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Relationship of Seam Smoldering Velocity and Oxygen Volume Fraction Gradient in Roadway

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Abstract

Smoldering is an oxygen control reaction and its velocity is determined by oxygen supplying rate. Oxygen volume fraction gradient was used to characterize oxygen supplying rate in roadway according to situation that the velocity of wind flowing is very low during smoldering in roadway. Relationship of smoldering velocity and oxygen volume fraction gradient in roadway during lignite smoldering was researched in experiment drawing support of seam smoldering simulating experiment device in roadway and one-variable linear regression technology was used to establish the relation equation of smoldering velocity and oxygen volume fraction gradient in roadway when lignite was smoldering. This relation equation showed that smoldering velocity and oxygen volume fraction gradient took on linear increasing relationship in roadway during lignite smoldering.

Keywords: roadway; seam; smoldering velocity; oxygen volume fraction gradient; equation

Smoldering is a no-flame slow combustion which takes place in porous fuel and can sustain advancing by itself [1]. Smoldering easily occurs in porous fuel, for one thing this structure fuel is good to translate oxygen to smoldering surface by means of convection and diffusion and make smoldering surface get continuous oxygen supply; for another this structure fuel is good for accumulating of heat, which can make smoldering spread steadily[2]. Materials easy to smoldering include coal, cotton, combustible dust, scraps of paper, polyurethane foam, heat insulation material and sawdust etc. Seam smoldering belongs to positive smoldering[3],for example seam smoldering caused by spontaneous combustion in Xinjiang

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Liuhuanggou coalfield lasts for hundred of years[4]. Smoldering is oxygen-control reaction. This kind of low oxygen condition restricts forming of combustion with flame and also restricts translating of smoldering [5]. Research on fiber grain (for example sawdust) show that smoldering velocity and wind flowing velocity take on linear increasing relationship and velocity of wind flowing affects the highest temperature of smoldering of fuel weakly[2,4,6]. The relationship of seam smoldering velocity and oxygen volume fraction gradient was researched in experiment in connection with smoldering of seam in a waste tunnel in this paper.

1. Analysis on wind flowing in roadway during smoldering

As shown in Fig.1, M was the remained coal smoldering spot. As the air temperature in the roadway was higher than the outside, hot air flowed out through the upper roadway while cool air flowed in through the lower roadway, so weak wind flowing formed in the roadway. Oxygen needed in smoldering surface was provided by means of wind flowing and diffusion. Because velocity of wind flowing was very weak, oxygen volume fraction gradient was used to characterize oxygen supply rate was more reasonable.

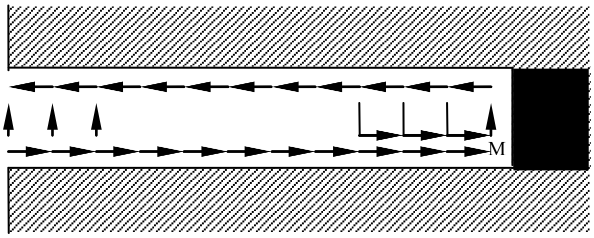

Fig.1 Air flow diagram of the coal seam smoldering in roadway

2. Experiment research on relation of seam smoldering velocity and oxygen volume fraction gradient in roadway

2.1 Experiment device and arranging of its measuring points

As shown in Fig.2, the experiment devices consisted of 5 parts: 1) Seam and roadway simulating device. It was made by ASFB (aluminum silicate fiber board) , which was covered by isolating board, and its specification was 400 mm×400 mm×76 mm, the thickness of the seam was 56 mm, the length, the width and the height of the roadway were F mm,42.5mm+E(42.5mm and E respectively was the distance between the heating stick and the left side wall and the one between the heating stick and the right side wall when coal sample was being heated , the heating stick was stretched into seam 15mm when heating ,the heating stick was extracted immediately after smoldering of coal sample occurred.) and 56 mm separately. 2) Coal sample. The fresh lignite sample was collected from the new exposed coal wall of the working face and packaged on the spot. In the experiment, the coal blocks were shattered into granules, whose granularity was 2mm~10mm during the experiment. 3) Heating device. The coal sample was heated by the stainless steel heating stick with 600W, whose heating temperature could reach to 1200 ℃. 4) Coal sample temperature measuring device. It was composed of the armored thermocouple and the color screen non-paper recorder. The measuring point 1 was 60 mm away from the throat of the experimental device， the measuring point 2 was also 60mm away from the measuring point 3 and the same distance existed between the measuring point 4 and the measuring point 9, the horizontal and vertical distances between the other various measuring points were all 30mm.The working range of the armored thermocouple was 0℃-1300℃. The color screen non-paper recorder served to record the temperature data of all channels once every 0.1 second. 5）Gas measuring device .It was composed of KM9106 synthetic smog analyzer and the exhaust pipe.

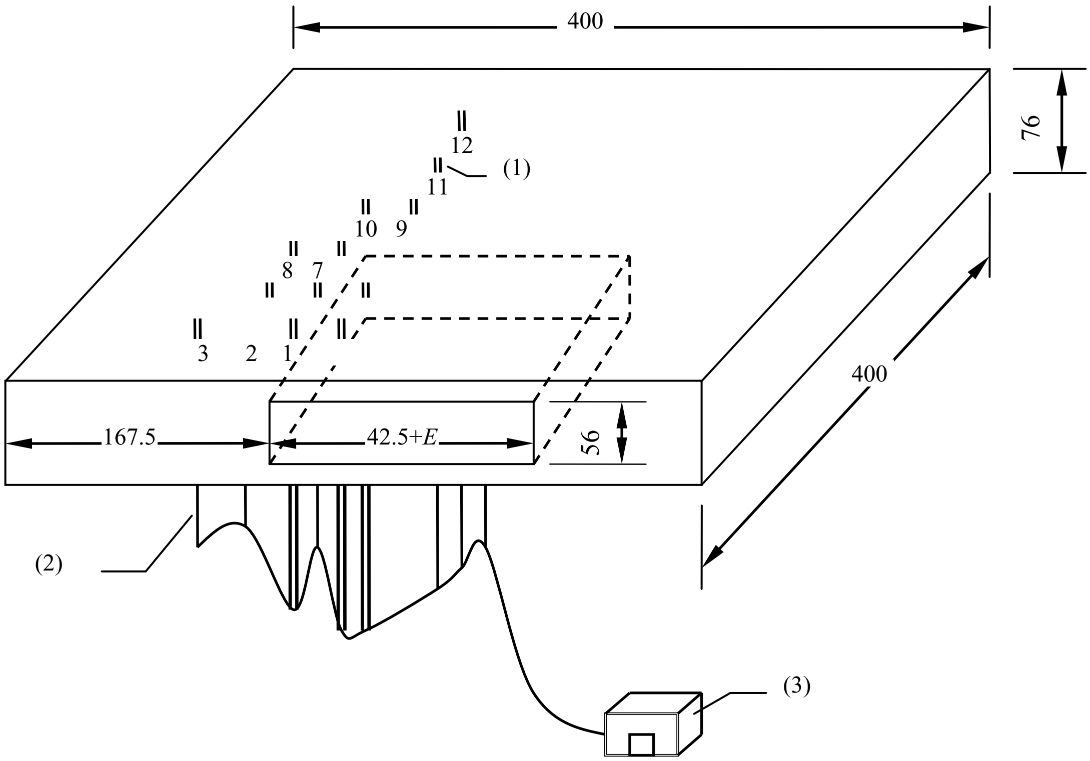

Fig.2 Experimental equipment diagram of simulating roadway coal Seam smoldering

(1)O_2measuring exhaust pipe; (2) armored thermocouple; (3) color screen non-paper recorder

2.2 Experiment and its result analysis

Heated by the heating stick, smoldering of the coal sample occurred. Then the heating stick was taken away in order to keep the lignite sample smolder in condition of diffusion. When the temperature of smoldering spot increased to smoldering temperature (smoldering temperature of the lignite determined by experiment was 305.4℃), smoldering began to be believed to occur. Experimental measuring results are shown in Table.1.

$$v_{j-k} = \frac{\Delta S_{j-k}}{\Delta t_{k-j}} \qquad (1)$$

$$E_{j-k} = \frac{\Delta F_{j-k}}{\Delta S_{j-k}} \tag{2}$$

where v_{j-k} is the seam mean smoldering velocity from the measuring point *j* to the measuring point *k*(m/s); ΔS_{j-k} is the straight-line distance between the measuring point *j* and the measuring point *k*(m); Δt_{k-j} is the time difference of the temperature of the measuring point *k* increasing to smoldering temperature and the temperature of the measuring point *j* increasing to smoldering temperature(s); E_{j-k} is the oxygen velocity fraction gradient from the measuring point *k* to the measuring point *j*(%/m); ΔF_{j-k} is the difference of the measuring point *j* oxygen volume fraction and the measuring point *k* oxygen volume fraction(%).

Table.1. Calculating of smoldering spreading velocity

Team	Δt_{k-j}/s	ΔF_{j-k}/%	ΔS_{j-k}/m	E_{j-k}/%·m^{-1}	v_{j-k} ×10^6/m·s^{-1}
1	Δt3-2=47280	ΔF2-3=1.4	ΔS2-3=0.06	E2-3=28.0	v2-3=1.27
2	Δt6-5=39480	ΔF5-6=0.8	ΔS5-6=0.03	E5-6=26.6	V5-6=0.76
3	Δt8-7=20640	ΔF7-8=1.3	ΔS7-8=0.03	E7-8=43.3	V7-8=1.45
4	Δt8-6=16800	ΔF6-8=1.6	ΔS6-8=0.03	E6-8=53.3	V6-8=1.79
5	Δt10-7=20340	ΔF7-10=1.5	ΔS7-10=0.03	E7-10=50.0	v7-10=1.47
6	Δt10-9=16200	ΔF9-10=1.8	ΔS9-10=0.03	E9-10=60.0	v9-10=1.85

The relationship of seam smoldering velocity *v* and oxygen volume fraction gradient *E* is assumed to be linear relationship. That is:

$$v = a + bE \tag{3}$$

where *v* is seam smoldering velocity (m/s); *E* is oxygen volume fraction gradient (%/m);*a* is constant; *b* is constant;

According to one-variable linear regression principle, *a* and *b* are given by the following expression:

$$a = \frac{\sum_{i=1}^{n} E_i \times \sum_{i=1}^{n} E_i v_i - \sum_{i=1}^{n} E_i^2 \times \sum_{i=1}^{n} v_i}{\left(\sum_{i=1}^{n} E_i\right)^2 - n\sum_{i=1}^{n} E_i^2} \tag{4}$$

$$b = \frac{\sum_{i=1}^{n} E_i \times \sum_{i=1}^{n} v_i - n\sum_{i=1}^{n} E_i v_i}{\left(\sum_{i=1}^{n} E_i\right)^2 - n\sum_{i=1}^{n} E_i^2} \qquad (5)$$

where v_i is the measured value of seam smoldering velocity(m/s); E_i is the measured value of oxygen velocity fraction gradient(%/m); n is the number of measured data teams.

Accuracy of model (3) could be decided by linear relationship coefficient R.

$$R = \frac{L_{xy}}{\sqrt{L_{xx} L_{yy}}} \qquad (6)$$

$$L_{xy} = \sum_{i=1}^{n} E_i v_i - \frac{1}{n}\sum_{i=1}^{n} E_i \times \sum_{i=1}^{n} v_i \qquad (7)$$

$$L_{xx} = \sum_{i=1}^{n} E_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} E_i\right)^2 \qquad (8)$$

$$L_{yy} = \sum_{i=1}^{n} v_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} v_i\right)^2 \qquad (9)$$

R lies between 0 and 1.1) If R=1, then equation (3) is fully in accordance with actual situation.2) If R=0, then equation (3) is hardly in keeping with actual situation. 3)If $0<R<1$,then equation(3) is in line with actual situation to a certain extent, and the more the R is ,the better equation(3) and actual situation agree; conversely , the less the R is, the worse equation(3) and actual situation agree.

On the basis of data in table 1, a=2.919×10-7 and b=2.618×10-8 were obtained with equation (4) and equation (5), v is given by:

$$v=2.919\times10^{-7}+2.618\times10^{-8}E \qquad (10)$$

According to equation (6) – equation (9) and table1, R=0.91 was obtained. Smoldering velocity and oxygen concentration gradient agreed linear relationship in equation (10).That is to say the higher the oxygen concentration, the faster the smoldering velocity.

3. Conclusions

(1) Oxygen volume fraction gradient is used to characterize supply rate of oxygen is reasonable during seam smoldering in waste tunnel because the velocity of wind flowing is very weak.

(2) The relationship of smoldering velocity and oxygen density gradient is linear increasing when coal seam is smoldering in the roadway.

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