Experimental Study on Influencing Factors of Dust Deposition on Mine Air Cooler Fins

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Abstract. In order to reduce the deposition of dust on the surface of the fin of the air cooler, the influencing factors of dust deposition were studied. Firstly, the airflow along the working face is observed, which provides variable reference and data support for the wing dust deposition experiment. Then, the dust collecting test platform was built to simulate the dust collecting on the air cooler fins. Finally, the key factors that affect the dust deposition on the fins are studied by controlling the variables. The results show that the condensate water plays an important role in the dust deposition of the air cooler fins in high temperature and high humidity environment. When the amount of condensed water is less, the condensed water is adhered to the surface of the fin, which has the effect of adhesion to the particles, thus speeding up the deposition of dust on the surface of the fin. When the amount of condensed water is large, the condensed water moves downward under the action of gravity and carries away the dust attached to the fin surface, thus slowing down or even reducing the deposition of dust on the fin surface.

1. Introduction

After deep mining, the coal mines are generally faced with the problem of deep thermal disaster[1,2]. As the key equipment of mine cooling system, the performance of Mine Air Cooler directly affects the cooling effect and safety production[3-7]. In recent years, the influence factors of fouling in heat exchanger are analyzed by Peihong Li et al[8], the contact between surface energy and elastic solid is studied by Johnson KL et al[9], and the adhesion of impacted particles is studied by Rogers LN et al[10].

The air cooler for mine is usually arranged at the end of the mine. The air pollution in these places is very serious, and the pollutants such as coal dust are easily attached to the fin surface of the Air Cooler for mine, which seriously affects the heat exchange effect of the air cooler. Dust deposition on air cooler's fins is a very complicated movement process, which can not be completely explained by related theories at present. Therefore, it is necessary to study the dust deposition on the fin of air cooler.

2. Determination of experimental variables

The dust deposition in fins of mine air cooler is closely related to its structural parameters and
environmental conditions. The structural parameters of air cooler mainly include fin type, fin spacing and fin material; the external environmental conditions mainly include dust characteristics, air temperature, air humidity and air velocity. From the field application point of view, the structural parameters of the mine air cooler itself are fixed, so only the external environment needs to be tested. Based on the mine measured data, the temperature variation range of the mine is 25–35℃, the relative humidity is 70 – 90%, and the dust concentration can reach up to 1.2 g/m³. In order to accelerate the deposition process of dust particles, the dust concentration used in this experiment was 2.1 g/m³.

3. Experimental method

3.1. Construction of experimental platform

In order to study the phenomenon of dust deposition in fins of mine air cooler, a test platform was designed. The test platform includes fan, temperature and humidity simulator, dust generator and sample observation platform. In order to study the phenomenon of dust deposition in fins of mine air cooler, a test platform was designed. The test platform includes fan, temperature and humidity simulator, dust generator and sample observation platform. Among them, the main function of the fan is to inhale air and regulate the air volume flow rate; the temperature and humidity simulation device is composed of a heating plate and a humidifier, which can obtain air with different temperature and humidity; the dust generation device is composed of a dust feeder and a dust mixing box, which regulates the concentration of dust and makes the dust and air mix evenly; the sample observation platform is composed of a temperature and humidity sensor, a pressure sensor, a semiconductor cooling unit refrigeration equipment and a test sample. The bottom of the sample observation platform is provided with a blowdown hole, which can discharge pollutants in time. The schematic diagram of the dust deposition test platform is shown in Fig.1.

![Figure 1. Schematic diagram of the model of the dust deposition test platform](image-url)

3.2. Preparation of test samples

In this study, samples were obtained by cutting the finished mine air cooler, as shown in Fig.2. The fin type of the test sample is plate fin, the fin spacing is 2.2 mm,
3.3. Data processing method

The temperature, humidity, and pressure drop of air can be directly measured by temperature sensors, humidity sensors, and differential pressure sensors, while the inlet air velocity $V$ is obtained by adjusting the volumetric flow rate of the air compressor, as expressed in Eq. (1).

$$v = \frac{V}{A_{\text{wind}}}$$  \hspace{1cm} (1)

Where $V$ is the air volume flow rate, m³/s; $A_{\text{wind}}$ is the windward area of the test and observation platform, m².

During the experiment, the expression of dust concentration $C$ is:

$$C = \frac{m_{\text{coal}}}{V}$$  \hspace{1cm} (2)

Where $m$ is the feed mass flow rate, kg/s; $V$ is the air volume flow rate.

The expression of dust mass per unit area of the air cooler fin is $m_{\text{11}}$:

$$m = \frac{m_2 - m_1}{A_{\text{fin}}}$$  \hspace{1cm} (3)

Where $m$ is the dust mass per unit area, g/m²; $m_1$ is the weight of the test sample in the Clean State, g; $m_2$ is the weight of the test sample in the Dust State, g; $A_{\text{fin}}$ is the surface area of the fin.

3.4. Experimental procedure

Step 1: Test preparation. Place the clean fin sample and tray on the analytical balance and weight it. Then place the fin sample and tray in order, turn on the semiconductor refrigeration unit, and control the surface temperature of the fin sample at 5 ℃ by adjusting the power.

Step 2: Simulation of experimental conditions. First turn on the fan to suck in air, then adjust the fan, heating plate, humidifier and dust feeder to achieve the predetermined experimental conditions, and finally pass the mixed air into the sample observation platform to start the test.

Step 3: Air-side performance test. The data acquisition system records the inlet and outlet air temperature, the relative humidity of the inlet and outlet air, and the air side pressure drop before and after the start of the dust deposition experiment.

Step 4: Sample dust quality test. An analytical balance was used to measure the fins with wet dust. The weight of the fins in the clean state was subtracted from the weight of the wet dust fins to obtain the fin dust deposition weight.

Step 5: Change the experimental parameters and repeat the above steps to continue the experiment.

4. Experimental results and discussion

4.1. Effect of different temperature on fin dust deposition
Fig. 3 shows the effect of inlet air temperature on the particle deposition weight and air side performance at RH = 90%, c = 2.1 g/m³, v = 4 m/s.

In the initial stage of dust deposition experiment, the condensate droplets formed on the surface of fins are smaller, and the surface tension of condensate droplets is greater than the resultant force (wind force and gravity force), so the condensate droplets adhere to the surface of fins, and the condensate droplets will adsorb the dust particles, thus accelerating the effect of dust deposition. In the same dust deposition time, the higher the inlet air temperature, the greater the dust mass and pressure drop. This phenomenon can be explained as follows: with the increase of temperature, the Brownian motion of dust is obvious, and the collision between dust and fin surface is violent. Meanwhile, with the increase of temperature gradient, the thermophoresis force is enhanced and the dust is easier to adhere to the fin surface.

4.2. Effect of different relative humidity on fins dust deposition

Fig. 4 shows the effect of relative humidity of inlet air on particle deposition weight and air-side performance under T = 35 °C, c = 2.1 g·m⁻³ and v = 4 m/s.

0-25 min, the higher the humidity of the inlet air, the greater the particle deposition weight and pressure drop.

25-60 min, the inlet air relative humidity is 80%, the particle deposition weight and pressure drop are the largest, and the inlet air relative humidity is 90% and 70%, respectively. This is because in the initial stage of the dust deposition experiment, a relatively high relative humidity of the intake air will
generate a relatively large number of condensed droplets, and the condensed droplets will adsorb dust particles, resulting in higher particle deposition. With the increase of the dust deposition time, the higher relative humidity of the intake air will generate a large amount of condensed water, and the condensed water will take away a large amount of dust during the falling process, thereby reducing the deposition of particles.

4.3. Effect of temperature and humidity on the pressure drop of dust deposition

Fig. 5 shows the evolution of particle deposition weight and pressure drop at $T = 30 - 35 \, ^\circ C$, $RH = 70 - 90 \, \%$, $c = 2.1 \, gm^{-3}$ and $v = 4 \, m/s$ operating conditions. It can be seen from the figure that the dust mass and pressure drop are proportional to the inlet air temperature when the inlet air relative humidity is constant. With the increase of temperature, the change of dust mass and pressure drop is not obvious when the relative humidity is low. With the increase of temperature, the dust mass and pressure drop increase obviously when the relative humidity is high.

Figure 5. Evolution of dust mass and pressure drop under different temperature and humidity

This situation can be explained as follows: for the airflow with lower relative humidity, the moisture content in the airflow is lower. With the increase of temperature, the condensation water from the fin surface is less and has little change, so the dust amount is less and has little change.

For the airflow with higher relative humidity, the moisture content in the airflow is higher. With the increase of temperature, the condensation water on the surface of the fin is more and changes greatly, so the dust deposition is more and changes greatly.

4.4. Fin dust distribution under high temperature and high humidity

Fig. 6 shows the dust deposition on the windward side (Fig. a, b) and leeward side (Fig. c, d) under the conditions of $RH = 80 \, \%$, $c = 2.1 \, g\cdot m^{-3}$ and $v = 4 \, m/s$. 

![Figure 5. Evolution of dust mass and pressure drop under different temperature and humidity](image)
From Fig. 6, it can be seen that there is condensation water on the windward side and the leeward side of the fin of the Mine Air Cooler. A small amount of dust on the windward side attaches to the FIN surface. The amount of dust on the windward side increases significantly with time, a small amount of dust adheres to the leeward side. This is because the dust with the wind first with the windward surface contact, and was condensed water adsorption, gradually formed dirt body, and finally reached a stable state.

5. Conclusions
1) At the same dust deposition time, the higher the inlet air temperature is, the more obvious the Brownian motion of dust is, and the collision between dust and fin surface is severe. Meanwhile, the increase of temperature gradient enhances the thermophoresis force, resulting in a larger dust mass and pressure drop.
2) 0–25 min, higher inlet air relative humidity would produce relatively more condensate droplets, which would adsorb the dust particles and thus higher particle deposition.
3) 25–60 min, a higher inlet air relative humidity will produce a large amount of condensate water, which will take away a large amount of dust during the fall, thus reducing the deposition of particles.

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