Analysis of Disaster Gas Accumulation Characteristics in Local Area of Upper Corner Based on Entropy Variable Dissipative Structure Model

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Abstract: This paper takes the angle CO of the 1406 working face of Fengjiata Coal Mine as main research object, by combining field measurement, theoretical research and numerical simulation, to explore essence of energy dissipation during gas accumulation in the upper lag zone and seek effective governance solutions. The result shows that the irreversible process such as eddy current loss caused by the spatial morphology of the upper sag angle is an important cause of gas accumulation. Thus, a flexible inflatable airbag for mining to change local ventilation mode is proposed and designed. The numerical simulation method is used to verify the venting of the mine inflatable airbag, which helps significantly eliminate the eddy current phenomenon in the lag zone.

1. Preface
In recent years, with the continuous improvement of mechanized mechanization level in northern Shaanxi mining area, the large-volume shifting device installed at the tail of the machine causes the tail of the working face to be in a state of partial bracket lag for a long time. The problem of gas gathering and exceeding limits of the working face returning to the wind and the corner is becoming more and more serious, which now is a major hidden danger that seriously restricts coal mine safety production.

Research and practice show that: accumulation of disaster gas in upper corner is the result of material, energy and information exchange between the local ventilation system of the upper corner and surrounding environment. However, currently there is limited research about energy dissipation characteristics of the gas accumulation process in the upper corner. Therefore, based on the equivalence and unity of information entropy and thermodynamic entropy, this paper conducts entropy analysis of the concentration of disaster gas accumulation in the lag zone of the upper corner, combing field tests and numerical simulations, to exploring the characteristics of disaster gas accumulation in the upper sag angle region from the perspective of energy dissipation, Finally, it is proposed to use the mine flexible inflatable airbag to deflate and drain, introducing "negative entropy flow" to control limitation exceeding of gas in the upper corner.
2. Analysis of dissipative structure characteristics of the upper corner ventilation system

The theory of dissipative structure was firstly proposed by Belgian unbalanced statistical physicist Prigogine at an international conference [1]. Dissipative structure refers to the open system that is far from equilibrium and the dynamic exchange of substances in the surrounding environment, energy and information, when the state of surrounding environment changes to a certain threshold, the induced system produces random fluctuations that are mutated from the previous chaotic state, and transition to a relatively stable orderly state in time and space. The process of dissipating energy and information must be accompanied by the generation of entropy and dissipative structures must constantly absorb negative entropy from the outside to maintain their order, as its formation must meet four conditions [2][3]:

1. The system must be open to introduce negative entropy flow by exchanging matter, energy and information with the outside world;
2. The system must be in a state of being far from equilibrium;
3. There must be nonlinear interactions between the various elements within the system;
4. The system implements the existing order through random rise.

Using information entropy to characterize the uneven accumulation of disaster gas in the local area of the upper corner, that is, the local area of the upper corner of the reaction is continuously subjected to material and energy exchange processes with the surrounding environment. Macroscopically, when external environment is interrupted due to periodic pressure, maintenance, and speed change, this will keep the upper corner ventilation system away from equilibrium. From the point of view of molecular motion theory, the molecules in the material system moving from order to chaos is a process of entropy increase; due to the elimination of disturbances, according to the system principle, the molecules in the system are exchanged with surrounding environment for substances, energy and forces due to different factors such as wind flow field, gas source and density. This exchange for the upper corner ventilation system, will transit equilibrium state to a new orderly steady state in time and space, that is, the air volume and flow field are dynamically stable. Due to constant mass transfer, disaster gas molecules changes in entropy within the transient steady state system. From the perspective of the principle of entropy, entropy is a state. “Negative entropy” is used to characterize the exchange of systems with the environment, and uses the exchanges absorbed from the environment to maintain their orderly state, resisting the irreversible entropy increase process of itself. The increase in negative entropy means a way to promote better synergy within the system. Thus the power of development towards ordering increases, finally making the local disaster gas accumulation phenomenon of the upper corner an orderly near equilibrium state.

Based on the points above, the upper corner local ventilation system is used as a subsystem of the mine ventilation system, maintaining its stability through dynamic material and energy exchange with the surrounding environment, fluctuating a system that is far from a steady state from an unstable state to a new state, meeting the conditions to form a dissipative structure.

3. Analysis of the entropy value of disaster gas concentration in the local area of the upper corner

3.1. The unified relationship between thermodynamic entropy and information entropy [4][5]

3.1.1. Information Entropy Deriving Thermodynamic Entropy
The s in information theory is called Shannon entropy, which represents the average amount of information of the source. If \( p(x_i) \) represents the probability of any microscopic state of the macroscopic state of the system, which is \( \sum p(x_i) = 1 \). The S of the source X can be seen as a function of the n-dimensional probability vector, which is:

\[ S = -\sum p(x_i) \log p(x_i) \]
\[ E[J(x)] = H(x) = -\sum_{i=1}^{N} p(x_i) \log p(x_i) \] (2.1)

The microscopic state is equal probability according to the balance of the system, and the information entropy is the maximum value when the equal probability is known, which is \[ p(x_i) = 1/\Omega \] substitute (2.1) get \[ H(X) = -K \ln \frac{1}{\Omega} = K \ln \Omega = S. \] Information entropy is the uncertainty that describes the falling of a single particle at any energy level, the significance of statistical entropy is the degree of disorder of the microscopic states of N particles distributed at all energy levels. This shows that, the information entropy is consistent with the essence of Boltzmann statistical entropy, and there is an equivalence and unity relationship between the two.

3.1.2. Thermodynamic Entropy Deriving Information Entropy
The upper corner is relative to the entire mining area ventilation system, is a local ventilation system, think of the upper corner as an isolated system. Set the microscopic state number \( \Omega \) of the local area system of the corner to be:

\[ \Omega = \frac{N!}{N_1!N_2!\cdots N_m!} \] (2.2)

Boltzmann statistical entropy is:

\[ S = K \ln \Omega \] (2.3)

Substituting (2.2) into (2.3):

\[ S = K \ln \Omega = K \ln \frac{N!}{N_1!N_2!\cdots N_m!} \] (2.4)

According to the Sterling formula \( \ln N! = N \ln N - N \), Substituting (1.3):

\[ S = K \ln \frac{N!}{\prod_{i=1}^{m} N_i!} = KN(-\sum_{i=1}^{m} \frac{N_i}{N} \ln \frac{N_i}{N}) \] (2.5)

Hypothesis \( \frac{N_i}{N} = p_i \), then the relationship between thermodynamic entropy and information entropy is:

\[ S = KN(-\sum_{i=1}^{m} p_i \ln p_i) = KNH \] (2.6)

3.2. Information entropy of disaster gas accumulation in the upper corner area and its calculation
3.2.1. Information entropy of disaster gas accumulation in the upper corner area
In information theory, information entropy represents the average degree of uncertainty of the source, which is a measure of information disorder. Let X denote a finite number of random states \( X_1, X_2, \ldots, X_n \) representative \( X_i(i=1,2,\ldots,n) \) probability of occurrence, Then the information entropy \( H(X) \) of the system is defined as[6]:

\[ E[J(x)] = H(x) = -\sum_{i=1}^{N} p(x_i) \log p(x_i) \]
\[ H = -\sum_{i=1}^{n} p(x_i) \ln p(x_i) \]  

among them: \(0 \leq p(X) \geq 1\) and \(\sum_{i=1}^{n} p(x_i) = 1\).

### 3.2.2. Entropy analysis

It can be seen from the above formula that the calculation of information entropy is mainly to determine a specific probability distribution or probability density function. However, in the actual mining process, due to the complex mining environment and numerous interference factors, it is impossible to determine the probability distribution function that can express the change in the concentration of the gas in the upper corner. Literature [7] proposes to obtain the entropy estimate directly based on the rank estimation method of the surveyed observation data. Details as follows:

The samples are \(x_1, x_2, ..., x_N\), arranged in a new sequence \(x_{(1)}, x_{(2)}, ..., x_{(n)}\) from small to large, and the rank is defined as \(nk\):

\[ r_k = \int_{-\infty}^{x_k} p(x)dx = \int_{-\infty}^{x_k} dp(x)dx = p(x_{(k)}) \quad 0 \leq r_k \leq 1 \]  

Where \(\bar{p}(x_{(k)}) = r = \frac{k}{n+1}\)

Then the information entropy calculation formula is:

\[ H(x) = -\int_{-\infty}^{+\infty} p(x) \ln p(x)dx = -\int_{-\infty}^{+\infty} \ln \frac{dp(x)}{dx} p(x)dx \]  

The entropy estimate based on the discretized form of the monitored data is:

\[ \overline{H}(x) = -\sum_{k=1}^{n} \ln \frac{\Delta P(x_{(k)})}{x_{(k)}} \overline{\Delta P(x_{(k)})} = -\sum_{k=1}^{n} \ln \frac{r_{k+1} - r_k}{x_{(k)}} (r_{k+1} - r_k) \]

### 4. Analysis of disaster gas accumulation characteristics in the local system of the upper corner

Combined with the upper corner angle to test the change trend of gas concentration, the grid size of the measuring point is in the form of non-uniform grid, and the measuring point is located at the intersection of the grid. As shown in Figure 1, in Fengjiata 50104 working face, the corner space \(y=1.6m\) height plane, with the intersection of the return air duct and the goaf as the starting point, a total of 26 measuring points are arranged. Among them, 7 measuring points are arranged along the direction of the return airway, and the measuring points are 0.2m, 0.7m, 1.4m, 2.4m from the junction, and 8 measuring points are arranged along the working surface, and the measuring points are respectively at a distance of 0.3m, 0.8m, 1.6m, 2.6m.

Finally, the sample mean value set of the upper corner CO concentration detection data is \(D=\{Xi \mid (=1, 2, ..., 78)\}\), using the Meshgrid function in MATLAB software and the Griddata function to perform plane difference processing on the data [8], then use the mesh function to draw the measured concentration distribution map of CO gas in different horizontal planes, as shown in the figure.
According to the CO concentration detection data sample of the upper corner, the information entropy of the upper corner gas concentration at \( y=1.6 \) m is calculated by using Equation 2.11, as shown in Table 1.

**Table 1** \( y = 1.6 \) m at the upper corner of the measuring point CO concentration statistical value and CO concentration information entropy calculated value

| Measuring point number | Concentration mean /ppm | Information entropy | Measuring point number | Concentration mean /ppm | Information entropy |
|------------------------|-------------------------|---------------------|------------------------|-------------------------|---------------------|
| Measuring point 1      | 24.81                   | 79.0594             | Measuring point 14     | 20.36                   | 76.5591             |
| Measuring point 2      | 25.94                   | 80.6659             | Measuring point 15     | 18.06                   | 76.5687             |
| Measuring point 3      | 25.06                   | 80.0184             | Measuring point 16     | 16.72                   | 69.8153             |
| Measuring point 4      | 20.56                   | 78.4855             | Measuring point 17     | 9.89                    | 76.7809             |
| Measuring point 5      | 20.75                   | 76.8278             | Measuring point 18     | 18.39                   | 71.9047             |
| Measuring point 6      | 16.69                   | 75.6577             | Measuring point 19     | 10.67                   | 71.3352             |
| Measuring point 7      | 17.72                   | 76.1856             | Measuring point 20     | 9.86                    | 71.3324             |
| Measuring point 8      | 17.61                   | 75.8823             | Measuring point 21     | 9.83                    | 68.0593             |
| Measuring point 9      | 22.78                   | 79.2725             | Measuring point 22     | 7.61                    | 67.9763             |
| Measuring point 10     | 17.61                   | 76.8995             | Measuring point 23     | 7.44                    | 66.2461             |
| Measuring point 11     | 15.00                   | 75.2192             | Measuring point 24     | 6.33                    | 62.0977             |
| Measuring point 12     | 18.72                   | 77.0312             | Measuring point 25     | 5.44                    | 57.4349             |
| Measuring point 13     | 21.44                   | 78.2494             | Measuring point 26     | 2.83                    | 51.4724             |
It can be seen from Fig. 2 that the information entropy of the CO angle of the upper corner and the CO concentration of the upper corner are generally in the plane of the direction of the working surface, and the overall fan-shaped change trend gradually decreases from the upper corner to the main wind region, and in the direction of the return airway, the higher variation law of the isolation coal wall is obtained, in the dissipative structure formed by the upper corner region, the gushing and diffusion process of harmful gases such as CO is an irreversible process of increasing entropy flow; In the direction of the cut-eye, there is a slight air leakage due to the goaf near the rear of the single hydraulic support, it is shown that there is a small area of air leakage near 0.2 to 0.7 m in the direction of the cutting eye, resulting in a relatively low concentration of CO gas in this range. Information entropy is a basic quantity used to measure the amount of information. As can be seen from Figure 3, there is also a small range of entropy relative reduction in the corresponding position of the upper corner. According to the theory of dissipative structure, external leakage introduces “negative entropy”, it is characterized by the exchange of substances, energy and information between the ventilation system in the upper corner area and the surrounding environment, forming the dissipation of energy and information; It can be seen from Fig. 2 and Fig. 3 that the trend of information entropy between CO concentration and CO concentration is basically consistent. It can be seen that information entropy can well characterize the cohesion characteristics of CO gas in the upper corner, the overall trend of the fan shape gradually decreases from the upper corner to the main airflow region, it indicates that the system tends to increase the order degree, and the direction of total entropy reduction, that is, the essence of CO gas accumulation in the local system of the upper corner is the entropy reduction process of the dissipative structure.
Numerical Simulation

(I) Model and boundary condition settings

The Fengjiata Coal Mine uses inclined shafts to develop. Main layout of the panel is to transport the main road, and the coal mining face is arranged in strips. The coal conveyor face scraper conveyor has high power, and a large-volume shifting device is installed at the tail, so that the tail of the working face is in a state of partial bracket lag for a long time. According to the actual arrangement of four fully mechanized mining supports and four single hydraulic supports in the return air corner of the 1406 working face of Fengjiata Coal Mine, the physical model of the local lag of the return wind angle is shown in Fig. 4. Among them, in order to facilitate the study, the influence of the working surface tail scraper transport equipment on the flow field is neglected, the gas emission source is only the rear goaf, and the hysteresis area is simplified to a space area of 6m×1.5m×3m.

According to the actual supply air, the inlet boundary condition is set to the speed inlet inlet1 with an average wind speed of 1.5 m/s, according to the field measurement and analysis, the air leakage at the single hydraulic support of 0.2~0.7m along the direction of the cutting eye is significant, it is set to a speed inlet inlet2 with an average air leakage wind speed of 0.22 m/s, and a return air outlet port is set as a free outlet outflow. As shown in Fig. 5, the cloud volume fraction distribution cloud map and the flow field velocity distribution cloud map of the upper corner angle at y=1.6 m are respectively taken.

As shown in Figure 5 (b), due to the partial lag of the upper corner, the special environmental boundary causes the wind flow flowing from the working surface into the lag zone to form a local eddy current zone inside the upper corner lag zone, the position of the upper corner is in a windless or breezy state. When the average wind speed of the working face is 1.5m/s, the average wind speed in
the lag zone of the upper corner is <0.3m/s. As shown in Figure 5 (a), due to the presence of eddy currents in the lag zone and lower wind speeds, the disaster gas that causes the rear goaf and the isolated coal pillar to overflow flows in this area, and it is difficult to merge into the return air lane with the main wind flow, the occurrence of disaster gas overruns often occurs at the upper corner; As shown in Fig. 5 (a, b), there is a wind leakage speed at a single hydraulic support of 0.2 to 0.7 m in the direction of the cutting eye, in the case where the air leakage of the single hydraulic support occurs, in the case where the average air leakage wind speed is 0.42 m/s, the CO volume fraction shows a small range of decline in the affected area, however, due to the intricate environment and various influencing factors, the degree of decline is different from the actual measurement on site, but the overall trend is in line with the actual situation on site.

(II) Numerical simulation analysis of the over-limit of gas in the upper corner of the mine with flexible inflatable airbag

The mine flexible inflatable airbag is a multifunctional mining equipment that integrates gas detection and alarm, temporary sealing and pressure air drainage. The airbag is made of wear-resistant and anti-static flame-retardant rubber material, and has the characteristics of softness, good sealing effect, simple operation and convenient movement. As shown in FIG. 6, the airbag is mainly composed of a main structure such as an airbag main body, a base, an adjustable dense grille vent, and a gas detector; the pressure air line is connected to the gas quantity detector through a sensor; the gas detector is connected to the gas alarm controller and the deflation valve through sensors, and two adjustable dense grid pressure relief ports are respectively placed at the front end of the airbag and the middle of the right side of the airbag. Mainly installed between the working face support and the isolated coal pillar, and the gas is expanded by the mine pressure air pipe, the control gas supply is between 30m³/min and 50m³/min, when the upper gas angle disaster gas is detected, automatically open 2 dense grille pressure relief ports to deflate, control the amount of venting from 10m³/min to 20m³/min, dilute the accumulated gas until the gas concentration will reach the safe range.

![Figure 6 Schematic diagram of a flexible inflatable airbag for mining](image)

In the numerical simulation, other boundary conditions remain unchanged, and only the mine flexible inflatable airbag vent is added as the speed inlet inlet3, the average draft wind speed at which the speed inlet is set is 0.42 m/s. As shown in Fig. 7, the cloud volume fraction distribution cloud map and the flow field velocity distribution cloud map of the upper corner of y=1.6m are respectively taken.
Fig. 7a Cloud flow velocity distribution diagram of the upper corner at y=1.6m with airbag b When there is a balloon, y=1.6m at the upper corner of the CO volume fraction distribution cloud map

When passing through the front and left ends of the airbag, the airflow of the dense grille vents to the upper corner space is 20m³/min, that is, when the average wind speed around the airbag shown in Fig. 7a is 1.5 m/s, the concentration of the disaster gas at the upper corner can be effectively reduced; as can be seen by comparing Figures 5b and 7b, the air pressure of the airbag can significantly increase the wind speed in the lag zone of the upper sag angle, it acts as a disturbance to the flow field in the lag space of the upper corner, and can obviously eliminate the eddy current existing in the lag space of the upper corner, significantly rectified the phenomenon of overcapacity of the gas in the upper corner.

5. Conclusion
Introducing information theory and comparing the field test results with the entropy value analysis, it is concluded that the information entropy can characterize the gas accumulation characteristics of the upper horn disaster. From the perspective of energy dissipation, through field measurement and numerical simulation, the characteristics of the gas accumulation in the upper corner of the fault are analyzed. It is concluded that essence of the gas accumulation in the local system of the upper corner is the entropy reduction process of the dissipative structure. The paper proposes and designs a flexible inflatable airbag for mining to introduce the “negative entropy” through the pressure-drainage method to control the CO accumulation problem of the upper corner. Practicality and effectiveness of CO gas accumulation in Fengjiata 1406 working face by airbag treatment were verified by numerical simulation.

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