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Research on the distributing law of the gas in the gob area based on flow-tube model

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Abstract

Based on network solution, the gob area wind field in air leak distribution is derived. Then stream-tube model and conservation equation between stream-tube gas volume and composition are established. Air leak field is analyzed and streamline is drawn by matlab2007a. According to gas concentration data of the monitored finite points, gob area concentration field can be simulated to get the gob gas distribution.

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Keywords: network solution; flow tube; gas distribution; gob caving band

1. Introduction

With the continuous extension of the depth of mining and the increase of mine intensification and the scale of mining, mine gas emission also increases, followed with the increasing gas hazard and accidents. In view of the scarcity of monitoring methods to the mine gob gas, how effectively predict gas distribution by numerical simulation becomes the problem to be solved now.

In article [1~2], the gas flow of mine gob area is analyzed by fluent, and CFD analyzes it by using gas concentration of fixed boundary and different turbulence models. However, boundary conditions are difficult to control and match the diversity and complexity of the gas distribution of mine gob area in the reality. In article [3], flow field distribution of gob area is simulated by air leak distribution computing model based on network solution. It can only calculate the potential energy of network nodes and wind speed, but the gas distribution. In article [4], stream-tube model of gob area is proposed and its relevant analytical solution is derived, whose gob area flow field is solved by fluent. Through network solution,

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this paper simulates mine gob area flow field, and gives the drawing and solution of streamline, and provides a new approach to the study of gob gas distribution with stream-tube model.

2. Simulation of gob area air leak based on network solution

Gob area is the anisotropic porous media. In the normal circumstance, the side of caving zone and working face are adjacent, other sides and air leak channel are linked to the upper and lower airway of working face, so the density of caving zone in the spatial distribution is uneven that pore space of gob area is not the same and density of caving zone increases with time\(^5\). Therefore, the mine gob area wind flow field is complex.

When the roof of working face caves, the caving rock is not immediately compacted, in the normal circumstance, more far distance from caving zone to working face will lead to far higher degree of compaction, so there is certain porosities in the mine gob area, which forms a series of air leak channel. Gob gas flows in the porous media, so the following basic assumptions can be done:

- Air flow through the gob caving zone is similar to through many crisscrossing short tubes
- The effect of air flow through many crises-cross short tubes is the same to the flow effect through large tubes (or so-called branches)

By the above assumptions, the mine gob area porous media is converted into the network system, which can simulate the gob air leak field according to network simulation technology.

3. Numerical simulation of gas concentration field in the gob area by flow-line model

3.1. The stream tube model in the gob area

The mathematical equation of component transport that the distribution of gas concentration field in the gob area is necessary to meet is essentially a non-linear equation, currently, it is still very difficult to solve in mathematics directly. When we don't consider that the concentration field has an impact on the velocity field, the velocity field is just a function of spatial coordinates, it is known that the equation of component transport of velocity field is a linear differential equation with variable coefficients, the traditional mathematical solution method is still more complicated. In this paper, it is provided a compute method of the gas concentration field under the known flow field based on the concept of flow tube.

![Fig.1.schematic diagram of flow tube](image-url)
As Fig 1 shown, it's named flow-tube that is constituted of flow lines on the composition of some nodes of E curves at a certain instant, the curves are non-flow-lines and non-self-intersecting closed in the flow field. If the curve E is infinitely small, called flow-tube element; otherwise, known as limited flow-tube. Because the surface of flow-tube is made up of flow-lines, the fluid can not flow in or out through the side of the flow-tube.

Let's assume there is a flow-tube in the mining area as shown in Fig 1, the cross-section $A_{in}$ of the entrance to the flow-tube and the average speed $v_{in}$ on the cross-section, the cross-section $A_{out}$ of the exit and the average speed $v_{out}$ on the cross-section, the length is $l$, so, the volume $V$ of the flow-tube can be expressed by the following formula:

$$V = l\overline{A} = l\theta(A_{in} + A_{out})$$

(1)

In the formula, $\overline{A}$ is the average cross-section area of the flow-tube, $\theta$ is the coefficient of the average cross-section.

(1) flow-tube volume conservation equation

Assuming at normal temperatures and pressures, the flow field where the flow tube is to exist is steady and incompressible gas flow-field, it can be obtained from mass conservation equation that:

$$v_{in}A_{in} + VI = v_{out}A_{out}$$

(2)

In the formula, the average speed on the cross-section of the flow-tube at the entrance is $v_{in}$, unit: m/s; $A_{in}$ is the cross-section area of the flow-tube at the entrance, unit: m$^2$; the average speed on the cross-section of the flow-tube at the exit is $v_{out}$, $A_{out}$ is the cross-section area of the flow-tube at the exit; $V$ is the flow-tube volume, unit: m$^3$; $I$ shows the gas emission volume in the flow-tube per volume and time, unit: 1/s, when using 2D model, $I$ shows the gas emission volume per volume and time, unit: m/s.

(2) Component of gas conservation equations in the flow-tube

Assuming the gas emitting from the flow tube is pure gas, the gas concentration at the entrance is $c_{in}$, the gas concentration at the exit is $c_{out}$, then:

$$c_{in}v_{in}A_{in} + VI = c_{out}v_{out}A_{out}$$

(3)

3.2. Solving the concentration field in the gob area where the flow field is known based on the flow-tube model

(1) The derivation of the formula to solve gas concentration at the exit

Known conditions: the volume concentration and velocity at the entrance: $c_{in}$, $v_{in}$, the velocity at the exit: $v_{out}$; the length: $l$, the strength of gas emission: $I$

Unknown conditions: the cross-section area at the entrance: $A_{in}$; the cross-section area at the exit: $A_{out}$; the gas concentration at the exit: $c_{out}$

Empirical parameters: the coefficient of the average cross-section: $\theta$, $\theta \in [\frac{1}{3}, \frac{1}{2}]$. The higher ratio between import and export speed, the $\theta$ is closer to 1/3, or the $\theta$ is closer to 1/2.

Assuming the extreme velocity of the flow-tube to achieve at both ends,

Assuming the extreme velocity of the flow-tube to achieve at both ends, monotone velocity variation. It can be obtained by putting (1) into (2),(3) that:

$$v_{in}A_{in} + l\theta(A_{in} + A_{out})I = v_{out}A_{out}$$

(4)
\[ c_{in}v_{in}A_{in} + l \theta (A_{in} + A_{out})I = c_{out}v_{out}A_{out} \]  
(5)

Then:

\[ c_{out} = \frac{c_{in}v_{in}v_{out} + l \theta l (v_{in} + v_{out} - c_{in}v_{in})}{v_{out}(v_{in} + l \theta l)} \]  
(6)

When the gas concentration at the entrance is 0, the formula (7) can be simplified that:

\[ c_{out} = \frac{l \theta l (v_{in} + v_{out})}{v_{out}(v_{in} + l \theta l)} \]  
(7)

(2) To solve the gas concentration at any point in the gob area

It can be considered that a series of flow-lines constitute the flow field in the gob area, every flow-line is a flow-tube element. Under the condition of the gob area flow-field is to be known, in other words, the shape of each flow line and the speed of each point on the flow line are to be known, assuming that the gas concentration at the entrance is 0 on each flow-line, the gas concentration at any point on each flow-line can be obtained by using the formula (7). Otherwise, if the gas concentration at the entrance on each flow-line was known, the gas concentration at any point on each flow-line can be obtained by using the formula (6). The gob gas concentration field will be got after solved the gas concentration at any point on each flow-line.

Because the solving of the gob gas concentration field can be converted to the solving of the length of each flow lines in the gob area, it's much easy that put this method into practice:

According to the figure of the flow-field and flow-line which has been done, take n nodes on the flow-line, well, the coordinates of the n points are known; The flow-line will be divided n+1 segments with n nodes, the two adjacent points are connected by straight lines, the length of a segment can be solved using the formula that the length of a straight line between two points, when the n is infinity, the summation length of the n+1 segments is the length of the flow-line, the formula is that:

\[ l = \sum_{i=1}^{n} \sqrt{(x_{i} - x_{i-1})^2 + (y_{i} - y_{i-1})^2} \]

In the formula, the length: \( l \), the number of points obtained on the flow-line: \( n \), the coordinates of the i-th points: \( x_i, y_i \).

4. Drawing of flow line

Flow line \([6]\) is a man-made smooth curve in the flow field, its tangent of each point and the velocity vector of this point on the flow line are coincident at the same instant.

Flow lines can be determined by the following simultaneous differential equations:

\[ \nabla \cdot \mathbf{V} = 0 \]

Fig. 2. Drawing of the flow-line
\[
\frac{dx}{V_x} = \frac{dy}{V_y} = \frac{dz}{V_z}
\]

The velocity distribution is given, equations can be integrated a series of flow-lines.

The wind speed of network nodes is obtained after the network solution, and its distribution is difficult to represent by a distribution function, in the view of the strong math library in matlab2007a\textsuperscript{[7]}, the gob area flow field can be obtained by the wind speed of the normalized network nodes, the results will be more precise with the encrypted grids, because of the simulation of the wind speed of network nodes, we can draw the flow-lines in the gob area flow-field according to the velocity vector of these network nodes, further on, the result can be calculated according to the flow tube.

5. Simulation examples and analysis

Given that the length of long wall coal face\textsuperscript{[5, 8]} is 120m, the strike length of caving mined area is 200m, mining height is 2m, Roof lithology is hard clay shale, advancing speed of working face is 1m/d, the pureness of caving zone is 0.10, the gob area has one air leakage source (a) and air leakage remit (b), which is shown in Fig.3 after network processing:

Some about parameters in the network as following: \(\Delta L=20\text{m}\); the empirical coefficient was taken according to the lithology of roof of coal seam: \(a=0.2, b=71\); The wind pressure which is the main ventilator acting on the system of work plane is taken 147Pa; the average wind velocity is 2m/s face into the airway, dynamical pressure of wind fluid is about 9.8Pa. The rule of the direction flow of air leakage passage in the seepage field: the upward is positive for the vertical branch, the right is positive for the horizontal branch.

The isopiestic line for the seepage field was drawn based on the nodes potential energy from the network solution of the seepage field as shown in fig 4, the flow-line in the seepage field was drawn based on the wind speed of network nodes, as the fig 5 shown. In this Simulation, the air flow rate from
the air leakage head (a) into the gob area is \( Q_4 = 0.252 \text{m}^3/\text{s} \), the air flow rate from the gob area into the air leakage sink (b) is \( Q_5 = 0.570 \text{m}^3/\text{s} \), the difference value between these is \( 0.318 \text{m}^3/\text{s} \), all these data play a decisive role in the distribution of air leakage in the gob area.

![Isopiestic lines](image1)

**Fig. 4. Isopiestic lines**

![Flow-field](image2)

**Fig. 5. Flow-field**

Now, it’s considered that the coordinate of two nodes is \( P_1 = (200, 0) \), \( P_2 = (180, 80) \), the length between the two nodes is \( l = 88.28 \text{m} \) by calculating. According to the result of the velocity field, \( v_1 = 0.003014 \text{m}/\text{s} \), \( v_2 = 0.002434 \text{m}/\text{s} \). Assuming the gas concentration at the entrance on the flow-line is \( 0 \), well, \( = 0 \), so-so the value of \( \) should be solved with use of the formula (8). Considering that the speed gap between two nodes is very small, so \( = 1/2 \) is also be ok. All these above data was used in the formula (7), we can obtained \( = 0.0481 \). Finally, The gob area concentration field was analyzed by using FLUENT.
software was $=0.0492$, which indicates that there are no differences between the results of the two methods: the formula (7) calculating the gob gas and the FLUENT software simulation of gob gas. However the former is more convenient and easier.

The draw which has been drawn according to the gob area concentration field as the fig 6 shown,

It's practical that the further from the gob caving band to the working plane, the higher concentration of the gas. In practice, we will investigate gas concentration field distribution at any point in the gob area according to the limited points data, we detected in the gob area.

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![Fig. 6. The concentration field in the gob area](image)

**6. Conclusions**

By network computing of air leakage field, the method of analyzing flow field and streamline of gob area with matlab mathematical software was proposed. The gas concentration distribution of gob area can be obtained by stream tube model, which has great practical significance to the law study of gas distribution of gob area.

- The simulation results show that in gob areas near working face, air leakage rate is big, and air speed is also great; the gas is considerably diluted and migrated, and its density is low. With the distance to working face increasing, air leakage rate of gob area gradually decreases, and gas concentration relatively increases. Gas accumulating is the key factor to its density increasing in gob area.
- According to the distribution law of gas concentration, the probability function of gas concentration distribution in gob area can be established, and gas emission rate in gob area can be simulated by the Monte Carlo random function.
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