

# Research Status of Wet Duster in Fully Mechanized Workface

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Cyclonic duster has become the mainstream in fully mechanized workface, better than any other kinds of dusters in dust removal efficiency, sewage discharge, disassembly and assembly, moving with the boring machine etc. This paper reveals the effect that the opening of the throttle plate significantly affects the water jet by Bernoulli equation, and the parameters related to the vibration effect by the vibration frequency formula, and also states that when the centrifugal force and the air resistance are in balance, dust particles began settling on the cavity. Wet dust removal technology has developed rapidly over the last two to three decades and become mainstream technology in coal mine

production. There are lots of papers focusing on dusting efficiency influenced by changing parameters, such as nozzle types, structure parameters, wind speed and ventilation volume. This paper summarizes characteristics related to mechanisms of wet dusting and dust capturing. It also outlines the research advance of mine wet duster and analyzes the existing problems. The paper focuses on the mechanisms of three types of wet duster in fully mechanized workface. The research and application of future are also prospected.

**Keywords:** wet duster, dust capturing mechanisms, dust removal mechanism, research situation

## **1. Instruction<sup>1</sup>**

The fully mechanized workface and tunneling workface are two major dust sources in coal mine production. The dust concentration at the fully mechanized workface range from 2000 to 3000 mg/m<sup>3</sup>, and 4000 to 8000 mg/m<sup>3</sup> at the tunneling workface, in which including 20 percent respirable dust. Dust exposed workers have the risk of getting pneumoconiosis. Airborne particulates in mine will cause instrument destruction and visibility reduction. Furthermore, an explosion or fire because of the character of dust spontaneous ignition and explosiveness will possibly bring serious disaster to the coal mine. The largest dust explosion in Europe occurred at Courrires Colliery in northern France, in which 1099 people died [1].

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Three principal methods of dust removal in China colliery production are described as follows. First, reasonable mining technology such as seam water injection is widely used. Second, keeping dust in the specific space and position prevents it further spreading. Applying dusters filtering or discharge dust is the third method [2].

Duster used in coal mine can be divided into two types, wet-type or dry-type. By comparison with wet duster, dry duster (eg. Venturi/bag/electrostatic duster) has the following disadvantages [3-5]:

- Venturi demands high negative pressure and air volume; bag precipitator requires low wind speed and big filtering area. Therefore, this two kinds of duster have large volume.
- Dry duster is suitable for removing the coarse dust particles larger than 50 μm, not for these smaller than 7 μm.
- Dry duster is not available to

wet dust particles and coagulate easily after dust spraying in working face.

Wet duster which has bright prospects in the application of coal mine production not only offers high air volume without big power, but also has the advantages of higher respirable dusts capturing efficiency, less pollution, more simple structure, more stable operation and easier movement. Recently researchers have focused on the techniques of combining wet dusting with Condar drum and high pressure sprayer which can substantially reduce respirable dust concentration.

There are extensive literatures on dust characteristics and particle collection mechanisms. However, little has reported the flow field characteristics in duster cavity and structure parameters effecting dusting efficiency. To optimize structural parameters and design efficient duster, the research should start with particle collection mechanisms and current duster mechanisms.

## **2. The developing situation of wet duster**

In brief, dusty airflow is sucked into the dust collector by negative-pressure fan and then wetted by nozzle. The dusty airflow becomes fresh by centrifugation or filtration in duster cavity. Recent years, researchers have tried to design new efficient duster with the characteristics of small volume, compact structure, reliability, low energy consumption and high respirable dust capturing efficiency. Some types of wet duster such as self-swash type, vibrating wire type and cyclonic type have a wide range of applications in mine dust removing.

### **2.1 The developing situation of duster out of China**

The application of wet duster can be traced back to 1892 when G. Zschohe developed a wet reticular duster and patented it. Ignoring the primitive design and inefficiency of the invention, it was the most advanced dust removal equipment. Mine wet

dusters in different structure principles are energetically developed and applied all over the world since 1950s among which filter type is mainstreamed [6]. The main types are as follows:

(1)The wetting layer duster (US) mainly consists of sprayers, metal-wire-woven filter, dusting cavity and water circulating system. The dusty airflow passes through the filter plates wetted by sprayers. Shortly thereafter, United States Bureau of Mines (USBM) transformed the filter plates instead of using stainless steel wire of 0.09 mm diameter, making it more efficient and difficult blocking.

(2)The British Mining Research Institute (BMRI) added axial flow fan and dehydrator to the filtering duster. Water spouting from nozzle is atomized by high-speed rotating fan impeller mixed with dusty airflow sucked by axial flow fan and then spurting onto the filter plate. The functions of dusting and dewatering are implemented

through a filter plate. The wet dusty airflow goes through the demisting plate made up by W-type plates and changes direction many times to remove liquid droplet. This design can reduce the air resistance, enhanced filtration area, hence to improve capture efficiency. China and Japan have introduced this kind of dust collector. However, the equipment is big and bulky.

(3)The former Soviet Union scientists combined filtering duster with sprayer and cyclone weaved by metal wire mesh. Perpendicularly moving airflow passes laterally across spinning metal wire meshes strengthening to wet and settle the fine dust.

(4)Rotary duster (US) contains a high-speed spinning wetting layer which stacked metal wire meshes together. The way meshes stacked is a effective method to dust and mist but intricately to maintain [7].

(5)Polack developed the revolutionary cyclone duster with the removal rate of 97% to 99% in 1996. Now it has become

mainstream technology of mining wet duster. The dusting mechanism will be described in detail in 4.3.

## 2.2 The developing situation of duster in China

### (1)Wet cyclone duster

Ma anshan Institute of Mining Research developed two specifications of wetting layer duster in the late 1970s. The machine consists of filter nets, nozzles, dehydrator and deflector, 14 L/min of water consuming.

### (2)JTC Series of wet duster

China Coal Research Institute (CCRI) developed a kind of wet duster equipped with stainless steel wire mesh which can be reversely flushed to prevent clogging by nozzles.

### (3)SLC Series of wet fibrous duster

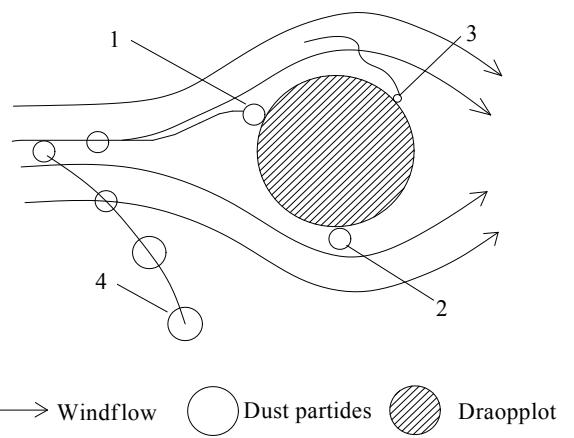
Researchers in Northeastern University (NU) systematically carried out the design in wet fibrous duster. The filter layer of this duster is made by polyester specifically for filtering respirable dust. This technique has been used to purify air at the

mine entrance [8].

## 3. Research on mechanism of wet duster

### 3.1 Dust-capturing mechanisms of liquid droplet

Duster efficiency depends on the situation of water trapping coal dust particles. In the process of dust removing, dust particles and water droplets approach to each other and highly mix in which three short-range mechanisms work [9]. The mechanisms are shown in Figure 1.



1-Inertial impaction 2-Interception

3-Brownian motion

Fig. 1: Typical mechanisms of dust capture by water-droplet

#### (1) Inertial impaction

Dust particles up to 1  $\mu\text{m}$  are captured by droplet based on the

mechanism of inertial impaction. In the process of dusty air flowing forward and encountering droplet, airflow bypasses the droplet while dust particles continue moving for inertia to be trapped by droplet. Inertial impaction efficiency improves as the increase of diameter of dust and the decrease of diameter of droplet.

#### (2) Interception

Ignoring the quality of dust particles, when the distance the streamline from the droplet surface is less than the radius of dust particle, the dust will come into contact with the droplet and be captured. Interception efficiency improves as the increase of diameter of particles and the decrease of diameter of droplets.

#### (3) Brownian motion

Brownian motion affects the particles with radius of less than 2 mm. The motion is related to temperature. The higher the temperature is, the higher level of particle's irregular motion will be, the easier the particles will be

captured on the droplet.

### **3.2 Influencing factors of the dust-capturing efficiency**

(1) The relative velocity between dust and droplet .

The greater the relative velocity is, the easier the air film of dust particles will be broken through and the droplet surface tension will be overcome, the easier the dust particles will be captured.

(2) Droplet intensity.

Under the circumstances of droplet particles in the same diameter size, the larger number of droplets per unit volume is, the more opportunities particles will contact with droplets. The droplet intensity is related to the water pressure and nozzle structure.

(3) Wettability of dust particles

Non-wettable dust will produce rebound phenomena contacting with droplets. It can be resolved to add wetting agent into water.

(4) Particle size

When the diameter of droplet is as large as 50 to 150 times as the diameter of dust particle, the dust particle is easier to be captured [10].

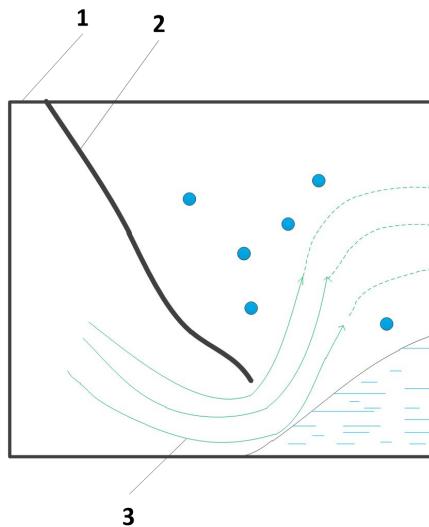
According to the capturing mechanisms and the influencing factors, improving the dusting efficiency is equivalent to increasing the efficiency of droplet capturing dust particles, and it is the main method to increase the relative velocity of gas-liquid two-phase flow.

#### **4. Variety and mechanisms of wet duster**

##### **4.1 Self-swash duster**

Self-swash duster consists of dust collecting mouth, a draught fan, a throttle plate and a dusting cavity. It makes full use of energy exchange in the process of

gas-solid two-phase flow convection. As shown in Figure 2, throttle plates are mounted in the dusting cavity. Dusty air goes through the slit between the plates and the liquid surface, of which kinetic energy converts into potential energy and kinetic energy of water, splashing parabolic water jet. Some dust particles of the wind flow are stuck on the liquid surface while others are captured by the parabolic jet. The flow continues to move to the next slit forming new water curtain and being further captured.



1-Dusting cavity 2-Throttle plate

3-Airline 4-Liquid surface

Fig. 2: The mechanism of self-swash duster forming water curtain

The more the water droplets produce by the airflow striking on the liquid surface, the smaller the

particle size and the higher the water jet, means the more energy will be converted from the

airflow, and the better the dust-removing effect will be. The kinetic energy of the wind flow is determined by the operating frequency of draught fan, and the energy converted from airflow depends on the opening degree of the throttle plates. The throttle plate opening is distance between the lower edge of the plate and the liquid surface.

This value will affect the wind velocity in the orifice, water pressure distribution in the dust cavity and the state of self-swash water curtain. Theoretically, the smaller the throttle plate opening is, the more the wind flow is resisted passing through the orifice and the greater its pressure loss, leading to ineffective parabolic jet distributing in the middle and lower part. On the contrary, the pressure loss reduces and liquid get more energy as the opening increases. However, it will have a short circuit that the wind flows laterally between two plates if the opening is excessively large. The

Bernoulli equation accounts for the process:

$$\frac{\Delta p}{\rho} + g\Delta z + \frac{\Delta v^2}{2} = C \quad (1)$$

$\Delta p$ —pressure variation in dusting cavity

$\Delta z$ —height variation

$\Delta v$ —velocity variation

$C$ —constant

$\rho$ —medium density

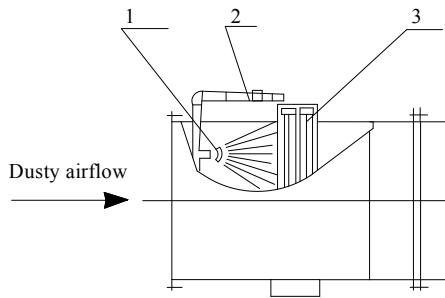
In 2010, Xiong Jian-jun used PLC acquisition module and micro-pressure detection technology to measure the values of negative pressure in different positions in dusting cavity, verifying the variation the water jet parabola change with the throttle plate opening [11].

#### 4.2 Vibrating wire duster

Vibrating wire duster consists of nozzle, water supply system, vibrating wire filter plate and dewatering device, as shown in figure 3. Nozzles in the wind direction spray to the vibrating filter plate constantly. When the dusty air passes the filter, the fiber with water curtain can make

dust wet, gain weight, agglomerate and detain. Simultaneously, acoustic waves produced by vibrating grid vibrate cause particles to coagulate in the same direction, making particles from minor to be major. Larger particles are easier to be captured by droplets,

consequently, improving the dusting efficiency. Dust ball of dust and droplet fall with flowing water for weight increase, washing off the dust on the filter plate at the same time. Dust ball after dewatering discharges from the sewage outfall while fresh air exhausts from the vent [12-15].



1-Nozzle    2-Water supply system  
 3-Vibrating wire filter plate  
 4-Dewatering device  
 Fig. 3: Internal structure of  
 vibrating wire duster

Acoustic vibration frequency that can create the strongest acoustic agglomeration effect between dust particles with diameter being D and d is calculated in following formula.

$$f_m = g\mu / (\pi Dd \sqrt{\rho_D \rho_d})$$

(2)

$\mu$  — coefficient of dynamic viscosity

$\rho_D$  — larger particle density

$\rho_d$  — smaller particle density

The vibration frequency of the vibrating grid should be greater than the value of  $f_m$ . In the process of dusting, when wind flow causes the vibrating grid to vibrate, it will produce standing wave. The vibration frequency of the vibrating string (symbols  $f_n$ ) is calculated in following formula:

$$f_n = n\sqrt{T/\rho} / (1.77l\phi)$$

(3)

$T$ —the tension that  
vibrating string  
suffers

$\rho$ — the density of the string 's  
material

$\phi$ — the string diameter

$l$ — the string length

According to the above formula,  
the vibration frequency of the  
vibrating string is related to the  
materials of the string. Suitable  
materials can improve the  
vibrating frequency, and then  
improve the dusting efficiency.

#### 4.3 Cyclonic duster

An atomizer is equipped at the entrance of the dust cavity. The humid dusty airflow under the action of the cyclonic fan produces a strong rotation. The powerful centrifugal force generated from the spiral motion, press dust particles and droplets against the cavity wall surfaces. Some tiny particles and droplets impinge on the blades of fan agglomerating into larger ones that are thrown to the wall surfaces by centrifugal force and fall to the sewage tank. Dust spiral in the dusting cavity under

the influence of centrifugal force and the air resistance , ignoring the gravity. When the two forces are in balance, dust particles began settling on the cavity [17].

$$C = m\omega^2 x$$

(4)

$$S = \xi F \frac{\rho_2 \omega_2^2}{2}$$

(5)

$$\xi = \frac{24\mu}{d\rho_2\omega_2}$$

(6)

$$F = \frac{\pi d^2}{4}$$

(7)

$C$ —centrifugal force

$F$ —air resistance

$x$ —distance between particles  
and rotation axis

$\rho_2$ —the airflow density

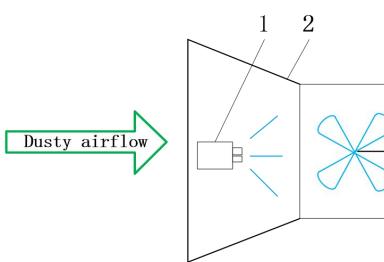
In recent years, researchers have transformed cyclonic duster with applying diagonal fan with reasonable blade angle at the inlet and outlet of the leaf. The airflow pressured by the diagonal fan

impeller has a smaller energy loss on account of velocity direction change and impact of blade. The airflow of which the central part can flow to the boundary is in hollow cone shape and moves forward spirally [16]. The airflow characteristic facilitates the separation of dust under the action of a strong centrifugal force, and makes dust particles not easy be attached to the impeller. Based on the aerodynamic characteristics of diagonal flow-fan, some researchers supplemented with spiral diversion channel in the dust cavity to improve dusting efficiency [18].

Liang Ai-chun did an experiment using a combined system of a dust-control device and dust-removal device. He drew a conclusion that controlling the reasonable proportion of blowing and exhausting air volume obviously impacts on the effects of cyclonic duster efficiency [18].

The efficiency of the dusting system increases with the decrease of this proportion. When the proportion of blowing and exhausting air volume is excessively high, that means pressure-air volume is greater than the exhaust-air volume, not only high-speed flow will blow depositional dust, but also it is too late to exhaust dust airflow to purify. In the actual production process, it is efficient to legitimately reduce pressing air volume and increase the air volume through duster, under the conditions of ventilation meets the requirements of gas dilution and staff breathing.

In recent years, some scholars have used Fluent software to simulate dust motion in dusting cavity. For example, Zou Zu-yun simulated the effect that changing cyclonic duster's structure parameters impacts on dusting efficiency and pressure loss [20-22].



1-Sprayer 2-Collector  
3-Spiral fan 4-Dust dehydrate  
cavity 5-spiral wind 6-Wind  
regulator

Fig. 4: Internal structure of  
cyclonic duster

## 5. Summary

(1)Comparing with the dry duster, the above three kinds of wet duster are much higher universal and convenient to dismantle, and they all can move along with the roadheader. Furthermore, they can be modified to apply the technology specialty of each other. For instance, self-swash and vibrating wire duster can be equipped with the diagonal fan producing spiral wind flow to improve efficiency. Cyclonic duster use both centrifugal force and vibrating plates to dehydrate airflow.

(2)The cost of self-swash dusting system is low. It does not need any power source and spray device. The vast majority of dusting water is recycled in the dusting cavity. However, the

airflow losses parts of energy after impacting water surface and the fresh wind power performance is poor. Vibrating wire duster also significantly hinder the wind flow movement and it's necessary to clean the vibrating wire filter plate regularly. Cyclonic duster has greater power and smaller energy loss in the process of dust removal. Chongqing Research Institute (administered to CCRI)use the experience of Polish vortex dust control and wet cyclonic dusting technology, combining techniques of diagonal fan, composite baffle dehydration, and developed KCS series cyclone duster. It basically stands for the most advanced level of wet duster in China.

(3)Improving the dusting

efficiency is equivalent to increasing the efficiency of droplet capturing dust particles.

Increasing the relative velocity of gas-liquid two-phase flow is the main method. However, The blind increase of air velocity will cause the fan's energy consumption. It is the point to choose appropriate wind flow velocity to keep the balance of dusting efficiency and fan energy consumption.

(4)At present, the studies of wet duster have mostly concentrated upon the measurement of dusting efficiency and ventilation volume. However, at the micro level, the researches are rare such as stress analysis of dust particles, the pressure distribution and velocity change in the flow field. And also, some researches and experimentations keep dusting efficiency as the only index, ignoring the economic benefits and environmental performance.

(5) The explorations of using fluent software provides a reference for the study in the flow

field characteristics

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