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Study on effects of plateau environment on mine fans' parameters of characteristic curves

In order to improve the lower performance of mine fans in China's Tibetan plateau, this article mainly studies the effects of plateau environment on the fans' parameters. The results show that (1) the main contributory factor of the variation of the air pressure and power is the air density, while the air flow and efficiency cannot be influenced by the air density; (2) through the tests of fan performance at different altitudes, it can be found that the characteristic curve of air pressure declines by about 1/2 at an altitude of 4000 m or more and by about 1/4 at an altitude of about 2000 m, compared to it in the standard state. It indicates that the higher the altitude is, the poorer the working condition of fan performance is. Based on the above results and the analysis of the influence of an altitude on miners' physiological conditions, this article has established a mathematical model of modified performance parameters of mine fans referring the atmospheric pressure at an altitude of 3000 m.

Keywords: *Characteristic curve of air pressure, characteristic curve of fan power, air flow of fans, the test of fans, similarity law of fans.*

1. Introduction

In general, the ideal model selection of fans is based on the intersection of the characteristic curve of mine ventilation network and the curve of fan performance as an indicator, including the air flow, air pressure, power and efficiency. In addition, it must meet the requirements of mine ventilation, and choose technically sound and economically advantageous fans as motive power of mine ventilation. However, for the lower air density, the curve of fan performance provided by manufacturers is depicted in accordance with the experiential data of model under the standard atmospheric conditions. Therefore, when the fans installed in the mountains are operating in the mine ventilation network, the curve of actual performance will inevitably change. This change leads to the variation of fans' working conditions, and brings forward the question of how to choose the fans appropriately.

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Based on the above, some scholars have studied and discussed the ventilation methods in the underground engineering of plateau environment [1-4]. Gou [5] studied that the air flow calculation of ventilation construction in the highlands should take the volume expansion and concentration limits of harmful gases at different altitudes into account. Fans selection and ventilation resistance calculation should be modified according to the ratio of air density on the plateau to the plain. Sun [6] studied that, the wind could smoothly reach the mining areas and other personnel-intensive mining workplaces by strengthening and maintaining air pressure to main fans as well as optimizing ventilation systems via theoretical reasoning. Thus, it would solve the hypoxia problem of mine ventilation at high altitude as soon as possible. Wu [7] researched the ventilation technology of tunnel construction at Zhe Gu mountain with the altitude of 3250 m and found that strengthening ventilation system could take place of concentrated oxygen supply, and reforming the fans could make the ordinary fans work properly at high altitude.

In accordance with the above previous studies, this article studies the model selection of fans based on the nature of air, the similarity law of fans, and the degree of hypoxia, to explore a more accurate method for model selection of fans, and to provide a certain degree of guidance on the model selection of fan parameters in the mine ventilation engineering on the plateau.

2. Tests of operation performance of mine fans at different altitudes [8]

This article tests local fans in operation in the mine mountains of Tibet plateau and Yunnan plateau, in which four mine fans made in China were selected (Model: I: FBD No8.2/2X55, II: FBD No7.1/2X37, III: 70B2-11 No.18 and IV: BY-18). The measured data is obtained from tests under operation conditions at the altitudes of 4490 m, 4490 m, 1989 m, and 2472 m, and the results are shown in Table 1.

The data of air pressure and air flow of four fans in

TABLE 1. TEST DATA OF FANS ON THE PLATEAU

Number	Altitude height(m)	Air density (kg/m^3)	Project	Measured points Q ($m^3 \cdot min^{-1}$) and P (Pa)									
				1	2	3	4	5	6	7	8	9	10
□	500	1.29	Q_0	410	460	510	560	610	710	760	810		
			P_0	8350	8450	8460	8300	7900	6550	5400	3950		
	4490	0.714	Q	440	477	489	512	565	660	748	710	760	809
			P	4739	4806	4706	4780	4575	4132	3432	3718	3140	2876
□	500	1.29	Q_0	360	400	420	480	520	560	600	680	720	
			P_0	5800	5950	5970	5780	5450	5000	4320	2060	700	
	4490	0.714	Q	520	546	560	591	600	608	640	680	588	480
			P	3126	3118	2853	3013	2453	2182	1940	1198	2348	3303
□	500	1.29	Q_0	1842	2640	2580	2856	2832	2682	2664	2988	3124	3261
			P_0	2169	1588	1645	1366	1392	1547	1565	1216	1050	872
	1989	0.97	Q	1944	2124	2796	2718	2964	2910	3204	3180		
			P	1588	1182	985	1088	632	568	454	405		
□	500	1.29	Q_0	1290	2006	2324	2699	2795	2995	3057	3114	3205	3290
			P_0	1861	2067	2027	1876	1819	1678	1627	1578	1495	1410
	2472	0.94	Q	1301	2398	2676	2995	3216	3382	3614	3676	3807	3989
			P	1088	1578	1419	1421	1303	1286	1009	821	862	745

working condition are obtained through the performance tests of fans in plateau mines. Due to the deviation in measurement, the measured data deviate from actual working condition of fans. Therefore, to obtain a more accurate characteristic equation of actual operating fans, measured data will be fit with the method of the least squares [8-12].

On the basis of Table 1, the polynomial equations for characteristic curves of two local fans in plateau environment can be achieved and expressed as follow, respectively:

$$p = -0.0237q^2 + 23.636q - 1147.7 \quad ... 1$$

$$p = -0.0458q^2 + 42.56q - 6569 \quad ... 2$$

$$p = -0.0003q^2 - 0.8154q + 1102.1 \quad ... 3$$

$$p = -0.0003q^2 + 1.6404q - 462.33 \quad ... 4$$

Where p, q are air pressure and air flow, respectively.

Thus, this article depicts the characteristic curve of four fans' performance at high altitude and of new fans' performance in the standard state. The contrast between them can be carried on and the results are shown in Fig.1.

The air pressure of four fans at different altitudes decreases in varying degrees as is shown in Table 1 and Fig.1. The results of the performance tests of two fans at an altitude of 4490m decrease by 45.9% and 44.8% respectively, and at the altitudes of 1989m and 2472m by 27.6% and 28.2% respectively compared to the characteristic curve of air pressure in the standard state. It indicates that the operation performance of fans decreases with the increasing altitudes. This conclusion is consistent with the previous theoretical analysis. Because the total pressure of fans is proportional to the air density, the only variable is the air density when the air flow and speed are constant. Hence, the higher the altitude height is, the lower is the performance parameters of fans.

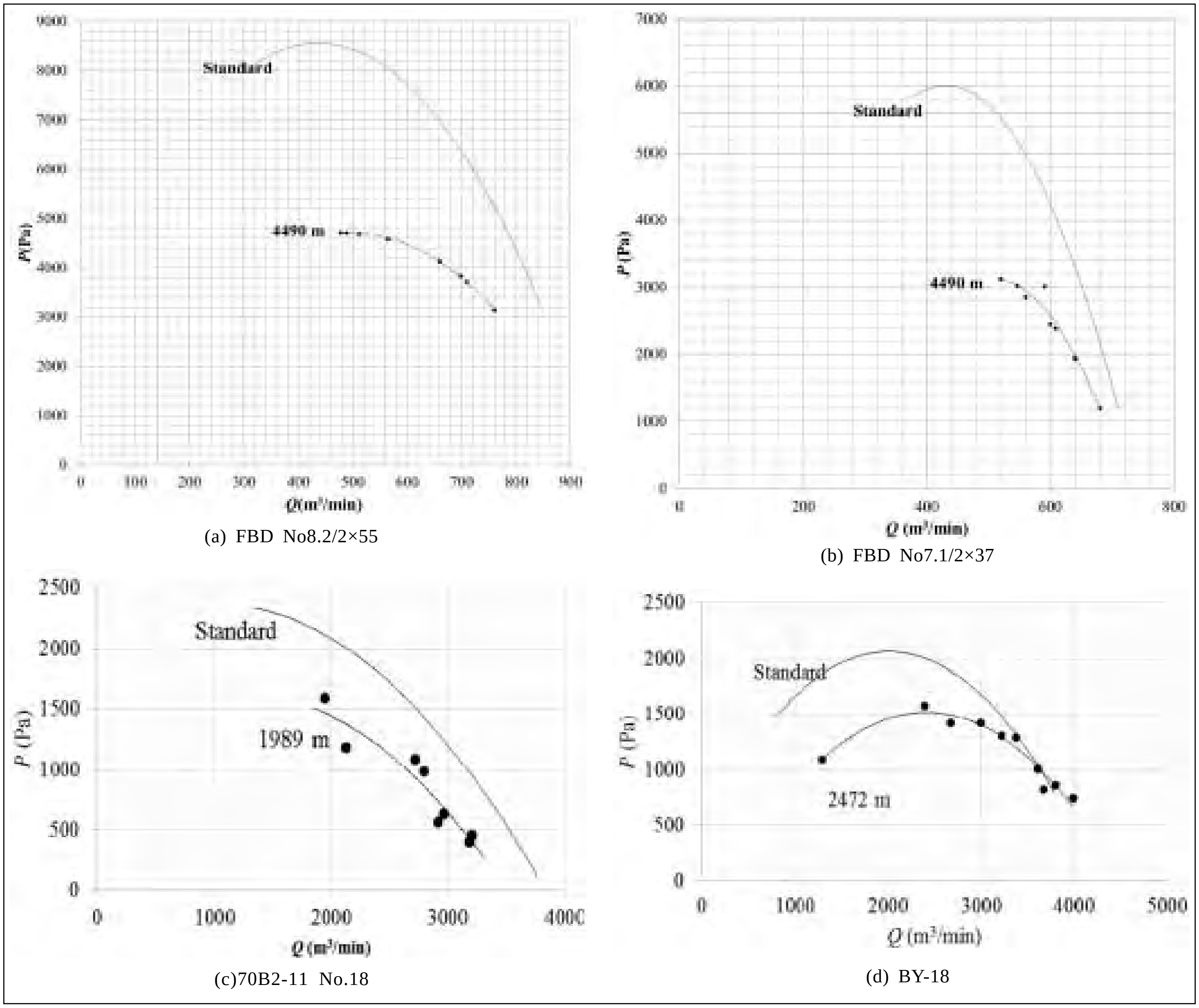
TABLE 2 AIR DENSITY AND OXYGEN CONTENT IN AIR AT DIFFERENT ALTITUDES

Altitude height (m)	Air density (kg/m^3)	Oxygen content (kg/m^3)
0	1.293	0.300
1000	1.161	0.268
2000	1.024	0.237
3000	0.905	0.209
4000	0.799	0.185
5000	0.703	0.163
6000	0.616	0.142
7000	0.538	0.124

3. Research on model selection of mine fans at different altitudes

The plateau features not only desearces the working performance of mechanical equipment, but also makes labour workers become anoxia and reduce labour capacity [13-14]. The variation of the air density and oxygen content in air at different altitudes is shown in Table 2.

According to the above analysis, the parameters of fans' working conditions on the plateau need to be modified by two steps: (1) working environment in mines at an altitude of less than 3000m cannot lower labour capacity of miners obviously. Thus, the only measure needed to take is to modify the characteristic parameters of air pressure and power in operation, which can make the performance of fans reach the state of sea level; (2) working environment in mines at an altitude of more than 3000m can lower labour capacity of



(a) FBD No8.2/2×55

(b) FBD No7.1/2×37

(c)70B2-11 No.18

(d) BY-18

Fig.1 Contrast of the P-Q characteristic curves of fans at different altitudes

miners obviously. Thus, the measures needed to take are not only to modify the characteristic parameters of air pressure and power in operation, but also to increase a degree of air pressure of fans to ensure the difference compensation of atmospheric pressure for miners in the shaft.

3.1 Analysis of modified parameters of mine fans' working condition at an altitude of less than 3000m

For the model selection of fans in ventilation system on the plateau, it must meet two factors: firstly, due to the characteristics of the plateau environment, the influence of air density on fan performance must be taken into account in the model selection of fans; secondly, the ventilation characteristics of plateau mines decide the impact of the compressibility of gases on the fan performance. Therefore, through the similarity theory, the conversion in the modified model selection of performance parameters of fans can be conducted on the basis of equal dimensionless performance parameters, comparison speeds and diameters but unequal air densities of two similar fans [15]. Namely:

$$\begin{cases} \varphi_0 = \varphi_H \\ \psi_{t0} = \psi_{tH} \\ \psi_{s0} = \psi_{sH} \\ \lambda_0 = \lambda_H \\ n_{s0} = n_{sH} \\ D_{s0} = D_{sH} \\ \rho_0 \neq \rho_H \end{cases} \quad \dots 5$$

Where φ_0, φ_H are the flow coefficients; ψ_{t0}, ψ_{tH} are the total pressure coefficients; ψ_{s0}, ψ_{sH} are the static pressure coefficients; λ_0, λ_H are the power coefficients; n_{s0}, n_{sH} are the comparison speeds; D_{s0}, D_{sH} are the comparison diameters; ρ_0, ρ_H are the air density.

3.1.1 Analysis of air density conversion relationship

According to the equation for gas state, the gas density in different inlet states can be expressed as follows:

$$\frac{\rho_0}{\rho_H} = \frac{p_0}{p_H} \times \frac{T'}{T} \qquad ...\ 6$$

Where p_H, p_0 are the air pressure of fans in mines at a high altitude and the sea level, Pa; T', T are temperatures of inlet and outlet gases of fans, K.

3.1.2 Analysis of performance parameters of plateau fans' gas compression

In general, when the total pressure H_{tf} is higher than 2500 Pa, the effect of gas compression needs to be considered. To conduct the conversion of performance parameters between the actual and ideal working conditions of incompressible gases, the total pressure coefficient of fans can be introduced, K_p.

$$k_p = \frac{p_{tf}}{p_t}\left[\left(\frac{\kappa-1}{\kappa} \times \frac{p_{tf}}{p_t}\right)^{\frac{\kappa}{\kappa-1}} - 1\right]^{-1} \qquad ...\ 7$$

Where κ is the isentropic exponent; air is 1.4; p_{tf} is the total pressure of fans without considering the gas compressibility, Pa; p_t is the state of air intake, Pa.

3.1.3 Modification on air flow of fans

The air flow of fans from a high altitude to a low altitude can be modified according to the similarity law of fans. When the flow coefficients of two similar fans are equal (namely, $\varphi_0=\varphi_H$) and the operation condition is $n_{s0}=n_{sH}$, $D_{s0}=D_{sH}$, $\rho_0 \neq \rho_H$, this situation can be considered that a fan is operating in the different air density, which means the selected fans are operating in the different air density at a high altitude and a low altitude. Therefore, the similarity law can be applied to the fan in two states.

The formula can be achieved according to the similarity law:

$$\frac{Q_0}{Q_H} = \frac{0.04108 n_{s0}}{0.04108 n_{sH}} \left(\frac{D_0}{D_H}\right)^3 = 1 \qquad ...\ 8$$

Where, Q_H and Q_0 are the air flow of fans in mines at a high altitude and the sea level, m^3/s.

As can been seen from the formula, the altitude does not affect the air flow of fans. There is no need to modify the parameters of fans' air flow as the altitude changes. Therefore, the air flow parameters of the selected fans are as follows:

$$Q_0 = Q_H \qquad ...\ 9$$

3.1.4 Modification on air pressure of fans

The air pressure of fans from a high altitude to a low altitude can be modified according to the similarity law of fans. When coefficients of total air pressure and static air pressure of two similar fans are equal (namely, $\psi_{t0}=\psi_{tH}$, $\psi_{s0}=\psi_{sH}$), and the operation condition is $n_{s0}=n_{sH}$, $D_{s0}=D_{sH}$, $\rho_0 \neq \rho_H$, this situation can be seen that a fan is operating in the different air density, which means the selected fans are operating in the different air density at a high altitude and a low altitude.

The formula can be achieved according to the similarity law:

1. When $H_{tf} < 2500$ Pa,

$$\frac{H_0}{H_H} = \frac{0.0274\rho_0 D_0^2 n_0^2}{0.00274\rho_H D_H^2 n_H^2} = \frac{\rho_0}{\rho_H} \qquad ...\ 10$$

2. When $H_{tf} > 2500$ Pa,

$$\frac{H_0}{H_H} = \frac{0.0274\rho_0 D_0^2 n_0^2}{0.00274\rho_H D_H^2 n_H^2} = \frac{\rho_0}{\rho_H} \times \frac{K_{p0}}{K_{pH}} \qquad ...\ 11$$

Where K_{p0} is the modified coefficient of total air pressure in the standard state, and K_{pH} is the modified coefficient of total air pressure measured in the plateau state.

3.1.5 Modification on power of fans

The power of fans from a high altitude to a low altitude can be modified according to the similarity law of fans. When the power coefficients of two similar fans are equal (namely, $\lambda_0=\lambda_H$) and the operation condition is $n_{s0}= n_{sH}$, $D_{s0}=D_{sH}$, $\rho_0 \neq \rho_H$, this situation can be seen that a fan is operating in the different air density, which means the selected fans are operating in the different air density at a high altitude and a low altitude. Therefore, the similarity law can be applied to the fan in two states.

The formula can be achieved according to the similarity law:

$$\frac{N_{i0}}{N_{iH}} = \frac{\rho_0}{\rho_H}\left(\frac{n_0}{n_H}\right)^3\left(\frac{D_0}{D_H}\right)^5 = \frac{\rho_0}{\rho_H} \qquad ...\ 12$$

Where N_{iH} and $N_{i0}$are the power of fans on the plateau and the sea level, kW.

3.2 ANALYSIS OF MODIFIED PARAMETERS OF MINE FANS' WORKING CONDITION AT AN ALTITUDE OF MORE THAN 3000 M

Considering ventilation safety of mines, in order to increase the air pressure in the mines and improve the working environment of miners, the method of plenum ventilation, as a booster, should be applied to the mine ventilation. In this section, the airflow inside ventilation network of positive air pressure area is seen as continuous airflow, and the relationship between the power and the resistance of fans can be analyzed with the energy equation. The formula can be achieved as follows according to the energy equation:

$$(P_{sf1} - P_{sf2}) + \left(\frac{v_1^2}{2}\rho_1 - \frac{v_2^2}{2}\rho_2\right) + (Z_1 g\rho_{m1} - Z_2 g\rho_{m2}) = h_{1,2} \qquad ...\ 13$$

Where $(P_{sf1}–P_{sf2})$ is the relative static air pressure of fans,

H_s; $(\frac{v_1^2}{2}\rho_1 - \frac{v_2^2}{2}\rho_2)$ is the difference of dynamic air pressure between any two points inside mine wells; $(Z_1 g\rho_{m1} - Z_2 g\rho_{m2})$ is the difference of natural wind pressure caused by the altitude difference between any two points inside mine wells, H_n; $h_{1,2}$ is the ventilation resistance of positive air pressure area; P_{sf1} and P_{sf2} are the values of relatively static air pressure of inlet and outlet points, respectively; ρ_1 and ρ_2 are air densities of any two points inside mine wells; v_{12} and v_{22} are wind speeds of any two points inside mine wells; Z_1 and Z_2 are the heights of any two points inside mine wells, respectively.

The above formula can be expressed as follows:

$$(H_s + \frac{1}{2}v_1^2\rho_1) + H_n = h_{1,2} + \frac{1}{2}v_2^2\rho_2 \qquad \text{... 14}$$

Then, according to the total air pressure of fans, $H_f = H_s + \frac{1}{2}v_1^2\rho_1$. If the natural wind pressure is not taken into account in positive pressure areas, the formula (14) can be expressed as follows:

$$H_f = h_{1,2} + \frac{1}{2}v_2^2\rho_2 \qquad \text{... 15}$$

If the resistance is calculated according to the theory $h_{1,2}$ at the sea level and the theoretically acquired amount of wind Q in the positive air pressure area is constant, the total air pressure of fans H_f must meet the requirements of ventilation resistance $h_{1,2}$ of mines and the loss of dynamic air pressure of air return way in the positive pressure area.

The relationship between the altitude height H and air atmosphere pressure is shown in Fig.1. On this basis, the modified formula of strengthening air pressure in plateau mines can be shown as follows when the altitude 3000 m is a boundary and the modified coefficients ñ$_0$/ñ$_H$ and total air pressure of fans on the plateau are taken into consideration.

1 When H_{tf} < 2500 Pa,

$$H_f = \left[(P_{3000} - P_H) + h_{1,2} + \frac{1}{2}v_2^2\rho_2\right] \times \frac{\rho_0}{\rho_H} \times \frac{K_{p0}}{K_{pH}} \qquad 16$$

2 When H_{tf} > 2500 Pa,

$$H_f = \left[(P_{3000} - P_H) + h_{1,2} + \frac{1}{2}v_2^2\rho_2\right] \times \frac{\rho_0}{\rho_H} \qquad 17$$

Where (P3000-PH) is the difference values of the atmospheric pressure between the altitude of 3000 m and the location of fan installation.

7. Conclusions

Through the theoretical analysis of the effects at different altitudes on the mine ventilation, this article concludes that air density is the main contributory factor of performance parameters of mine fans. As the altitude increases, the air density, pressure and power of fans decline, but the air flow and efficiency are not affected by the increasing altitudes.

Through the test analysis of fans' operating performance at different altitudes, this article gets the variation of four fans' air pressure at different altitudes. When two fans are operating in Tibet at an altitude of 4490 m, the characteristic curve of air pressure has dropped by 45.9% and 44.8%, respectively, compared to the value in the standard state. The performance test of two fans shows that the characteristic curve of air pressure has dropped by 27.6% and 28.2% respectively at the altitudes of 1989 m and 2472 m in Yunnan province. The results show that as the altitude increases, the operation performance declines greatly.

Through the research on model selection of mine fans at different altitudes, this article has established a modified mathematical model of mine fans' performance parameters when the atmospheric pressure at an altitude of 3000 m is a division point.

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Continued on page 647