Research Article

Research on the Distribution Regularity of Air Volume in the Pipelines of Mining Ventilation Clothing

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In order to study the air volume distribution regularity of mine ventilation clothing, the influence of ventilation clothing of different pipeline structures on airflow distribution is discussed. By establishing the simulation models of three different structures and using software simulation, the air volume distribution under different ventilation air volume and different pipeline structures is analyzed; the relationship between the air volume of the pipelines and the frictional resistance along the course is studied. The results demonstrated that the air volume of the pipelines farther from the ventilation inlet in the transverse type and longitudinal type is larger, while the air volume of the pipelines close to the ventilation inlet is smaller, and the air volume of the intermediate pipelines is medium and relatively stable; regularity of air volume distribution in pipelines: transverse type > spiral type > longitudinal type. Total air volume in the ventilation tubes: spiral type > longitudinal type > transverse type, with the increase of ventilation volume, the air volume in the spiral type tube increases greatly, and a small increase in air volume for transverse type and longitudinal type. Based on the data obtained from the transverse type simulation, the air volume of the pipelines airflow is inversely proportional to the frictional resistance along the course.

1. Introduction

The exploitation of coal resources is still an important part of China’s industrial development [1], and the problem of underground heat damage has seriously affected the operational efficiency of workers. In high-temperature mines, miners are more likely to emerge symptoms such as dizziness, headaches, difficulty breathing, inattention, and movement errors [2]. Emotionally, it is mainly manifested in the increase in negative emotions such as tension, depression, anxiety, fear, and anger [3, 4]. Mine ventilation clothing have the advantages of light weight, safety, and easy to wear and take off, which are suitable for use in high-temperature underground environments.

At present, the most used types of cooling suits include liquid cooling suits [5, 6], gas cooling suits [7, 8], and phase change cooling suits [9, 10]. Nowadays, many scholars have done systematic research on cooling suits. Xu [11] used CFD software to analyze the coupling of the environment-clothing-human trinity model, analyzed the influence of different inlet wind speeds on the refrigeration effect of air-cooled clothing, and also compared the flow and heat transfer characteristics and refrigeration performance of different models. Shang Bofeng [12] analyzed the flow and heat transfer process in liquid cooling suits by numerical simulation method, studied the influence of human metabolic rate, inlet water temperature, flow rate, and pipeline distribution on the cooling effect of liquid cooling suits and verified its correctness with engineering calculations. Ke and Zhou [13] summarized the evaluation index system of individual cooling suits, in order to evaluate the cooling effect of cooling suits, the physical, physiological, and psychological
indicators of the cooling effect of cooling suits were analyzed from objective and subjective perspectives. Dang et al. [14] comprehensively analyzed the characteristics of gas, liquid, phase change materials, mixed, and new material cooling suits and found that the factors affecting the effect of cooling clothes are ambient temperature and humidity, clothing fabrics, clothing structure design, and human activity and discussed the development prospects of cooling clothing. Qian et al. [15] elaborated the finite difference method, finite volume method, and finite element method to solve the model, proposed a simplification of the model, and should consider the impact of the internal air gap of the garment material on the system heat and moisture transport, as well as the distribution of the air layer inside the multilayer garment. Wang et al. [16] used experimental studies to prove that wearing a cooling suit can significantly improve human comfort and work efficiency and concluded that the cooling effect and duration are the best when the phase change temperature is 20°C. Zhao and Song [17] studied the heat and humidity properties of ventilation suits and the impact on human thermal comfort through the combination of sweat warm body dummy experiment and real person dress experiment. According to Li et al. [18] based on the mass and heat transfer analysis of the man-garment-environment system, the human thermoregulation simulation model under ventilation condition was developed and verified the rationality of the analysis model through experiments. An Ruiping [19] in order to evaluate the cooling effect of ventilation cooling suits measured the cooling efficiency of ventilation cooling clothes under the relative humidity of different environments and different ventilation volume through real-person dress experiments. Mao et al. [20] used numerical simulation methods to study the influence regularity of ventilation temperature and air volume on human skin temperature of mining gas cooling suit in high temperature and high humidity environment.

Most of the studies on cooling clothes at home and abroad aim at clothing materials, refrigeration capacity, and ventilation volume. There are few studies on the regularity of air volume distribution in the internal tubes of clothing, and the distribution of pipelines air volume in mining ventilation clothing is closely related to the cooling effect of clothing. In this paper, the air volume distribution of different pipeline structures in three models is mainly studied through simulation. The uniformity and change regularity of pipeline airflow distribution are discussed, so that the air flow plays a greater function in the tubes. At the same time, the study of the internal airflow distribution of ventilation clothing pipelines has profound significance for the development of gas cooling clothing and can also provide a reference basis for the optimization of the pipeline structure of mining ventilation clothing.

2. Mining Ventilation Clothing

Mining ventilation clothing rely on compressed gas as a cold source to achieve cooling of the human body. Its working principle is that the air compressor compresses and cools the air in the environment in the way of strong pressure and sends it into the tube of ventilation clothing, and the airflow flows directionally and quantitatively in the ventilation tubes. Then, the air flow is released through small holes in the tubes to the microspace inside the clothes and the surface of human skin, and the heat exchange with the human skin and the air in the clothes is carried out in the form of convective heat exchange and radiation heat exchange, and the heat dissipation of the human skin is promoted. Finally it is released into the environment from the neckline, cuffs, and under the garment outlet. The cooling principle of the ventilation clothing is shown in Figure 1.

The cooling effect of the ventilation clothing is related to the uniformity of the air volume distribution of the tubes and the wind speed of the outlet hole. When the air flow enters the ventilation tube, the pipeline structure brings limitations to the flow environment of the air flow, forcing the wind flow to form a distributary in the tubes or release from the pipeline pores and become sparse. Due to the viscosity and inertia of the wind flow itself, the blockage and interference of the pipeline wall facing the wind flow have caused the energy loss of the wind flow. At the same time, when flowing along the flow of the pipeline, the friction between the air flow fluid layers or the friction between the fluid and the tube wall material will also bring frictional resistance to the wind flow. Therefore, the release of air currents from the outlet holes requires the energy loss caused by many factors. In order to reduce the energy loss during the flow of the air flow, the air volume in the pipelines is distributed more evenly, thereby improving the cooling effect of the ventilation clothing. It is of great significance to study the wind speed magnitude and distribution regularity of air flow in the pipelines.

3. Numerical Simulation

3.1. Ventilation Clothing Simulation Model. According to the national standard GB/T5703-1999 [21], the establishment of mine ventilation clothing model was completed by Solid-Works software. The simulation model was divided into two layers, the inner layer was human skin, and the outer layer was clothing. The space between the two layers was the microspace inside the clothes, and the thickness of the microspace was 3 centimeters. The space was arranged to layout the ventilation tubes of ventilation clothing. The transverse type (Figure 2), longitudinal type (Figure 3), and spiral type (Figure 4) mine ventilation clothing models as follows.

The ventilation tubes of the transverse ventilation clothing were composed of six longitudinally distributed pipelines and one horizontal distribution of the pipeline, the diameter of the tubes was 10 millimeters, and the ventilation inlet was on the left side of the ventilation clothing. In order to distinguish the six longitudinally distributed ventilation pipelines, the clockwise direction was named k1, k2, k3, k4, k5, and k6, and each longitudinally distributed ventilation pipeline was provided with 8 small holes as ventilation outlets, and the small holes were 2 millimeters in diameter. Due to the drapability of clothing, the underwear space of chest and back becomes smaller, and the sweating of these two parts was
relatively large when moving [22], and the human abdomen was not easily stimulated by cold, the small holes located in the upper part of the pipelines were relatively dense, the small holes in the lower part of the pipeline were more sparse, and the middle area of the longitudinal pipelines was not set with small holes, and the small holes in each pipeline were numbered from top to bottom as 1 to 8. In order to allow the air volume to be released relatively uniformly to the farther ends of the pipeline, the transverse distribution of the pipeline was not provided with small holes, and the upper and lower ends of each longitudinal pipeline were sealed. The ventilation tubes of the longitudinal mining ventilation clothing were basically the same as the transverse type, which mainly changes the inlet mode of the pipeline, and the longitudinal inlet position was located at the lower end of the ventilation tube $k5$ on the back of the ventilation clothing. The spiral type had only one ventilation tube, the ventilation entrance was at the lowest end, and there were 27 ventilation holes with a diameter of 2 millimeters on the tube. Except for the absence of small holes in the human abdomen, the density of small holes was encrypted sequentially with the increase of the distance from the inlet end. Since there were many holes in the pipeline, the 10 representative pores were numbered from 1 to 10 in turn to facilitate the analysis of data.

3.2. Simulation Parameters. This study mainly aims at the simulation of air volume in pipeline, to ensure that the air volume distribution of air volume in pipeline is relatively uniform, so that the air volume size of the vent hole is better, thereby improving the utilization rate of air volume. When meshing in ANSYS software, the vent hole locations on each ventilation tube are encrypted to make their calculations more accurate, as shown in Figure 5. In the SETUP step, double precision was selected, and before checking the mesh, the gravity in the direction of the longitudinal axis was taken into account, so the gravitational acceleration of the $y$-axis was set to $-9.81 \text{ m/s}^2$, and the time state was selected to steady when simulating. The calculation model was realizable $k-\varepsilon$ turbulence model [23]. Since the realizable $k-\varepsilon$ model can meet the Raynaud stress constraints, can ensure the same Raynaud stress as the real turbulence, and has favorable results in simulating diffusion velocity, rotational flow, flow separation, and secondary flow [24], which is opposite the simulation of pipelines wind flow in this study. In the simulation, the initialization method adopted the standard initialization of all zones. Therefore, the tube wall causes local resistance to the wind flow at the inlet position, which affects the wind speed of the airflow in the pipeline. The simulation results obtained that the inlet air volume in the transverse type was 8 m$^3$/h, 10 m$^3$/h, and 12 m$^3$/h, and the maximum wind speed in the tubes was 35.55 m/s, 39.39 m/s, and 42.46 m/s, respectively (converted from 8 m$^3$/h, 10 m$^3$/h, and 12 m$^3$/h).

3.3. Simulation Results Analysis. Regardless of the influence of environmental factors, the three models have the distribution of air volume inside the tubes under different ventilation speeds. The simulation results demonstrate the velocity distribution streamline figures as follows.

It can be seen from Figures 6–8 that the wind speed near the ventilation inlet of each model was the largest. In the transverse type, the inlet is on the left side; the air flow near the inlet is forced to form a shunt due to the limitation of the pipeline structure. Therefore, the tube wall causes local resistance to the wind flow at the inlet position, which affects the wind speed of the airflow in the pipeline. The simulation results obtained that the inlet air volume in the transverse type was 8 m$^3$/h, 10 m$^3$/h, and 12 m$^3$/h, and the maximum wind speed in the tubes was 35.55 m/s, 39.39 m/s, and 47.78 m/s, respectively. Conventionally, the transverse type airflow is less affected by the pipeline structure at the inlet end, which also affects the flow to the farther end. In order to prevent this situation, subjectively, the longitudinal type had been improved on this basis; inlet was located at the lower end of the $k5$ pipeline on the back of the ventilation clothing, so that the airflow is likely to flow to other positions of the pipeline at a greater velocity. The maximum wind speed of the airflow in the longitudinal type could reach 45.25 m/s, 50.24 m/s, and 60.58 m/s, respectively, which was much larger than the maximum wind speed of the transverse type. The spiral type was modified on the above two models, only a single pipeline, there was no shunting phenomenon inside the tube, and the maximum wind speed inside the tube was 48.42 m/s, 52.80 m/s, and 63.95 m/s, respectively. The above results demonstrated that after the wind flow enters the tube, the wind speed is not limited to decreasing all the time. Conversely, it increases within a certain range. Therefore, there is still a lot of space for improvement in the pipeline structure. A good pipeline model not only reduces the resistance of pipeline but also makes the air volume play a greater role. In short, the maximum wind speed in the pipelines of the three models is greater than the corresponding ventilation inlet wind speed.
The above analysis is only for the preliminary judgment of the maximum wind speed and cannot compare the advantages and disadvantages of the pipeline structure. For mining ventilation clothing, the advantages and disadvantages of the pipeline structure are related to the uniformity of air volume distribution and the comfort of human body dress.

4. Air Volume Distribution in the Tube

4.1. Wind Speed Distribution. In order to analyze the air flow distribution in each pipeline more intuitively, the simulation calculation could obtain the distribution of wind speed in the pipeline holes in each model.

The wind speed of the stomata on the transverse type of ventilation pipelines $k_1 \sim k_6$ is shown in Figure 9, and it can be seen from the figure that the wind speed of the stomata tends to be V-shaped, so the wind speed of the stomata near both ends of the pipeline is larger, and the wind speed in the middle is smaller. At the same time, under different inlet air volumes, the distribution regularity of pipeline wind speed size is basically the same, and when the import air volume increases, the hole wind speed size is closer to V-shaped. Figure 10 can be seen that the wind speed gap between the stomata on the longitudinal ventilation tube is large, and the wind speed of the $k_5$ tube is much larger than that of other pipelines. Human body dress this model is possibly to cause local overcooling and overheating problems. Spiral type structure is special, in different inlet air volume under
the pipeline stomata wind speed size distribution as shown in Figure 11. Since the spiral type only has a single ventilation tube, the air flow will not form a diversion in the pipeline. With the increase of the pipeline along the course, the air flow will become more and more sparse, to the end of the snorkel tends to zero.

4.2. Air Volume Distribution Regularity and Comparative Analysis. Analyze the air flow distribution of different models in depth through simulation. The spiral type air volume distribution regularity is relatively clear. In order to explore the distribution regularity of pipeline air volume in transverse type and longitudinal type, the simulation results of inlet air volume of 10 m$^3$/h are analyzed.

From Table 1, it can be seen that the wind speed of the uppermost air hole of each longitudinal distribution is larger, and the air volume is larger. The data showed that the air volume in the upper part of the tube is larger than that in the lower part, which is largely due to the lighter air mass and the upward lift. According to the transverse type pipeline layout, $k_1 \rightarrow k_6$, $k_2 \rightarrow k_5$, and $k_3 \rightarrow k_4$ pipelines are symmetrical to each other, and the wind speed of the symmetrical tubes is relatively close. However, the air is unstable in normal environments, and the air volume distribution of symmetrical pipelines is not exactly the same. Pipelines $k_1$ and $k_6$ are the closest ventilation tubes to the inlet, but the corresponding stomata wind speed of these two tubes is smaller than that of other tubes. $k_3$ and $k_4$ are
far from the ventilation inlet, the corresponding pipeline stomata wind speed is large, $k_3, k_4$ pipeline position is centered, the size of the wind speed is also centered, and analysis data found that the air volume of these two tubes is relatively stable. In summary, the air volume of the pipelines far from the ventilation inlet in the transverse type is large, the air volume of the pipelines near the ventilation inlet is small, and the air volume of the pipeline in the middle position is medium and relatively stable.

From Table 2, it can be seen that the minimum wind speed on the ventilation inlet tube $k_5$ in the longitudinal type has exceeded 25 m/s, while other pipelines are below 5 m/s, which demonstrates that the air volume distribution is seriously uneven. The pipe furthest from the ventilation inlet in this model is $k_2$, which is similar to the transverse type, except for the inlet tube, the tube furthest from the inlet end has a larger air volume than other tubes. Due to the relatively large air velocity of the $k_5$ pipeline, a large amount of airflow is released in the pipeline, resulting in less airflow distributed to other tubes. Two datasheets can determine the size of the stomatal air velocity of each tube of the two models. The lateral type stomata wind speed is about 2 to 6 m/s, and the maximum value of the longitudinal type is about 1 to 2 m/s. Obviously, the lateral air volume

![Figure 9: Stomatal wind velocity figure of transverse type: (a) when the ventilation rate is 8 m$^3$/h, the stomatal wind speed of each pipeline; (b) when the ventilation rate is 10 m$^3$/h, the stomatal wind speed of each pipeline; (c) when the ventilation rate is 12 m$^3$/h, the stomatal wind speed of each pipeline.](image-url)
distribution is better. Therefore, it is considered that the lateral type is more uniformly distributed than the longitudinal type. Combined with Figures 9–11, it is easy to see that the longitudinal air volume distribution is the most uneven. The uniformity of air volume distribution in the transverse type and spiral type requires further analysis.

By analyzing the air volume output of the pipelines under the same ventilation air volume (12 m$^3$/h), the uniformity of air volume distribution in the transverse type and spiral type could be explored. The transverse type can be directly compared to the air volume output of the six tubes. The spiral type is a single tube, which divides the air volume output of the tube into five areas, which correspond to the abdomen, lower waist, middle waist, back, and prothorax position of the human body. The air volume output results is as follows.

As shown in Figure 12, the difference in air volume output of each tube in transverse type is relatively small. In addition to the position of the prothorax, the air volume output in other positions of the spiral type is far more than that of the transverse type. However, the gap between the local air volume output is larger than that of the transverse type. Therefore, it is considered that the transverse type is more evenly distributed than the spiral type air volume. From
Figure 11: Stomatal wind speed figure of spiral type: (a) when the ventilation rate is 8 m$^3$/h, the wind speed of 10 representative pores on the pipeline; (b) when the ventilation rate is 10 m$^3$/h, the wind speed of 10 representative pores on the pipeline; (b) when the ventilation rate is 12 m$^3$/h, the wind speed of 10 representative pores on the pipeline.

Table 1: Datasheet of transverse type (10 m$^3$/h).

<table>
<thead>
<tr>
<th>Stomata number</th>
<th>$k_1$</th>
<th>$k_2$</th>
<th>Stomatal outlet speed (m/s)</th>
<th>$k_3$</th>
<th>$k_4$</th>
<th>$k_5$</th>
<th>$k_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.5498</td>
<td>5.1350</td>
<td>6.6930</td>
<td>7.1386</td>
<td>4.7727</td>
<td>3.7193</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.6034</td>
<td>5.2446</td>
<td>6.9774</td>
<td>7.2812</td>
<td>4.5468</td>
<td>3.5910</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3.2816</td>
<td>4.9374</td>
<td>6.8567</td>
<td>3.7148</td>
<td>4.2535</td>
<td>3.5164</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.1305</td>
<td>1.4768</td>
<td>2.3443</td>
<td>6.4591</td>
<td>2.7184</td>
<td>1.1738</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.3361</td>
<td>4.5926</td>
<td>2.4152</td>
<td>5.2121</td>
<td>3.5229</td>
<td>0.7004</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2.2138</td>
<td>4.5809</td>
<td>6.6619</td>
<td>7.1259</td>
<td>4.1805</td>
<td>2.3900</td>
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</tr>
<tr>
<td>7</td>
<td>1.9685</td>
<td>4.5679</td>
<td>6.3749</td>
<td>7.2580</td>
<td>4.2335</td>
<td>2.3181</td>
<td></td>
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<tr>
<td>8</td>
<td>1.8334</td>
<td>4.2098</td>
<td>5.9825</td>
<td>6.7392</td>
<td>3.9753</td>
<td>2.1222</td>
<td></td>
</tr>
<tr>
<td>Average wind speed</td>
<td>2.3765</td>
<td>4.3431</td>
<td>5.5382</td>
<td>6.1981</td>
<td>3.8662</td>
<td>2.5151</td>
<td></td>
</tr>
</tbody>
</table>
In order to compare the total air volume of the pipelines in each model, the simulation calculates the average air volume in the ventilation tubes of the three models as follows (Table 3). Obviously, under the same ventilation rate, the average air volume of spiral type is the largest, so that the total air volume in the ventilation tube is much larger than that of other models. With the increase of the inlet air volume, the air volume in the tube of spiral type increases greatly, and the increase of the transverse and longitudinal type air volume is small.

In summary, compared with the uniformity of the distribution of the air volume of the pipelines, the transverse type > spiral type > longitudinal type. However, the total air volume in the tube, spiral type > longitudinal type > transverse type.

5. Pipeline Air Volume and Frictional Resistance

When the air flow flows along the inside of the ventilation tubes, the friction between the fluid layers and the friction between the fluid and the tube wall form a frictional resistance, also known as the resistance along the path. The air volume in the tubes is closely related to the frictional resistance along the course. By analyzing the flow state of the air flow in the pipelines, the relationship between the size of the internal wind flow of the pipelines and the frictional resistance can be explored. Since the air velocity at the stomata on the pipelines can represent the wind speed at the cross-section of the stomata corresponding to the stomata, the frictional resistance along the local flow of the tube can be calculated by two adjacent stomata.
With reference to the frictional resistance of industrial ventilation and mine ventilation, each longitudinally distributed pipeline is divided into 4 subsections. Paragraphs 1-2 indicate the corresponding tube sections from stomata 1 to stomata 2, and other tube sections are segmented in turn. The following transverse type data are still taken for analysis at a ventilation volume of 10 m$^3$/h.

\[
Re = \frac{vd}{\nu}, \tag{1}
\]

wherein \(v\) represents the average wind speed of the section, m/s; \(\nu\) represents the kinematic viscosity coefficient of the air, usually taken \(15 \times 10^{-6}\) m$^2$/s; and \(d\) is the tube diameter, m.

When the air flow moves in the circular tube, the Reynolds number \(Re \geq 2320\), and the flow state is laminar flow; the Reynolds number \(Re > 4000\), and the flow state is turbulent flow; in the area of \(Re = 2320 \sim 4000\), it is a transition zone, and the flow state is extremely unstable. Depending on external conditions such as the roughness of the tube wall and the situation when the fluid enters the tube, the flow state will change as long as there is a slight disturbance [25].

Therefore, it is difficult to judge the frictional resistance of the transition zone, which will not be considered here.

As shown in Table 4, there are many cases in which the flow state of the air flow in the tubes transverse type is in an unstable transition zone. When the wind speed in the pipeline is large, the flow state is turbulent, and when it is small, the flow state is in the transition zone or laminar flow state. Studying the flow state of pipeline airflow can provide a reference for the microspace of mining ventilation clothing and human comfort.

When the airflow is laminar flow in the pipelines, use the following formula:

\[
h_f = 2\nu \cdot \frac{LU}{S^2} \cdot v, \tag{2}
\]

wherein \(\nu\) is the kinematic viscosity coefficient of air; \(\rho\) is the air density, kg/m$^3$; \(L\) is the length of the pipeline, m; \(U\) is the sectional circumference, \(m\); \(S\) is the cross-sectional area of the pipeline, m$^2$; and \(v\) is the average wind speed of the section, m/s.

When the airflow is turbulent flow in the pipelines, use the following formula:

\[
h_f = \frac{\lambda \cdot \rho LU}{8S} \cdot v^3, \tag{3}
\]

wherein \(\lambda\) is the resistance coefficient along the path, obtained by Nicholas experiment and \(\rho\), \(L\), \(U\), and \(S\) have the same meaning as above.

The results of frictional resistance in the two flow states are shown in the following table.

As shown in Table 5, except the friction resistance of unstable transition zone cannot be judged, the friction resistances of pipelines \(k1\) and \(k6\) closest to the ventilation inlet are relatively large. The \(k3\) and \(k4\) pipelines are far from the ventilation inlet, and the friction resistance is much smaller than that of other pipelines. Therefore, it can be judged that the pipeline with large friction resistance has less air flow, and the pipeline with small friction resistance has large air flow. The conclusion obtained is consistent with the actual situation, so the frictional resistance in the transition zone cannot be judged which will not affect the content of this study.

For friction resistance of longitudinal type and spiral type is no longer described, the method is the same.

### 6. Conclusions

(1) In the three models, the maximum wind speed in the ventilation tube exceeds the inlet wind speed, and the wind speed will increase within a certain range after the air flow enters the ventilation tube. The distribution regularity of air volume in the transverse and longitudinal tubes is basically the same. The air
volume of the pipelines farther from the ventilation inlet is larger, the air volume of the pipelines nearer from the ventilation inlet is smaller, and the air volume of the middle pipelines is medium and relatively stable. Symmetrical pipeline air volume distribution is asymmetrical.

(2) The stomatal wind speed of transverse type is V-shaped distribution. The wind speed gap of pipelines of transverse type is large, and the distribution of air volume was seriously uneven. The wind speed of spiral type decreased sequentially with the increase of the pipeline path. For air volume distribution uniformity, transverse type > spiral type > longitudinal type. The total air volume in the vent tube, spiral type > longitudinal type > transverse type. And with the increase of imported air volume, the air volume in the tube of spiral type increase greatly, and the increase in transverse type and longitudinal type of air volume is small.

(3) The results of transverse type demonstrate that the air volume is inversely proportional to the frictional resistance along the way. In the pipelines with similar wind speed, the airflow state is basically the same, and the friction resistance is also close. When the flow state in the tube is in an unstable transition zone, the friction resistance is difficult to obtain.

Data Availability

The necessary data for this study are included in the paper.

Conflicts of Interest

The authors declare that they have no conflict of interest regarding the publication of this article.

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