Influence of Atmospheric Pressure Fluctuation on Air Leakage Rate of Airtight-wall

SU Fu-peng*, ZHOU Xin-quan, WANG Yi

China University of Mining & Technology (Beijing) State Key Laboratory of Coal Resources & Safety Mining, Beijing 100083, China

Abstract

Aiming at strengthening the airtight-wall tightness, reducing its leakage rate, so that extinguishing the combustion in the burning area as soon as possible, this paper proposes the new ideas that the atmospheric pressure changes is important affecting factor to airtight-wall leakage rate in airtight burning area. Adopting the comprehensive research method of theoretical analysis, field measurement, and numerical calculation, this paper studies the influence law of the periodical change of the atmospheric pressure on the airtight-wall leakage rate, the results show that: the curve of underground pressure is sinusoid approximately; the atmospheric pressure changes is the main reason for the internal and external pressure difference of the airtight-wall; the gas exchange capacity of internal and external burning area is large, the gas exchange capacity of calculation example is more than 1400 m³ every day. To reduce the firewall leakage rate, this paper proposes the specific solutions including building gas pressure balance room, strengthening airtight-wall tightness, and reducing the burning area volume, etc.

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Key words: sealing burning area; airtight-wall; air leakage rate; atmospheric pressure

* Corresponding author.
E-mail address: sfp08@163.com.
1. Foreword

The main function of burning area firewall is to cut off the oxygen supply condition of coal combustion, so that control the flames. Airtight-wall tightness directly affects the sealing burning area air leakage rate, the higher tightness, and the smaller air leakage rate\[1\]. Airtight-wall air leakage rate also relates to the internal and external draught head of firewall, the higher draught head, and the higher air leakage rate, conversely the smaller. The formation of draught head is affected by a variety of factors, the atmospheric pressure\[2, 3\] changes is a very important factor.

2. Mathematical model of atmospheric pressure periodical changes

Because of the atmospheric temperature periodical changes, the earth’s surface atmospheric pressure will then present cyclical volatility, when the atmospheric temperatures rises, the atmospheric pressure lowers, when the atmospheric temperature drops, the atmospheric pressure rises\[4\]. The earth’s surface atmospheric pressure changes cause pressure distribution changes within the roadway of mine, this will cause the internal and external pressure difference of the airtight-wall in burning area, and lead to inside air leaking out or outside air inflowing, similar to the respiration, this phenomenon is unfavorable to suffocate burning area and prevent the fire from further development\[5\]. Given the atmospheric pressure change is the important reasons that caused sealing burning area "breathing" and air leakage of the firewall, studying the variation law of atmospheric pressure is very necessary. Various materials\[6-8\] shows that when the weather condition is relatively stable, the atmospheric pressure changes follow certain rules. In order to convenient for study, establish mathematics model as follows: suppose the atmospheric pressure on a fixed period and make sine wave, amplitude changeless, as formula (1) shows:

\[
p_a = p_{a0} - \Delta p_a \cos\left(2\pi \frac{\tau}{\Delta \tau}\right)
\]

In the formula, \(p_{a0}\)——average pressure; \(\Delta \tau\)——cycle period; \(\Delta p_a\)——amplitude of pressure change

3. air leakage calculate of firewall

Assume the air inside sealing burning area is laminar flow, and air leakage direction is inflowing, it is namely:

\[
\dot{q} = \frac{1}{R} (p_a - p_s)
\]

In the formula, \(p_a\)——air pressure outside sealing area, Pa; \(p_s\)——air pressure inside sealing area, Pa; \(R\)——total wind drag of air leaking channel and firewall, N·min/m5.

Let be \(a = \frac{p_{a0}}{VR}\), \(b = \frac{\Delta p_a}{R \Delta \tau}\), and \(c = \frac{2\pi}{\Delta \tau}\), solving over formula:

\[
\dot{q} = \exp\left(-a \tau\right) \left(\dot{q}_0 + \frac{bc}{a^2 + b^2} + \frac{b}{(a^2 + b^2)^{1/2}} \sin\left(c \tau - \tan^{-1}\frac{c}{a}\right)\right)
\]

In the formula, \(V\)——total air volume inside sealing area; \(p_{a0}\)——initial air pressure value within sealing area

Formula (3) is the relational expression of firewall air leakage rate and atmospheric pressure changes.

When \(\tau \to \infty\) :

\[
\dot{q} = \frac{b}{(a^2 + c^2)^{1/2}} \sin\left(c \tau - \tan^{-1}\frac{c}{a}\right)
\]

\[
\frac{b}{(a^2 + b^2)^{1/2}}\] is the amplitude of the \(\dot{q}\) cycle, \(\tan^{-1}\frac{c}{a}\) is phase difference between \(\dot{q}\) and \(p_s\)
The total air leakage into or out of the sealing burning area is

$$Q = \frac{\dot{q}_{\text{max}} \Delta \tau}{\pi}$$

4. Atmospheric pressure measurement results and analysis

The atmospheric pressure measurement experiment proceeded in Xing An Coal Mine, He Gang Bureau of Mining Affairs, Hei Longjiang Province, the specific location is nearby the burning area in second level, whose elevation is -97.8m. The instrument is CPD2/20 mining portable air pressure measurement (developed by Aerospace Aerodynamic Research Institute and Fu Shun Branch of China Coal Research Institute). Device parameters is showed in reference[9].Fixed point measurement continuous 24 hours (every 5 minutes records the data), obtained the atmospheric pressure changes data of 24 hours near the burning area. The key experimental data is shown in table 1.

According to the experimental data and graph, it can be seen, from morning 8:40, atmospheric pressure continued to decline, and reach the lowest 100258Pa at 13:40; then began to rise gradually, until the next morning 6:10 reached the highest 100790Pa finally; then began to decline, and always has such a cyclical change. The experiment results basically tallies with the established mathematical model of atmospheric pressure changes.

5. Analyzing the influential factors of airtight-wall air leakage

From the formula (7), the main 5 factors affecting the airtight-wall air leakage includes: air pressure changes amplitude $\Delta p$, firewall wind resistance $R$, air pressure change cycle $\Delta \tau$, initial pressure within burning area $P_{s0}$ and burning area volume $V$, and the air pressure change cycle has been determined after the modeling, and the initial pressure within the burning area is certain too, so just another three factors need be considered.

Table 1. Important Data of Atmospheric Pressure Measurement

<table>
<thead>
<tr>
<th>ime of experiment begin</th>
<th>ime of experiment stop</th>
<th>ime of Lowest air pressure appear</th>
<th>ime of highest air pressure appear</th>
<th>ime of highest air pressure pressure</th>
<th>ime of highest air pressure pressure</th>
<th>average of air pressure</th>
<th>amplitude of air pressure</th>
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<td>00790</td>
<td>00524</td>
<td>66</td>
</tr>
<tr>
<td>m8: 40</td>
<td>m8:40</td>
<td>m13:40</td>
<td>a</td>
<td>m 6:10</td>
<td>a</td>
<td>a</td>
<td>a</td>
</tr>
</tbody>
</table>
Through data sorting, making a graph as shown in figure 1

![Figure 1. The 24 hours variation curve diagram of atmospheric pressure nearby the fire zone of Xing’an coal mine](image)

5.1. Relationship of air pressure changes amplitude and maximum airtight-wall air leakage rate

On the influence analysis of the air pressure changes amplitude to the airtight-wall air leakage, other factors taken fixed value, just the air pressure changes amplitude change the size, so that the relationship between them can be clearly seen, the same methods adopted in after analyzing. The experimental data shows that the atmospheric pressure changes amplitude $\Delta p_a = 266$ Pa, wind resistance $R = 1.35 \times 10^4$ N·min/m$^5$, $\Delta \tau = 24 \times 60$ min, the initial pressure within sealing burning area $P_{s0} = 1 \times 10^5$ Pa, total volume of sealing burning area $V = 3 \times 10^3$ m$^3$, set wind resistance $R$, cycle $\Delta \tau$, initial pressure $P_{s0}$, burning area volume $V$ taking experimental value, and change the pressure amplitude $\Delta p_a$, according to the formula (5):

$$\dot{q}_{max} = \left( \frac{\Delta p_a}{R} \right) \frac{2 \pi}{\Delta \tau} \frac{\Delta p_a - 2 \pi \frac{R}{\Delta \tau}}{\left[ \left( \frac{P_{s0}}{RV} \right)^2 + \left( \frac{2 \pi \frac{R}{\Delta \tau}}{\Delta \tau} \right)^2 \right]^{1/2}}$$

Substituting the experimental data of $R$, $\Delta \tau$, $P_{s0}$, $V$, and calculating, so

$$\dot{q}_{max} = \frac{\Delta p_a - 58.86}{67.63}$$

This is the relation formula of $\dot{q}_{max}$ and $\Delta p_a$, according to the relation formula, made a graph as figure 2 shows, it can be clearly seen that maximum firewall air leakage rate and pressure changes amplitude is in linear relation.

5.2. Relationship of wind resistance and maximum airtight-wall air leakage rate

Analyzing as 4.1, according formula (8), substituting the experimental data of $\Delta p_a$, $\Delta \tau$, $P_{s0}$, $V$, and calculating, so

$$\dot{q}_{max} = \frac{266 - 0.00436R}{\left( 111 + 0.000019R^2 \right)^{1/2}}$$
This is the relation formula of \( q_{\text{max}} \) and \( R \), according to the relation formula, made a graph as fig.3 shows, it can be seen that the biggest air leakage rate \( q_{\text{max}} \) and wind resistance \( R \) is similar in inverse relationship, when wind resistance is lesser, maximum air leakage rate decreases rapidly with wind resistance increases, when the wind resistance is more than \( 3 \times 10^4 \) N\cdot min/m\(^5\), maximum air leakage rate down slowly with wind resistance increase.

5.3. Relationship of burning area volume and maximum airtight-wall air leakage rate

Analyzing as 4.1, according formula (8), substituting the experimental data of \( \Delta P_a \), \( \Delta \tau \), \( P_{s0} \), and calculating, so

\[
q_{\text{max}} = \frac{207.14}{\left[ \frac{10^{10}}{V^2} + 3469.78 \right]^{\frac{1}{2}}}
\]

This is the relation formula of \( q_{\text{max}} \) and \( V \), made a graph as figure 4 shows, it can be seen that the maximum air leakage rate and the burning area volume is similar in exponential relationship, maximum air leakage rate increases with burning area volume increases, when \( V \) is smaller than 2500m\(^3\), \( q_{\text{max}} \) rapidly increases with \( V \) increases, when \( V \) is more than 2500m\(^3\), \( q_{\text{max}} \) increase slowly with \( V \) increases.
Fig. 3. The relationship between the Max air leakage and ventilation resistance

Fig. 4. The relationship between the Max air leakage and the volume of fire zone
6. Countermeasures

Sealing burning area aims to reduce oxygen supply to fire belt, but the internal and external pressure difference of airtight-wall still causes different degree of air leakage. And according to the formula (5) and the actual experimental measurement data, the air leakage rate of airtight-wall is \( q_{\text{max}} = 3.06 \text{ theory m}^3 / \text{min} \); according to the formula (7), it can be calculated that the gas exchange capacity between burning area and outside in one day is \( Q = 1402.6 \text{ m}^3 \), it reached almost half of the burning area volume. Completely avoiding air leakage is unlikely, but reasonable steps can be taken to reduce air leakage. According to the several influence factors of airtight-wall air leakage mentioned below, the corresponding countermeasures is put forward.

1. Establish pressure balance room, adjust internal and external partial pressure difference of airtight-wall. Pressure balance room is setting the second airtight-wall close to and outside the original airtight-wall, and installing tube or pressure ventilator on the second airtight-wall to adjust the air pressure difference of the space between the first and the second airtight-wall so that it is equal to the air pressure in the sealing burning area. The specific methods and application practices has been introduced in many literatures [10, 11], and no introduces in this paper.

2. Increasing airtight-wall tightness. There have two kinds of methods can improve the airtight-wall tightness, one is the technology, such as when building a airtight-wall, using plastic scrub-brush instead of slice to paint surface mortar, this can increase the leakproofness and durability of firewall [5], the other is the material, adding fiberglass in mortar, this can increase the strength and viscosity of cement mortar and be easier to smear. In addition, some new materials also begin to use in coal fire extinguishing, such as Luokexiu foam products [12].

3. Decrease burning area volume. If when initially building the airtight-wall considering security or terrain is urgent, a wider range of burning area has to be sealed, and want to compress the burning area afterwards, the shrinkage sealing method must be adopted, this is of some risk. But this can be put the effects on the normal production to minimize, and also can reduce the maximum air leakage of airtight-wall, to extinguish burning area as soon as possible.

7. Conclusion

1. Put forward the atmospheric pressure changes is important affecting factor to the firewall air leakage, and established the mathematical model of atmospheric pressure sine wave, and verified the rationality of the model by experiments in some degree, and combining examples calculated the air leakage of burning area in a cycle (one day), the air leakage of the example is almost half of the volume of burning area.

2. Analyzed the atmospheric pressure fluctuation range, airtight-wall tightness, burning area volume, this three factors’ influence on the maximum airtight-wall air leakage rate. The maximum air leakage rate increases with the air pressure fluctuation range and the burning area volume increases, and decreases with the increase of firewall tightness. Aiming at three influence factors of maximum firewall air leakage rate, proposes the specific solutions including building gas pressure balance room, strengthening firewall tightness, and reducing the burning area volume.

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