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Dust Dispersion Analysis Based on the Rosen-Rammler Distribution Function

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ABSTRACT
According to the principle of deriving mine dust distribution from the Rosen-Rammler distribution function, dust particle size distribution data at four places on the 4339 working face in Wangzhuang Coal Mine were regression-analyzed so as to get the dust particle size distribution law. The results show that in the area of 5 m away from the working face in the intake airway, the percentages of mine dust of less than 5μm, 5 to 10μm and larger than 10μm in particle size are 14.8%, 32.5% and 52.7%, respectively, with a concentrated distribution of 5 to 20μm. The size of mine dust concentrates in the range of 5 to 10μm for the transfer point, in the range of 5 to 10μm for the 50# support of the working face, and in the range of 5 to 20μm for the area of 20 m away from the working face in the outlet lane. Some corresponding dust-proof suggestions were finally put forward on the basis of the characteristic of mine dust distribution in different places.
KEY WORDS: mining; mine dust; dispersion; distribution functions; regression analysis

1. INTRODUCTION

As one of the most important properties of dust, dispersion is defined as the ratio of various sizes of dust in the whole composition, which has important relationship with miner’s silicosis (Jin, 1993). The particle size distribution law of dust has closed relationship with the labor environment, the implementation of dust-suppression measure and the choice of dust-suppression equipment (Shi et al., 2007).

All the dust particle size distribution measured by various methods and instruments are needed to explore the accurate distribution law using a suitable mathematical method (Isabelle et al., 2005). The common distribution laws are as follows: normal distribution, logarithmic normal distribution and Rosen-Rammler distribution (Wang, 1991).

The mineral and rock that can generate dust during mine production are brittle materials. The dust formed by brittle materials demonstrates the skewed distribution law which has higher bias coefficient (Wang and Hu, 1994). The logarithmic normal distribution can be used to fit the skewed distribution, but it can’t fit accurately because of the bias coefficients of different dust particle size distribution can’t be no difference (Bhaskar, 1988). It is reported that the Rosen-Rammler distribution function as a kind of empirical formulas which has closed relationships with specific dust particle size distribution, can be used to express skewed dust particle distribution (Ou, 2006; Zhen et al., 2005). The reasonable dust-suppression measures can be proposed by the evaluation of workplace environment and dust effects according to the Rosen-Rammler distribution.

2. THE DERIVATION MECHANISM OF THE FORMULA

The expression of Rosen-Rammler distribution function as follows (Dai, 2000),

$$R = 100e^{-\beta \cdot x^n} \quad (1)$$

R——The cumulative distribution of quality, indicate the ration of greater than the accumulative total value of one kind of dust in all kinds of dust, that is the residual rate on the sieve (or named cumulative distribution on the sieve), %;

x——The dust particle size， μm;

β, n——The coefficients related with dust particle size.

The relationship between R and dust particle size is nonlinearity according to the Rosen-Rammler distribution function. The nonlinear relation can be transformed to linear relation by the transformation method.

The detailed process as follows:

$$R = 100e^{-\beta \cdot x^n} \Longrightarrow \frac{100}{R} = e^{\beta \cdot x^n} \Longrightarrow \ln\left(\frac{100}{R}\right) = \beta \cdot x^n$$

Natural logarithm:

$$\ln\left[\ln\left(\frac{100}{R}\right)\right] = \ln\beta + n\ln x_i \quad (2)$$

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Imagine $\ln x_i = x_i'$, $\ln\left[\ln\left(\frac{100}{R}\right)\right] = y_i'$, $\ln\beta = a$, $n = b$, formulation (2) can be exchanged to: $y_i' = a + bx_i'$ 。

Actually, the regression value can be named estimated value (expressed by $\overline{y_i'} = a + bx_i'$) because of the deviation between regression value and actual value. Then this issue can be calculated by linear regression methods.

The common standard to evaluate the regression line is the least squares theory. The existed experimental point: $(x_i', y_i')(i = 1,2,3,\cdots,n)$, the minimum regression line of quadratic sum $\sum_{i=1}^{n}\left(y_i' - \overline{y'}_i\right) = \sum_{i=1}^{n}\left(y_i' - a - bx_i'\right)^2$ is the best.

The minimum of regression line of quadratic sum is existed according to the quadrature methods in calculus. a, b are:

$$b = \frac{Lx'y'}{Lx'x'};\ a = \overline{y'} - b\overline{x'} \tag{3}$$

In the equation:

$$\overline{x'} = \frac{\sum_{i=1}^{n} x_i'}{n};\ \overline{y'} = \frac{\sum_{i=1}^{n} y_i'}{n}$$

$$Lx'x' = \sum_{i=1}^{n}\left(x_i' - \overline{x'}\right)^2 = \sum_{i=1}^{n} x_i'^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i'\right)^2;$$

$$Lx'y' = \sum_{i=1}^{n}\left(x_i' - \overline{x'}\right)\left(y_i' - \overline{y'}\right) = \sum_{i=1}^{n} x_i'y_i' - \frac{1}{n}\sum_{i=1}^{n} x_i'\sum_{i=1}^{n} y_i'$$

The detailed regression calculated procession:

(1) Calculated the number of various dust particle sizes according to the analysis result of dust sample using microscope.

(2) Calculated the weight of various dust particle size. The volume of dust is calculated according to the volume calculated method of sphere because of homogeneous of dust.

(3) Calculated the ratio of the weight of various dust particle size in the total weight.

$$P_{wi} = \frac{n_i d_i^3}{\sum_{i=1}^{n} n_i d_i^3} \times 100\% \tag{4}$$

3. THE EXAMPLE ANALYSIS

3.1 The Introduction of Working Face

3# coal seam as the continental lake type coal mined in the 4339 working face in Wangzhuang Coal Mine is in lower-middle part of geological stratification located in Shanxi group of Permian System. The thickness of stable coal seam is about 7.06~7.30m, average 7.18m, the angle of coal seam is about 0° ~15° , average 7.5° . The outside of working face is westward uniclinal structure, the angle of inclination is relative larger (can achieve to 15° partly).

The dust of coal is explosive. The length of flame is 30mm, spontaneous combustion has not happened. The pressure and temperature of ground is normal. The temperature is 16~18℃. The tangent line of working face is 185.5m which has the direction of north-south; the length of excavation: wind road is 730m, shipping road is 710m. Working face is inclined longwall, retreating comprehensive mechanized top-coal, backward type comprehensive mechanized top-coal drawing a low mining overall height all caving mining method. The ventilation of working face is E type.

3.2 The Statistical Parameters of Dust Dispersion in Working Face

The parameters of dust particle size dispersion in 4339 working face were listed in Table 1~4. The test places are 5m away from the working face in intake airway, transfer point, the 50# support of the working face and 20m away from the working face in outlet lane.

Table 1: Statistical parameter of dust particle size distribution 5m away from the working face in intake airway

Particle size (μm)	<2	2～5	5～10	>10	∑
Particle Number (n)	204	17	7	1	229
Number particle size dispersion n/∑n	89.08%	7.43%	3.06%	0.43%	100.00%
Represent particle sized (μm)	1	3.5	7.5	15	
The equivalent amount of weight nd^3	204	729	2953	3375	7261
Number particle size dispersion $nd^3/\sum nd^3$	2.81%	10.04%	40.67%	46.48%	100.00%
Quality of the cumulative $\sum nd^3$	204	933	3886	7261	7261
Quality of the cumulative dispersion R	100.00%	97.19%	87.15%	46.48%	

Table 2: Statistical parameter of dust particle size distribution in transfer point

Particle size (μm)	<2	2～5	5～10	>10	∑
Particle Number (n)	190	49	18	2	259
Number particle size dispersion n/∑n	73.36%	18.92%	6.95%	0.77%	100.00%
Represent particle sized (μm)	1	3.5	7.5	15	
The equivalent amount of weight nd^3	190	2101	7594	6750	16635

Number particle size dispersion $nd^3/\sum nd^3$	1.14%	12.63%	45.65%	40.58%	100.00%
Quality of the cumulative $\sum nd^3$	190	2291	9885	16635	16635
Quality of the cumulative dispersion R	100.00%	98.86%	86.23%	40.58%	

Table 3: Statistical parameter of dust particle size distribution in 50# support of the working face

Particle size (μm)	<2	2～5	5～10	>10	∑
Particle Number (n)	222	106	22	1	351
Number particle size dispersion $n/\sum n$	63.25%	30.20%	6.27%	0.28%	100.00%
Represent particle sized (μm)	1	3.5	7.5	15	
The equivalent amount of weight nd^3	222	4545	9281	3375	17423
Number particle size dispersion $nd^3/\sum nd^3$	1.27%	26.08%	53.27%	19.37%	100.00%
Quality of the cumulative $\sum nd^3$	222	4767	14048	17423	17423
Quality of the cumulative dispersion R	100.00%	98.73%	72.65%	19.38%	

Table 4: Statistical parameter of dust particle size distribution 20m away from the working face in outlet lane

Particle size (μm)	<2	2～5	5～10	>10	∑
Particle Number(n)	230	65	22	4	321
Number particle size dispersion $n/\sum n$	71.65%	20.25%	6.85%	1.25%	100.0%
Represent particle sized (μm)	1	3.5	7.5	15	
The equivalent amount of weight nd^3	230	2787	9281	13500	25798
Number particle size dispersion $nd^3/\sum nd^3$	0.89%	10.80%	35.98%	52.33%	100.0%
Quality of the cumulative $\sum nd^3$	230	3017	12298	25798	25798
Quality of the cumulative dispersion R	100.00%	99.11%	88.31%	52.33%	

3.3 The Regression Calculation of Dust Dispersion Degree in Working Face

The representative particle sizes d (listed in Table 1~4) and regression calculated data obtained by the cumulative distribution of quality were listed in Table 5~8.

Table 5: Regression dust particle size 5m away from the working face in intake airway

Particle size X(μm)	y'_i $(\ln\cdot\ln\frac{100}{R})$	x'_i $(\ln x)$	$(y'_i)^2$ $(\ln\cdot\ln\frac{100}{R})^2$	$(x'_i)^2$ $(\ln x)^2$	$x'_i\cdot y'_i$ $(\ln\cdot\ln\frac{100}{R}\cdot\ln x)$
2	-3.5578	0.6931	12.6577	0.4804	-2.4659
5	-1.9838	1.6094	3.9356	2.5902	-3.1928
10	-0.2664	2.3026	0.0710	5.3020	-0.6134
∑	-5.8080	4.6051	16.6643	8.3726	-6.2721

Table 6: Regression dust particle size in transfer point

Particle size X(μm)	y'_i $(\ln\cdot\ln\frac{100}{R})$	x'_i $(\ln x)$	$(y'_i)^2$ $(\ln\cdot\ln\frac{100}{R})^2$	$(x'_i)^2$ $(\ln x)^2$	$x'_i\cdot y'_i$ $(\ln\cdot\ln\frac{100}{R}\cdot\ln x)$
2	-4.4684	0.6931	19.9667	0.4804	-3.0971
5	-1.9095	1.6094	3.6463	2.5902	-3.0732
10	-0.1033	2.3026	0.0107	5.3020	-0.2378
∑	-6.4812	4.6051	23.6236	8.3726	-6.4080

Table 7: Regression dust particle size in 50# support of the working face

Particle size X(μm)	y'_i $(\ln\cdot\ln\frac{100}{R})$	x'_i $(\ln x)$	$(y'_i)^2$ $(\ln\cdot\ln\frac{100}{R})^2$	$(x'_i)^2$ $(\ln x)^2$	$x'_i\cdot y'_i$ $(\ln\cdot\ln\frac{100}{R}\cdot\ln x)$
2	-4.3598	0.6931	19.0076	0.4804	-3.0218
5	-1.1409	1.6094	1.3018	2.5902	-1.8362
10	0.4953	2.3026	0.2453	5.3020	1.1404
∑	-5.0055	4.6051	20.5546	8.3726	-3.7176

Table 8: Regression dust particle size 20m away from the working face in outlet lane

Particle size X(μm)	y'_i $(\ln\cdot\ln\frac{100}{R})$	x'_i $(\ln x)$	$(y'_i)^2$ $(\ln\cdot\ln\frac{100}{R})^2$	$(x'_i)^2$ $(\ln x)^2$	$x'_i\cdot y'_i$ $(\ln\cdot\ln\frac{100}{R}\cdot\ln x)$
2	-4.7172	0.6931	22.2523	0.4804	-3.2695
5	-2.0849	1.6094	4.3469	2.5902	-3.3555
10	-0.4345	2.3026	0.1888	5.3020	-1.0004
∑	-7.2366	4.6051	26.7880	8.3726	-7.6254

3.4 The Deduction of Distribution Function of Dust Dispersion Degree in Working Face

Take the place of 5m away from the working face in intake airway for example. According to the datum in Table 1, the follows can be achieved:

$$Lx'y' = \sum_{i=1}^{n} x'_i y'_i - \frac{1}{n}\left(\sum_{i=1}^{n} x'_i\right)\left(\sum_{i=1}^{n} y'_i\right)$$

=-6.2721-(4.6051)×(-5.8080)/3

=2.6434

$$Lx'x' = \sum_{i=1}^{n} x'^2_i - \frac{1}{n}\left(\sum_{i=1}^{n} x'_i\right)^2$$

=8.3726-(4.6051)2/3

=1.3036

b=Lx'y'/Lx'x'=2.6434/1.3036= 2.0277

$$a = \overline{y'} - b\overline{x'} = \frac{1}{n}\sum_{i=1}^{n} y'_i - b\cdot\frac{1}{n}\sum_{i=1}^{n} x'_i$$

$$= \frac{-5.8080}{3} - 2.0277\times\frac{4.6051}{3} = -5.0486$$

n=b=2.0277，a=lnβ= -5.0486，

$$\beta = e^{-5.0486} = 0.0064$$

The dust particles distribution function in the place of 5m away from the working face in intake airway in Wangzhuang Coal Mine:

$$R = 100e^{-0.0064x^{2.0}} \quad (5)$$

When R=50％，the dust and particles size is median diameter expressed by x_{50}, then $\ln\left(\frac{100}{R}\right) = \beta x^n$, $\ln\left(\frac{100}{R}\right) = \beta x_{50}^n$, that is $\ln 2 = \beta x_{50}^n$, so $x_{50} = \sqrt[n]{\frac{\ln 2}{\beta}} = \sqrt[2]{\frac{\ln 2}{0.0064}} = 10.407\mu m$.

The deduction method is the similar to the above. The dust particles distribution function of transfer point, 50# support of the working face and 20m away from the working face in outlet lane can be obtained as follows:

$$R = 100e^{-0.0018x^{2.72}} \cdots x_{50} = 8.92\mu m \quad (6)$$

$$R = 100e^{-0.0018x^{3.04}} \cdots x_{50} = 7.09\mu m \quad (7)$$

$$R = 100e^{-0.0015x^{2.67}} \cdots x_{50} = 9.95\mu m \quad (8)$$

The dust particles size dispersion law can be obtained by Rosen-Rammler distribution function and the method is similar to the above.

3.5 The Analysis of the Quality Cumulative Distribution of Dust Dispersion Degree in Working Face

The dust particles distribution function in the place of 5m away from the working face in intake airway in Wangzhuang Coal Mine is $R = 100e^{-0.0064x^{2.0}}$ and Table 9 can be listed.

Table 9 showed the value of dust dispersion degree in some range of particle size. The percentage of the particle size lower than 5μm is 14.8%, 5~10μm is 32.5%, larger than 10μm is 52.7%, larger than 30μm is 0.3% in the place of 5m away from the working face in intake airway. It is indicated that the dust particle size is within 5~20μm. It is reported that the dust size lower than 5μm is the most harmful to human and is the key element leading to miner's silicosis (Liu, et al., 2007). The air in intake airway is fresh, so the big particle size entrained dust is the reentrainment of dust after blow excitation deposition, which is less harmful to human.

Table 9: Quality cumulative distribution of dust distribution5m away from the working face in intake airway

X(μ)	0	1	2	3	4	5	6	7	8	9	10	20	30	40	50
R(%)	100	99.4	97.5	94.4	90.3	85.2	79.4	73.1	66.4	59.5	52.7	7.7	0.3	3.6E-03	1.1E-05

The dust particles distribution function in the place of transfer point in Wangzhuang Coal Mine is $R = 100e^{-0.0018x^{2.72}}$ and Table 10 can be listed.

It can observed from Table 10 that the percentage of the particle size lower than 5μm is 13.4%, 5~10μm is 47.75%, larger than 10μm is 38.9%. And the particle size larger than 20μm is 0.2%. It is indicated that the dust particle size is mainly in 5~10μm, and there are few big size particles. As one of the most important dust generated places, automatic sprinkling water spray can be used to restrain the dust in transfer point.

Table 10: Quality cumulative distribution of dust distribution in transfer point

X(μ)	0	1	2	3	4	5	6	7	8	9	10	20	30	40	50
R(%)	100	99.8	98.8	96.5	92.5	86.6	79.0	69.9	59.8	49.2	38.9	0.2	7.2E-07	1.5E-16	2.1E-31

The dust particles distribution function in the place of 50# support of the working face in Wangzhuang Coal Mine is $R = 100e^{-0.0018x^{3.04}}$ and Table 11 can be listed.

It can observed from Table 11 that the percentage of the particle size lower than 5μm is 21.3%, 5~10μm is 64.8%, larger than 10μm is 13.9%. And there are few particles whose size is larger than 20μm. It is indicated that the dust particle size is mainly in 5~10μm and the concentration of respirable dust is higher. So this place is the key prevention area of this working face.

It can be concluded that the method of coal seam water injection, coal winning machine interior and exterior spray and air curtain dust technology play good effects in this working face. However, the better effect can be achieved by other elements such as the properties of coal, the condition of coal layer and the choice of the parameter of cutting mechanism (the type, size, amount, acutance and setting direction of picks). For the situation that the dust has spread, the flow field of airflow should be tested and the nozzle and wet dust collector should be rightly set to prevent the dust spreading to sidewalk area.

Table 11: Quality cumulative distribution of dust distribution in 50# support of the working face

X(μm)	0	1	2	3	4	5	6	7	8	9	10	20	30	40	50
R(%)	100	99.8	98.5	95.0	88.5	78.7	65.9	51.3	36.7	23.9	13.9	8.9 E-06	6.6 E-23	1.0 E-56	5.4 E-113

The dust particles distribution function in the place of 20m away from the working face in outlet lane in Wangzhuang Coal Mine is $R = 100e^{-0.0015x^{2.67}}$ and Table 12 can be listed.

It can be observed from Table 12 that the percentage of the particle size lower than 5μm is 10.4%, 5-10μm is 40%, larger than 10μm is 49.6%. And the particle size larger than 20μm is 1.2%. It is indicated that the dust particle size is mainly in 5-20μm.

Dust removal by ventilation and water wet are the main dust prevention measures in intake airway. The two measures have good effect in first settling but it cannot last as the increasing of dust. The dust will be risen again by the wind and the concentration of dust in intake airway will be increased again. Spray binder can prevent dust, dust will be wetted and cannot fly again (Qi et al., 2007).

Table 12: Quality cumulative distribution of dust distribution 20m away from the working face in outlet lane

X(μm)	0	1	2	3	4	5	6	7	8	9	10	20	30	40	50
R(%)	100	99.9	99.0	97.2	94.1	89.6	83.6	76.3	67.9	58.9	49.6	1.2	1.9E-04	4.6E-11	4.0E-21

4. CONCLUSION

In this work, the properties, range of application, deduction mechanism and regression method of the Rosen-Rammler distribution function were discussed. The usage and analysis method of this function was explained by the example of 4339 working face. According to the related advices and evaluations obtained by the regression law on the effect of dust prevention measures, we can get the conclusions as follows:

(1) The Rosen-Rammler distribution function as a kind of empirical formulas can explain skewed dust particle distribution. The data processed by the Rosen-Rammler distribution function can describe the dust particle distribution law.

(2) The percentage of the particle size lower than 5μm is 14.8%, 5~10μm is 32.5%, larger than 10μm is 52.7%, larger than 30μm is 0.3% in the place of 5m away from the working face in intake airway. It is indicated that the dust particle size is in 5~20μm.

(3) The dust particle size is mainly in 5~10μm, and there are few big size particles in the place of transfer point. Transfer point can restrain the dust by automatic sprinkling water spray.

(4) It is indicated that the dust particle size is mainly in 5~10μm and the concentration of respirable dust is high in the place of 50# support working face. It can be concluded that the method of coal seam water injection, coal winning machine interior and exterior spray and air curtain dust technology play good effects in this working face. However, the better effect can be achieved by other elements such as the properties of coal, the condition of coal layer and the choice of the parameter of cutting mechanism (the type, size, amount, acutance and setting direction of

picks). For the situation that the dust has spread, the flow field of airflow should be tested and the nozzle and wet dust collector should be rightly set to prevent the dust spreading to sidewalk area.

(5) It is indicated that the dust particle size is mainly in 5~20μm in the distance of 20m away from the working face in outlet lane. Spray binder can prevent dust, dust will be wetted and cannot fly again.

5. ACKNOWLEDGEMENT

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