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Research Article

Research on the Influence of Natural Wind Pressure in Deep Mines on Ventilation Stability

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Deep mines are greatly affected by changes in natural wind pressure because of their large buried depths and long ventilation paths. Changes in natural wind pressure do affect the air flow of the underground ventilation system, and even change the direction of individual branches. If the dynamic changes of natural wind pressure are not monitored constantly, it is very likely to cause disasters such as gas overrun and may even lead to heavy casualties. In this paper, the changes of natural wind pressure and the air volume entering the mine are measured on-site in the 630 mining area in the south wing of Tangkou Coal Mine, Then, compare the change law of natural wind pressure with the change law of ventilation air volume. Finally, through numerical simulation by FLUENT, the change of internal flow in the gob where there is a loosely closed condition is simulated. Through research, the annual natural wind pressure change and the change of air intake in the 630 mining area of the south wing of Tangkou Coal Mine were obtained; The influence of changes in external conditions on the ventilation air volume of deep mines is obtained; The importance of the influence of natural wind pressure on the stability of the deep mine ventilation system is verified.

1. Introduction

Mine ventilation is a fundamental measure to change coal mine safety. It is used to remove and dilute the dust and gas in the mine to ensure the normal breathing of underground operators. This is very important for improving the economic benefits of the mining area and promoting the stable and healthy development of the mining area.

Numerous researchers have studied natural wind pressure theoretically and numerically. The real research on natural wind pressure originated around 1940 [1–3]. At that time, American researchers began to explore natural wind pressure indoors. By systematically applying the thermal and dynamic principles, they discovered the law of changes in indoor natural wind pressure. However, due to the rudimentary technical equipment and the weak research foundation, the research at that time was not perfect. Around 1970, in order to satisfy the needs of mine production, researchers began to study the influence of natural wind pressure on mines and explain the mechanism of natural wind pressure causing pressure changes in the ventilation system [4–7]. This laid the foundation for airflow research. Later, natural wind pressure calculation algorithm [8–10] was applied to explain the influencing factors and degree of natural wind pressure, discuss the main action section of underground natural wind pressure, and propose methods and ventilation system management concepts on how to use or limit the impact of natural wind pressure on the main action section. With the development of science and technology, the calculation method of natural wind pressure has been constantly improved, and the calculation equation of natural wind pressure has been derived using methods such as thermodynamics, CFD, coupled thermal pressure and thermal air pressure [11–16]. Nowadays, with the extensive application and development of mathematical modeling and computer numerical simulation [16–19], the study of natural wind pressure has entered the stage of research and design. Through the analysis and integration of a large amount of on-site measurement data, the natural wind pressure change law and network solution algorithm algorithm are combined into the computer program to achieve the automatic computation of natural wind pressure in the computer.

The mine ventilation system [20–23] generally consists of a ventilation shaft network, ventilation power equipment, air flow monitoring and control facilities, etc. The system stability of mine ventilation is based on the concept of system stability in cybernetics, but it is slightly different. The system stability in cybernetics mainly refers to the ability of the system to return to the original equilibrium state after being deviated from the equilibrium state by the instantaneous external force, while the system stability of mine ventilation refers to the change of various parameters in the system with the change of the continuous external force, ventilation structure or ventilation parameters [24–26]. Among numerous research results, the stability theory of a former Soviet scholar Lyapounov [27] is the most prominent. In his theory, the system stability of ventilation can be measured by mathematical statistics. At present, researchers use the standard deviation of mathematical statistics to analyze the change of air volume in mine roadways. Combined with the ventilation network solution model, they can determine the degree of stability of the mine ventilation system and the location in the roadway that affects the stability of the mine ventilation system [28]. Moreover, they use the ventilation system network solver tool [29] to analyze the network airflow stability of the mine ventilation system by establishing the network airflow stability coefficient matrix and analyzing the overall stability index of the network airflow, the network airflow change range index and the network change influence range index. In addition, they use the method of numerical computation to derive general formulas for stability analysis of any ventilation network through inductive analysis.

Currently, most studies on mine natural wind pressure and ventilation system stability stay in shallow mines. For deep mines, the influence of natural wind pressure on the stability of the ventilation system is more significant and complex. In order to study the influence of natural wind pressure on the ventilation system in deep mines, the deep mine, Tangkou Coal Mine in China, is taken as the research background in this paper.

2. Overview of Tangkou Coal Mine

As shown in Figure 1, Tangkou Coal Mine is located about 10 km west of Jining City, Shandong Province, China. The mine is separated from Yunhe Mine by the connecting line of the $T_{5\text{-}9}$ and $A_{24\text{-}16}$ boreholes in the north, separated from Daizhuang Coal Mine by Jining Fault in the east, connected to Jining security coal pillar in the southeast, separated from Xinhe Mine by Jiaxiang Fault and its third branch. The area of the mine field is 72.2189 km^2.

In this mine, vertical shaft development and zoned extraction ventilation are adopted. Air enters from the north service shaft, north main shaft and south service shaft, and returns from the north return air shaft and south return air shaft. The existing production level is −990 m, the designed production capacity is 3 million t/a, and the approved production capacity in 2015 is 4.8 million t/a. The main coal mining method is the retreating longwall method where the roof is completely collapsed or filled with gangue. In general, the blasting technology is adopted for the rock roadway, and the comprehensive excavation technology is applied for the coal roadway.

The ventilation method of the mine is zoned extraction ventilation. The ventilator room in the north of the mine is equipped with two FBCDZ-10-№32 counter-rotating axial flow ventilators with a motor power of 2 × 560 kW. The southern ventilator room is equipped with two GAF33.5-18-1FB hydraulic movable blade adjustable axial flow ventilators with a motor power of 1,800 kW. The required air volume of the mine is 21,466 m^3/min, the actual total air intake volume of the mine is 22,929 m^3/min, and the total return air volume is 24,061 m^3/min. The effective air volume of the mine is 21,470 m^3/min, the effective air volume rate is 93.64%, and the equivalent orifice of the mine is 10.41 m^2. At present, there is sufficient air volume at each mining operation site, no diffusion ventilation, no old waste ventilation, no windless and breeze operation, no unreasonable series ventilation, and no production exceeding ventilation capacity. The mine ventilation diagram is shown in Figure 2.

3. Measurement and Analysis of Natural Wind Pressure

3.1. Calculation Equation of Natural Wind Pressure in Mine. As shown in Figure 3, as the atmospheric pressure and temperature change with the seasons, the ground air enters the mine and exchanges heat with various underground heat sources, resulting in different air temperatures in various sections of the underground. At the same time, the increase in atmospheric pressure with the depth and the self-compression of airflow during the flow process will cause the density of the air to change, resulting in an energy difference by the imbalance of the gravity of the air column in the air inlet section and the air return section, which promotes the air to flow along the roadway.

The density of air is a variable that depends on the change process of the gas state, which is related to the pressure, temperature and humidity. The main change processes include isovolumetric process, isobaric process, isothermal process, and polytropic process. The following is a comparative analysis of each change process of the gas.

3.1.1. Isobaric Process. When P is a constant, $1/\rho T = R/P$ is a constant. In the isobaric process, P does not change, and v is proportional to T. Because $\mathrm{d}P = 0$, the change in pressure energy is:

Figure 1: Location of tangkou coal mine.

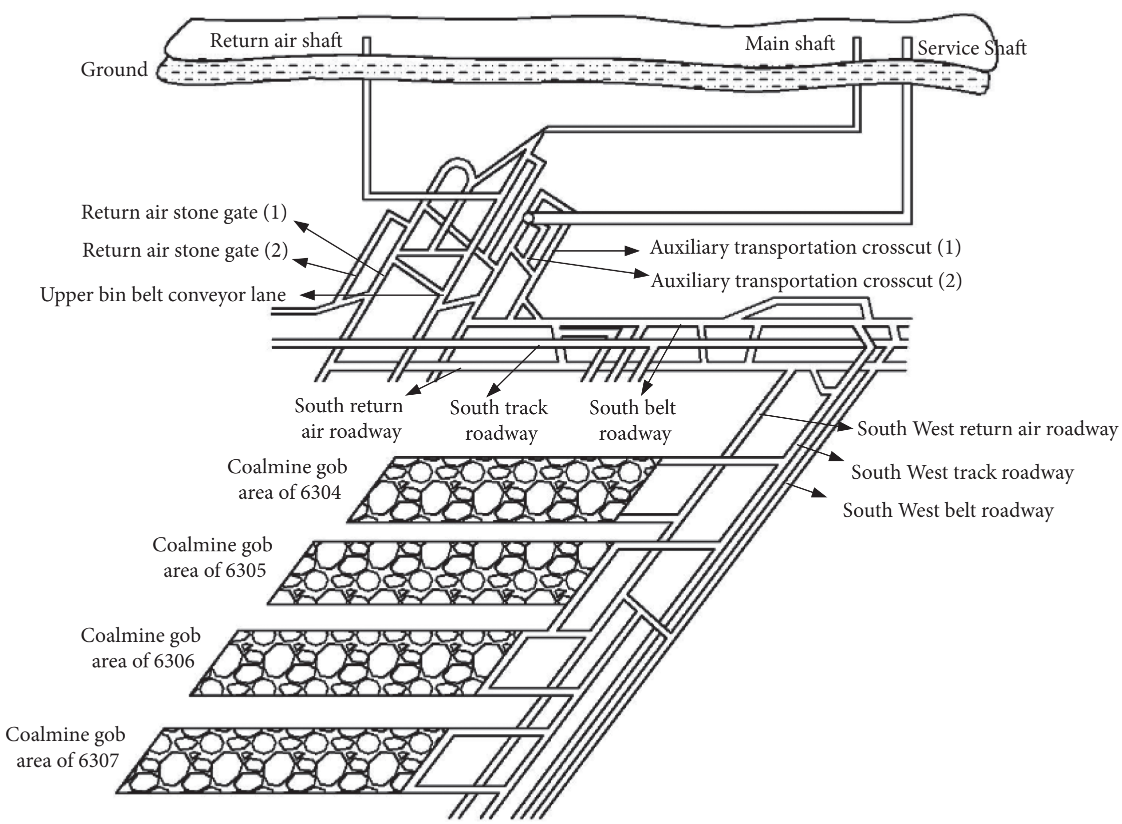

Figure 2: Three-dimensional schematic diagram of ventilation system in south wing shaft area.

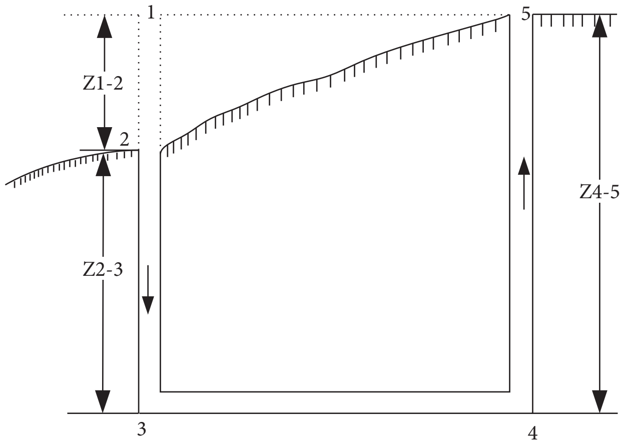

FIGURE 3: Schematic diagram of natural ventilation in mine.

$$\int_2^1 \frac{dP}{\rho} = 0. \tag{1}$$

3.1.2. Isovolumetric Process. In the isovolumetric process, the gas volume V does not change, and then the air density ρ does not change. Hence, the change in pressure energy is:

$$\int_2^1 \frac{dP}{\rho} = \frac{(P_1 - P_2)}{\rho}. \tag{2}$$

3.1.3. Isothermal Process. In the isothermal process, T is a constant, and then $P/\rho = \mathrm{RT}$ is a constant. P is inversely proportional to ρ. Hence, the change in pressure energy is:

$$\int_2^1 \frac{dP}{\rho} = \int_2^1 \frac{P_1}{\rho_1}\frac{dP}{P} = \frac{P_1}{\rho_1}\ln\frac{P_1}{P_2}. \tag{3}$$

3.1.4. Polytropic Process. For the polytropic process ($P/\rho^n = \text{constant}$), the variation law of P with V is shown in Figure 4, where n is the polytropic index, which can be any real number. The value of n is different under different state change laws. When $n = 0$, it is an isostatic process; when $n = 1$, it is an isothermal process; when $n = k$, it is an adiabatic process (After the air enters the well, there is no heat exchange between the air and various heat sources in the well); when $n = \infty$, it is an isovolumetric process.

Because of the fact $1/\rho = (P_1/P)^{1/n} 1/\rho_1$, the change in pressure energy is:

$$\int_2^1 \frac{dP}{\rho} = \int_2^1 \frac{P_1^{1/n}}{\rho_1}\frac{dP}{P^{1/n}} = \frac{n}{n-1}\cdot\frac{P_1}{\rho_1}\left[\left(\frac{P_1}{P_2}\right)^{n-1/n} - 1\right] = \frac{n}{n-1}\left(\frac{P_1}{\rho_1} - \frac{P_2}{\rho_2}\right), \tag{4}$$

where the polytropic index n can be calculated from the measured data P_1, P_2, T_1, T_2 of the mine, and the specific calculation is shown in equation (5).

$$n = \frac{\ln(P_2/P_1)}{\ln(P_2/P_1) - \ln(T_1/T_2)} = \frac{\ln(P_2/P_1)}{\ln(\rho_2/\rho_1)}, \tag{5}$$

where T_1, T_2 are the absolute temperature of the gas at the beginning and end, respectively, K; P_1, P_2 are the pressure of the gas at the beginning and end, respectively, Pa.

3.2. Measurement of Natural Wind Pressure in Tangkou Coal Mine. The indirect measurement method is adopted to measure the natural wind pressure in the south wing shaft area of Tangkou Coal Mine. The indirect measurement method is that a precision barometer records the pressure, temperature, humidity and time every 5 minutes at the wellhead of the air inlet well, and another precision barometer enters the well to perform pressure, temperature, humidity and time at the designated measurement location. After the measurement, the natural wind pressure is calculated by the formula. In order to obtain a more comprehensive change in the natural wind pressure throughout the year and reduce errors caused by meteorological changes, according to the actual situation of the south wing shaft area of Tangkou Coal Mine, the most representative day of each season is selected for measurement. Moreover, the data measured on the selected four days are taken as the main research object. Other data are only used as references. The measured data of the four seasons of spring, summer, autumn and winter are shown in Table 1.

The spring in Jining is the period of atmospheric circulation adjustment, in which it is prone to drought and windiness, and warms up quickly. During the three months of spring, March, April and May, the temperature in Jining gradually rises. The three months of summer, June, July and August are the hottest period in Jining. The temperature changes during the three months of autumn, September, October, and November, are the fastest compared to those in spring, summer and winter. The surface temperature of the three months of winter, December, January and February, is the lowest in the whole year. The change of surface temperature will inevitably bring about the change of underground temperature, which in turn will lead to the change of natural wind pressure in the mine.

In order to obtain a more accurate evolution law of the natural wind pressure in the south wing shaft area of Tangkou Coal Mine in spring, according to the actual production situation, the natural wind pressure is measured every 3 hours at 3:00, 6:00, 9:00, 12:00, 15:00, 18:00, 21:00, 24:00, 8 times a day. The measurement results of the natural wind pressure of Tangkou Coal Mine are shown in Figure 5.

Figure 5 clearly shows that the changes in natural wind pressure on one representative day in each of the four

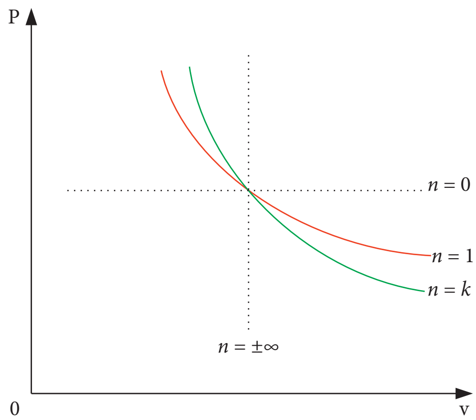

Figure 4: (P-V) diagram of isothermal process.

seasons. Firstly, the natural wind pressure decreases gradually from 3:00 to 15:00, and increases gradually from 15:00 to 3:00 the next day. Secondly, the time of the day when the natural wind pressure is the highest is 3:00, and the time of the day when the natural wind pressure is the lowest is 15:00. Finally, in spring, the highest natural wind pressure is 411 MPa, and the lowest natural wind pressure is 375 MPa; in summer, the highest natural wind pressure is -10.6 MPa, and the lowest natural wind pressure is -59.3 MPa; in autumn, the highest natural wind pressure is 195.2 MPa, and the lowest natural wind pressure is 166.7 MPa; in winter, the highest natural wind pressure is 495.5 MPa, and the lowest natural wind pressure is 457.2 MPa.

In order to more intuitively show the changing trend of the natural wind pressure throughout the year, the change trend of the natural wind pressure of the year in the south wing shaft area of Tangkou Coal Mine is obtained with the most representative day of each season of the year taken as the seasonal natural wind pressure, as shown in Figure 6.

Figure 6 shows that the natural wind pressure in the south wing shaft area of Tangkou Coal Mine fluctuates sinusoidally throughout the year with large fluctuations. The natural wind pressure in the south wing shaft area of Tangkou Coal Mine reaches a maximum of about 500 Pa in winter, and a minimum of about −75 Pa in summer. And thus the range of the natural wind pressure fluctuation is 575 Pa. The natural wind pressure is positive in spring, autumn and winter, i.e., the direction of natural wind pressure is consistent with the blowing direction of the ventilator, which is conducive to mine ventilation. It is negative in summer, i.e., the direction of natural wind pressure is opposite to the blowing direction of the ventilator, which hinders mine ventilation.

4. Analysis of Influence of Natural Wind Pressure on Air Supply Volume

4.1. Evolution of Natural Wind Pressure and Ventilator Air Volume. In the normal working sate of the mine, the ventilation of the entire mine relies on the mine ventilator, and the function of the mine ventilator depends on the characteristic curve of the ventilator. When the wind pressure and ventilator air volume at the new operating point are greater than those at the previous operating point, it indicates that the change of the natural wind pressure is beneficial to the air supply of the mine ventilator. When the wind pressure and ventilator air volume at the new operating point is less, indicating that the change of the natural wind pressure hinders the air supply of the mine ventilator.

Based on the influence mechanism of natural wind pressure on mine ventilation, the influence of natural wind pressure on the stability of ventilator air volume in the south wing shaft area of Tangkou Coal Mine is studied. The method of measuring the natural wind pressure on the most representative day of each season is also adopted. The natural wind pressure is measured every 3 hours at 3:00, 6:00, 9:00, 12:00, 15:00, 18:00, 21:00, 24:00, 8 times a day. The measurement data of the air volume of the main ventilator in the south wing shaft area of Tangkou Coal Mine are shown in Figure 7.

Figure 7 indicates that the fluctuation of the natural wind pressure have a certain impact on the air supply volume of the ventilator. In general, the change of the air volume of the ventilator is consistent with the change of the natural wind pressure. When the natural wind pressure is small, the air supply volume of the ventilator is small. When the natural wind pressure is higher, the air supply volume of the ventilator is greater. With the horizontal line where the median value is located taken as the central axis, it can be seen that from 0:00 to 24:00 on one representative day in each of the four seasons, both the natural wind pressure and the air volume of the ventilator first increase, then decrease and then increase. Although the change trends of the natural wind pressure and the supply air volume of the ventilator are basically the same, the inflection points of the changes are slightly different, with a difference of 0~4 h. The change of the air supply volume of the ventilator will affect the stability of the entire ventilation system, and bring hidden safety hazards to underground production.

4.2. Correlation Analysis of Natural Wind Pressure and Ventilator Air Volume. In order to further analyze the influence of natural wind pressure on the air volume of the ventilator, the correlation between the natural wind pressure and the air volume of the ventilator in Tangkou Coal Mine is analyzed by using the correlation analysis method in the field of mathematics. In this correlation analysis method, Pearson's correlation reflects the degree of linear relationship between two variables and its coefficient is between -1 and 1. The Pearson correlation coefficient between two variables is defined as the quotient of the covariance and standard deviation between the two variables, as shown in equation (6):

$$\rho X, Y = \frac{\operatorname{cov}(X, Y)}{\sigma_X \sigma_Y} = \frac{E\left[\left(X - \mu_X\right)\left(Y - \mu_Y\right)\right]}{\sigma_X \sigma_Y}, \quad (6)$$

where ρ is the overall correlation coefficient.

By estimating the covariance and standard deviation of the data sample, the Pearson correlation coefficient can be obtained, as shown in equation (7):

Table 1: Measured data of four seasons in shaft area.

Season	Measuring position	Absolute pressure HPa	Dry temperature ˚C	Absolute partial pressure of saturated water vapor HPa	Relative humidity %	Density kg/m^3
Spring	Service shaft mouth	1022.81	17.2	20.12	93	1.219444
	Service shaft bottom	1139.46	22.6	27.42	89	1.332117
	Main shaft mouth	1016.18	23.4	28.78	87	1.183332
	Main shaft bottom	1124.2	28.2	38.25	92	1.284983
Summer	Service shaft mouth	1003.29	33	52.62	62.7	1.128109
	Service shaft bottom	1110.13	35.5	57.83	72.3	1.235861
	Main shaft mouth	991	26.7	35.04	94.1	1.137544
	Main shaft bottom	1095.26	30.7	44.18	99.9	1.237327
Autumn	Service shaft mouth	1012.78	24.8	31.3	72.7	1.174801
	Service shaft bottom	1120.69	27.4	36.5	68.2	1.288849
	Main shaft mouth	1002.75	24.7	31.12	91.1	1.160983
	Main shaft bottom	1107.25	28.9	39.82	96.1	1.261101
Winter	Service shaft mouth	1024.73	10.2	12.45	92	1.255323
	Service shaft bottom	1141.15	15.4	17.48	87	1.371615
	Main shaft mouth	1018.83	15.8	17.84	78	1.222741
	Main shaft bottom	1128.4	26	33.61	87	1.301952

$$r = \frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)\left(Y_i - \overline{Y}\right)}{\sqrt{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}\sqrt{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2}}. \tag{7}$$

As shown in Table 2, according to the calculated r value, the correlation between two variables is divided into 8 levels from highly negative correlation to highly positive correlation.

Through the SPSS software, the measured data of the natural wind pressure and ventilator air volume of Tangkou Coal Mine throughout the year are substituted into the Pearson model, and the correlation coefficient between the natural wind pressure and the air volume of the ventilator is obtained, as shown in Table 3.

As shown in Table 3, the Pearson's correlation between the natural wind pressure and the air volume of the ventilator is a moderately positive correlation in spring, a highly positive correlation in summer, a weak positive correlation in autumn, and a weak negative correlation in winter. Through the analysis of the correlation results obtained, in the temperate monsoon climate of Tangkou Coal Mine, for deep mines, the natural wind pressure in spring and summer has a very significant influence on the air volume of the ventilator, while the natural wind pressure in autumn and winter has a lower degree of influence on the air volume of the ventilator.

5. Verification of Shaft Bottom Airflow Characteristics through Numerical Simulation

5.1. Model Establishment and Mesh Division. In order to verify that the influence of natural wind pressure on the stability of the ventilation system poses a hazard threat to underground production, with the ventilation air volume of each season taken as the parameter and the 630 mining area in the south wing shaft area of Tangkou Coal Mine taken as the background, the model is established through the Soldworks software, as shown in Figure 8. In this model, each gob has an air intake roadway and an air return roadway. In addition, the dimensions of this model are summarized in Table 4.

The entire gob is divided into Submap quadrilateral grids through the ICEM in the software FLUENT [30–33]. The result of mesh division is shown in Figure 9.

After the mesh division, the boundary conditions of the model are set as follows. The surfaces between the gobs are

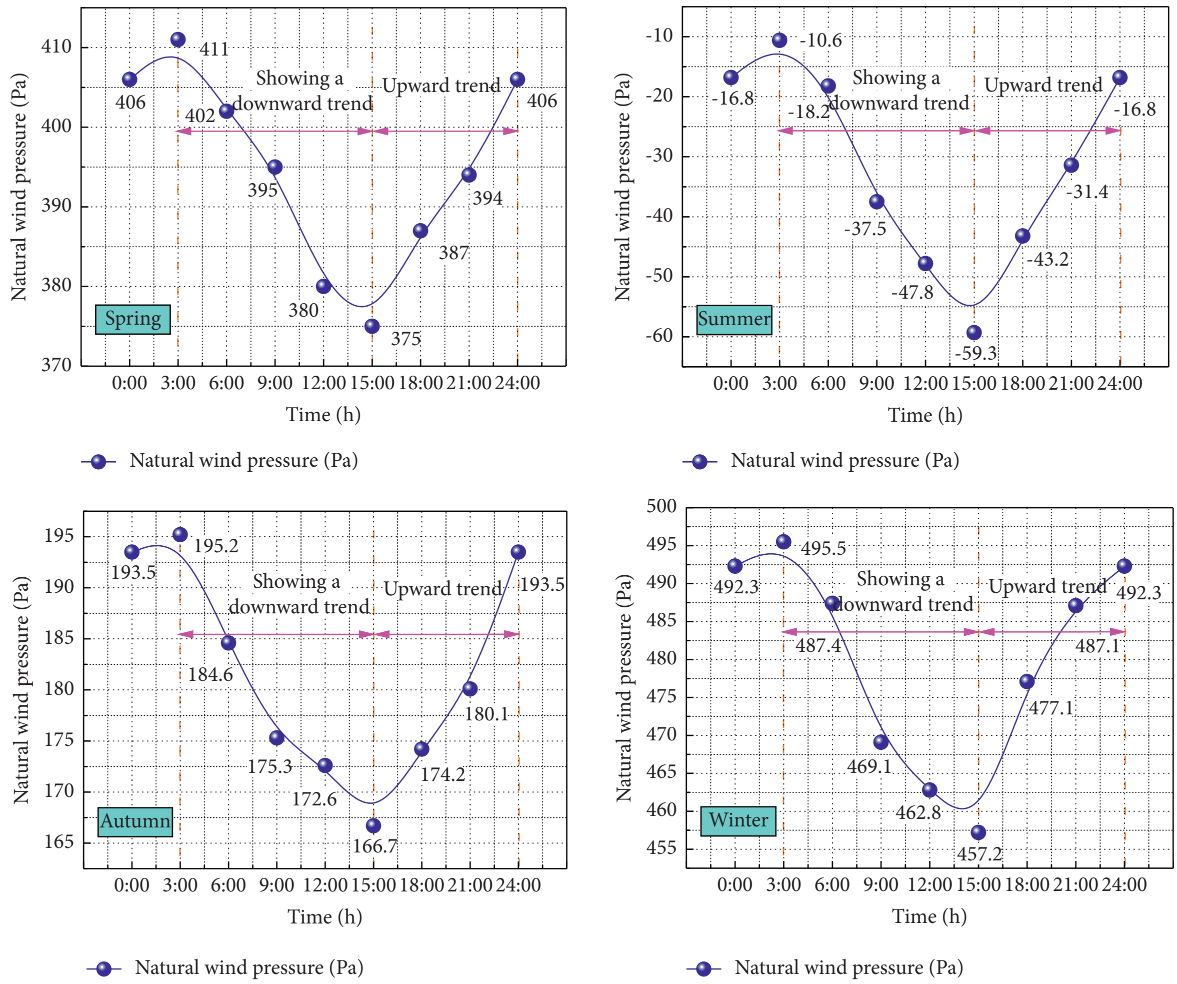

Figure 5: Changes in natural wind pressure on one representative day in each of the four seasons.

set to walls without ventilation. The contact surface between the working face and the gob is set to interior, the contact surface between the air intake roadway and the working face is set to interior, and the contact surface between the air return roadway and the working face is set to interior. The air inlet is set as pressure-inlet, and the air outlet is set as pressure-outlet. The air inlet pressure values of the 6304, 6305, 6306 and 6307 gobs are given, the internal pressure value of each gob is given, and the return air outlet is set as a free outlet. The boundary conditions of each area in the gob are set to Fluid. The boundary conditions of the coal pillars are set to wall, and set to porous media for FLUENT solution. The air inlet is set to air.

5.2. Simulation Results and Analysis of U-Shaped Ventilation. Figure 10 clearly shows the pressure distribution in the gob at three different inlet absolute pressures of 112,400 Pa, 112,000 Pa and 111,800 Pa. It indicates that when the absolute pressure of the air inlet is the largest, the influence on the gob is the greatest. As the absolute pressure of the air inlet decreases, the degree of influence on the gob gradually decreases. When the absolute pressure of the air inlet is 111,800 Pa, it basically only has a certain influence on the part of the gob near the air inlet, and has no influence on the inside of the gob.

Figure 11 shows the simulation results of transverse slices at different air inlet pressures. It is indicated that whether the absolute pressure of the air inlet is 112,400 Pa, 112,000 Pa or 111,800 Pa, the bottom part of the gob is affected more than the top part for the affected area. As the height increases, the affected area gradually decreases. When the absolute pressure of the air inlet is 112,400 Pa, the pressure at the top part of the gob near the working face is close to 112,400 Pa. When the absolute pressure of the air inlet is 111,800 Pa, the pressure at the top part of the gob near the working face becomes 111,570 Pa, and the degree of change is small relative to the absolute pressure of 112,400 Pa.

Figure 12 shows the simulation results of longitudinal slices at different air inlet pressures. Obviously, the internal pressure in each gob is affected more near the air inlet, and less near the air outlet. When the absolute pressure of the air inlet is 112,400 Pa, the interiors of the 6304 and 6307 gobs are basically affected. Since the 6305 and 6306 gobs are relatively long along the stoping direction, their parts far away from the working surface are basically unaffected.

Figures 11 and 12 indicate that the 6304, 6305, 6306 and 6307 gobs all have large areas of air leakage. The readings of the U-shaped tubes measured in the airtight area of the gob

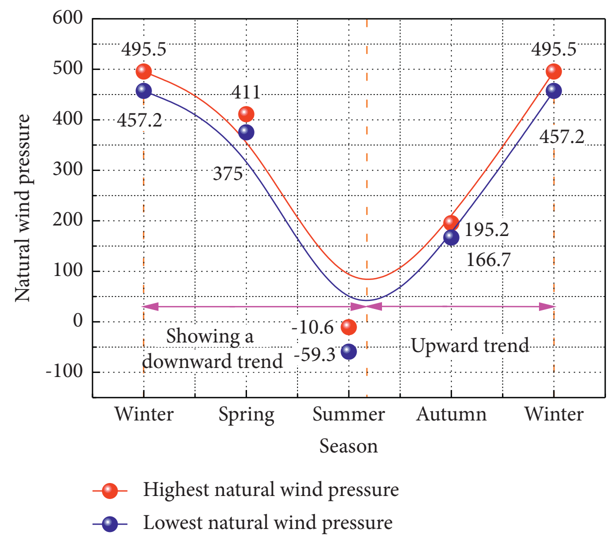

FIGURE 6: Change of natural wind pressure in south wing shaft area of tangkou coal mine.

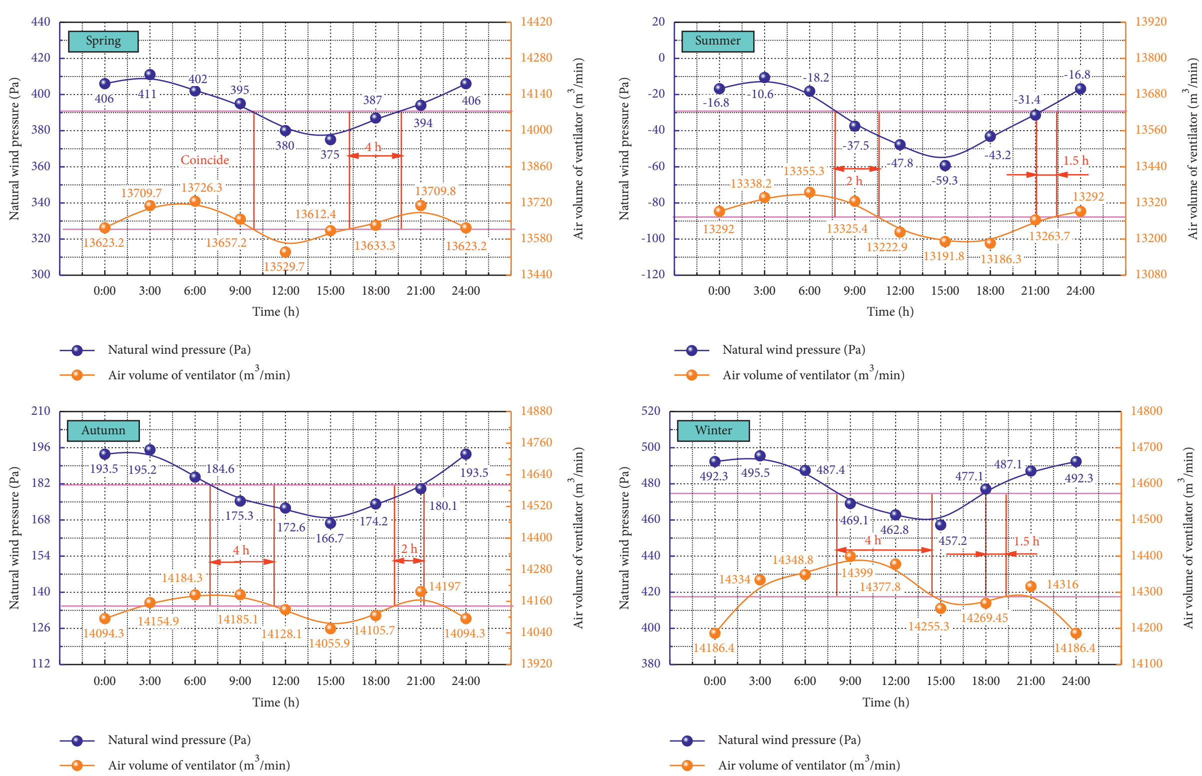

FIGURE 7: Changes of natural wind pressure and ventilator air volume on one representative day in each of four seasons.

are basically 0, and thus the pressure inside the airtight space is the same as the pressure outside the airtight space, which also indicates large areas of air leakage in the 630 gob, as shown in Figure 13. The change of the working face pressure outside the gob has a certain impact on the gob, and it can be inferred that the instability of the ventilation system would have a certain impact on the gob. When the pressure outside the gob is greater than the pressure inside the gob, air leakage may occur and even cause fire in the gob. When the pressure outside the gob is lower than the pressure inside the gob, the gas inside the gob will rush into the working face, which may cause harmful gas in the working face to exceed the limit, endangering the lives of underground personnel.

The air intake roadway in the 6304 gob is obviously affected by the change of natural wind pressure. In order to explore the impact of this change on the gob, the FLUENT simulation software is used to simulate the 6304 gob. The simulation results are shown in Figures 14 and 15.

Figures 14 and 15 indicate that when the airflow enters the working face from the air intake roadway, part of the

Table 2: Correlation evaluation criteria based on r value.

r value	−1∼−0.8	−0.8∼−0.5	−0.5∼−0.3	−0.3∼0	0∼0.3	0.3∼0.5	0.5∼0.8	0.8∼1
Correlation	Highly negative correlation	Moderately negative correlation	Low negative correlation	Weak negative correlation	Weak positive correlation	Low positive correlation	Moderately positive correlation	Highly positive correlation

Table 3: Pearson correlation coefficient between natural wind pressure and ventilator air volume.

Season	Pearson correlation coefficient	Significance	Number of cases
Spring	0.666	0.071	8
Summer	0.823	0.012	8
Autumn	0.283	0.497	8
Winter	−0.225	0.591	8

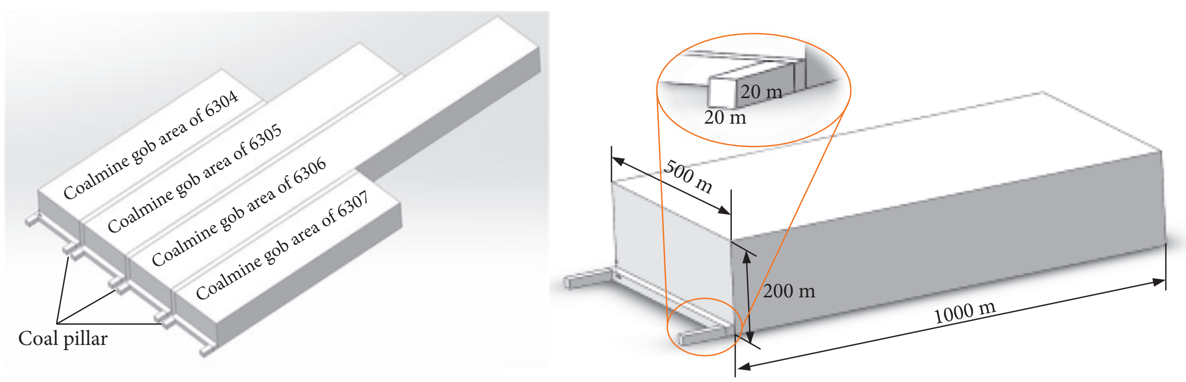

Figure 8: Deep mine model established through solidworks.

Table 4: Summary of dimensions of each part of model.

Gob	6304	6305	6306	6307
Length of working surface/m	100	100	100	100
Length in stoping direction/m	400	500	800	400
Height/m	60	60	60	60

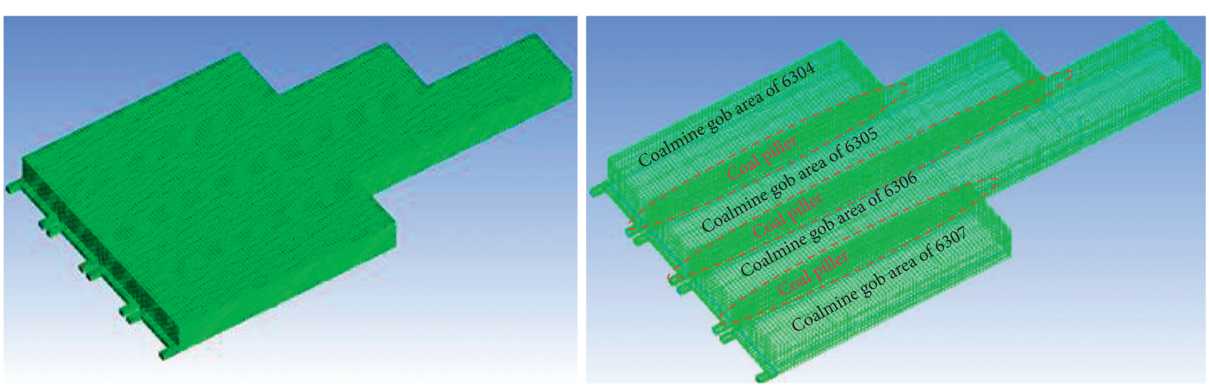

Figure 9: Mesh division of model.

airflow enters the gob. The airflow in the gob close to the return air roadway is forced into the return air roadway under the action of the pressure difference, and no airflow enters the working face.

According to the results of the numerical simulation using the ventilation data of each season in Tangkou Coal Mine, the sealing effect of the gob in Tangkou Coal Mine is poor. Under different ventilation conditions, the states of the

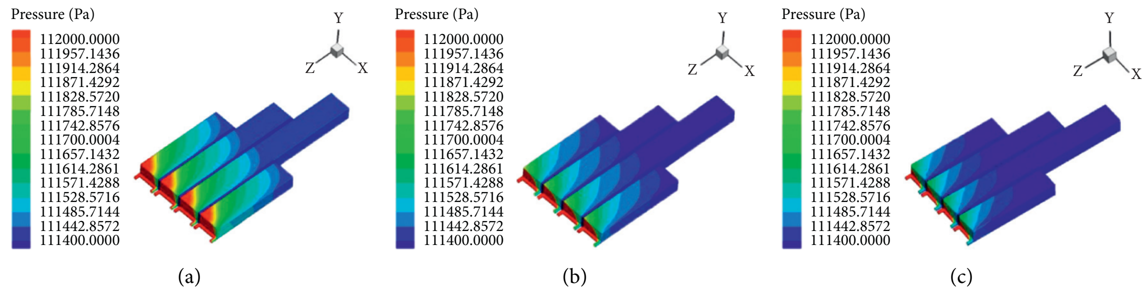

FIGURE 10: Simulation results at different air inlet pressures. (a) At air inlet pressure of 112,400 Pa. (b) At air inlet pressure of 112,000 Pa. (c) At air inlet pressure of 111,800 Pa.

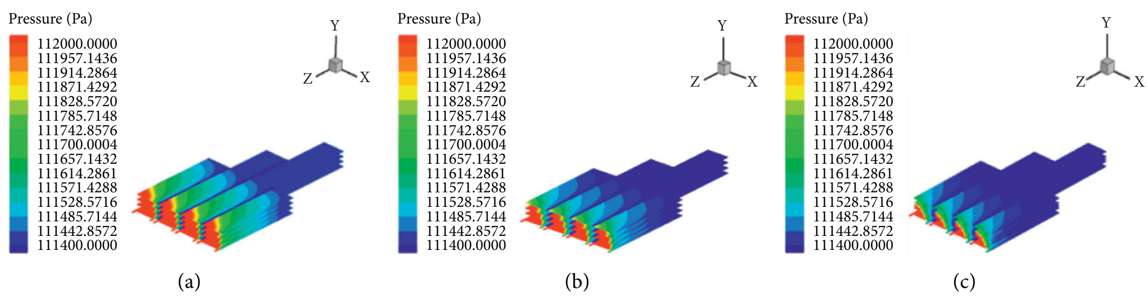

FIGURE 11: Simulation results of transverse slices at different air inlet pressures. (a) At air inlet pressure of 112400 Pa. (b) At air inlet pressure of 112000 Pa. (c) At air inlet pressure of 111800 Pa.

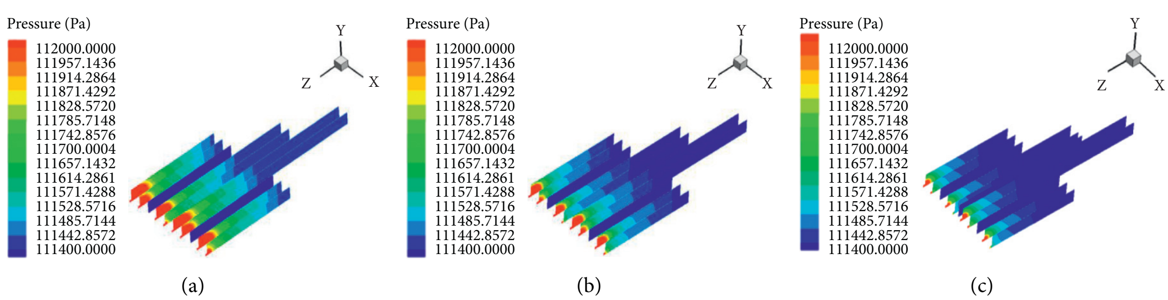

FIGURE 12: Simulation results of longitudinal slices at different air inlet pressures. (a) At air inlet pressure of 112,400 Pa. (b) At air inlet pressure of 112,000 Pa. (c) At air inlet pressure of 111,800 Pa.

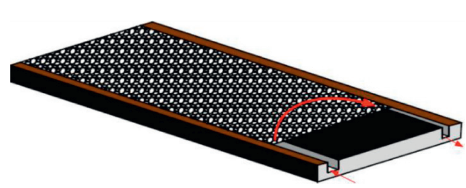

FIGURE 13: Flow field pattern inside gob.

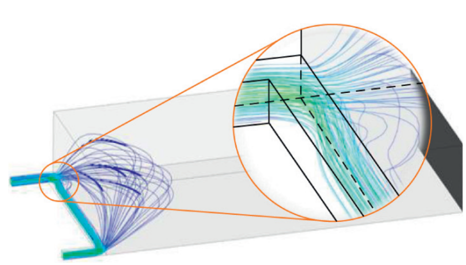

FIGURE 14: Airflow in gob 6304.

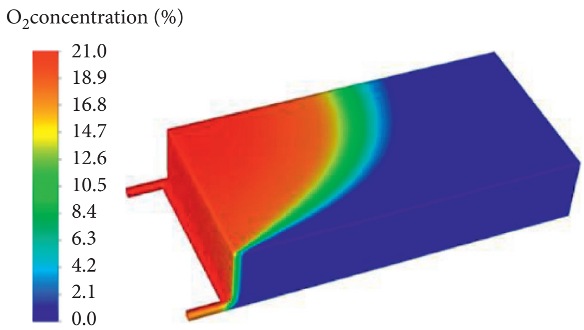

Figure 15: Oxygen concentration in gob 6304.

"three zones" inside the gob are different. This indicates that for deep shaft coal mines, changes in natural wind pressure have a close influence on the stability of the ventilation system.

6. Conclusions

In this paper, with the south wing shaft area of Tangkou Coal Mine taken as the research background, the influence of natural wind pressure on the stability of the ventilation system is studied through field measurement, and the importance of the stability of the ventilation system to the deep shaft coal mine is verified through numerical simulation. Through analysis and discussion, the following conclusions are drawn:

(1) In different seasons, the change trends of natural wind pressure and ventilator air volume are basically the same, and fluctuations in natural wind pressure will cause synchronous changes in ventilator air volume. The changes of natural wind pressure and ventilator air volume in a one-year cycle present a sinusoidal law.

(2) Based on the sensitivity analysis of natural wind pressure, the air intake roadway in the gob is significantly affected by natural wind pressure, while the return air roadway is less affected by natural wind pressure.

(3) In the temperate monsoon climate zone, the natural wind pressure in spring and summer has a more significant influence on the air volume of the ventilator than that in autumn and winter, and the natural wind pressure has a linear relationship with the air volume of the ventilator throughout the year..

Data Availability

The Underlying data can be found in the project "Stability of Deep Shaft Ventilation System and Research on Fire Prevention and Control Technology for Large Area Gobs."

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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