konjac glucomannan) | $5 \times 10^5$~$2 \times 10^6$ [26] | Natural polymer polysaccharides | Henan Wanbang Chemical Technology Co., Ltd., China |
| | PAM (Polyacrylamide) | $4 \times 10^6$~$1.5 \times 10^7$ [27] | Organic polymer flocculant | Tianjin Kemio Chemical Reagent Co., Ltd., Tianjin, China |
| | PFS (poly ferric sulfate) | 2000–5000 [28] | Inorganic polymer flocculent | Tianjin Kemio Chemical Reagent Co., Ltd., Tianjin, China |
| surfactant | SDBS (Sodium dodecylbenzene sulfonate) | 348.48 [29] | Anionic surfactants | Tianjin Kaitong Chemical Reagent Co., Ltd., Tianjin, China |
| | CTAB (Hexadecyltrimethylammonium bromide) | 364.45 [29] | Cationic Surfactant | Tianjin Huasheng Chemical Reagent Co., Ltd., Tianjin, China |
| | TX-100 (Octylphenyl polyoxyethylene ether) | 625 [30] | nonionic surfactant | Tianjin Guangfu Fine Chemical Research Institute, Tianjin, China |

## 3. Analysis and Discussion

### *3.1. Analysis of Coal Dust Particle Size*

$D_{10}$, $D_{50}$, and $D_{90}$ represent the volume average diameter of particles, whose cumulative frequency distribution is 10%, 50%, and 90%, respectively. The median diameter D50 is a typical value representing the size of the particle diameter. The particle size analysis diagram is shown in Figure 3. It was observed that the proportion of particles with a diameter less than 4.563 μm in the dust was 10%, the proportion of particles with a diameter less than 22.62 μm was 50%, and the proportion of particles with a diameter less than 66.88 μm was 90%. The particle size of dust in coal-fired power plants is small and has a wide distribution range, mainly distributed between 0.4 μm and 170 μm. Particles with a diameter of less than 2 μm account for 3.81%, and particles with a diameter of less than 10 μm account for 29.36%. These particles entering the atmosphere can cause harm to the environment and human health. Therefore, this study introduces chemical agglomeration and humidification agglomeration to increase the agglomeration efficiency of fine particles, thereby improving the removal efficiency of fine particles by electrostatic precipitators.

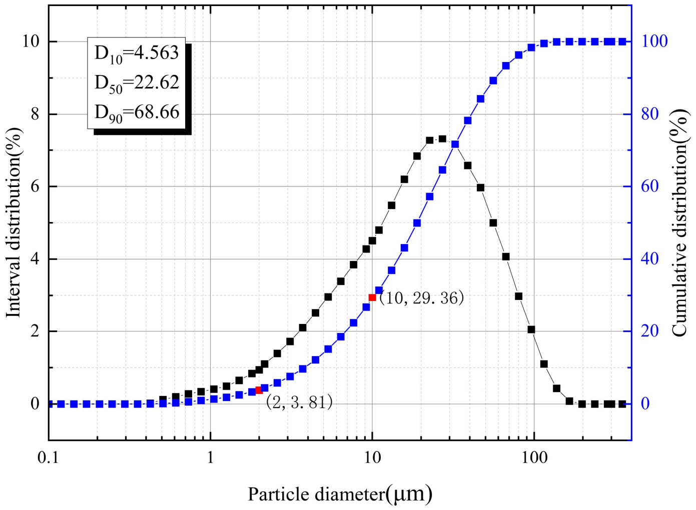


**Figure 3.** Particle size distribution of coal dust.

### *3.2. Morphological Analysis*

Figure 4a is a SEM image of the original coal-fired power plant dust. It can be seen that the coal-fired power plant dust particles do not have a fixed shape, and the dust particles are relatively dispersed, mostly irregular block particles with different sizes. As shown in Figure 4b, after the particles were collected by electrostatic precipitator when sprayed in the water vapor, some small-sized particles were adsorbed onto the large-sized dust particles, and loose-structured particle agglomerates began to appear. In Figure 4c, after adding SG to the electrostatic precipitator, the particles showed a significant clumping phenomenon and were more tightly bonded. In Figure 4d, after adding SG and CTAB while injecting water vapor into the electrostatic precipitator, the surface of large particle agglomerates is smoother than that of particles under the above two conditions, and the irregularly shaped dispersed small particles decrease.

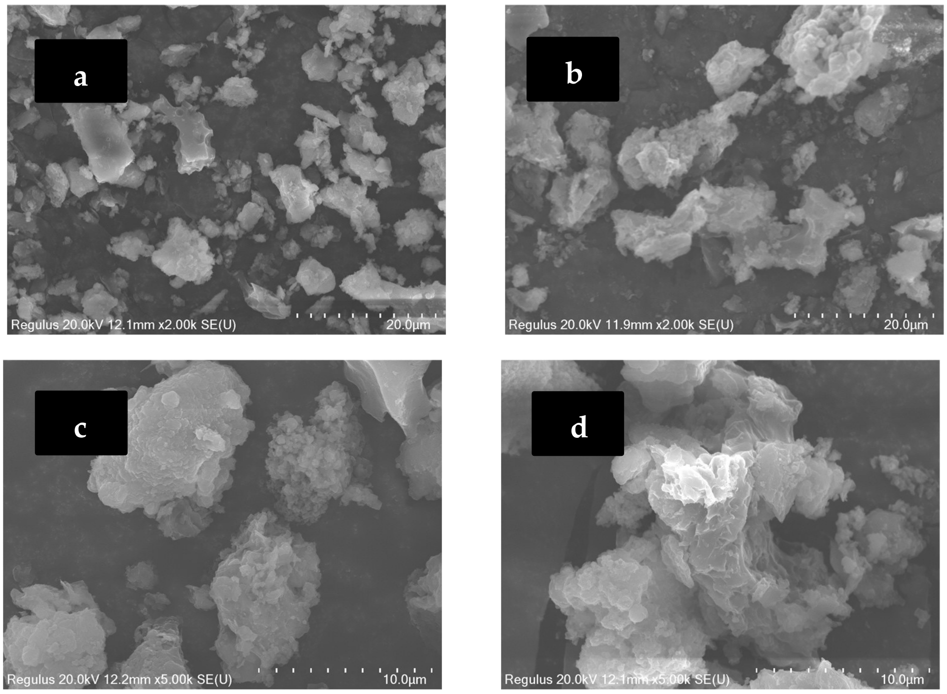


**Figure 4.** Microscopic morphology of dust. (**a**) Original dust. (**b**) Dust added with water vapor. (**c**) Dust added with SG. (**d**) Dust added with water vapor, SG, and CTAB.

### *3.3. Influence of Chemical Coagulation Agents on Dust Agglomeration*

#### 3.3.1. Influence of Chemical Coagulation Agents Types

It has different agglomeration effects on dust when changing the type of chemical coagulation agent. Five chemical coagulation agents were selected for the experiment: xanthan gum (XTG), sesbania gum (SG), konjac glucomannan (KGM), polyacrylamide (PAM), and polymeric ferric sulfate (PFS). The chemical coagulation agents were added to the circulating water tank to prepare an aggregating solution with a concentration of 10 mg/L. At this concentration, only about 21 g/h consumption of chemical agglomerant is needed to treat 10,000 $m^3$/h flow of flue gas, and the cost of the agglomerant is very low. The dust collected after the experiment was measured for its particle size distribution, and the results are shown in Figure 5. It can be seen that when SG is added, the $D_{10}$ is 12.73 μm and the $D_{50}$ is 48.22 μm, which is greater than that of other agglomeration agents. Compared to $D_{90,}$ the $D_{90}$ of KGM, PAM, and PFS are 106.3 μm, 98.15 μm, and 82.5 μm, respectively. The $D_{90}$ of XTG and SG are much larger than these three agglomerants, at 147.2 μm and 153.2 μm, respectively. The reason is that SG is a non-ionic polymer with a main chain and side chains composed of mannose and galactose. Due to the presence of a large number of hydroxyl groups in the molecule, it can form hydrogen bonds with ions in the system, resulting in good hydrophilicity. Compared to XTG and KGM, both of which are also natural polymeric polysaccharides, SG has better solubility in cold water. After dissolution, the polar groups of the large molecular chains are relatively evenly distributed in the agglomerated droplets. They further form the high-viscous network structure, which greatly increases the probability of fine particles being trapped by the agglomerated droplets. PAM is an organic polymeric flocculant whose functional groups on the carbon chain adsorb onto the surface of fine particles to form flocs, which achieve particle aggregation through the interconnection between flocs. PFS is an inorganic polymeric flocculant, and there are polynuclear hydroxyl complexes in the dissolved solution. These complexes can adsorb and neutralize the electric charges of colloidal particles; they play a certain role in agglomeration. However, the agglomeration effect of PAM and PFS is significantly inferior to that of the adsorption-bridging effect of the polymer chain on fine particles.

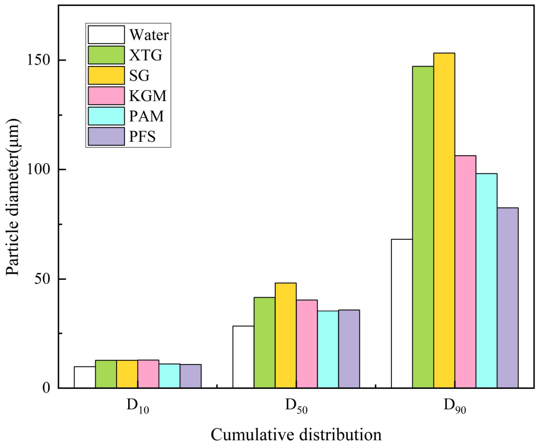


**Figure 5.** Histogram of particle size cumulative distribution of chemical coagulation agent types.

### 3.3.2. Influence of Surfactant Types

Surfactants have wettability and permeability and can significantly reduce the surface tension of water. To investigate the agglomeration effect of surfactants on coal-fired power plant dust, this experiment selected three surfactants, namely sodium dodecylbenzene sulfonate (SDBS), cetyltrimethylammonium bromide (CTAB), and Triton X-100 (TX-100), and added them to the circulating water tank at a concentration of 5 mg/L. The results are shown in Figure 6. The agglomeration effect after adding TX-100 is very small; the dust particle size of $D_{10}$ is 9.899 μm, $D_{50}$ is 28.92 μm, and $D_{90}$ is 69.69 μm. After adding CTAB, the $D_{10}$ is 12.12 μm, the $D_{50}$ is 34.19 μm, and the $D_{90}$ is 82.29 μm. After adding SDBS, the $D_{10}$ is 11.65 μm, the $D_{50}$ is 32.72 μm, and the $D_{90}$ is 78.23 μm. Among them, CTAB has the largest median diameter and the best agglomeration effect. This is because surfactants can reduce the surface tension of water due to their wetting effect [31–33] and can also reduce the surface free energy of wet dust particles. In addition, the fly ash from the coal-fired power plant used in the experiment carries a negative charge, while CTAB is a cationic surfactant. The positively charged groups that dissociate from it can neutralize the surface charge of particles, reduce the potential at the interface of the adsorption layer and diffusion layer, thereby reducing the repulsive energy and zeta potential between dust particles, enable the particles to reach a destabilized state and promote their agglomeration [34]. On the contrary, there are a large number of anions in SDBS solution, which leads to energy barriers between particles and is not conducive to the formation of agglomerates. As a nonionic surfactant, TX-100 has less effect on the stability of particles, so its agglomeration effect is better than SDBS.

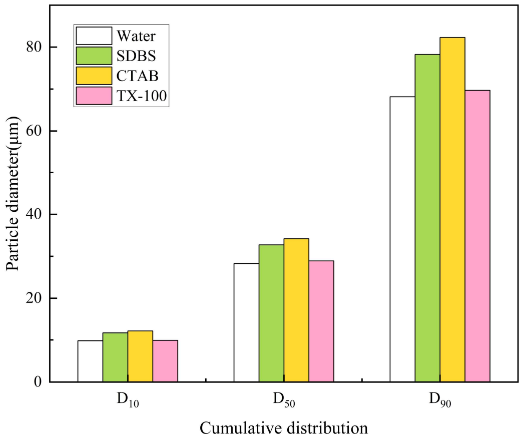
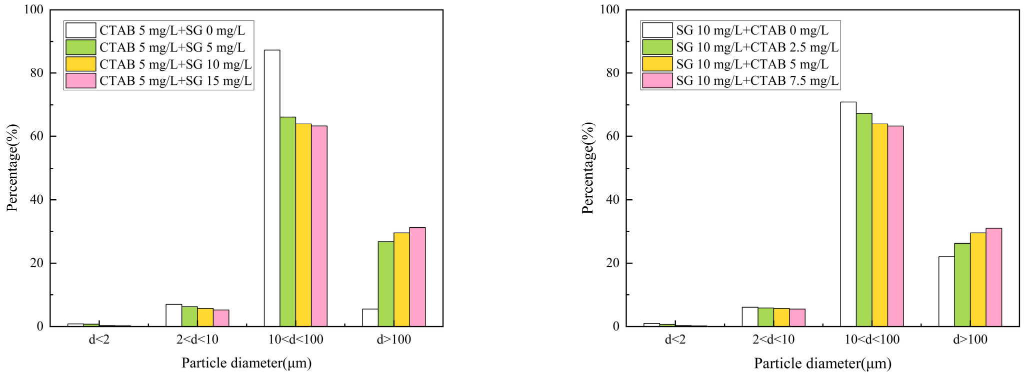


**Figure 6.** Histogram of particle size cumulative distribution of surfactant types.

### 3.3.3. Additive Effect of Chemical Coagulation Agent and Surfactants

Although surfactants can agglomerate dust, the effect is not obvious. Therefore, the additive effects of surfactants and chemical coagulation agents are explored. The chemical coagulation agents SG and surfactant CTAB were selected in the synergetic coagulation experiment based on the above results. Experiments were conducted by varying the concentrations of SG and CTAB, with SG concentrations being 0 mg/L, 5 mg/L, 10 mg/L, and 15 mg/L, and CTAB concentrations being 0 mg/L, 2.5 mg/L, 5 mg/L, and 7.5 mg/L. The results are shown in Figure 7. It can be seen that the additive coacervation effects of SG and CTAB are significantly enhanced compared to the addition of each substance alone. When SG and CTAB are added simultaneously, the content of fine particles is lower than when they are added separately. When CTAB is added alone, there are still fine particles with a particle size of less than 1 μm and a content of 0.2%. After adding SG, fine particles below 1 μm are removed. When the additional concentration of SG is 15 mg/L and the content of particles below 2 μm is the lowest. The reason is that dust and agglomerant droplets in flue gas collide with each other in the electric field. Liquid bridges are formed between the particles, and the aggregates gradually reach a critical state. Subsequently, the pores between the particles are filled, forming new agglomerated particles. With the continuous action of the agglomeration liquid, the large particles repeat this process. Therefore, the fine particles form large particle agglomerates under the action of chemical agglomeration agents, and the capture effect on fine particles is better as the concentration of SG increases to 15 mg/L. The content of particles above 100 μm is the highest, accounting for 31.32%. In addition, CTAB is a cationic surfactant with more polarizable counterions. When agglomerated droplets collide with negatively charged dust particles, they can bind to the dust particles to a greater extent [35], resulting in relatively less entropy loss during the agglomeration process of particulate matter, which is more conducive to the adsorption of particulate matter.



(**a**) Change the concentration of SG (**b**) Change the concentration of SG

**Figure 7.** Histogram of particle size interval content of surfactant and chemical coagulation agent.

## *3.4. Influence of Humidification on Dust Agglomeration Performance*

### 3.4.1. Influence of Water Vapor Humidification

As the steam phase transition can promote fine particle condensation and growth, water vapor was introduced to humidify the flue gas and investigate its effect on the agglomeration of dust from coal-fired power plants. Change the spray rate of water vapor at 0 kg/h, 1.5 kg/h, 2.2 kg/h, 2.9 kg/h, and 3.6 kg/h at the ESP inlet, as shown in Figure 8. When the water vapor spray rate is 0 kg/h, the proportion of particles with a diameter less than 1 μm is 0.25%, and the proportion of particles with a diameter greater than 100 μm is 2.65%. As the spray rate increases, the content of particles with a diameter less than 1 μm gradually decreases. When the spray rate increases to 3.6 kg/h, the content of particles with diameter less than 1 μm will decrease to zero. and the content of particles with diameter greater than 100 μm will be the highest, accounting for 10.63%. The reasons for this are analyzed as follows: on the one hand, due to the injection of water vapor, the water mist condenses on the surface of dust particles, enhancing the adhesion of fine particles. With the Brownian motion of particles, the fine particles wrapped in water mist and small droplets adhere to larger particles together, increasing the size of dust-containing droplets. On the other hand, under the action of water vapor, the humidity of flue gas increases, reducing the inception voltage and increasing the ionization coefficient, thus promoting the improvement of corona discharge performance and facilitating particle collision and agglomeration. However, due to the limitation of particle concentration, when the injection of water vapor increases to 3.6 kg/h, the number of droplet embryos cannot continue to increase, thus limiting the agglomeration effect.

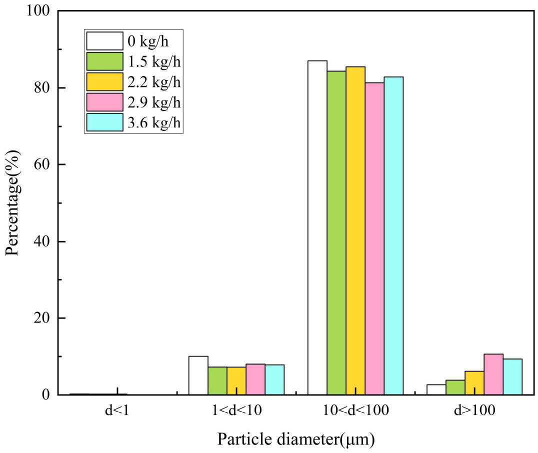


**Figure 8.** Histogram of particle size interval content of water vapor content.

### 3.4.2. Additive Effect of Water Vapor and Chemical Coagulation Agent

Adding water vapor and SG simultaneously to investigate the additive effect on the dust agglomeration. The concentration of SG was 10 mg/L, and the spray rate of water vapor was varied sequentially. The results are shown in Figure 9. Under the additive effect of SG and water vapor, fine particles below 1 μm have been removed, but fine particles below 2 μm still exist. When SG and 2.9 k/h water vapor are additively applied, the proportion of fine particles below 2 μm is 0.21%. When only SG is added, particles with a diameter of 2 μm–10 μm account for 6.09%, and particles with a diameter greater than 100 μm account for 22.34%. Under the additive action of 2.9 kg/h Water Vapor and SG, the proportion of particles with a diameter of 2 μm–10 μm decreases to 3.87%, and the proportion of particles with a diameter greater than 100 μm increases to 31.52%. Due to the effective thickening of fine particles under the action of the polymer chain of the agglomeration agent, and the addition of water vapor at the same time, based on the heterogeneous nucleation theory proposed by Fletcher [36], when the particle size increases, the supersaturation of water vapor can be reduced to achieve nucleation conditions, which is more conducive to stimulating nucleation. Therefore, the agglomeration effect under the additive action of water vapor and SG is better. Due to the condensation of water vapor on the surface of particulate matter into small droplets, when spraying 3.6 kg/h of water vapor, there are too many droplets attached to the surface of dust particles, which reduces the binding force of dust, causing the dust to break up again under the action of airflow, and the agglomeration performance no longer improves.

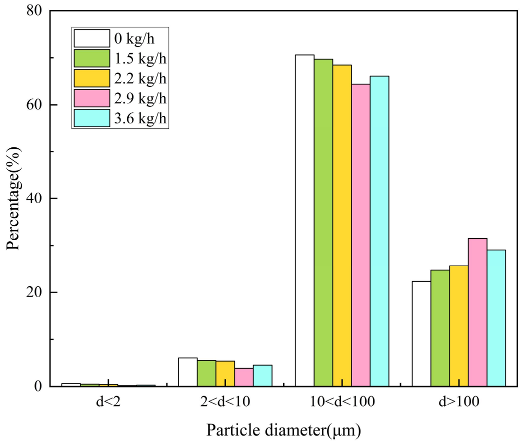


**Figure 9.** Histogram of particle size interval content of water vapor synergy chemical coagulation agent.

### 3.4.3. Water Vapor, Chemical Coagulant and Surfactant on the Coagulation Process

Adding water vapor and SG and CTAB simultaneously to investigate the additive effect on dust agglomeration. The concentrations of SG and CTAB were 10 mg/L and 5 mg/L, respectively. The spray rate of water vapor was varied in turn, and the results are shown in Figure 10. When only SG and CTAB are added, the proportion of fine particles below 2 μm is 0.3%. After spraying water vapor, the proportion of particles below 2 μm began to decrease, reaching a minimum of 0.03% when the spray rate increased to 2.9 kg/h. Compared with agglomerated particles above 100 μm, the proportion is 29.6% when only SG and CTAB are added, and it reaches 40.43% after 2.9 kg/h of water vapor is sprayed. This indicates that the addition of water vapor can effectively reduce the content of fine particles. This is because the Brownian motion of small-sized particles is more pronounced, so fine particles can come into contact and collide with other particles more quickly, forming dust-containing droplets under the action of water vapor. At the same time, the wetting effect of SG and CTAB enhances the hydrophilicity of dust. Under the action of liquid bridging force, fine particles are more easily adsorbed on large particles and aggregate, enhancing the agglomeration effect between particles.

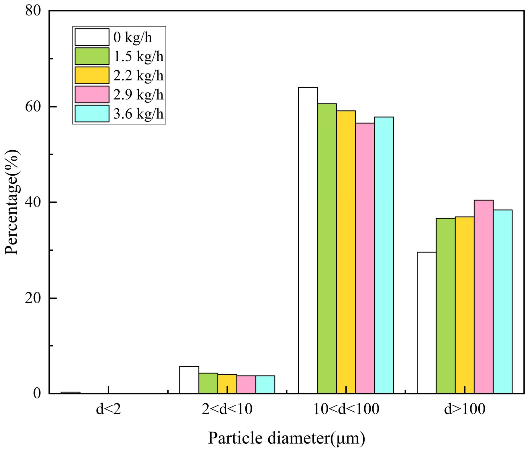


**Figure 10.** Histogram of particle size interval content of water vapor additive chemical coagulation agent and surfactant.

### *3.5. The Influence of Humidifying Chemical Coagulation Agent on Dust Removal Efficiency*

In order to explore the impact of humidifying chemical agglomeration on the coal dust removal performance of WESP, the dust content at the inlet and outlet under different operating conditions was tested, and the dust removal efficiency was calculated.

#### 3.5.1. Influence of Chemical Coagulation Agent on Dust Removal Efficiency

The types of chemical agglomeration agents vary, and the dust removal efficiency also varies. When the concentration of the chemical agglomeration agent was 10 mg/L, the dust content at the inlet and outlet was measured in order to calculate the dust removal efficiency. The results are shown in Figure 11. It can be seen that the removal efficiency of WESP for coal dust without any agglomeration agent is 92.8%, and the addition of five types of chemical agglomeration agents can all improve the dust removal efficiency. The dust removal efficiency after adding SG was the highest; it was about 96.57%. The dust removal efficiency of the other four coagulants is ranked from high to low as XTG, KGM, PAM, PFS. This is consistent with the coagulation effect of various coagulants on particulate matter, once again demonstrating that the addition of SG can effectively reduce the content of fine particulate matter. The reason behind this is that chemical agglomerants cause fine particles to aggregate into large clusters, and the driving speed of dust increases with the increase in particle size, making it easier for dust particles to be captured by WESP, thereby improving dust removal efficiency.

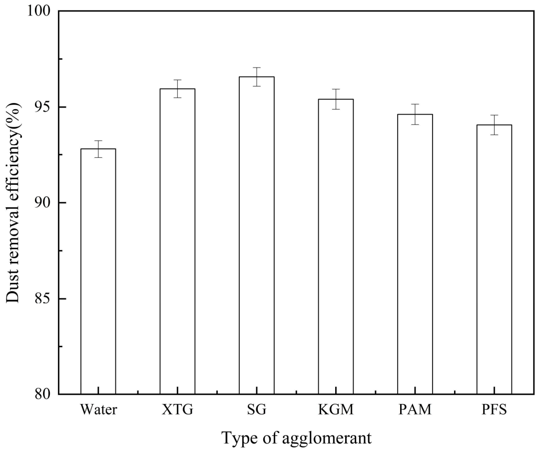


**Figure 11.** Dust removal efficiency of different types of chemical coagulation agent.

#### 3.5.2. Influence of the Additive Effect of Water Vapor and Chemical Coagulant

SG was selected as the agglomeration agent, and the SG solution concentration was 10 mg/L. The Spray rate of water vapor was changed to 0 kg/h, 1.5 kg/h, 2.2 kg/h, 2.9 kg/h, and 3.6 kg/h. The dust content at the inlet and outlet was measured, and the dust removal efficiency was calculated, as shown in Figure 12. It can be seen that after adding water vapor, the dust removal efficiency increases. When the spray rate of water vapor is 2.9 kg/h, the dust removal efficiency reaches the highest level of 97.88%. After the spraying rate of water vapor increases to 3.6 kg/h, the dust removal efficiency will decrease. This is because fine particles have small inertia and obvious Brownian motion, and the amount of condensed water vapor on the surface area of individual particles rapidly increases, forming droplet embryos. However, the dust content at the inlet is fixed, and the limited droplet embryos adsorb a large number of water molecules, gradually reaching equilibrium. Therefore, when the water vapor content reaches a certain value, the dust removal efficiency no longer increases, which is consistent with the content of the particle size range mentioned in Section 3.4.2.

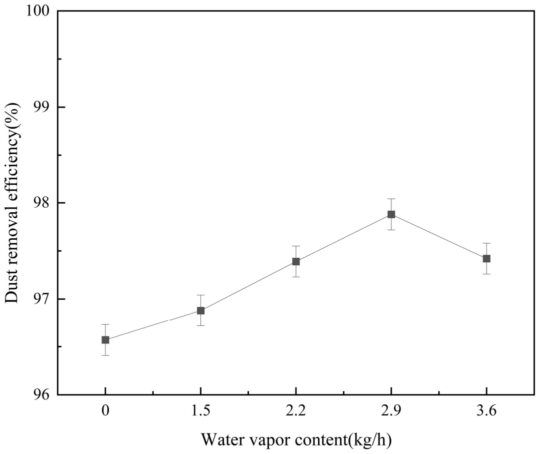


**Figure 12.** Dust removal efficiency of water vapor and SG additive effect.

#### 3.5.3. Influence of Water Vapor, Chemical Coagulant and Surfactant on the Coagulation Process

The concentration of the reunion agent SG was 10 mg/L, and the concentration of the surfactant CTAB was 5 mg/L. The spray rate of water vapor was changed to 0 kg/h, 1.5 kg/h, 2.2 kg/h, 2.9 kg/h, and 3.6 kg/h. The dust content at the inlet and outlet of WESP was measured, and the dust removal efficiency was calculated. The results are shown in Figure 13. It can be seen that the addition of CTAB increases the removal efficiency of WESP for fine particulate matter. When the spray rate of water vapor is 2.9 kg/h, the dust removal efficiency is the highest; it is approximately 98.62%. The reason is that while adding CTAB to promote chemical agglomeration, a large amount of cations are dissociated from the solution, increasing the number of ions between the two poles, which enhances the corona discharge performance. Combining these factors, the addition of CTAB in conjunction with water vapor and SG further improves the dust removal efficiency.

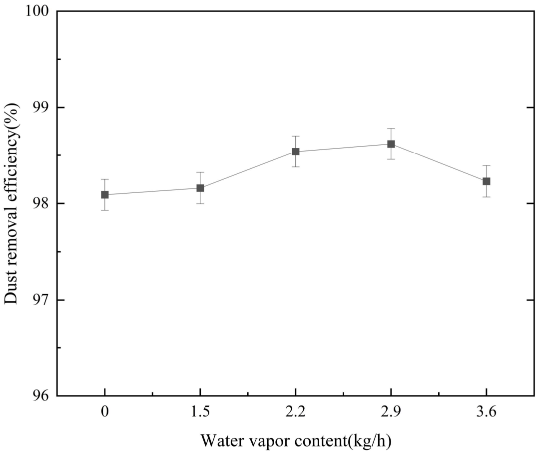


**Figure 13.** Dust removal efficiency of water vapor, SG, and CTAB additive effect.

## 4. Conclusions

This study conducted humidification chemical agglomeration experiments and dust removal efficiency experiments to determine the impact of humidification chemical agglomeration on the dust removal efficiency of coal-fired power plants in WESP. It draws the following conclusions:

1. Adding agglomeration agents can promote the coagulation of dust from coal-fired power plants. Among the five chemical agglomeration agents, SG has the best effect

on dust coagulation. When the concentration of SG is 10 mg/L, the dust removal efficiency is 96.57%.

2. Spraying water vapor can promote the coagulation of dust. When no water vapor is sprayed, the content of particles with a diameter less than 1 μm is 0.25%, and the content of particles with a diameter greater than 100 μm is 2.65%. When the spray rate of water vapor is 3.6 kg/h, the fine particles below 1 μm are removed, and the content of particles with a diameter greater than 100 μm increases to 10.63%.
3. The additive effects of water vapor, chemical coagulant agents, and surfactants can significantly enhance the agglomeration effect. When 2.9 kg/h of water vapor is combined with 10 mg/L of SG and 5 mg/L of CTAB, the content of particles with a diameter over 100 μm is 40.43%, and the dust removal efficiency reaches 98.62%.

In summary, the use of humidified chemical agglomeration in WESP can effectively promote the coarsening of dust particles in coal-fired power plants and improve the removal efficiency of fine particles by WESP.

**Author Contributions:** Conceptualization, H.C. and L.X.; Data curation, S.W.; Formal analysis, H.C.; Funding acquisition, L.X.; Investigation, H.L.; Methodology, L.X.; Project administration, L.X.; Resources, Y.H.; Software, S.W. and X.Z.; Supervision, X.Z.; Writing—original draft, H.C. and H.L.; Writing—review and editing, Y.H. and L.X. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was supported by the Natural Science Foundation of Hebei province, China (E2015203236), This research is supported by Qinhuangdao science and technology research and development program (202003B033).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Data are contained within the article.

**Acknowledgments:** The authors are grateful to Hebei Provincial Key Laboratory of Applied Chemistry for providing electron microscopic characterization. The authors thanks Zhu for his help with the experiment.

**Conflicts of Interest:** The authors declare no conflicts of interests.

## Nomenclature

| | |
|---|---|
| d | Particle diameter |
| $D_{10}$ | Diameter when the cumulative distribution of dust is 10% |
| $D_{50}$ | Diameter when the cumulative distribution of dust is 50% |
| $D_{90}$ | Diameter when the cumulative distribution of dust is 90% |
| $PM_{2.5}$ | Particulate matter with an aerodynamic diameter of less than or equal to 2.5 microns in the atmosphere |

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