

<sup>1</sup>\*Shanshan Tang<sup>2</sup>Mohd Danial Ibrahim<sup>3</sup>Andrew Ragai Henry Rigit<sup>4</sup>Wei Zhang<sup>5</sup>Chaokun Wei

# A Systematic Review of Dust Suppression Methods by Experiment Based on Intelligent Technology in the Coal Mines



**Abstract:** - The mining and its transportation processes generate a substantial quantity of dust, which harms miners' health. The extended inhalation of dust particles could result in pneumoconiosis. There are numerous studies on coal mine dust removal, but only a handful of articles critically comment on it. A systematic coal mine dedusting literature review has been conducted to attempt a comprehensive and reproducible analysis. This article reviews dust suppression methods by experiment in coal mines from three aspects: chemical modification of dust removers, structural improvement of dust removers, and other factors. The review showed that independent experimental research suits dust remover's structural improvement and chemical modification. Compared to non-phytochemical modifications, phytochemical modifications are more efficient and environmentally friendly. The development of dust remover structures concentrates primarily on the nozzle structure, nozzle diameter, the number of holes, and the distance, with the nozzle diameter being of particular significance. Sometimes, tweaking the nozzle structure does not yield significant efficiency improvements. However, supersonic nozzles demonstrate high efficiency and are likely to be a key area of future research. Experiments also investigated other factors' effects on coal mines' dust removal efficacy, including ventilation system, metamorphic degree of coal, and particle diameter. This review provides the latest dust removal technology information for coal mines. Intelligent technology provides the basis for experimental research on dust removal in coal mines. The future trends of experimental research in the coal mine dust control field include intelligent and automated dust control systems, comprehensive control of multiple pollutants, application of new materials and technologies, and interdisciplinary collaboration and cross-disciplinary research.

**Keywords:** Coal mine, Intelligent technology, Experiment, Chemical modification, Structural improvement

## I. INTRODUCTION

Coal mine dust is generated during coal mining and processing. According to statistics, coal mine dust is one of the leading causes of coal mine fires and explosions, resulting in many casualties and property losses. Furthermore, miners exposed to coal mine dust for long periods are at high risk of occupational lung diseases such as coal workers' pneumoconiosis. Coal mine dust control is a critical environmental management task. With the continuous improvement in environmental protection and occupational health requirements, coal mining companies and research institutions are dedicated to conducting experimental research to seek efficient and feasible coal mine dust control technologies. For example, the internal and external spray used for coal dust is illustrated in Figure 1 [1].

Experimental coal mine dust removal research is conducted in a laboratory environment that can effectively simulate a natural coal mine dust removal system. It entails constructing an experimental system and setting experimental parameters to study the principle of coal mine dust removal technology, its efficiency, the scope of application, and the impact of various factors. In the experimental research of coal mine dust removal, a system consisting of dust removal equipment, a fan, a particulate generator, a sampler, a laser particle size analyzer, etc., is typically established. Controlling experimental parameters, such as airflow velocity, liquid velocity, airflow flow, and liquid flow, enables experimental operation, data collection, and analysis. During the experiment, relevant parameters, such as atomizing cone angle, particle concentration, and particle size distribution, can be measured to evaluate and optimize the performance and effectiveness of various coal mine dust removal equipment.

The advantages of experimental research in coal mine dust removal include systematic study, precision and controllability, safety, flexibility, and economy. Experimental study can systematically study and evaluate dust

<sup>1</sup> Faculty of Engineering, Anhui Sanlian University, Hefei 230601, China; Faculty of Engineering, University of Malaysia Sarawak, Kota Samarahan Sarawak 94300, Malaysia

<sup>2</sup> Faculty of Engineering, University of Malaysia Sarawak, Kota Samarahan Sarawak 94300, Malaysia

<sup>3</sup> Faculty of Engineering, University of Malaysia Sarawak, Kota Samarahan Sarawak 94300, Malaysia

<sup>4</sup> Dongguan Mistec Spraying Technology Co., Ltd, Dongguan 523000, China

<sup>5</sup> Chery Automobile Corporation, Wuhu 241007, China

\*Corresponding author: Shanshan Tang

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removal technology; a variety of factors can be precisely controlled in the laboratory environment; dust removal experiments in coal mines can be carried out in a safe laboratory environment, which avoids the risks that may be caused by testing in actual coal mine workplaces; laboratory research can compare and evaluate different dust removal technologies as needed; the coal mine dust removal experiment is cheaper than the actual coal mine test. Laboratory research can use equipment and materials on a smaller scale, saving a lot of resources and costs.



Figure 1: Internal and external spray used to coal dust [1]

Intelligent technology provides the basis for experimental research of dust removal in coal mines. It is mainly reflected in sensor technology and data analysis and fault prediction. A variety of sensors are used to monitor information such as dust concentration, temperature, humidity, and gas concentration; Artificial intelligence and machine learning techniques are used to analyze and process the collected data. For example, Chaulya et al. did dust control study for a developed smart dry fog system [2].

## II. METHODOLOGY

A systematic coal mine dedusting literature review has been conducted to attempt a comprehensive and reproducible analysis. The included works are from 2014 to the present. The dust control device for coal mines consists of dust remover and ventilation systems. Figure 2 summarizes improvements in dust removal technology gleaned from an extensive literature review. Dust remover enhancements primarily involve optimizing the dust collector's structure, operating conditions, and chemical modification. There are numerous articles on the chemical modification method of coal mine dust removers, but very few on ventilation and operating environment. This paper focuses on the chemical modification of a coal mine dust remover to improve its effectiveness. An analysis of existing dust removal methods based on the experiment is shown in Figure 3.

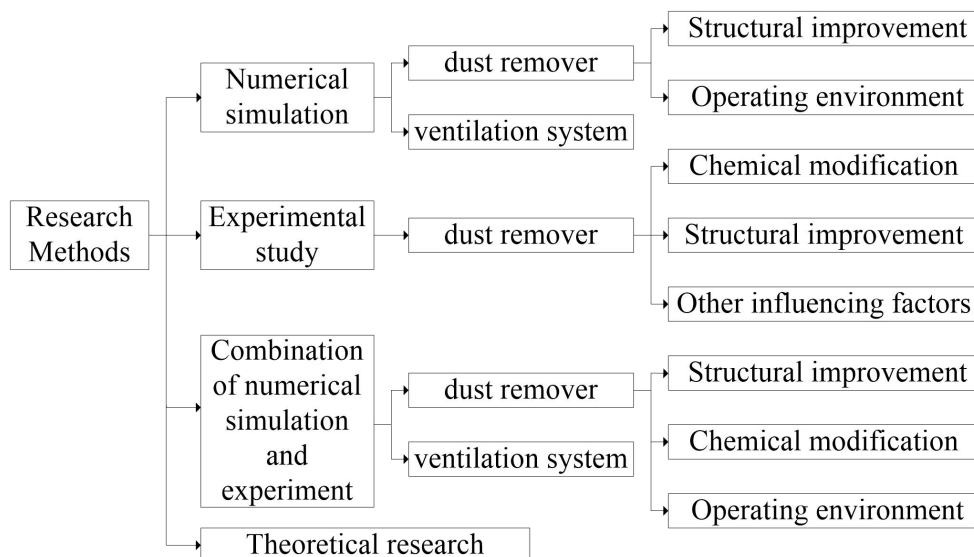


Figure 2: A summary of the improvement of dust removal technology

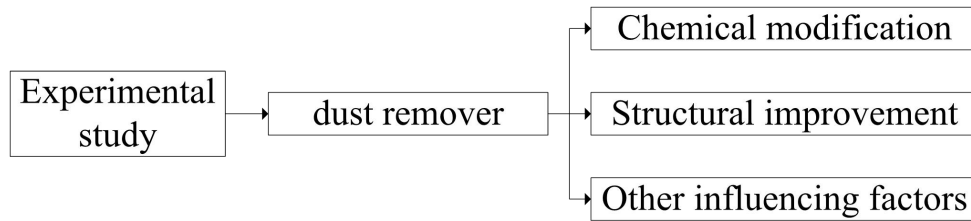


Figure 3: An Analysis of Existing Dust Removal Methods Based on Experiment

### III. EXPERIMENT TO IMPROVE THE EFFICIENCY OF DUST REMOVER

#### A. Improvement of Chemical Modification of Dust Remover by Experiment

In coal mine dust removal, chemical modification dust removal is usually done by adding specific chemical substances to dust to change dust properties and behaviors and improve the dust removal effect. Typical techniques include humidification, adhesive addition, surface modification, and chemical reaction. Since chemical modification involves complex reactions, reactor design, and chemical reagent selection, experimental studies are required to optimize this technology. Chemical modification mainly includes two aspects, phytochemical modification and non-phytochemical modification.

##### 1) Non-phytochemical modification of dust remover by experiment

Non-phytochemical modification of dust remover in coal mines refers to using chemical reagents, chemical reactions, or chemical processes to enhance the efficiency of dust removal systems without using plants. Standard techniques include the application of binders, wetting agents, dust suppressants, and surfactants, among others. A summary of the papers on non-phytochemical modification of dust remover by experiment is listed in Table 1.

Foam dust control is a method of non-phytochemical modification. It involves using specific foaming agents to form a layer of foam that reduces coal dust dispersion and diffusion through adhesion, aggregation, and coverage. In particular, the surfactants in the foaming agent interact with the surface of coal dust particles, saturating and adhering them together.

Xi et al. proposed an investigation into foam-sol-based coal dust control and designed a novel foam-sol generating system with a conical diffuser outlet. The research indicates that foam-sol could significantly enhance the effectiveness of particulate control [3]. In a similar fashion, Lu et al. created a new foaming device by integrating the foaming agent adding device and foam generator and evaluated its performance under varying water pressure, air pressure, water flow, and compressed air pressure. The effectiveness of foam dust suppression could attain between 87.1% and 88.8% [4]. Simultaneously, Ren et al. explored a new technique for controlling suspended dust using foam and analyzed the structure and stability of foam under the influence of dust [5].

Foam dust control provides benefits such as effective dust reduction, extensive coverage, and simple operation. However, it is associated with increased costs, decreased visibility, and environmental impact. Numerous researchers concentrate on wetting agents. For coal mine dust control, wetting agents enhance the coal dust's wetting and adhesion properties. In the dust control system, they enhance the contact between particles and water droplets, fostering the accumulation of particles into larger clusters in a wet environment, which makes their capturing and removal easier.

Wang et al. added ionic liquids to the mixture in order to generate a series of wetting agent compounds and created the high-pressure spray system. The dust removal efficiency reached 90%, while the respiratory dust efficiency reached 87% [6]. In addition to wetting agents, dust suppressant is commonly used. Dust suppressants can enhance the adhesion and cohesion between coal dust particles, causing them to create larger clumps. Yan et al. synthesized a modified polymer dust suppressant. A spraying test was conducted to evaluate the efficacy of the dust suppressant. The comparison among membrane surface morphologies before and after spraying with different agents is shown in Figure 4. The experimental results demonstrated that the eco-friendly dust suppressant possessed excellent water retention, viscosity, and wettability and could accomplish satisfactory dust bonding and settlement performance. The newly developed dust suppressant was also eco-friendly and economically beneficial [7].

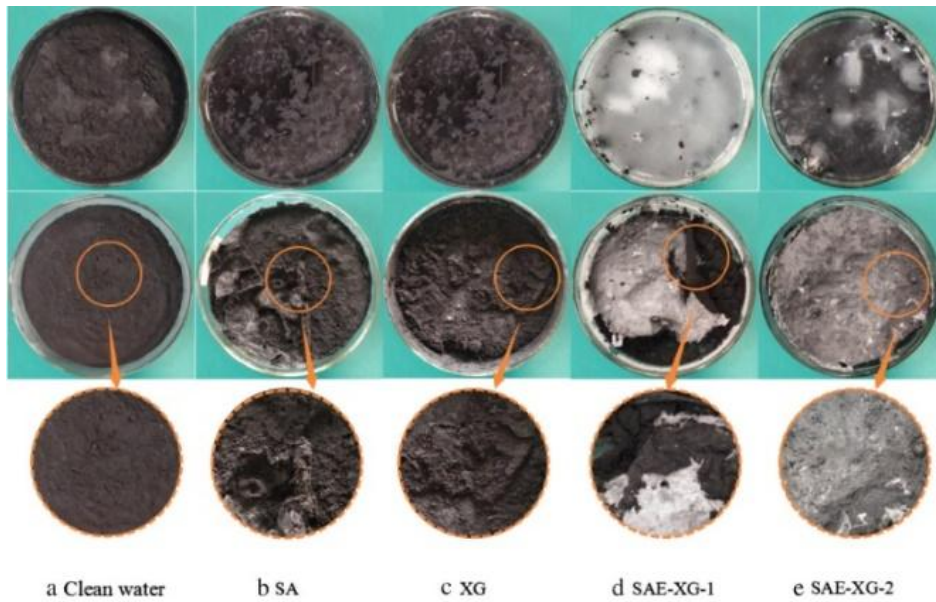


Figure 4: Comparison Among Membrane Surface Morphologies Before and after Spraying with Different Agents [7]

Moreover, surfactant was studied to enhance coal dust's wettability and suppression efficiency. Surfactants are a class of chemicals that reduce the surface tension of liquids and improve the interaction between liquids and solids or liquids. They are commonly used as components of wetting agents and dust suppressants. Wang et al. conducted experiments on four surfactant solutions, which were sodium dodecyl sulfate (SDS), Sodium dodecyl benzene sulfonate (SDBS), Sorbitan monooleate polyoxyethylene ether (Tween-80), and Alkylphenol ethoxylate (OP-10) [8]. By examining surfactants' surface tension, wettability, and contact angle, Jiang et al. discovered Alkylphenol ethoxylate (OP-10) had the most excellent performance [9]. To further improve the wettability of surfactants, Wang et al. performed a series of experiments to determine the effect of four inorganic salt additives on the wettability of OP-10 solution. The experiment demonstrated that inorganic salt could improve the wettability of surfactant and increase the spraying's dust reduction efficacy. When inorganic salt additives were added to the OP-10 solution, the effectiveness of removing respirable dust increased more than that of total dust [10].

Recently, Bai et al. discovered a composite of ionic surfactants with ultra-high surface activity and opposite charges. Findings indicated that ionic surfactants with oppositely charged compounds enhanced wettability, making them promising dust suppressants [11].

As illustrated in Figure 5, there are four common non-phytochemical modification methods for dust removers, namely foam, wetting agents, dust suppressants, and surfactants. Figure 5 enumerates their respective advantages and disadvantages.

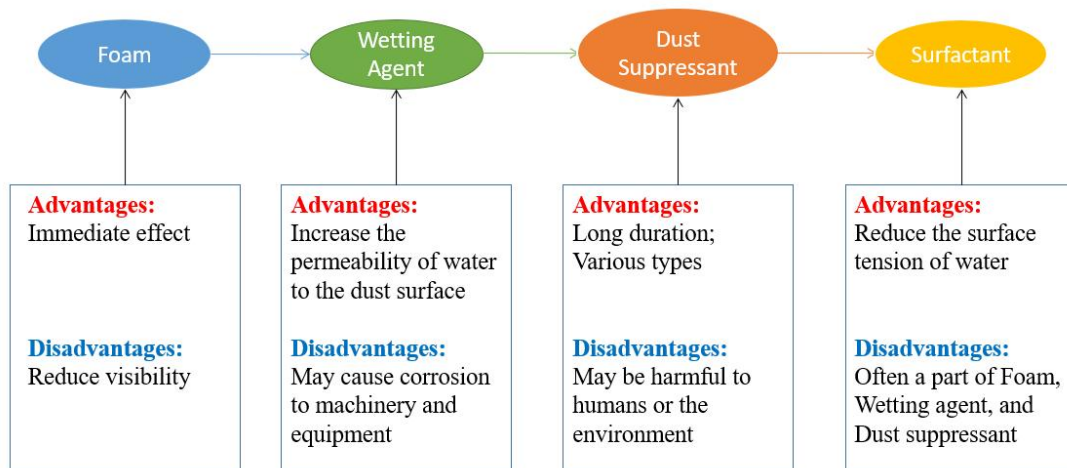


Figure 5: Common Non-Phytochemical Modification Methods for Dust Removers

In conclusion, non-phytochemical modification dust control methods can effectively control and reduce dust production and diffusion. During the application process, it is necessary to consider factors like the choice of

chemical reagents, dosage control, and operating conditions to ensure the stability and safety of the effects. However, non-phytochemical modification may have environmental consequences, such as causing soil and water pollution or harming surrounding ecosystems. Consequently, numerous researchers are investigating environmentally friendly phytochemical modification dust control methods.

Table 1: Summary of the Papers on Non-Phytochemical Modification of Dust Remover By Experiment

Author & Time	Materials	Object	Effects
Xi et al. [3]	Foam-sol	A new foam-sol generating system with a conical diffuser outlet	Excellent surface viscosity, strong cohesiveness, and less volatile property
Lu et al. [4]	Foaming agent adding device; Foam generator	A new design of foaming device	The foam dust suppression efficiency is 87.1%-88.3%; Use less water
Ren et al. [5]	Foam	A new technique to control suspended dust by making use of foam	Dust particles affect foam stability; Dry foam is more stable
Wang et al. [6]	Anionic, cationic, and non-ionic surfactants; The mixture	A complex wetting agent	When wetting agent E is added, the dust removal efficiency is 90%; Respiratory dust efficiency: 87%; A 30% reduction in water consumption
Yan et al. [7]	Sodium alginate (SA); Water-retaining agent CMS; SAE-XG-3	A modified polymer dust suppressant	Good water retention, viscosity, and wettability; Suitable dust bonding and settlement performance; Environmentally friendly
Wang et al. [8]	Sodium dodecyl sulfate (SDS); Sodium dodecyl benzene sulfonate (SDBS); Sorbitan monooleate polyoxyethylene ether (Tween-80); Alkylphenol ethoxylate (OP-10)	Surfactant solution	Promote the atomization effect; More conducive to respirable dust deposition; As the pressure increased, the ability of surfactants to enhance the efficiency of dust reduction through spraying decreased; The OP-10 solution has superior wettability and minimum contact angle
Wang et al. [10]	CaCl <sub>2</sub> ; Na <sub>2</sub> SO <sub>4</sub> ; Na <sub>2</sub> SiO <sub>3</sub> ; NaCl.	OP-10 solution	Improve the wetting performance of surfactants; CaCl <sub>2</sub> and Na <sub>2</sub> SO <sub>4</sub> have better wetting performance; CaCl <sub>2</sub> has better water retention performance; More conducive to respirable dust deposition
Jiang et al. [9]	Sodium dodecyl sulfate (SDS); Sodium dodecyl benzene sulfonate (SDBS); Sorbitan monooleate polyoxyethylene ether (Tween-80); Alkylphenol ethoxylate (OP-10)	Surfactant Solution	SDBS and OP-10 have higher efficiency in decreasing the surface tension; The wettability of the OP-10 solution is optimal; The higher the concentration of additives, the greater the moisture absorption of coal dust; As surfactant concentration increases, contact angle decreases, and wettability improves.
Bai et al. [11]	Sodium alpha olefin sulfonate; Octadecyltrimethylammonium chloride	A composite anionic-cationic (AC) surfactant with ultra-high surface activity	Enhanced wettability; Enhanced water retention and wind resistance



## 2) *Phytochemical Modification of Dust Remover by Experiment*

The method of phytochemical modification in coal mine dust removal refers to utilizing the chemical properties and biological activities of plants or plant extracts to enhance the efficacy and performance of coal mine dust removal systems. This modification method enhances the wettability, adhesion, or dust suppression effect of particulate matter by incorporating plant bioactive substances, such as extracts and plant fibers, thereby improving the efficacy of the dust removal system.

Typical applications and characteristics of phytochemical-modified dust removal include the following:

**Application of plant extracts:** Plant extracts are prepared and utilized in the dust removal system by extracting the plant's active constituents. Plant extracts can suppress dust, improve adhesion, and enhance wettability. Standard plant extracts include plant essential oil, polysaccharide, and extract; **Application of plant fiber:** The microstructure and absorption properties of plant fiber make it suitable for dust removal or filter material. For instance, plant fibers make filter paper, fabric, and filters.

The following are the characteristics and benefits of phytochemical modification of coal mine dust removal:

**Environmentally friendly:** Phytochemical modification is a relatively environmentally friendly technique that employs the chemical properties of plants to enhance dust removal and reduce pollution and environmental damage; **Renewable resources:** Phytochemical modification using plants as raw materials can fully use renewable resources; **Versatility:** The chemical compositions and biological activities of various plants or plant extracts vary. According to specific dedusting requirements, suitable plants or extracts can be selected to accomplish a variety of effects.

Phytochemical modification is frequently used in the production of dust suppressants. Guar gum, soybean, corn, sugarcane, microalgae, peanuts, and other plants are commonly utilized. Table 2 summarizes the papers on the phytochemical modification of dust remover by experiment. Through experiments, Zhang et al. developed a novel, environmentally benign dust suppressant using Guar gum [12]. The flow chart of the preparation process is shown in Figure 6. The new dust suppressant possessed good water retention, hardening, cementing, anti-compression, and degradability properties. The average dust removal rate exceeds 80% [13]. Likewise, Jin et al. took naturally biodegradable soybean protein isolate (SPI) as the primary raw material, prepared a novel environmentally friendly coal dust suppressant, and tested its performance at different concentrations [14]. The dust suppression has good cementation performance, and the dust suppression efficiency can reach more than 90% [15].

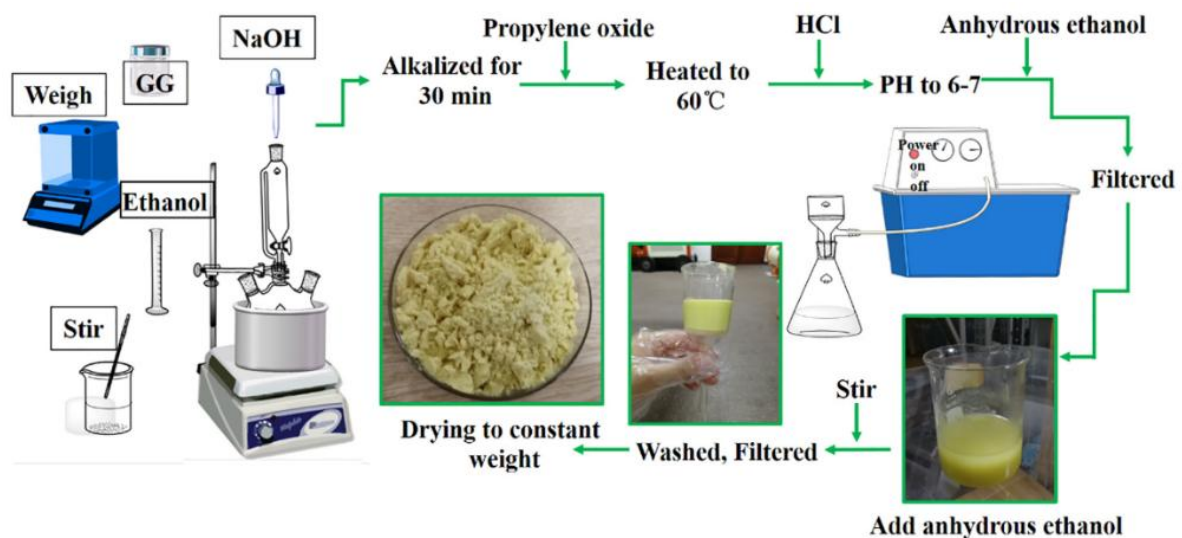


Figure 6: Flow Chart of the Preparation Process [13]

On the other hand, Bao et al. prepared a highly water-absorbing dust suppressant for coal transportation with corn starch as the primary component. They determined the optimal reaction conditions through experiments to reduce the dust generated [16]. Moreover, Zhou et al., using bagasse-extracted cellulose as the substrate, developed a wetting-crusting type highly efficient environmental protection dust suppressant to address the inefficiency and cost-ineffectiveness of existing biomass dust suppression methods. When the wind speed was  $10 \text{ ms}^{-1}$ , the dust suppression rate could be maintained above 90%, and the dust suppression is biodegradable, non-toxic, and safe [17]. Similarly, Wang et al. synthesized microalgae oil-based coal dust suppressant (MODS) with superior hard water resistance and conducted a series of experiments to optimize the extraction conditions for microalgae oil, which laid the foundation for hard water-resistant coal dust suppression [18].

In summary, phytochemical modification is an innovative technique for removing coal mine dust that is environmentally friendly and uses renewable resources. However, its application is still in the development stage. Further experimental studies and engineering application verification are needed to determine the best plant selection, extract treatment method, and application mode.

Table 2: Summary of the Papers on Phytochemical Modification of Dust Remover by Experiment

Author & Time	Materials	Object	Effects
Zhang et al. [12]	GGTCS; Glycerol (GLY); Sodium dodecyl benzene sulfonate (SDBS) ; Fatty alcohol polyoxyethylene ether (AEO)	A novel guar gum modification based environmentally friendly degradable dust suppressant	Decent water retention, hardening, cementing, anti-compression, and degradability characteristics
Jin et al. [14]	Soybean protein isolate (SPI); Sodium dodecyl sulfate (SDS); Carboxymethylcellulose sodium; Sodium silicate; Other auxiliary agents	The SDS-SPI coal dust suppressant	Dust suppression efficiency can reach 93.47%; A hardened, compact shell forms on the surface of the coal powder; A strong cementing effect among dust particles
Bao et al. [16]	Corn starch; Acrylic acid; Acrylamide	A binary-graft-based, water-absorbing dust suppressant	The optimal performance was achieved when the concentration of the dust suppressant was 6%; The dust suppressant's ability to prevent evaporation improved as its concentration increased
Jin et al. [15]	Soybean protein isolate (SPI); Sodium dodecyl sulfonate (SDS); Carboxymethylcellulose sodium; Methanesiliconic acid sodium	The SDS-SPI cementing dust suppressant	The optimal dust suppressant concentration is 3%; A dust suppression efficiency of up to 92.13% can be achieved at peak performance; Strong cementation between coal dust particles
Zhang et al. [13]	Moisture agent W; 0.8% Hydroxypropyl guar gum (natural polymer guar gum+ propylene oxide)	A novel polymeric spraying dust suppression agent	Enhanced wetting and coagulation properties; Dust removal rates of total dust: 83.94%; Dust removal rates of respirable dust: 84.08%
Zhou et al. [17]	Bagasse extracted cellulose; Polyvinyl alcohol; Polyacrylamide	A wetting-crusting type highly efficient environmental protection dust suppressant	The dust suppression rate of the product remained above 90% at 10 ms <sup>-1</sup> simulated wind speed; Greater average permeation rate; Non-toxic; Environmentally friendly
Wang et al. [18]	microalgae oil	A microalgae oil-based coal dust suppressant (MODS)	Good resistance to hard water; Better wettability

### B. Structural Improvement of Dust Remover by Experiment

Through experimentation, the structure of dust removers can be enhanced. Table 3 summarizes the papers on the structural improvement of dust remover by experiment. Wang Pengfei is an expert in this field, as the Table 3 shows. Wang et al. investigated X-type swirl pressure nozzles with a Sauter mean diameter (SMD) multivariate nonlinear prediction mathematical model and the effect of outlet diameter on atomization characteristics and dust reduction performance. Figure 7 illustrates an experimental spray system for dust reduction [18, 19]. Wang et al. studied the internal-mixing air-assisted atomizer nozzle. They analyzed structural parameters on atomization characteristics and reduction performance. The primary parameters consist of the diameter of the water-injection holes, the number of air-injection holes, and the diameter of the air cap outlet [20].

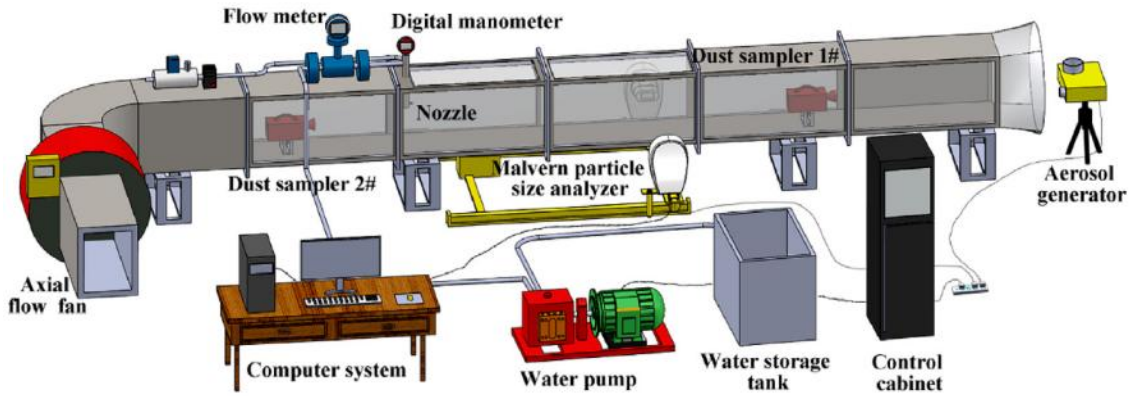


Figure 7 Spray Experimental System for Dust Reduction [21]

On the other hand, Zhu et al. studied foam dust removal. They modified key foam device components and used a cavitating jet pump. Their findings aid in the progression of foam dust removal [22]. In addition, Zhang et al. studied a supersonic siphon antigravity atomization nozzle. They combined a Laval nozzle with an existing ultrasonic atomization nozzle, with the Laval nozzle serving as the core. The new nozzle showed outstanding atomization performance, with droplet sizes smaller than 10  $\mu\text{m}$ , as demonstrated by the experimental results. Under the same water flow rate, its dust removal efficiency was double that of the ultrasonic nozzle. Additionally, the energy consumption decreased when the dust removal efficiency remained unchanged. Furthermore, the siphon atomization had low gas pressure, demonstrating the siphoning and nozzle internal atomization process in supersonic atomization dust removal for the first time [23].

Lastly, Li et al. designed a built-in open-hole dust cleaner (BODC). BODC significantly addressed the issue of uneven cleaning in the upper part of traditional filter cartridges. The device was applied on-site at the Donghuantuo Coal Mine's excavation face, attaining a dust removal effectiveness of more than 90% [24].

According to the research above, the development of dust remover structures focuses primarily on the nozzle structure, nozzle diameter, hole number, distance, and other factors, with the nozzle diameter being of particular value. There is extensive research on nozzles. As shown in Figure 8, among the randomly retrieved articles, improvements in nozzle structure account for 67% of the structural enhancements of dust removers.

However, the research also has limitations, such as a lack of exploration of a broad spectrum of parameter space. It is typically conducted within restricted parameter ranges, making it difficult to comprehensively investigate a vast parameter space. Consequently, there may be limitations in optimizing the results, preventing the discovery of superior solutions. In conjunction with experiments, numerical simulations can settle these limitations. A more exhaustive evaluation of the impact of various parameters on the dust remover's performance can be attained through numerical simulation. This method reduces the time and expense of experiments, permits the exploration of a larger parameter space, and yields more precise optimization results.

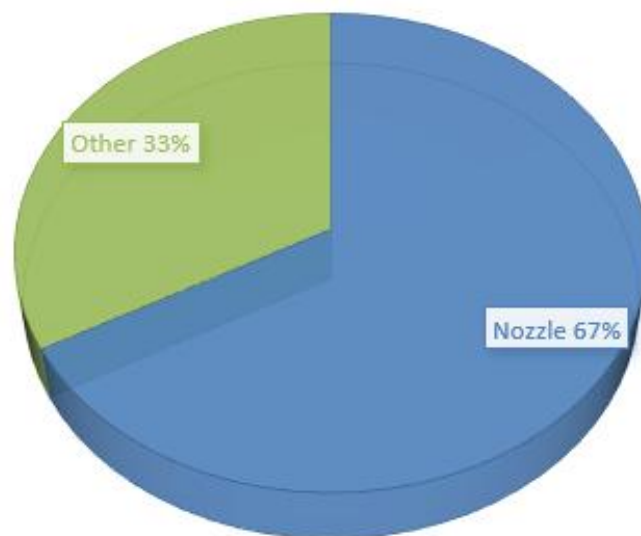


Figure 8: The Proportion of Research Focused on Nozzle Design Within the Structural Improvement of Dust Remover by Experiment



Table 3: Summary of the Papers on the Structural Improvement of Dust Remover by Experiment

Author & Time	Object	Structure parameters	Main findings
Wang et al. [19]	X-type swirl pressure nozzles	Axial distance; Nozzle diameter; Radial distance	Sauter mean diameter increases with the increase of axial distance, absolute radial distance value, and nozzle diameter
Wang et al. [21]	Internal-mixing air-assisted atomizer nozzle	Diameter of the water-injection hole; Number of air-injection holes; Diameter of the air cap outlet	Diameter of the water-injection hole: 1.5 mm; Number of air-injection holes: 4; Diameter of the air cap outlet: 2.0~3.0 mm
Zhu et al. [22]	Foam device	Agent mixing device; Foam generator; Nozzle	A cavitating jet pump; A vertical foam generator; two-layered foam nozzles; average total dust suppression efficiency: 86.8%; long-term time average respirable dust concentration: 3.9–5.7 mg/m <sup>3</sup>
Wang et al. [20]	X-swirl pressure nozzle	Outlet diameters	Water supply pressure $\geq$ 4 MPa, outlet diameter: 1.2 mm; Low water supply pressure, a larger outlet diameter
Zhang et al. [23]	A supersonic antigravity siphon atomization nozzle	A Laval nozzle	The particle size of the droplets is less than 10 $\mu$ m; At an equivalent water flow rate, the new nozzle achieves a dust removal rate that is twice as high as that of ultrasonic nozzles
Li et al. [24]	Pleated cartridge dust collectors	Hole number; Round hole diameter	Hole number: 4; Round hole diameter: 6 mm; Average total dust removal efficiency: 95.2%; Average respirable dust removal efficiency: 93.2%

IV. INFLUENCE OF OTHER FACTORS ON DUST REMOVAL EFFECT BY EXPERIMENT

In addition to the chemical modification and structural improvement of dust removers, the effects of other factors on the dust removal efficiency of coal mines have also been investigated through experiments, including ventilation system, metamorphic degree of coal, and particle diameter. A summary of other factor is listed in Table 4. Wang Pengfei has contributed a lot to this field.

Wang et al. respectively examined the effects of particle diameter and metamorphic degree of coal on the wettability and dust suppression efficiency. The experimental results show that the wettability of the same property dust decreased with decreasing particle diameter [25]. In the experimental investigation of the metamorphic degree of coal, Wang et al. selected 6 samples of coal dust with varying metamorphic degrees. Figure 9 displays SEM images of different coal samples at a magnification factor of 300. As the metamorphic degree of coal continued to progress to anthracite, coal dust wettability increased [26].

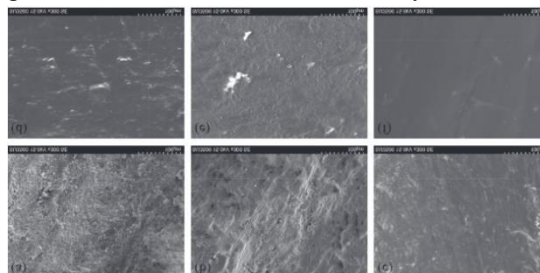


Figure 9: SEM Images of Different Coal Samples at A Magnification Factor of 300: (A) Lignite; (B) Gas Coal; (C) Fat Coal; (D) Coking Coal; (E) Meager-Lean Coal; (F) Anthracite [26]

On the other hand, Wang et al. explored the effect of the forced-to-exhaust ratio of air volume on wall-attached swirling ventilation. The result of the experiment was that when the ratio was 0.8, the driver’s vicinity had the lowest total and respirable dust concentration, with separation efficiencies of 93.64% and 98.18%, respectively [27].

Table 4: Summary of the Papers on the Effect of Other Factors on Dust Removal Efficiency by Experiment

Author & Time	Influence factor	Key parameters	Main findings
Wang et al. [25]	Particle Diameter	18 different samples	The quantity of hydrophilic functional groups containing oxygen progressively decreases with the particle size reducing
Wang et al. [27]	The forced-to-exhaust ratio of air volume	A scaled-down model depicting the mechanized excavation face of D04 at Dong Huai Coal Mine	Ratio is 0.8, the driver’s vicinity has the lowest total and respirable dust concentration, with separation efficiencies of 93.64% and 98.18%, respectively
Wang et al. [26]	Metamorphic Degree of Coal	Six coal dust samples with different metamorphic degrees	With the metamorphic degree improving, the surface content of hydrophilic oxygen-containing functional groups, surface roughness, specific surface area, and inter-pore diameter all decrease

V. DISCUSSION

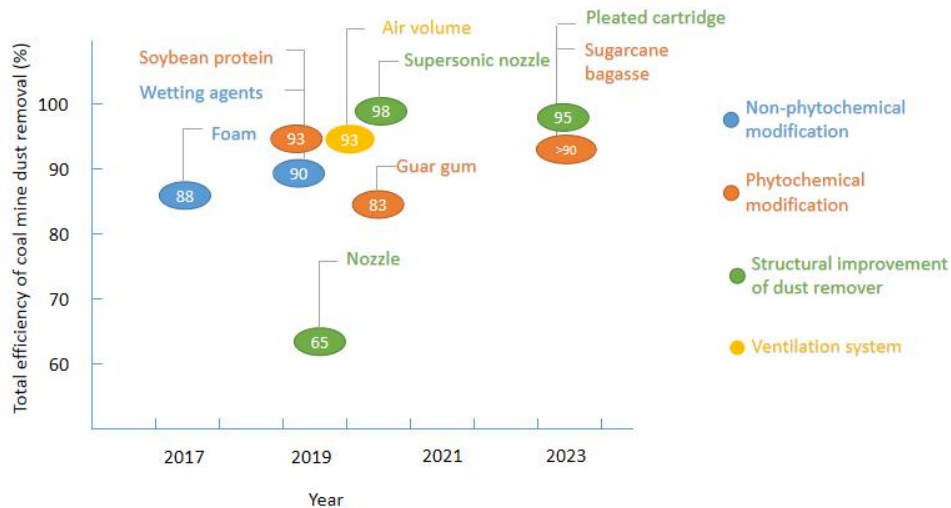


Figure 10: The Total Efficiency of Coal Mine Dust Removal for Four Improved Methods by Experiments in Recent Years

Figure 10 shows the total efficiency of dust removal in coal mines for various primary improvement methods, as determined by experiments. Independent experimental research is suitable for the structural improvement and chemical modification of dust removers. Due to the convenience and low cost of these experimental operations, there has been a surge in such studies in recent years. The data reveals that both phytochemical modifications and supersonic structures can achieve high efficiencies in dust removal. When compared to non-phytochemical methods, phytochemical modifications are not only more efficient but also more environmentally friendly. Phytochemical modifications are expected to be the dominant trend in experimental research, with increased exploration into plant species and the development of innovative manufacturing methods.

In many instances, tweaking the nozzle structure does not yield significant efficiency improvements. However, supersonic nozzles demonstrate high efficiency and are likely to be a key area of future research. There has been limited solely experimental research on ventilation systems, primarily because the necessary equipment is challenging to construct and comes at a high cost. Studies on ventilation systems are often better realized through numerical simulations. With the development of computer technology, dust removal technology has been greatly improved both in numerical analysis and experimental research[28-30].

## VI. CONCLUSION

Due to the complexity of coal extraction conditions, dust control in mines is highly variable. Experimental studies are summarized after critically reviewing prior research. The experiments provide a wealth of research on the chemical modification of the dust remover. Chemical modification of dust remover can be divided into phytochemical modification and non-phytochemical modification. Non-phytochemical modification dust control methods can effectively suppress dust. However, non-phytochemical modification may result in environmental pollution, such as soil and water contamination or the endangerment of surrounding ecosystems. So numerous researchers are investigating eco-friendly dust control strategies based on phytochemical modification. Commonly used plants in phytochemical modification include guar gum, soybeans, corn, sugarcane, microalgae, peanuts, etc. Phytochemical modification, which employs renewable resources, is eco-friendly and innovative. However, its application is still in the early stages of development. Additional experimental research and engineering verification is necessary to determine the optimal plant selection, extract treatment method, and application mode. The development of dust remover structures concentrates primarily on the nozzle structure, nozzle diameter, the number of holes, and the distance, with the nozzle diameter being of particular significance. In addition to the chemical modification and structural improvement of dust removers, experiments also investigated the effects of other factors on the dust removal efficacy of coal mines, including ventilation system, metamorphic degree of coal, and particle diameter. Therefore, experimental research is a crucial research method for the suppression of coal mine dust.

There are several noteworthy future development trends about dust suppression experimental research: 1) Intelligent and automated dust control systems: As intelligent technology develops rapidly, future experimental research will concentrate on the intelligence and automation of dust control systems, which includes the surveillance and control of the dust control process in real time using sensors, data acquisition, and monitoring systems, thereby enhancing system stability and operational efficiency. 2) Comprehensive control of multiple pollutants: Additional pollutants, such as sulfides and nitrogen oxides, are also emitted in the coal mine. Future experimental research will explore comprehensive control technologies for multiple pollutants to achieve comprehensive emission reduction and resource recycling. 3) Application of new materials and technologies: Researchers may develop novel filtration materials with high particle-capturing efficiency or utilize nanotechnology to improve particle-capture effectiveness. Additionally, environmentally friendly dust control agents can be studied. 4) Interdisciplinary collaboration and cross-disciplinary research: Coal mine dust control is a complex system engineering problem that requires interdisciplinary collaboration and cross-disciplinary research. Experimental research should promote the participation of experts from different disciplines, such as mechanical engineering, materials science, chemical engineering, environmental science, etc., to facilitate innovation and technological exchange.

## ACKNOWLEDGEMENT

This research was funded by the Key Project of the Anhui Natural Science Foundation, KJ2021A1188.

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