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Characteristics of Water Absorption and the Loss of Dust-Sticking Agent

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Abstract: The development of NCZ-1 dust-sticking agent was first introduced in china. The speed of water absorption of dust-sticking agent was measured and studied on mining site and in laboratory, and then the law of water absorption of dust-sticking agent was analyzed. In addition, the mathematical model of the loss rate of dust-sticking agent was established by the application of fluid mechanics theory, and the method of determining the sprinkle parameters of dust-sticking agent was obtained. Through practical verifi cation, it is found that the error of this mathematical model is less than 10%. So it can be used in the field.

Key words: dust-sticking; water absorption; loss rate; mathematical model

The harm of dust is one of the main disasters in the production of mine, especially in coal-mine. Great and fatal accidents caused by the blasting of coal dust occur sometimes. Sprinkle dust-sticking agent on the roadway in coal-mine is an effective method to prevent the flying of settled dust and the blasting of dust [1]. But the dust-sticking agent will have loss phenomenon occur after water absorption, so only by mastering the details of water absorption of dust-sticking agent, the sprinkle period of dust-sticking agent at the slope of different roadway can be accurately mastered and decided. This paper is mainly aimed at the study of water absorption and the loss rate characteristics of NCZ-1 dust-sticking agent which is developed by both Luan Coal Mining Administration and China University of Mining and Technology. NCZ-1 agent is a powder agent that has many functions including continuous absorption, sticking dust, resisting combustion [2]. That dust-sticking agent mainly consists of $CaCl_2$ and some kinds of surface active agents. Industrial experiment was accomplished successfully in 1996 [3].

1 Measurement of Water Absorption Speed of NCZ-1 Agent

The measurement of water absorption speed of NCZ-1 agent was carried out in Zhangcun coal-mine of Luan Coal Mining Administration [4, 5]. In view of coal pit conditions, the method of the multiple-plate measurement was used. Four plates were arranged in pit, and 80 g dust-sticking agent was put on each plate. One plate was taken to the ground to be weighed and calculated every other a regular time. During measurement, the average temperature in pit was 22 ℃, the average relative humidity of air was 90%. The measurement results are shown in **table 1**.

Table 1 The parameters of water absorption of dust-sticking agent measured on the sport

t/h	Q_{jx}/ g	Q_{xx}/ (g·g^{-1})	U_x/ (g·h^{-1}·g^{-1})
24	131.3	1.641	0.068
48	149.4	1.868	0.039
72	161.6	2.041	0..028
151	197.2	2.465	0.016
>200	348.1	4.351	0.009

Note: (1) t is the time of water absorption ; (2) absolute quantity of water absorption Q_{jx} means water absorption quantity of 80 g dust-sticking in a certain time; (3)relative quantity of water absorption Q_{xx} means the quantity of water absorption of each gram dust-stcking(g/g). Therefore in this paper: there is $Q_{xx} = Q_{jx}/80$; and while $t > 200$ h, parameter tends to a stable value.

In laboratory, the relative humidity of air was manually controlled between 65% and 75%. Average humidity is 72%, and average temperature is 15 ℃. The water capacity of dust-sticking agent made in lab is 22%. The test example of 35 g was weighed and measured continuously with the same square plate. The results are shown in **table 2**.

According to the above measurement, following remarks can be concluded:

(1) As the time going on, both the absolute quantity and the relative quantity of dust-sticking agent increase linearly, and the speed of water absorption decreases exponentially.

Table 2 The parameters of water absorption of dust-sticking measured in the lab

t/ h	Q_{jx}/ g	Q_{xx}/ (g·g^{-1})	U_x/ (g·h^{-1}·g^{-1})
16	29.7	0.0 85	0.053
24	34.6	0.989	0.041
32	40.1	1.146	0.036
36	42.4	1.211	0.034
42	43.7	1.249	0.030
64	46.2	1.320	0.021
>160	65.8	1.882	0.004

Note: (1) Here, $Q_{xx}= Q_{jx} / 35$, the other parameter are the same as in table 1. (2) While $t > 200$, every parameter tends to a stable value.

(2) At the beginning of water absorption, the bigger the air humidity the larger the speed of water absorption, but its drop extent enlargers as the time going on. It is shown in **figure 1**.

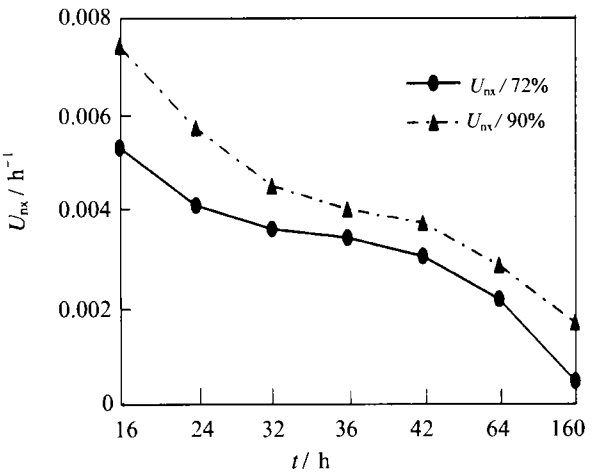

Figure 1 The tendency of water absorption of dust-sticking agent at different humidity

(3) As shown in figure 1, after the time of water absorption reaches a certain value, the speed of water absorption trends toward zero, other parameters also tend to a constant. The balance phenomenon of water absorption of dust-sticking agent occurs, and the dust-sticking agent loses from the beginning of its sprinkle to the balance of water absorption.

According to the above data, the recurrent equation of water absorption speed of dust-sticking agent is obtained:

$$U_{nx}= 7.18\times10^{-2}\, e^{-0.0105t} \tag{1}$$

2 Flow Characteristics of Water Absorption and Its Simplify

According to the above analysis, it is found that the water absorption process of NCZ-1 agent is relatively slow. The viscosity of NCZ-1 agent varies from 8.52 to 29.15 mPa·s at different water absorption speed [2]. Generally, the slopes of mine roadway do not change greatly, so its loss process is laminar flow and very close to a homogeneous flow. Thus the loss regularity can be approximately explained by homogeneous flow. On the basis of the law of homogeneous flow [3], the loss process of dust-sticking agent is simply considered as follows [6]:

(1) Distributions of flow velocity do not change alone at the wetted cross-section. It is a fixed velocity flow. Its wetted cross-section area ω, depth of the lost fluid h_1, average flow velocity U_1 and so on all are constant.

(2) The component of gravity force at flow direction is balanced with the resistance force.

(3) Roadway bottom slope i_d, water surface slope i_m and hydraulic gradient i_s all are equal. It is written as:

$$i_d = i_m = i_s = i \tag{2}$$

Therefore the essential hydraulic factors of duststicking agent's lost fluid in roadway are as follows:

$$\omega= B h_1 \tag{3}$$

$$x= B+2h_1 \tag{4}$$

$$r_s= \omega/ x= Bh_1/(B+2h_1) \tag{5}$$

where x is the wetted perimeter, m; B the width of the floor of roadway, m; r_s the hydraulic radius of lost fluid, m.

3 Mathematical Model

In the case of homogeneous flow, we can calculate directly according to Xiecai formula [7], so loss speed of dust-sticking agent U_1 (m/s) is

$$U_1= C_s\sqrt{r_s i} \tag{6}$$

where C_s is Schetschie coefficient ($\sqrt{\text{m}}$ /s). Two kinds of calculation methods are as follows.

(1) Manning formula is

$$C_s= \frac{1}{n_s} r_s^{1/6} \tag{7}$$

where C_s is wall roughness degree, as for the floor of roadway, its wall roughness degree does not change greatly, n_s can be calculated by synthetical roughness degree. Its calculated formula is:

While $n_{s,\max} / n_{s,\min} > 1.5\sim2$,

$$n_s = \left(\frac{x_1 n_{s1}^{1.5} + x_2 n_{s2}^{1.5} + \cdots + x_m n_{sm}^{1.5}}{x_1 + x_2 + \cdots + x_m}\right)^{2/3} \tag{8}$$

While $n_{s,\max} / n_{s,\min} < 1.5\sim2$,

$$n_s = \left(\frac{x_1 n_{s1} + x_2 n_{s2} + \cdots + x_m n_{sm}}{x_1 + x_2 + \cdots + x_m} \right)^{2/3} \quad (9)$$

where $n_{s,\max}$, $n_{s,\min}$ stand for the maximum and minimum roughness degree in a certain roadway; x_1, x_2 $\cdots$, x_m stand for wetted perimeters correspond to roughness degree of each part n_{s1}, n_{s2} $\cdots$ n_{sm}, m.

(2) Н · Павповский formula is

$$C_s = \frac{1}{n_s} r_s^y \quad (10)$$

where y is an exponent, it is calculated by

$$y = 2.5\sqrt{n_s} - 0.13 - 0.75\sqrt{r_s}\,(\sqrt{n_s} - 1) \quad (11)$$

Н · Павповский formula has many advantages for calculated accuracy and so on. Since its application range ($0.1\text{m} \le r_s \le 3.0$ m) is limited, it is not suitable for this study, so Manning formula has been adopted in this paper. According to formula (5), (6) and (7), the equation of the loss volume of dust-sticking agent is obtained:

$$Q_l = \omega U_l = \frac{Bh_l}{n_s} \left(\frac{Bh_l}{B + 2h_l} \right)^{2/3} \cdot i^{1/2} \quad (12)$$

$$\lim_{B\to\infty} \left(\frac{Bh_l}{B + 2h_l} \right) = \lim_{B\to\infty} \frac{h_l}{1 + 2h_l / B} = h \quad (13)$$

Substituting in equation (12) yields

$$Q_l = \frac{Bh_l^{5/3}\sqrt{i}}{n_s} \quad (14)$$

Changing equation (1) get

$$Q_{nx} = 7.18 \times 10^{-5} Q_{sb} B L_{sb} \mathrm{e}^{-1.05\times 10^{-2} t} / \rho_n \quad (15)$$

where Q_{nx} is the quantity of water absorption of dust-sticking agent in sprinkle range, m^3/h; Q_{sb} the quantity of sprinkle of dust-sticking agent, kg/m^3; L_{sb} the sprinkle length of dust-sticking agent, m; ρ_n the density of dust-sticking, kg/m^3.

On the basis of equations (14) and (15), the formula of dust-sticking agent's loss rate (η_l) is obtained:

$$\eta_l = \frac{Q_{nx} - Q_l}{Q_{nx}} \times 100\% = 100\% \times \frac{7.18 \times 10^{-5} Q_{sb} L_{sb} n_s \mathrm{e}^{-0.0105t} - 3.6 \times 10^3 h_l^{5/3} i^{1/2} \rho_n}{7.18 \times 10^{-5} Q_{sb} L_{sb} n_s \mathrm{e}^{-0.0105t}} \quad (16)$$

4 Method of Practical Verification

The sprinkle experiment was carried out at the return of the number 1407 coal face of Zhangcun coal mine of Luan Coal Mining Administration. Main parameters in the experiment are as follows: sprinkle quantity is 500 g/ m^3; roadway slope is 8°; density of dust-sticking agent is 1.68 g/ cm^3; roadway parameter (up length × down length × slant height × circumference) is 2.9 m × 3.9 m × 3.05 m × 12.0 m, $n_{s,\max}/n_{s,\min}$<1.5~2; air humidity in roadway is more than 80%. Substituting in equation (9) and (6) got η_l= 60%. Therefor the sprinkle period T is calculated with the following formula:

$$T = 5\eta_l Q_{sb} L_z / Q_m \quad (17)$$

where 5 is when air humidity is more than 80%, 1 kg dust-sticking agent can stick more than 5 kg dust; L_z the roadway circumference-roadway up length, m; Q_m the depositing quantity of roadway dust per unit meter. By a practical measurement Q_m= 450 g/(m · d) is obtained.

According to the above formulae, sprinkle period of dust-sticking agent is 31.6 days. There are only 3 days difference compared with the particle measurement result (28 days).

5 Conclusions

After dust-sticking agent is sprinkled in roadway of coal mine the speed of water absorption of dust-sticking agent drops in negative exponent form. There is a balance of water absorption after some time, and the loss of dust-sticking agent occurs mainly in the time before reaching the balance of water absorption. The mathematical model of loss rate established in this paper is close to the result of practical measurement, and its error is less than 10%, therefore it can be used directly on the mining sites or other construction sites.

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