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Research Article

Research on Index for Assessment of Mine Ventilation Capability

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Abstract: In order to perfect the current index equivalent orifice for assessment of coal mine ventilation capability checking, we put forward a new evaluation methodology to accomplish this aim based on existing research and the present practical conditions in China. In addition, indexes for calculating reasonable values of equivalent orifice for all kinds of mine ventilation systems are given. The new way is more reasonable and scientific by example. Equivalent orifice equation is analyzed and then it can be found that for the mines with different ventilation systems the calculation methods of total equivalent orifice and total windage are different. Equivalent orifice calculation needs the total amount of the return air in the mine; total windage is calculated according to the specific form of ventilation.

Keywords: Assessment index, equivalent orifice of coalmine, mine ventilation

INTRODUCTION

Mine ventilation system is the general term of the ventilation network, the ventilation power and the ventilation control facilities that provide fresh air to each job site of the mine and exhaust polluted air, of which the main task is to ensure that the mine air quality meets the requirements. A good mine ventilation system should reflect both safety and economic feasibility, of which the impact factors are various and therefore the standards for evaluating the mine ventilation system (good or bad) cannot be unitary. How to evaluate the mine ventilation system is an important and complex problem.

The equivalent orifice of mine is usually taken as a measure of the difficulty degree of mine ventilation. The concept "Mine ventilation equivalent orifice" was proposed by Murgue (1873), who proposed classification method as well, by which the difficulty degree of mine ventilation is divided into three levels according to the size of the equivalent orifice (Table 1) and has been used by now (Wu, 2008). But after more than 100 years, modern mine size, mining methods, the degree of mechanization and fan capacity have been greatly developed and improved compared with the old ones. So in this study, the aim is to find whether the equivalent orifice and the data in Table 1 aren't applicable to the current mine. So we put forward a new evaluation methodology of coal mine ventilation capability. Also, the calculation methods of total equivalent orifice and total windage are analyzed. Equivalent orifice calculation needs the total amount of the return air in the mine; total windage is calculated according to the specific form of ventilation.

MATERIALS AND METHODS

Equivalent orifice is the area value of an imaginary plate orifice for measuring the difficulty degree of the mine ventilation (Zhang, 2007). As for the definition of equivalent orifice, there are two different sayings at present (Li, 2008).

First definition of equivalent orifice: Assuming there is a thin wall in infinite space, the orifice with the area of a (m^2) is opened on the thin wall (Fig. 1). When the air flow through the orifice is equal to that of the mine Q and the air pressure difference of both sides of the orifice is equal to ventilation resistance of the mine h, the orifice area A is regarded as the equivalent orifice of the mine (Wu, 1989).

The area of equivalent orifice is calculated according to the definition, which is to get the parameters of equivalent orifice and mine ventilation, namely the relation between the airflow amount and air pressure.

The cross-section of 1-1 is selected from the section far enough away from the orifice in the left of orifice A, where the static pressure is p_1 and wind speed $v_1 = 0$. The cross-section of 2-2 is taken from the section in which the contraction of airflow in the right of the orifice, where the cross-sectional area of is A_2, the static pressure is p_2 and wind speed is v_2. The energy loss in the flowing process is negligible. According to the definition "the air pressure difference

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Table 1: Classification standard of difficulty degree of mine ventilation

Equivalent orifice (A)	Difficulty degree of ventilation
A<1 m^2	Difficult
A = 1~2 m^2	Moderate
A>2 m^2	Easy

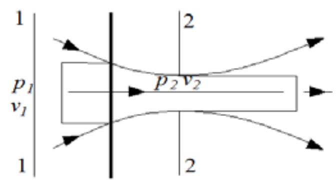

Fig. 1: Principles of equivalent orifice

on both sides of the mine ventilation orifice is equal to the ventilation resistance h" and the relation is shown as:

$$p_1 + \frac{\rho}{2}v_1^2 - (p_2 + \frac{\rho}{2}v_2^2) = h$$

Which can be simplified as:

$$v_2 = \sqrt{\frac{2(p_1 - p_2 - h)}{\rho}}$$

where, ρ is the density of the air. It can be known according to the hydromechanics:

$$A_2 = 0.65A, \; Q = A_2 v_2$$

Then,

$$v_2 = \sqrt{\frac{Q}{0.65A}}$$

From which the area of the equivalent orifice can be obtained:

$$A = \frac{Q}{0.65\sqrt{\frac{2(p_1 - p_2 - h)}{\rho}}}$$

In the equation above, can be the density of the air in the standard mine, the specific values of p_1 and p_2 cannot be certain, therefore, this calculating formula is not valuable, different from that for the equivalent orifice.

Second definition of equivalent orifice: Equivalent orifice is the area value of an imaginary plate orifice for measuring the difficulty degree of the mine ventilation (Zhang, 2007). Assuming there is a thin wall in infinite space, the orifice with the area of a (m^2) is opened on the thin wall (Fig. 1). When the air flow through the orifice is equal to that of the mine and the wind pressure difference of both sides of the orifice is equal to ventilation resistance of the mine, the orifice area A is regarded as the equivalent orifice of the mine. It is worth noting that the definition of wind pressure difference on both sides of the orifice refers to the static pressure. Assuming airflow is from I and II without any energy loss, then:

$$P_1 + \frac{\rho}{2}v_1^2 = P_2 + \frac{\rho}{2}v_2^2$$

$$P_1 - P_2 = \frac{\rho}{2}v_2^2 = h_{Rm}$$

$$v_2 = \sqrt{(2/\rho)h_{Rm}}$$

where, h_{Rm} is the total resistance of mine ventilation, with the unit Pa. The ratio of the cross-sectional area at right airflow contraction A_2 to orifice area A is known as contraction coefficient φ and generally φ = 0.65 according to hydraulics, so A2 = 0.65A. Then v_2 = Q/A2 = Q/0.65A. After substituted into the equation above, it can be obtained that:

$$A = \frac{Q}{0.65\sqrt{(2/\rho)h_{Rm}}}$$

Making ρ = 1.2 kg/m^3, then:

$$A = 1.19\frac{Q}{\sqrt{h_{Rm}}}$$

where, R_m is the total wind resistance of mine. N·s^2/m^8 or kg/m^7. As $R_m = h_{Rm}/Q_2$, then:

$$A = \frac{1.19}{\sqrt{R_m}}$$

From which it can be seen that A is the function of R_m, so it can represent the difficulty degree of mine ventilation.

Analysis of the two kinds of definitions of equivalent orifice: The assumptions are the same for these two definitions of equivalent orifice, except for one word on the assumption on the mine ventilation resistance. The first one emphasizes "the air pressure difference on both sides of the mine ventilation orifice is equal to the ventilation resistance h"; the second definition emphasizes "the static air pressure on both sides of the mine ventilation orifice is equal to the ventilation resistance." Air pressure includes static pressure, dynamic pressure and bit pressure. The air pressure difference on both sides of the mine ventilation orifice should be the difference of the sums of static, dynamic and bit pressures on both sides of the orifice.

Seen from the above derivation, the formula for the equivalent orifice derived from the first definition cannot be used, different from that for the equivalent orifice, while the derivation result according to the second definition is the same as that for the equivalent orifice. Therefore, the first definition of the equivalent orifice is wrong. Therefore, the correct definition of equivalent orifice should be: assuming there is a thin wall in infinite space, the orifice with the area of A (m^2) is opened on the thin wall; when the air flow through the orifice is equal to that of the mine Q and the static air pressure difference of both sides of the orifice is equal to ventilation resistance of the mine h, the orifice area A is regarded as the equivalent orifice of the mine.

RESULTS AND DISCUSSION

Limitations of equivalent orifice: Equivalent orifice was proposed by Murgue (1873), which has been used for more than one century by now. The measure standard of equivalent orifice holds favorable reference value for some small-scale mines. However, with the development and improvement of coal mine mechanization, mining intensity and depth and mine scale, the required fan capacity is different for the mines of which the amounts of methane emission are different, which makes the measure standard of equivalent orifice lose the reference value for these large mines.

When there is air leakage in the mine, A value fails to reflect the difficulty degree of mine ventilation and to meet with the needs of the wind point, the total amount of wind must be increased, which leads to that the calculation result is too large. In addition, because of poor design or poor management, short circuit, string winds and other phenomena may appear which cannot be reflected by A value.

A value cannot reflect differences in levels of harmful gases. In the same mining condition, the air volumes required are different if amounts of gas emission are different and thus A values are different. So a value cannot be used as a measure standard of the difficulty degree of the mine ventilation.

With continuous improvement of coal mining mechanization, the mines with the annual amount of more than one million tons are not rare. Increased degree of exploitation leads to deeper mining, increased harmful gases and increased terrestrial heat, which requires increased ventilation and increased air pressure. However, the increase of fan airflow pressure will bring many negative effects. If airflow increases, air leakage of the mine will be increased and then the effective amount of wind is reduced, which provides the appropriate condition for the coal rakes of natural tendency. Increased air pressure leads to the increase of energy consumption of the fan. Due to the fan selection and with consideration of the energy consumption and other factors (Zhou and Yang, 2007), the air pressure of fan cannot be increased without limitation. According to the mine design specification of the national coal industry, “Generally, negative (positive) pressure in mine ventilation design should not exceed 2940 Pa. For the great deep mines, of which the topsoil is especially thick, the mining depth is large, the total intake air volume is large and ventilation network is long, the post negative pressure of the mine ventilation design may be increased appropriately, but later negative pressure of ventilation should not exceed 3920 Pa”. Therefore, in order to meet the ventilation requirements, the wind drag of the mine needs to be reduced, namely lifting the A value of equivalent orifice. Therefore, actually in some large-scale mines, of which the A value reaches 4 m^2, ventilation is still difficult, so the A value measure standard in Table 1 loses reference value for large mines.

Table 2: Requirements for mine ventilation resistance

The total amount of return air in the mine Q_h (m^3/min)	Upper limit of mine ventilation h_{max} (Pa)	Lower limit of mine ventilation h_{min} (Pa)
<3000	1500	1000
3000-5000	2000	1500
5000-10000	2500	2000
10000-20000	2940	2500
>20000	3920	2940

Rectification of mine ventilation Equivalent orifice: With regard to the problems above, Huang (1964) and Zhao (1985) have deduced the calculation equation of minimal reasonable values from the perspective of economic rationality for the comprehensive evaluation of mine ventilation (Zhao, 1985):

$$A = 1.6\eta TE(1-\rho)/h^{1.5}$$

where,

- T = The daily output of mine
- h = The air pressure of mine
- E = The power consumption per ton permitted by economics for the mines of different methane levels
- ρ = Permitted air leakage rate
- η = The operating efficiency of fan

With reference to the specification of “Ventilation Technology Conditions of Coal Mining” on ventilation resistance for different outputs and combined with the actual situation of coal mine ventilation in China, ventilation resistance range is drafted for the mines of different outputs (Hu and Wang, 2009), as shown in Table 2.

When the mine ventilation resistance is greater than the upper limit in Table 2, it is considered that the mine ventilation resistance is large, the ventilation is

Table 3: Evaluation method for mine ventilation system

			Low-gas mine		High-gas mine	
Annual output (Mt/a)	h_{max} (mmH_2O)	h_{min} (mmH_2O)	A_{min} (m^2)	A_{max} (m^2)	A_{min} (m^2)	A_{max} (m^2)
0.10	80	60	1.0	2.0	1.0	2.0
0.20	100	80	1.5	2.5	2.0	3.0
0.30	120	100	1.5	2.5	2.0	3.0
0.45	140	100	2.0	3.0	3.0	4.0
0.60	160	110	2.0	3.0	3.0	5.0
0.90	200	150	2.0	3.0	4.0	6.0
1.20	230	180	2.5	3.5	5.0	7.0
1.80	290	240	2.5	3.5	6.0	8.0
2.40	350	300	2.5	4.0	7.0	10.0
3.00	400	350	2.5	4.0	7.0	11.0

When 5% outer air leakage is permitted, A_{min} is reduced by 10%; When 15% outer air leakage is permitted, A_{min} is reduced by 15%, which is the minimal A value of the mine

Table 4: Classification of difficulty degree of mine ventilation

Equivalent orifice (A)	Difficulty degree of ventilation
$A<A_{min}$	Difficult
$A_{min}<A<A_{max}$	Moderate
$A>A_{max}$	Easy

Table 5: Evaluation on ventilation of three mines affiliated to Hancheng mining

Mine name	Equivalent orifice	A_{min}	A_{max}	Difficulty degree of ventilation
Sangshuping mine	6.31	6.0	8.0	Moderate
Xiayukou mine	6.31	5.0	7.0	Moderate
Xiangshan mine	4.50	5.0	7.0	Difficult

difficult, so the equivalent orifice when the mine ventilation resistance reaches the upper limit value is defined as the grading value for mine ventilation difficulty, namely:

$$A_{\min} = 1.19\alpha \frac{Q_h}{\sqrt{h_{\max}}}$$

When the mine ventilation resistance is smaller than the lower limit value in Table 2, it can be considered that the mine ventilation resistance is small, the ventilation is easy and the grading value of the easy mine ventilation, namely:

$$A_{\max} = 1.19\alpha \frac{Q_h}{\sqrt{h_{\min}}}$$

In the two equations above:

A_{min} = The lower limit value of the equivalent orifice, m^2
A_{max} = The upper limit value of the equivalent orifice, m^2
h_{max} = The upper limit value of the ventilation resistance *Pa*
h_{min} = The lower limit value of the ventilation resistance *Pa*
Q_h = The total amount of return air in the mine, m^3/min
a = Airshaft coefficients, 1 for single airshaft and 1.2 for multiple airshafts

As for different kinds of mines, the known variables are substituted and with consideration of safety coefficients *a*, A_{min} and A_{max} in Table 3 can be obtained. If the result of *A* is less than A_{min}, then the ventilation is regarded as difficult; if more than A_{max}, the ventilation is easy; if the value is between the two limits, the ventilation is moderate as shown in Table 4.

If it is multi-fan mine, there may be mutual interference among the mines. There may be sufficient amount of wind in some places, but the condition may be reverse in some other sites and the overall assessment is well ventilated. The reason that leads to this situation needs to be analyzed specifically and take ventilation technological innovation to improve the situation of wind usage.

Application cases: For example, annual production capacity of Hancheng Mining of Shanxi was approved as 4.51 million tons in 2004 and the coal production of 2004 was 4.24 million tons. There were three large coal mines in the coal area, of which the annual production of Sangshuping mine was 2.1 million tons; the production of Xiayukou Mine was 1.2 million tons (Guo, 2005). Both were the mines prominent for coal and gas. The annual production of Xiangshan Mine was 1.25 million tons, as high-gas coal mine. The air leakage of Sangshuping Mine was 9.9%. According to the formula of the second section, the equivalent orifice of each mine was calculated as shown in Table 5.

From Table 5, it can be seen that the ventilations of Sangshuping Mine and Lower Meiyukou Mine were moderate and the ventilation of Xiangshan Mine was difficult. So Xiangshan Mine should take some auxiliary measures. There were three gas drainage systems settled for Xiangshan Mine, which were ground permanent gas drainage system, 12 gas drainage systems and 25 gas drainage systems, respectively. The gob gas drainage method was mainly used, which was to use a external high position drilling of working surface combined with buried pipe in upper corner to drain the gob gas, to drain the gob gas in the upper coal rake of working surface and to drain the gob gas near the working surface. The total amount of mine gas drainage was 23.2 m^3/min; mine gas drainage rate was 49.79%.

Table 6: Report on the ventilation in Xinzhuangzi mine (part)

Airshaft	Return air amount of the total air passage (m^3/min)	Negative pressure (Pa)
The whole mine in total	31808	3716
No. 2 airshaft	8346	4395
New quasi airshaft	13021	3064
No. 5 airshaft	10441	3679

Table 7: Evaluation on the ventilation in Xinzhuangzi mine

Airshaft	Equivalent orifice A (m^2)	A_{min} (m^2)	A_{max} (m^2)	Ventilation
The whole mine in total	10.34	12.21	14.12	Difficult
No. 2 airshaft	2.58	3.34	3.67	Difficult
New quasi airshaft	4.80	4.82	5.00	Difficult
No. 5 airshaft	3.49	3.86	4.18	Difficult

Another example is Xinzhuangzi Mine of Huainan Mining Group, which was founded in May 1947 (Hu and Wang, 2009). After repeated technical transformation and horizontal expansion, the scope of the well field was expanded with gradual increase in production capacity. Now the production capacity is 3 Mt/a and the actual yield is 2.8 Mt/a. The mine has three return airshafts in total currently; Table 6 is part of the monthly report of the mine ventilation. The grading values of equivalent orifice Amax and Amin of the ventilation systems of the whole mine and each airshaft is calculated according to the calculation formula of Amax and Amin, as shown in Table 7.

The areas of ventilation system equivalent orifices of each airshaft in the mines of Table 7 are greater than 2 m^2. In accordance with the existing criteria for the classification, the mines belong to the easy ventilation ones, but in fact, the ventilation network of the mines is complex, the resistance is big with the lack of wind in the wind sites; moreover the gas is over the limit for several times during the month, obviously belonging to difficult ventilation ones. In Table 7, from the equivalent orifice degrading range calculated according to the new classification method, the equivalent orifice area is too small and ventilation is difficult, especially the equivalent orifice of No. 2 airshaft ventilation system is too small, which needs to be adjusted for the ventilation technology to improve the ventilation condition.

Total air amount used to calculate the mine equivalent orifice: During the calculation of equivalent orifice, in order to guarantee the calculations of the equivalent orifice A and total resistance R_m away from the influence of affected by external leakage Q_l (Huang, 1964), the air amount of main fan Q_f should not be used, but the total amount of the return air in the mine Q_h (El-Nagdy, 2013), namely:

$$Q_h = Q_f - Q_l$$

External leakage rate γ can also be used to represent the external leakage condition (Wang and Mutmansky, 1982), namely:

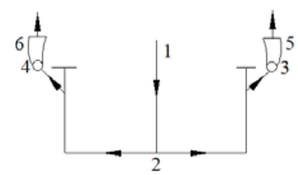

Fig. 2: Mine with diagonal wings and two withdrawable fan machines for ventilation

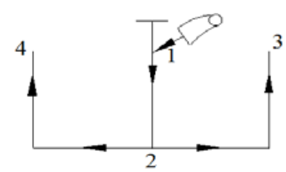

Fig. 3: Mine with diagonal wings and a push-fan for ventilation

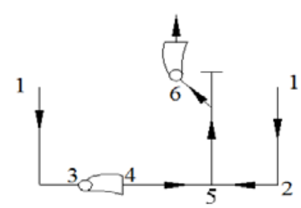

Fig. 4: Wings diagonal and withdrawable ventilation

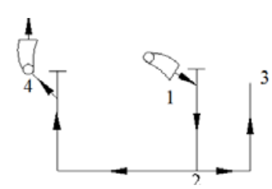

Fig. 5: Mine with the combination of wings diagonal pressing and withdrawable ventilation

$$\gamma = \frac{Q_l}{Q_f} = \frac{Q_f - Q_h}{Q_f}$$

Then,

$$Q_h = (1-\gamma) Q_f$$

Total air resistance of different ventilation systems: Mine ventilation system is the general term for ventilation mode, ventilation method and ventilation network and other elements (Xie *et al*., 1999). As for the mines with different ventilation systems, the calculation methods of the area of total equivalent orifice A and total air resistance R_m are different (Xie *et al*., 2008).

As shown in Fig. 2 (Sui *et al.*, 2011), for the mine with diagonal wings and two with drawable fan machines for ventilation, the relationship equation of the total air resistance R and the air resistances in two air passages R_1 and R_2 is shown as:

$$R = \left(R_I Q_{2-3}^3 - R_{II} Q_{2-4}^3\right) / \left(Q_{2-3} + Q_{2-4}\right)^3$$

Figure 3 shows the mine with diagonal wings and a push-fan for ventilation and the calculation formula of total air resistance *R* is:

$$R = R_I R_{II} / \left(\sqrt{R_I} + \sqrt{R_{II}}\right)^2$$

Figure 4 shows the mine with the main fan machine operated combined with auxiliary fan machine and with diagonal wings for with draw able ventilation and the calculating formula for the total air resistance is:

$$R = \left(h_I Q_{2-5} + h_{II} Q_{3-4-5}\right) / Q^3{}_{5-6}$$

In the equation above, h_I is the air pressure of the wind road 1-2-5-6 needed, h_{II} is the air pressure of the wind road 1-3-4-5-6 needed.

Figure 5 shows the mine with the combination of wings diagonal pressing and withdrawable ventilation, and the calculating formula for the total air resistance is:

$$R = \left(h_I Q_{2-3} + h_{II} Q_{2-4}\right) / \left(Q_{2-3} + Q_{2-4}\right)^3$$

CONCLUSION

Equivalent orifice can be taken as measure standard for the difficulty degree of the mine ventilation and the air pressure difference on both sides of the orifice in the definition of equivalent orifice refers to the static pressure.

Equivalent orifice as measure standard can serve as a good reference for some small mines, while for large-scale modern mines, it should be amended based on many aspects to consider.

The evaluation method for the modernized mine ventilation system is proposed and this approach has been proved to reflect the effect and the condition of mine ventilation more comprehensively through some examples.

As for the mines with different ventilation systems, the calculation methods of the area of total equivalent orifice A and total air resistance R_m are different. The total return air amount of the mine is used for the calculation of equivalent orifice, while the total air resistance is calculated according to the specific ventilation mode.

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REFERENCES

El-Nagdy, K.A., 2013. Stability of multiple fans in mine ventilation networks. Int. J. Mining Eng., 23(4): 569-571.

Guo, R., 2005. Prevention and cure of gas disaster in Hancheng mining area. Safety Coal Mines, 36(11): 15-18.

Hu, C.S. and D.M. Wang, 2009. Research on index for difficult or easy of mine ventilation capability. Safety Coal Mines, 39(9): 89-92.

Huang, Y.P., 1964. Some relationships and their applications of the total equivalent orifice of mines. J. China Coal Soc., 1(3): 28-39.

Li, Z.H., 2008. Analysis about the definitions of equivalent orifice for mine ventilation. Coal, 17(7): 28-29.

Murgue, D., 1873. Theories and Practices of Centrifugal Ventilating Machines. London.

Sui, J.X., L. Yang and Z.L. Zhu, 2011. Mine ventilation optimization analysis and airflow control based on harmony annealing search. J. Comput., 6(6): 1270-1277.

Wang, Y.J. and J.M. Mutmansky, 1982. Application of CPM procedures in mine ventilation. Proceeding of the US First Mine Ventilation Symposium, pp: 159-168.

Wu, C., 2008. Mine Ventilation and Air Conditioning. Central South University Press, Changsha, China.

Wu, Z.L., 1989. Ventilation and Safety of Mine. China University of Mining and Technology Press, Xuzhu, China.

Xie, X.P., C.G. Feng and H.L. Wang, 1999. Analysis of mine ventilation network using genetic algorithm. J. Beijing Inst. Technol. English Edn., 8(2): 145-149.

Xie, X.P., C.H. Luo and Y.P. Yu, 2008. Optimization of mine ventilation system based on genetic algorithms. Prog. Safety Sci. Tech., 7: 1546-1550.

Zhang, G.S., 2007. Ventilation and Safety. China University of Mining and Technology Press, Xuzhu, China.

Zhao, Y.H., 1985. Evaluation method of mine ventilation system. J. China Univ., Mining Technol., 30(3): 24-31.

Zhou, D.Y. and W.H. Yang, 2007. The application research on frequency conversion and speed regulating. Mine Mach., 30(6): 164-165.