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Research on the local pressurized ventilation in high altitude mines and its main influence parameters

For protecting miners' safety and health when they were under severely low-pressure and oxygen-deficient working condition in the high altitude mines, this paper put forward a theoretical research on the local pressurized ventilation in high altitude mines. In this paper, the relevance between air pressurization and ventilation was analysed. Meanwhile, based on single factor analysis and orthogonal experiments, this research analysed the significant difference of relevant factors on achieving the local pressurized ventilation target. The results showed that to reach the local pressurized ventilation target value, the following methods could be adopted, which included adjusting the resistance in return aircourse, amending the air flow rate and the wind pressure in ventilating fan in intake airway. Combined application of these methods could achieve the target of local pressurized ventilation. Based on the regression analysis, the parameters of high altitude mines local pressurized ventilation and the quantificational effects of local pressurized ventilation were obtained. This research provided technical references to the safety in production in the high altitude mines low-pressure and oxygen-deficient working condition.

Keywords: High altitude mine, low-pressure and oxygen-deficient condition, local resistance, wind pressure in fan, wind quantity of fan.

1. Introduction

In the high altitude areas, since the atmosphere pressure and the oxygen content were low, the anoxia was a common phenomenon both in underground mines and opencast mines. Besides, in mining engineering, the severe working condition could also lead to the diminution of oxygen content in mine. Above 3000 m, people who are engaged in hard manual work are likely to suffer from anoxia, which decreased efficiency of workers and might lead to other mountain sickness. So far, technological measures for easing the altitude hypoxia lied in two aspects: oxygenation and pressurization. The methods of oxygenation were basically the same as oxygen therapy methods used in flatland. Oxygen therapy was the most commonly used method to treat the altitude hypoxia for its advantages such as easy to use, suitable to be applied in various situations and low initial investments [1]. When it came to mining engineering on plateau, however, in many cases, the oxygen resources could not meet the demands of all miners. So, the oxygen resources commonly became the crucial factor limiting oxygen therapies in mines. Pressurization was the other method for treating the altitude hypoxia. The problem of low air pressure, which causes the altitude hypoxia, could be solved fundamentally by pressurization techniques. Since the pressurization equipment was complicated and so far it was only used in medical institutions. Many researchers had been focusing on simplifying the procedures and equipment of artificial pressurization. In Sun Xinyi's opinion [2-3], he adopted the plenum ventilation and divided the process of mine ventilation into six parts: pressurization part → stable pressure part → pressure-increasing part → pressure-holding part → pressure-releasing part → original pressure part. By increasing the main fan pressure, he optimized the ventilation system to achieve the modification on the problem of oxygen deficiency in mines. Xin Song [4-6] had researched the mines at the altitude of 3850 m (under the pressure of 63.2 kPa). He adopted the artificial pressurization and increased the ventilation resistance in return aircourse. These methods could make the whole ventilation system integrated into a pressurized space. In his research, it is put forward that the setting of artificial pressurization target parameters should be based on the human labour indexes (at 3000 m), and he set the air pressure at the altitude of 3200 m (under the pressure of 67.9 kPa) as the referenced value. Wu Xuedu [7] had investigated the ventilation condition of some mines in China above the altitude of 3000 m (under the pressure of 70 kPa), he adopted the methods of local oxygenation and increasing the pressure of fan, which could take place of supplying oxygen to solve the problem of oxygen deficiency. Such as in Zhe Gu Tunnel (Sichuan Province, at the altitude of 3250 m, overall length 4423 m and under the pressure of 68 kPa), the wind pressure in fan was increased and miners carried oxygen individually. In Tie Li

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Ma Tunnel (Xin Jiang province, at the altitude of 3500 m, overall length 1893 m and under the pressure of 66 kPa), the wind pressure in fan was increased also. In Leng Long Ling Tunnel (Gansu province, at the altitude of 3500 m, overall length 8864 m and under the pressure of 66 kPa), the wind pressure in fan was increased and oxygen was supplied in local areas. In Da Ban Shan Tunnel (Gansu province, at the altitude of 3850 m, overall length 1530 m and under the pressure of 64 kPa), the wind pressure in fan was increased to solve the problem of oxygen deficiency.

In view of these phenomenons, this essay focused on the local pressurized ventilation in high altitude mines, aiming to find out the parameters, which could improve the low-pressure and oxygen-deficient condition in mines, and relieved miners from anoxia, besides, improved workers' work efficiency.

2. Basic principles and main influence parameters of local pressurized ventilation in mines

2.1 The background of ventilation engineering

2.1.1 Target values of local pressurized ventilation

The background of local pressurized ventilation in mines was set in a copper mine located in Tibet, China. In this copper mine, the underground mining areas lied from the altitude of 4300 m to 4700 m. In the mine, the average air pressure approximately reached 59.3 kPa (443 mmHg), the oxygen in partial pressure was 12.3 kPa (92.3 mmHg), and the oxygen content in the air was about 0.173 kg/m^3. The standard atmospheric pressure on the sea level is 101.33 kPa (760 mmHg), the oxygen partial pressure is 21.2 kPa (159.22 mmHg), the oxygen content in the air is 0.298 kg/m^3, the pressure difference between the sea level and the mine was approximately 42 kPa. In the mine, alveolar oxygen partial pressure of miners was appropriate 6.12 kPa (46 mmHg) and the human pulmonary respiratory pressure difference merely could reach 0.667 kPa~2.666 kPa. Considering the reality, it is quite difficult to raise the air pressure in the mine to reach the air pressure on sea level.

According to “The Standard Classification of Intensity for Manual Work”, in China, for workers' health, the maximum energy consuming value was set 6278 kJ per day. Based on the relevance between the altitude and the maximum workload value of human, it could be calculated that below the altitude of 2700 m, the maximum workload value of human was below the maximum energy consuming value and could meet the requirement of the national standard [8]. According to the relevance among the altitude and indexes of workers such as the oxygen partial pressure and the blood pressure saturation, it could also be calculated that areas below altitude of 3000 m were suitable for manual work. Based on the influence of oxygen concentration on human, the pressure in local pressurized area was set to higher than the pressure at the altitude of 2900 m. Considering climate parameters and concentration parameters of different kinds of gas [9], the pressure in local pressurized area was set to higher than the pressure at the altitude of 2700 m. However, based on practical researches in mines, miners showed strong acclimation ability in high altitude environment. By adapting suitable measures, the acclimation process of miners could be accelerated.

Based on miners’ physical indexes measured at the altitude of 4000 m, it was found out that firstly, miners' average oxygen saturation of blood value was at the level of 86.4% on 7th day after they arrived at mines, it reached 87.38% on 30th day, and it kept increasing and reached 90.42% after 180 days. It totally increased about 4.02%, closely approaching the human average oxygen saturation of blood value (90%) at the altitude of 3000 m. Miners' average alveolar oxygen partial pressure was 72.6 hPa on 7th day, then reached 74.3 hPa on 30th day, it finally reached 82.5 hPa after 180 days. The total increment of it was 9.9 hPa. After the acclimation, miners’ average alveolar oxygen partial pressure was a little higher than the theoretical value of it (81.91 hPa) at the altitude of 3000 m. Miners’ average alveolar oxygen partial pressure was 72.6 hPa on 7th day, then reached 74.3hPa on 30th day, it finally reached 82.5 hPa after 180 days. The total increment of it was 9.9 hPa, after the acclimation, miners’ average alveolar oxygen partial pressure was a little higher than the theoretical value of it (81.91 hPa) at the altitude of 3000m. Based on the drift rate of oxy-hemoglobin dissociation curve, the affinity between oxygen (O_2) and hemoglobin (Hb) increased. The value of ventilation index was same with that at the altitude of 3000 m and the intensity of labor increased by 0.5 grade to 1 grade.

So, the target of local pressurized ventilation in high altitude mines could be set as: increasing the air pressure in high altitude mines to the air pressure after miners' fully acclimation at the altitude of 4000 m. By local pressured ventilation in the mines, the local air pressure in mines could be raised from 59.3 kPa to 62 kPa and the range of compensation was around 2.7 kPa, which could make the parameters of air pressure met miners' body requirements.

2.1.2 The set of local pressurized area

The local pressurization, aiming at establishing suitable pressurized ventilation system on working faces, which not only could make working faces fitted the demands such as dividing the wind, reasonably pressurizing, but also could cooperate with the whole system, such as emitting blasting fume and reduce the ventilation leakage. Static patterns were needed while some flexible adjustments for application were also required. Due to the following factors such as large size of orebody, large amount of faces, long distance of ventilation, after the analysis, the proposal turned out to be that faces were set as core area and pressurized ventilation was adapted in local areas as is shown in Fig.1.

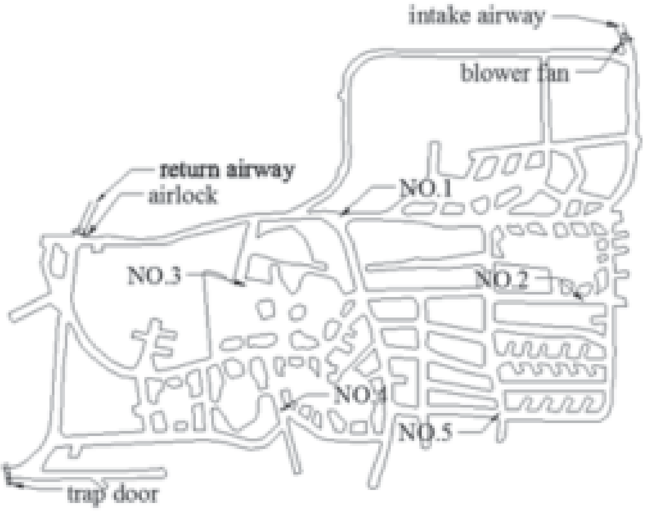


Fig.1 Sketch map of local pressurized ventilation in mine faces

2.2 The energization adjustment model

In order to improve the oxygen partial pressure in underground mines, the method of pressurized ventilation was adapted to maintain the barotropic air stream in mines. Assuming that the air current in pressurized area was consistent, energy equation was used to analyze the relevance between dynamic force and resistance of ventilation fan according to the equation below:

$$(P_1 - P_2) + \left(\frac{v_1^2}{2}\rho_1 - \frac{v_2^2}{2}\rho_2\right) + (Z_1 g\rho_{m1} - Z_2 g\rho_{m2}) = h_{1,2} \quad ... (1)$$

In formula, $(P_1$-$P_2)$ signified the relevant static pressure in ventilation fan, represented by H_s; $(Z_1gp_{m1}$-$Z_2gp_{m2})$ was used to represent the potential energy difference between two cross-sections, which was equal to natural wind pressure caused by the height difference, the latter, represented by Hn, h12 signified the ventilation resistance in pressurized area. Then, the formula (1) could be expressed as:

$$\left(H_s + \frac{1}{2}v_1^2\rho_1\right) + H_n = h_{1,2} + \frac{1}{2}v_1^2\rho_2 \quad ... \quad (2)$$

Based on the total pressure in fan, $H_f = H_s + \frac{1}{2}v_1^2\rho_1$, if the natural wind pressure was neglected in network structure in pressurized area, the formula (2) could be simplified as:

$$H_f = h_{1,2} + \frac{1}{2}v_1^2\rho_2 \quad ... \quad (3)$$

If $h_{1,2}$ was set as the value of resistance based on the plain theory, and assuming the theoretical demanded quantity of wind Q_{wind} to be stable, then the total pressure of fan H_f must meet both the ventilation resistance $h_{1,2}$ and the loss of velocity pressure $\frac{1}{2}v_2^2\rho_2$ near air return grilles in pressurized area. According to the relevance between the altitude H and air pressure, along with the equivalent altitude after miners' fully acclimation $H_{acclimation}$, and the ventilation fan correction coefficient on plateau p_0/p_H, the pressurization formula was:

$$H_f = \left(H_{acclimation} - 101.3_e^{-E-4H} + h_{1,2} + \frac{1}{2}v_2^2\rho_2\right)\frac{\rho_0}{\rho_H} \quad ... (4)$$

The results indicated that, (1) based on formula (1), the influencing factors of pressurization include parameters of fan (2), based on the energy equation of wind, if in pressurization work, only the fan were used, the fan power would increase.

2.3 The background of ventilation engineering

The incremental-resistance adjustment model referred to set down some structures in the return air inlet in zones of evaluated pressure, in order to form a suddenly decreasing sectional areas, by pushing the air current to make a sudden change of direction or of flow rate, which could produce a strong impact so that the additional resistance could be created and the wind pressure in the mines could be increased [10]. Under turbulence condition, the frontal resistance h_{er} caused by the sudden decrease of sectional areas, was in direct ratio with the velocity pressure h_{v1} and h_{v2}.The local resistance could be described as the following formula:

$$h_{er} = \xi_1 h_{v1} = \xi_1 h_{v2} = \frac{1}{2}\xi_1 v_1^2\rho = \frac{1}{2}\xi_2 v_2^2\rho \quad ... \quad (5)$$

In this formula, v_1 and v_2 referred to the average flow rate before and after the section, m/s. p referred to the air density $\xi_1 = Q/S_{small}$ on the section, kg/m³. ξ_1, ξ_2, without dimension, which $v_2 = Q/S_{large}$ could be chosen based on S_{small}/S_{large}, referred to the local resistance coefficients respectively corresponding to h_{v1} and h_{v2}. As is indicated in Table 1 showed.

Table 1: The coefficient of part resistance corresponding with the fracture surface

S_{small}/S_{large}	1	0.9	0.8	0.7	0.6	0.5
ξ	0	0.05	0.1	0.15	0.2	0.25
S_{small}/S_{large}	0.4	0.3	0.2	0.1	0.01	0
	0.3	0.35	0.4	0.45	0.5	

If the amount of wind Q stayed constantly, the value of average flow rate could be calculated:

... (6)

Substituting the formula (5) in the formula (4):

$$h_{er} = \frac{1}{2}\xi_1\frac{Q^2}{S_{small}^2}\rho = \frac{1}{2}\xi_2\frac{Q^2}{S_{large}^2}\rho \quad ... \quad (7)$$

According to the ventilation resistance formula, $R_{er} = \frac{\xi_1\rho}{2S_\lambda^2} = \frac{\xi_2\rho}{2S_\lambda^2}$, a new formula could be deduced as follow:

$$h_{er} = R_{er}Q^2 \quad \ldots \quad (8)$$

In the formula, h_{er} referred to the total resistance in zones of pressurization, Pa. R_{er} referred to the total wind resistance, of which the unit was NS^2/m^8. Q referred to the total amount of wind, of which the unit was m^3/s.

In order to meet the demands of supplying the wind and improving the oxygen partial pressure in mines, it was necessary to set a damper regulator with an area-adjustable air regulator. Wind flowed through the air regulator and its energy would decrease. Then, the h_r would appear, the area of the air regulator could be calculated as follows.

On the premise of $S_w/S_{max}<0.5$,

$$S_w = \frac{S_{max}}{0.65 + 0.84 S_{max}\sqrt{\Delta R_{er}}} \quad \ldots \quad (9)$$

On the premise of $S_w/S_{max}>0.5$,

$$S_w = \frac{S_{max}}{1 + 0.759 S_{max}\sqrt{\Delta R_{er}}} \quad \ldots \quad (10)$$

In this formulation, S_w referred to the area of the air regulator, the unit of which was m^2. ΔR_{er} referred to the increased air resistance, NS^2/m^8.

According to the formula (8), pressurization control must base on the premise of the increase of the local resistance, the decrease of S_w. However, the decrease of S_w would inevitably lead to the difficulty of ventilation increase. In order to guarantee ventilate in mines, in here, constraint conditions were brought in, such as the characteristic of windage (equivalent orifice) to judge the difficulty of ventilation. The area A could be calculated from the following formulation:

$$A = 1.189Q/\sqrt{h} \quad \ldots \quad (11)$$

In this formulation, A referred to the area of the equivalent orifice, m^2.

Based on formula (4) to formula (10), the result indicated that: (1) The incremental-resistance adjustment method could increase the frontal air return resistance. Due to the increasing-resistance adjustment, if parameters of fan remained unchangeable, the amount of wind in the mines would decrease. So, merely using increasing-resistance method might fail to achieve the prospective purpose. (2) In increasing-resistance adjustment method, the influencing factors on the pressurization included: The equivalent orifice was in the inverse proportional with the ventilation resistance or to the windage resistance. Ventilating in the mines was proved more difficult when the resistance increased or area of the equivalent orifice decreased. Because of this, the partial windage resistance should be taken into consideration when it came to the pressurization in the mines.

2.4 The air leak plugging adjustment model

According to law of resistance of air leak [11-12], $h_L = RQ^n$, $1<n\leq2$, $Q \to 0$ was a premise of decreasing the amount of air leakage. The solutions included increasing the resistance in ventilation laneway, $R_L \to 0$, and reduce differential pressure between the left side and right side in the ventilation laneways, $h_L \to 0$.

If the differential pressure of inside and outside pressurization area was huge, severe air leak would be caused. The technology of localized pressurizing ventilation aims at controlling the air differential pressure between different ventilation leakage areas to stop the wind exchange, keeping the wind pressure stability in each laneways and preventing the air leakage appearing in branches of the mines. According to law of resistance of air leak, plugging up the air leak source could increase the leakproofness and plugging up the air leak laneway could stop the wind exchange. In laneways, reducing the differential pressure between different areas was not effective.

Based on the technology features of local pressurized ventilation, in order to plug up pressure leakage areas and strengthen the leakproofness, comprehensive analysis on compression strength, structure and the constructive feasibility of the airproof wall should be made firstly. The leakproofness between settlement of doorframe and laneways structure must be guaranteed, and method of setting two air regulators to prevent pressure leakage. Since the differential pressure between the intake airways and return airways was high, suitable distance should be left between each other. When it came to ventilation breakthrough, two linkage ventilation doors should be mounted.

3. Single factor experiment

3.1 The influence of resistance adjustment on factors in pressurized area

3.1.1 The influence of resistance adjustment on wind pressure in pressurized area

The experimental model of the network solution in mines ventilation was made, all statistics are shown in Fig.2. On the premise of the stability of other parameters, according to the principle of mines ventilation, the ventilation resistance and the equivalent orifice were corrected. To guarantee the ventilation condition in mines meeting a moderate level, based on equations from formula (5) to formula (11), researchers chose 0.76, 0.6, 0.47, 0.31 as resolvable experiment coefficients of partial air resistance. The monofactorial experiment had been implemented under different ventilating resistance conditions.

According to the experiment, when local air resistance changed, the average wind pressure variation tendency cohered with the theoretical research. As it is shown in Fig.3,

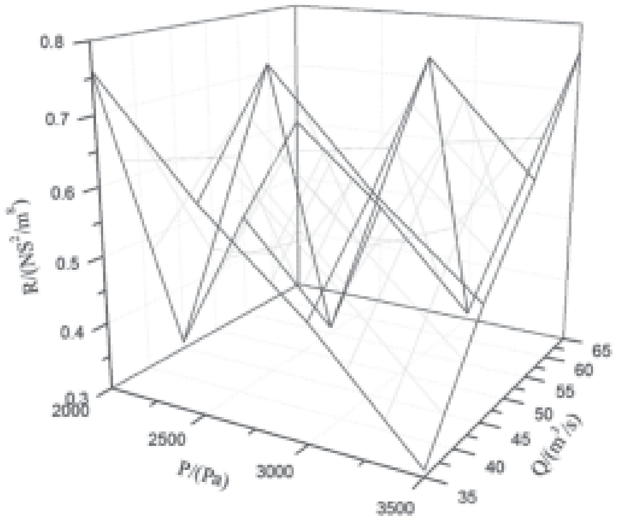


Fig.2 The experimental model of relevance among air resistance, wind pressure and air flow rate in pressurized area

when other ventilation parameters reminded steadily, the wind pressure in pressurized area and the wind resistance were in linear positive correlation. Combined with the experimental statics, the following formula was deduced:

$$p = -387.28r^2 + 618.33r + 270.84 \quad \text{...} \quad (12)$$

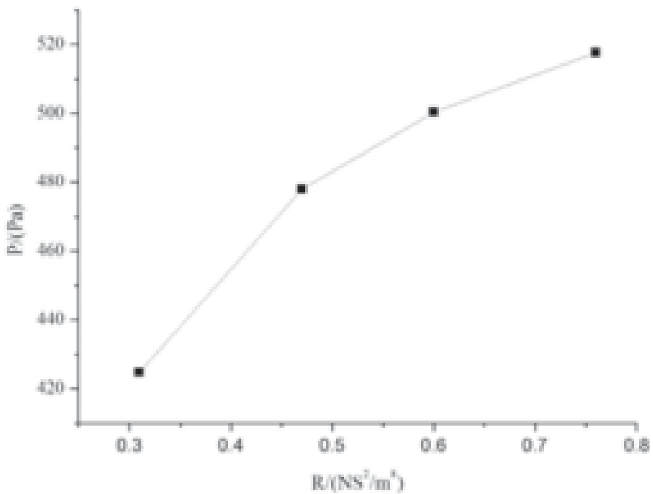


Fig.3 The numerical experiment of the relevance between the wind pressure in pressurized area and the local air resistance

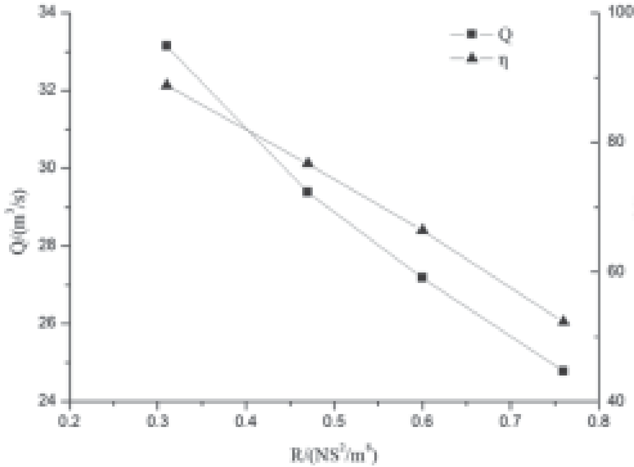


Fig.4 The numerical experiment of the relevance among the total intake, working efficiency of fan and local wind resistance

It was judged that the total intake in pressurized area and the working efficiency of the fan showed a downward trend as the local wind resistance rose, which is shown in Fig.4.

3.1.2 The influence of resistance adjustment on wind pressure in pressurized area

Wind pressure changed with local wind resistance, which led to the changes in each unit velocity field and pressure field. Results are shown in Fig.5. The air flow rate and the wind velocity decreased, wind pressure rose while local wind resistance increased.

3.2 THE INFLUENCE OF AIR FLOW RATE ADJUSTMENT ON PARAMETERS IN PRESSURIZED AREA

3.2.1 Researches on the influence of air flow rate in fan and the wind pressure in pressurized area

Since the air volume in the ventilation fan had nothing with air weight, there was no need to adjust the coefficients on air flow rate in ventilation fan. Meanwhile, according to "GB1623-2006 Safety Regulations for Metal and Nonmetal Underground Mines", the wind speed in mines must meet the requirements. The wind speed in ventilation fan should be set reasonably based on the demanding air flow rate in mines. The respectively air speed of selected ventilation fan were 35 m/s, 45 m/s, 55 m/s and 65 m/s. The single factor experiment

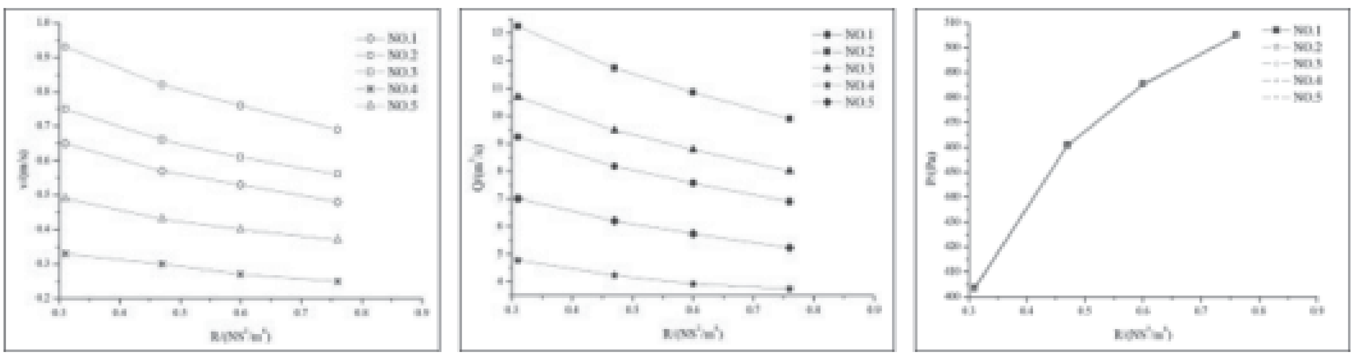


Fig.5 The numerical research on the relevance among ventilation parameters of main laneways and local wind resistance

had been made, the average values of wind pressure under conditions of different air speeds could be gained from the numerical experiment, which is shown in Fig.6. If other parameters remained steadily, the air flow rate in fan and the wind pressure in pressurized area were in linear positively correlation. The following formula could be deduced combined with some statistics.

$$p = 0.036q^2 + 2.3826q + 31.053,\ R^2 = 0.9996 \quad \text{...} \quad (13)$$

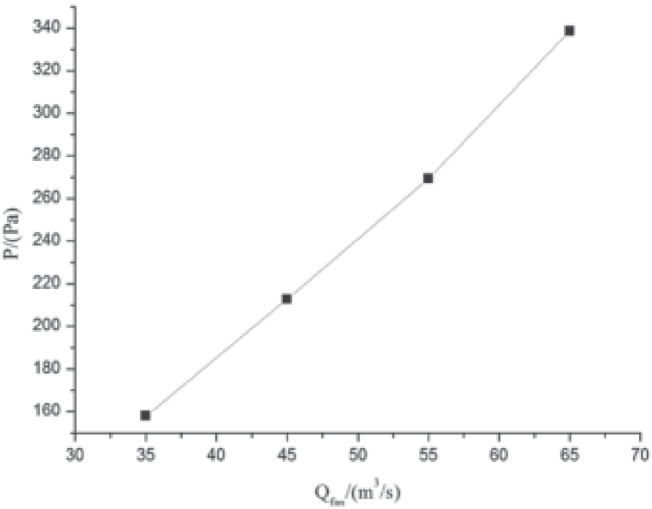


Fig.6 The numerical experiment on the relevance between air flow rate in fan and pressure in pressurized area

Based on the numerical experiment, shown in Fig.7, the total intake in pressurized area and the working efficiency of ventilation fan changed with the variation of air flow rate in ventilation fan. On the one hand, the larger the air flow rate in ventilation fan, the larger the power rate of fan. On the other hand, the increase of fan efficiency illustrated the decrease of the internal resistance and the well performance of fan.

3.2.2 Researches on the influence of air flow rate in fan and the wind pressure in pressurized area

The air flow rate in ventilation fan changed the wind pressure in pressurized area, which included the air flow rate, wind speed, and the wind pressure in each laneway,

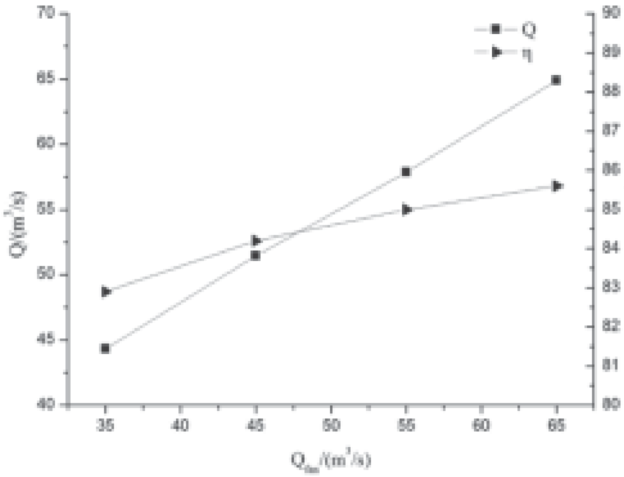


Fig.7 The numerical experiment on the relevance among the total intake, the working efficiency of fan and the air flow rate in fan

underground chamber, drivage entry and air outlet. Fig.8 shows results of experiment on the variation of wind speed and wind pressure in main laneways. Differences in sectional areas leaded to the variation of air flow rate, wind velocity and wind pressure.

3.3 The influence of wind pressure in ventilation on factors in pressurized area

3.3.1 The research on the wind pressures in ventilation fan on the wind pressure in pressurized area

Based on experiment, at the premise of other parameters` remained invariant, In order to make the oxygen partial pressure in pressurized area reach the oxygen partial pressure at altitude of 4000 m, the wind pressure in ventilation fan should be calculated according to formula (4). In standard states, the wind pressures in ventilation fan were respectively 3500 Pa, 4375 Pa, 5250 Pa, 6125 Pa. Taking the plateau effect into consideration, wind pressures in ventilation fan were respectively 2000 Pa, 2500 Pa, 3000 Pa, 3500 Pa. As the variation of wind pressure shown in Fig.9, merely using fan to pressurize produced little effect on the wind pressure in pressurized area and could not reach the target of pressurization. The pressure in fan would decrease and the

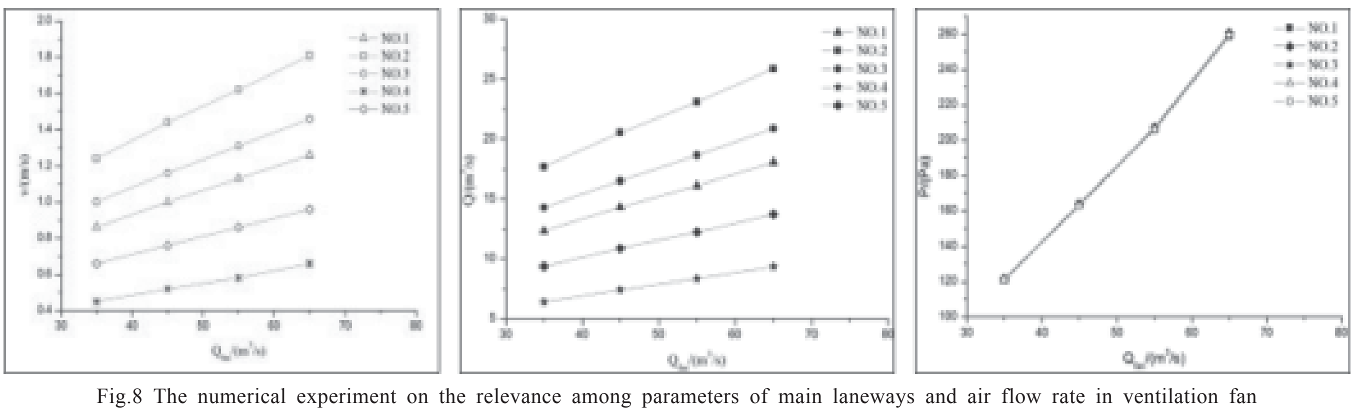


Fig.8 The numerical experiment on the relevance among parameters of main laneways and air flow rate in ventilation fan

working efficiency of fan would be astable. The wind pressure in ventilation fan and the wind pressure in pressurized area was in linear direct correlation.

$$p = 0.0001h^2 + 0.4551h + 735.62, R^2 = 0.9501 \quad ... \quad (14)$$

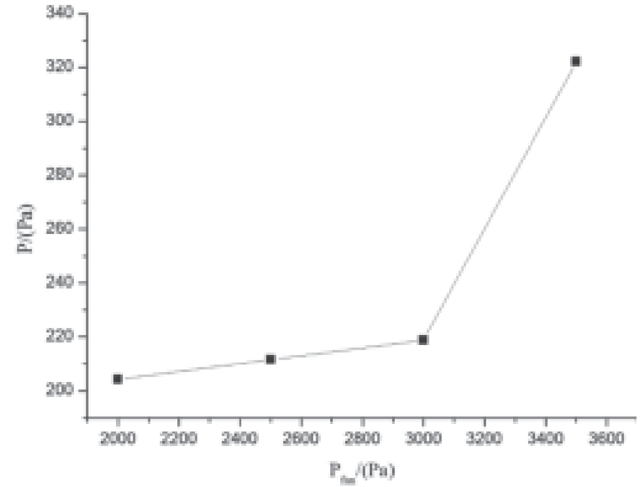


Fig.9 The numerical experiment on the relevance between the wind pressure in pressurized area and the wind pressure in ventilation fan

As the wind pressure in ventilation fan increased, the total intake in pressurized area increased and the working efficiency of ventilation fan fell, which was varying in irregular patterns

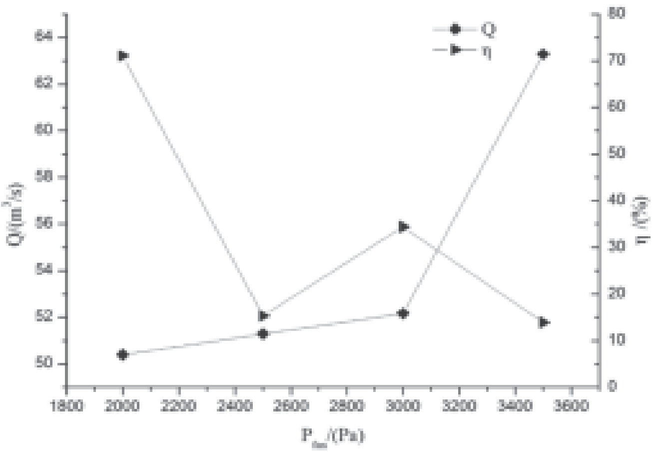


Fig.10 The numerical experiment on the relevance among the total intake, the working efficiency of fan and the wind pressure in fan

and did not meet the requirement of "Safety Regulations", in which the working efficiency of fan could not lower than 60% of the power rating, as Fig.10 shows.

3.3.2 Research on the influence of wind pressure on conditions of main laneway

From the experimental results, the air flow rate and wind speed in main laneways increased with the increasing of wind pressure in ventilation fan. However, the increasing degree was not very apparent, maintaining in theoretical ranges of pressure in pressurized area. As Fig 11 Showed.

4. Research on the local pressurization in mines based on the orthogonal experiment

On the basis of the single factor experiment, the orthogonal experiment was carried to explore the effect of the combination process of local wind resistance, the air flow rate in ventilation fan and the wind pressure in fan on main laneways air pressure [13].

In the mine, three faces were chosen as 4400 m, 4450 m and 4500 m. The air pressure compensation of miners were set between 2500 Pa~3000 Pa. The main air inlets altitude and the average altitude of the lowest mining face. According to formula (14), the average altitude of mines was 4450 m. Based on it, the target value of the orthogonal experiment was set as the average value of altitudes of each faces, the air pressure compensation of miners was 2750 Pa.

$$\overline{H} = \frac{H_1 + H_2}{2} \quad ... \quad (15)$$

4.1 Design of experiments

4.1.1 Design principle of orthogonal experiments

Orthogonal experiments involved in using normalized orthogonal tables to set the experiment condition and arrange the experiment reasonably so that the frequency of experiment could be reduced effectively and the mathematical theories of statistics could be used to analyze the experimental results [14-17]. Range analysis was involved as the main analysis method, which referred to as the difference between the maximum average value and the minimum average value, the

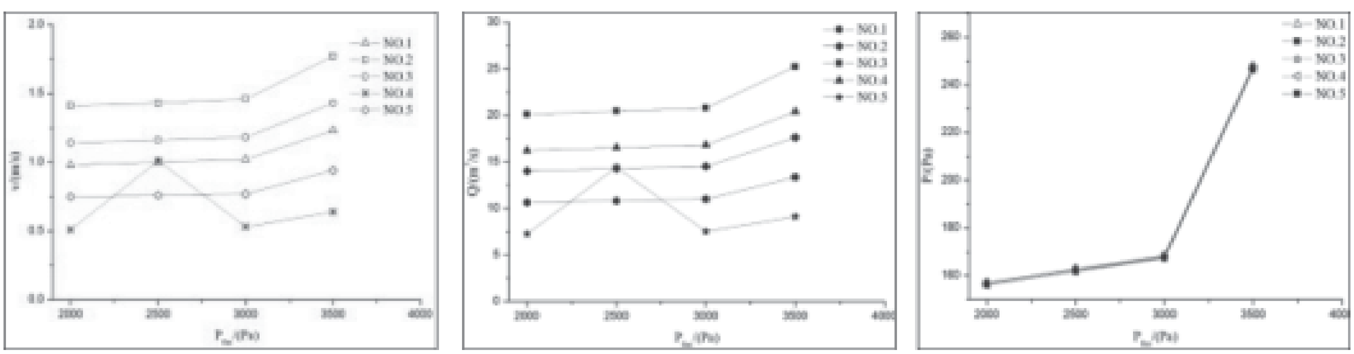


Fig.11 The numerical experiment on the relevance among the speed, the air flow rate, the wind pressure in main laneways and air flow rate in ventilation fan

significant difference of influencing factors could be illustrated by the value.

4.1.2 Principle of orthogonal experiments

4.1.2.1 The factor level table

According to the experimental model, factors referred to local wind resistance r_0, air flow rate in ventilation fan q_0 and wind pressure in ventilation fan p_0. According to the numerical simulative condition of the single factor experiment, the factor level values are listed in Table 2.

TABLE 2: FACTOR LEVEL TABLE

Factor / level	A $r_0(Ns^2/m^8)$	B $q_0(m^3/s)$	C p_0(Pa)
1	0.76	35	2500
2	0.6	45	3000
3	0.47	55	3500

4.1.2.2 Selection of indexes

This paper aimed at figuring out the influence of pressurization on wind velocity fields in laneways and the distribution condition of wind pressure. Because of this, the indexes of the orthogonal experiment were set as the air flow rate, the wind speed and the wind pressure in main parallel tunnels, intake airway and return airway.

4.1.2.3 Arrangement of the orthogonal experiments

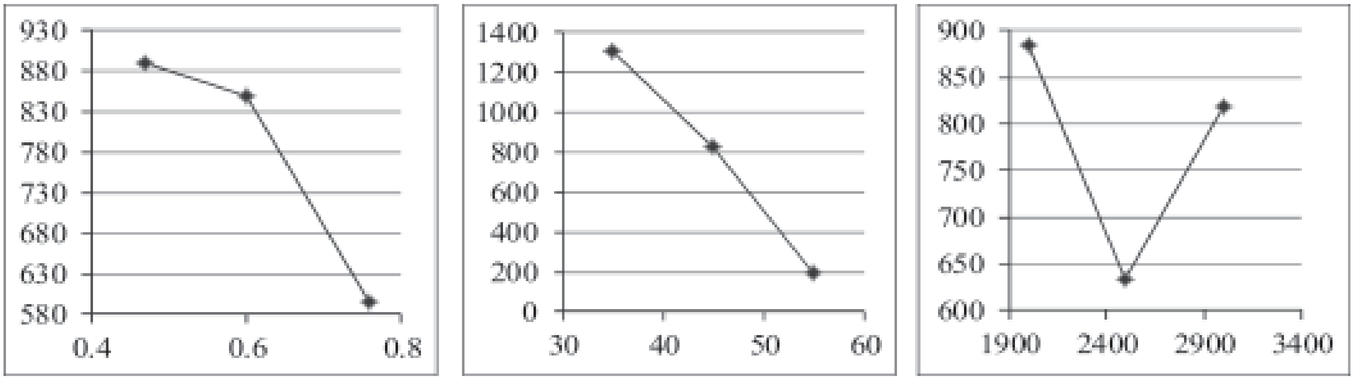
Arrangement of the orthogonal experiments must meet following conditions: (1) The occurrence number of each factor stays at the same level; (2) Frequency of each factor combination level was the same. For that reason, the orthogonal layout L9 (33) was designed according to features of the orthogonal experiment arrangement. The orthogonal layout L9 (33) implemented 9-group experiment to analyze the relevance among the local wind resistance in return airways, the wind flow rate in fan in intake airway, the pressure in ventilation fan and the significant difference of parameters in laneways.

4.2 PROCESS OF ORTHOGONAL EXPERIMENTS

Setting wind pressure in pressurized area as index, the range analysis results are shown in Table 3. In this table, $\sum X_{ij}$ represented the sum of '*j*' factors and '*i*' level, *i* = 1, 2, 3. $\overline{X}_{ij}$ referred to the average values of '*i*' level statistics,

TABLE 3: THE RANGE ANALYSIS RESULTS BASED ON INDEXES OF THE WIND PRESSURE IN PRESSURIZED AREA

Factor / level		A	B	C	Experimental statistics The average wind pressure in pressurization area (Pa)
Experimental numbers		Local wind resistance	Wind quantity of fans	Wind pressure in fans	$\min\left\|P_{experimnt} - P_{t\arg et}\right\|$
1		1(0.76)	1(35)	1(2500)	1132
2		1(0.76)	2(45)	2(3000)	542
3		1(0.76)	3(55)	3(3500)	112
4		2(0.60)	1(35)	2(3000)	1288
5		2(0.60)	2(45)	3(3500)	845
6		2(0.60)	3(55)	1(2500)	418
7		3(0.47)	1(35)	3(3500)	1498
8		3(0.47)	2(45)	1(2500)	1104
9		3(0.47)	3(55)	2(3000)	69
Sum	$\sum 1j$	1786	3918	2654	
	$\sum 2j$	2551	2491	1899	
	$\sum 3j$	2671	599	2455	
Average value	$\overline{X}_{1j}$	595.33	1306.00	884.67	
	$\overline{X}_{2j}$	850.33	830.33	633.00	
	$\overline{X}_{3j}$	890.33	199.67	818.33	
Extreme difference	R_j	295	1106.33	251.67	
Optimized level		(2)A1	(3)B3	(1)C2	



(a) r_0 (Ns^2/m^8) (b) q_0 (m^3/s) (c) p_0 (Pa)

Fig.12 The experimental results of the range analysis on wind pressure factors and levels

'*j*' factor, i = 1, 2, 3. As for R_j, it referred to the minimun value selected from differences of all level numbers' average values of factor 'j'. The optimized level of factors illustrated the scale of average values for every factor.

By comparing every factor`s range, every single factor`s influence level could be found out, which is shown in Fig.12.

It could be seen from Table 3 and Fig.12 that setting wind pressure as index, the influence level of factors were sorted from high value to low as: the wind pressure in fan C2,the local wind resistance A3, the air flow rate in fan B3. The most optimized proposal turned out to be A1B3C2. However, the results calculated by the orthogonal experiment was A3B3C2, besides, A1B3C2 could not been found among 9 proposals, which needed further orthogonal experiment. So, the experiment were carried out to tested the proposal A1B3C2 and the proposal A3B3C2. The values turned out to be 111.4 and 69 respectively, which proved A3B3C2 being the best option.

Among 9 proposals, the average working efficiency of the fan was beyond 70%. The best proposal was A3B3C2, of which the total intake in pressurized area was 71.97 m^3/s, the total wind pressure was 2769.1 Pa, the total wind resistance was 0.5357 Ns^2/m^8, the area of the air regulator was 1.63 m^2 and the difficulty of ventilation remained the middle level. The regulated value of air pressure reached to 62.069 kPa, the oxygen content of air reached to 0.182 kg/m^3. The result of study indicated that in the theoretical analysis and the orthogonal experiment, pressurization and ventilation had been fully taken into consideration, which meant adopting both the difficulty of ventilating in mines and the working efficiency of fan as the constraint conditions, considering miners fully acclimation and setting the target value of pressurization. The pressure in specific area could be controlled and the met the demand in different area.

4.3 Quantification of pressurization effect

Based on the single factor experiment and the orthogonal experimental analysis, the pressure fields and velocity fields in pressurized area changed with the local resistance in return airways, the air flow rate in fan and the wind pressure. By using the statistical software SPSS to do regression analysis, the prediction equation on factors in the high-altitude pressurizing and ventilating was established.

4.3.1 Regression equation of wind pressure in pressurized area

$$p = 75.15q_f + 1093.44r - 0.137h_f \frac{\rho_H}{\rho_0} - 1651.862,$$

$$R^2 = 0.929 \qquad \text{... (16)}$$

4.3.2 Regression equation of air flow rate in pressurized area

$$Q = 0.498q_f - 11.645r - 0.001h_f \frac{\rho_H}{\rho_0} + 14.621,$$

$$R^2 = 0.937 \qquad \text{... (17)}$$

4.3.3 Regression equation of wind speed in pressurized area

$$v = 0.035q_f - 0.814r - 0.00009h_f \frac{\rho_H}{\rho_0} + 1.026,$$

$$R^2 = 0.938 \qquad \text{... (18)}$$

In these equations, P referred to the wind pressure in pressurized area, Pa. Q referred to the air flow rate in pressurized area, m^3/s. v referred to the wind speed in pressurized area. q_f referred to the air flow rate in fan, m^3/s. r referred to the local resistance adjustment value in the return airway, Ns^2/m^8. h_f referred to the wind pressure in fan, Pa. As for the ρ_H/ρ_0, it referred to the coefficient of pressure drop effect.

5. Conclusions

(1) Based on the energy equation, the relevance among air pressure, air intensity and altitude were found. Combined with miners' fully acclimation in plateau, the calculation formula of pressurization by fan at high altitude mines was deduced.

(2) Based on single factor experiment, the influence of the local wind resistance, the wind pressure in fan and the air

flow rate in fan on pressure fields and velocity fields in laneways were explored. The result showed that the effect of adjusting single factor (the local wind resistance, the wind pressure in fan or the air flow rate in fan) was rather limited to the wind pressure fields and wind speed fields in laneways, failing to reach the target of pressurization.

(3) In the orthogonal experiment, the wind pressure in pressurized area could reach the target value by using the combination process of the local resistance, the wind pressure in fan and the air flow rate in fan. The significant difference of the local resistance, the wind pressure in fan and the air flow rate in fan on the average air pressure, the air flow rate and the wind speed in laneways were found out. Based on the regression analysis, the parameters prediction equations of high altitude mines local pressurized ventilation were also obtained.

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COMPARATIVE CHARACTERIZATION OF OVERBURDEN MATERIAL VIS-A-VIS SAND AS AN ALTERNATIVE FOR STOWING IN UNDERGROUND MINES

(Continued from page 53

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