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Simulation Study of Mine Reversal Ventilation Test Based on Ventsim

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Abstract: As metal mines advance into deeper levels, the design and management of mine ventilation systems become increasingly critical. Reversal ventilation, as one of the key emergency response strategies for mine disasters, plays a vital role in redirecting airflow and smoke flow from the perspective of mine ventilation. Its purpose is to expel smoke in the shortest possible time through the optimal path, thereby providing better conditions and more time for the safe evacuation of personnel and underground emergency rescue operations. It also helps to limit the spread of fire and reduce secondary hazards caused by mine fires. To scientifically address the challenges associated with reversal ventilation tests, this study employed the Ventsim 3D ventilation simulation software to establish a ventilation network model for the Anqing Copper Mine. The model was validated using field-measured data, including tunnel parameters and ventilation infrastructure settings. The validation results indicate that the model meets practical application needs and provides a solid foundation for subsequent on-site reversal ventilation experiments. Based on a carefully designed test plan for reversal ventilation at the Anqing Copper Mine, pre- and post-reversal ventilation system inspections were conducted. The test data show that the average ratio of reversed airflow to normal intake airflow at the -460 m, -510 m, and -580 m levels was approximately 70.5%, meeting the requirement that reversed airflow should exceed 60% of normal operating airflow. The reversal ventilation test achieved the intended goals in terms of airflow reversal time and airflow volume, confirming that the smoke flow followed the expected direction in the event of a fire occurring in the assumed area. The results effectively verified the reliability and practicality of the mine's reversal ventilation system.

Keywords: Mine Ventilation; Mine Ventilation Reversal Simulation; Ventsim, Ventilation Simulation

1. Introduction

In the process of metal mine exploitation, the design and management of mine ventilation systems are of critical importance. Their primary function is to supply sufficient fresh air to underground operations, while promptly removing hazardous gases, dust, and heat to ensure the safety and health of underground workers. As mining activities extend to greater depths, the underground environment becomes increasingly complex—particularly with the emergence of high-temperature, high-humidity, and high-gas conditions—placing higher demands on ventilation systems. Improper design or poor management of these systems can not only hinder production efficiency and resource utilization but also pose serious safety risks to the mine.

To ensure mine safety, research on emergency ventilation strategies for critical situations—such as fires, gas outbursts, and other major disasters—has become a focal point in both safety management and academic circles. Among these strategies, reversal ventilation technology has received growing attention as an effective method for rapidly altering the direction and distribution of underground airflow during emergencies.

Originally, reversal ventilation was predominantly applied in the field of coal mine ventilation safety, particularly in coal mines prone to gas outbursts and underground fires, where both theoretical and practical foundations have been well established. However, as metal mines are also advancing to deeper levels and encountering increasingly harsh underground environments, similar demands for emergency ventilation have emerged. In the event of a sudden disaster in a specific underground work area, it is essential to quickly isolate the affected zone from other safe areas and discharge harmful gases or smoke to the surface to prevent escalation. In such cases, by reversing fan rotation or rerouting airflow through dedicated infrastructure, the direction and distribution of ventilation can be swiftly altered, significantly improving the effectiveness of emergency responses.

Given the differences between metal and coal mines in terms of geological conditions, orebody characteristics, and mining techniques, a key challenge in applying reversal ventilation to metal mines lies in developing rational and practical designs that account for their unique ventilation network structures and hazard profiles. This requires both robust numerical simulation and thorough on-site validation.

Currently, research on reversal ventilation technology in metal mines has gained increasing attention. Yang Tiejiang[1] proposed a regional reversal ventilation strategy based on the issue of smoke dispersion during a mine fire at the Lingnan Gold Mine. By constructing a three-dimensional ventilation model, he simulated and verified the effectiveness of reversal ventilation tests, significantly enhancing the mine's ability to cope with sudden fire-related hazards. Yang Hua [2] applied Fire Dynamics Simulator (FDS) to analyze safety evacuation scenarios in a copper mine, proposing and optimizing a fire evacuation model that serves as a valuable instructional case for emergency response planning in mining environments. Sheng Jianhong [3], using computational fluid dynamics (CFD) methods and Fluent software, conducted three-dimensional numerical simulations of axial fan operation under forward and reverse conditions. His study explored the reverse performance of axial fans in detail and analyzed the effects of blade installation angle, blade camber, and rotation speed on reversal airflow capacity, providing a scientific basis for improving fan performance in emergency ventilation scenarios. Ji Changfa [4] developed a FORTRAN-based simulation program to address the complexity of reversal ventilation in multi-shaft, multi-fan systems. Through this approach, various combinations of reversal ventilation configurations were simulated, contributing valuable insights for the optimization of complex mine ventilation systems.

In metal mining, several unique challenges—such as high underground temperatures, spontaneous combustion risks, and complex, irregular tunnel layouts—make the practical application of reversal ventilation difficult. These conditions require more targeted solutions, which depend on sufficient field data and deeper analysis. Therefore, studying real-world reversal ventilation designs, field tests, and 3D simulations is essential. Such research not only advances the theory of mine ventilation but also provides technical support for improving emergency ventilation systems in practice.

This study focuses on the Anqing Copper Mine as a case study. The mine features a complex ventilation network, numerous underground tunnels and chambers, and high demands for airflow and pressure, making quick airflow reversal during emergencies especially important. By analyzing the design, field measurements, and 3D simulations of reversal ventilation in this mine, the study aims to support both theoretical development and practical applications for metal mines facing similar conditions.

2. Current Status of Mine Ventilation

The Anqing Copper Mine, operated by Tongling Nonferrous Metals Group, is one of its key mines, located in Yuèshān Town, Huaining County, Anhui Province. The mine is developed using a combination of shaft and ramp systems. With continued deep-level development, the Dongma'anshan orebody now uses a blind shaft and ramp system for access. The main ramp connects all mining levels, while the auxiliary shaft connects to major sublevels, and the hoisting shaft links to the main rail transport levels. Sublevels are also interconnected via auxiliary ramps. The mine primarily uses large-diameter long-hole stoping, with a two-step mining method of stoping and pillar recovery. Stopes are backfilled with cemented tailings at ratios ranging from 1:4 to 1:10, and pillars are backfilled with classified tailings.

The mine adopts a single-wing diagonal exhaust ventilation system. Fresh air is drawn in through the auxiliary shaft, main shaft, and ramp, then distributed via crosscuts into level drifts to ventilate the working faces. Contaminated air is collected in the upper-level return airways and directed through various sublevel return shafts to a main return airway at the -280 m level. From there, the airflow is expelled to the surface by the main fan at the Xifeng Shaft.

For the Dongma'anshan orebody, return air is guided from the -510 m level via an auxiliary fan to the -340 m level air bridge and then into the return shaft. The ventilation network is complex, comprising 17 levels and 43 return air raises.

In terms of fan configuration, the Xifeng Shaft fan station is equipped with two main fans (one standby), with the older model being DK-8-No28 and the newer model FKCDZ-8-No29. Additionally, a high-power auxiliary fan (DK-12-No29) is installed at the -510 m level return shaft of the Dongma'anshan orebody. The main fan parameters are summarized in the table below.

Table 1: Main fan basic parameters table

Fan Model	Volume (r/min)	Speed (m^3/s)	Pressure (Pa)	Rated Power (kW)
DK-8-No28	170	744	2700	2×355
FKCDZ-8-No29	170	744	2650	2×355
DK-12-No29	68	490	2100	2×160

3. Design of Anti-Wind Scheme

Anti-wind mode

（1）Ventilation system reverse wind using axial flow fan reverse wind

Anqing Copper Mine adopts a single-wing diagonal extraction ventilation system, and the west wind shaft uses mining energy-saving axial flow fans. Compared with centrifugal fans, axial flow fans have directional steering. By reversing the axial flow fan, the fan airflow can be quickly reversed, thereby achieving reverse wind in the ventilation system.

（2）Reverse air operation of the main fan of the ventilation system

The Anqing Copper Mine adopts a unit-based underground ventilation system, where each working unit is equipped with its own auxiliary fan to enhance airflow. Currently, the mine operates one main fan and eight auxiliary fans (including air curtains), all of which are axial-flow type and capable of direct reversal through motor rotation. To ensure efficient response during emergency conditions, the reversal ventilation plan was designed based on the assumed disaster location and timing. The objective was to achieve effective airflow reversal at the disaster site while minimizing the number of fans requiring reversal or shutdown. This approach reduces unnecessary operational changes, shortens reversal time, and improves overall ventilation efficiency. Through analysis of the disaster site and selected airflow reversal paths, specific fans were identified for reversal, shutdown, or continued operation. During the trial, only one fan was reversed and one was shut down, while the remaining auxiliary fans and air curtains continued operating as normal (see Table 2 for details). This configuration ensured a rapid response, allowing the ventilation system to complete airflow reversal in major tunnels within 10 minutes of receiving the command.

Table 2: Statistics of the operating status of each fan in the mine during reverse wind period

No	Sublevel	Fan model	Fan type	Single fan power (kW)	Number of units	Fan operating status during airflow reversal	The fan is installed at the main shaft entrance
F1	Ground	FKCDZ-8-No28	Main fan	2×355	1	Reverse	West Shaft Fan House
F2	-510m	DK-12-No29	Auxiliary fan	2×160	1	Turn off	-510m middle section 10-line fan chamber.
F5	-340m	K40-4-No10	Auxiliary fan	15	1	*Keep the state before reversal*	In the return air shaft connecting lane of line VI.
F6	-400m	K40-4-No13	Auxiliary fan	55	1	*Keep the state before reversal*	In the return air connecting tunnel of 2# return air shaft of 2# ore body.
F7	-400m	K45-6-No13	Auxiliary fan	30	1	*Keep the state before reversal*	-400m in the connecting lane of the return air shaft of Matou Mountain.
F8	-618m	K40-4-No10	Auxiliary	15	1	*Keep the state*	The 0 line is on the return

No	Sublevel	Fan model	Fan type	Single fan power (kW)	Number of units	Fan operating status during airflow reversal	The fan is installed at the main shaft entrance
			fan			*before reversal*	wind lane.
F12	-510m	K40-4-No10	Auxiliary fan	15	1	*Keep the state before reversal*	From the stone gate of the auxiliary shaft to the connecting lane of the blind main shaft.
F15	-580m	Air curtain 18.5kW	Air curtain	18.5	2	*Keep the state before reversal*	Ramp near -580m level.
Total				1787	9		

Disaster location confirmed

According to the actual situation of underground production, this anti-wind test assumes that the possible fire locations are the following four locations: ①-460m middle section ramp; ②-510m middle section ramp and large equipment road; ③-580m middle section Matoushan ramp.

The above locations are selected as disaster locations mainly because they are located in the air intake section and close to the auxiliary shaft. The pit bottom parking lot is the main channel for the transportation of various materials and the laying of pipelines. The underground central transformer and distribution chamber is also located in the pit bottom parking lot. Therefore, once a fire occurs at this location, if the mine cannot reverse the wind in time, a large amount of toxic and harmful gases, smoke, etc. generated by the fire will be brought into the main production and transportation middle section operation area, thereby endangering the lives of underground workers and seriously affecting the evacuation of personnel in the underground operation area along the air intake side safety exit. Once a fire occurs on the air inlet side of the mine, if the main fan can be reversed in time, it can not only effectively prevent the fire and the toxic and harmful gases produced by the fire from spreading to the working area, but also ensure that the lines leading to the ramps in the middle mining areas are not affected by the fire, and underground workers can safely evacuate to the surface via the ramps.

Anti-wind detection content

(1) Normal operation of ventilation system

① Mine air volume: air volume detection at the openings of all shafts on the ground, -460m middle section ramp, -510m middle section ramp and large piece road, -580m middle section Matoushan ramp, and main working places;

② West wind shaft fan working condition: air volume and fan power detection when the west wind shaft fan is in normal operation.

(2) Reverse wind operation of ventilation system

① Mine reverse air volume: air volume detection at the openings of all shafts on the ground, -460m middle section ramp, -510m middle section ramp and large piece road, -580m middle section Matoushan ramp, and main working places;

② West wind shaft fan working condition: air volume and fan power detection when the west wind shaft fan is in reverse wind.

Anti-wind safety measures

(1) Before the anti-wind test, the security department shall conduct a comprehensive inspection and maintenance of the ventilation structures above and below the mine, the main ventilation fan, the frequency conversion control cabinet, the power supply system, etc. to ensure that the system fan can operate normally and reversely. Clean the fan shroud and diffuser to prevent the fan from sucking in debris. The above work must be completed one day before the anti-wind test.

(2) Before the anti-wind test, the anti-wind test command will organize a preparatory meeting for the anti-wind test, convene relevant personnel for the anti-wind test to divide the personnel, implement tasks and responsibilities, emphasize various safety precautions, and issue an anti-wind test notice (including anti-wind time, anti-wind test personnel and division of labor, safety precautions, etc.).

(3) During the anti-wind test, each unit must implement vehicles and personnel according to the requirements of the notice. There must be no vehicles, production equipment or other objects in the main passageways, air inlets and return air ducts in the mine to ensure that the ventilation system is unobstructed.
(4) All personnel participating in the anti-wind test must take personal protective measures and must not leave their posts without authorization. If any abnormal phenomenon is found, they must report it to the dispatcher in a timely manner.

4. Three-dimensional Ventilation Model Construction and Simulation Verification

Introduction to Ventsim

Ventsim is a simulation and engineering design tool specifically used for ventilation systems in enclosed spaces such as underground mines and tunnels. It has important application value in the field of mine ventilation optimization (reference [93]). The core functional system of the platform includes:
(1) 3D visualization modeling: Based on AutoCAD engineering drawings or measured geographic information data, the system can realize parametric modeling of tunnel networks, support 3D visualization to present the spatial topological structure of tunnels and the spatial distribution relationship of ventilation structures, and effectively improve the intuitiveness of engineering design;
(2) Multi-condition dynamic simulation: Using a nonlinear equation group solver to solve the ventilation network, it can simulate the dynamic response of airflow under 23 control variable combination conditions including fan frequency regulation, auxiliary ventilation facility start and stop, etc., which is especially suitable for quantitative analysis of the coupling effect of natural wind pressure and mechanical ventilation;
(3) Environmental parameter coupling analysis: integrating thermodynamic equations and pollutant diffusion models, supporting quantitative simulation of environmental factors such as seasonal temperature gradients and dust migration trajectories, and providing decision-making basis for ventilation path optimization in disaster emergency plans;
(4) Economic optimization module: by establishing an evaluation system including economic parameters such as equipment operation and maintenance costs and energy consumption indicators, using genetic algorithms to perform multi-objective optimization of ventilation schemes, a dynamic balance between safety and economy is achieved.

Model building

According to the plan drawings of each middle section of the mine, CAD is imported into the Ventsim software using a three-dimensional polyline method. The Ventsim three-dimensional visualization simulation model of Anqing Copper Mine is established by setting ventilation structures such as dampers and wind windows and wind resistance as shown in Figure 1. The specific steps are as follows:
(1) Use the plan drawing of the mining project with elevation to draw the center line of the tunnel, import the drawn tunnel center line CAD file into the Ventsim software, and convert it into a physical tunnel;
(3) Based on the field measured data, complete the drawing of the shaft, wind tube, ramp and tunnel dimensions;
(4) The tunnel connectivity detection and correction of the preliminary mine model;
(5) The fan parameters such as the fan blade deflection angle, fan characteristic curve, power speed, etc. are input into the model to complete the fan setting;
(6) The tunnel ventilation structures and their parameters are set, mainly including the setting of dampers, wind windows, wind walls, wind bridges and friction coefficients;
(7) Compare the plan CAD drawings of the mining project, analyze the three-dimensional visualization modeling errors, and further improve the mine model construction;

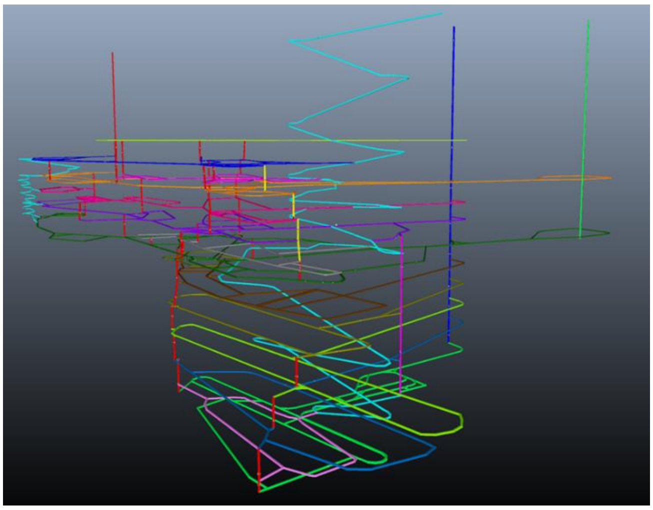

Figure 1: Three-dimensional ventilation network model of Anqing Copper Mine

Verification of on-site measured air volume and simulation results

After the ventilation system model is established, in order to ensure that the model has high simulation accuracy, it is necessary to calibrate the measured air volume and the built model based on the field measured data to meet the accuracy requirements.

Ventsim ventilation simulation mainly calculates the air volume, wind speed, pressure distribution and flow resistance in each air duct, and helps design and optimize the ventilation system through the principles of air volume balance and pressure loss. It is mainly based on the physical laws of air flow (such as air volume balance law, resistance law, energy balance law), focusing on describing the flow state of air in each node and air duct. The purpose is to ensure that the mine ventilation system can provide sufficient and balanced air flow to maintain safe operation and remove harmful gases.

The air volume of the main air duct of the mine is used as an evaluation indicator to compare the difference between the measured value and the simulated value. As shown in Table 3. The relative error between the simulated air volume and the measured air volume of the main tunnel is within 5%, which is within the acceptable range. This shows that the reliability of each branch parameter is high and meets the requirements of network analysis. Therefore, the subsequent mine backwind simulation can be carried out.

Table 3: Comparison between simulated and measured air volume of main lanes in autumn

Measuring point	Measured data	Simulated data	Error
Total return air	197.7	199.5	0.9
Total air intake	188.8	192.1	1.7
Auxiliary shaft total air intake	105.4	107.2	1.7
Main shaft total air intake	49.7	52.1	4.8
Ramp air intake	33.7	32.8	2.7
-580m main shaft	40.2	41.37	2.9
-640m auxiliary shaft	17.1	17.91	4.7
-700m auxiliary shaft	8.3	8.45	1.8
-760m auxiliary shaft	20.3	19.4	4.4
-820m auxiliary shaft	20	19.12	4.4
-900m auxiliary shaft	26.1	25.13	3.7

Three-dimensional simulation and solution of mine reverse wind test

After building a ventilation network model that meets the accuracy requirements, we can start the reverse wind simulation of the mine. According to the previously planned reverse wind route and fan change, the wind direction of the main fan and the -510m auxiliary fan of the west wind shaft are reversed and shut down in the software, as shown in the figure below.

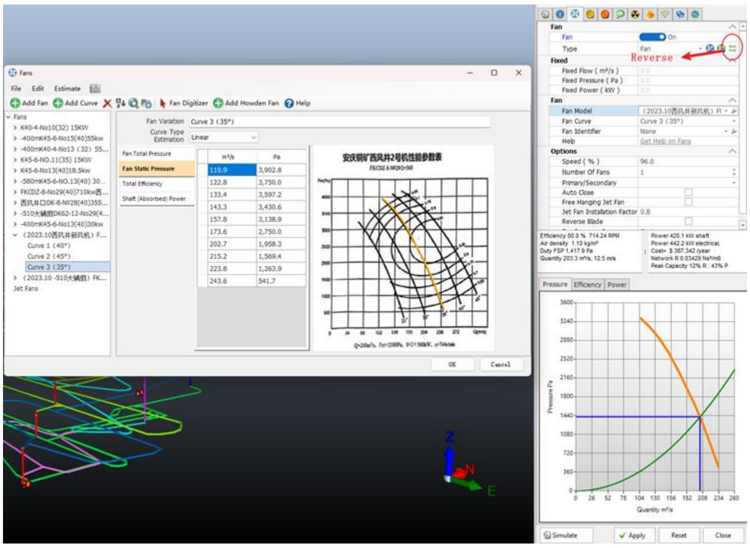

Figure 2: West wind well main fan reverses

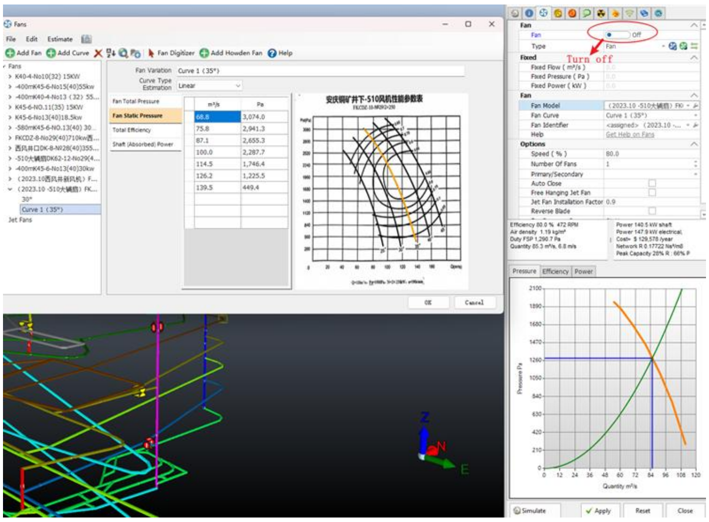

Figure 3: 510m auxiliary fan shut down

On-site measurement

According to the design of the on-site anti-wind scheme, the anti-wind test of the ventilation system of Anqing Copper Mine was carried out, and the ventilation system was measured under normal conditions before the start of the anti-wind test, so as to compare and analyze the anti-wind test effect. The test data when the ventilation system is operating normally are as follows.

Table 4: Actual measured data of each measuring point before the backwind test

No.	Measurement point	Measurement location	Cross-sectional area (m^2)	Average Wind speed (m/s)	Average wind volume (m^3/s)	Wind direction	Measurement time
1	1'	In the surface wind tunnel of the west wind shaft	9.62	21.07	202.61	Air outlet	6:50
2	1’	Ramp to -460m middle section	13.12	1.16	15.16	Air inlet to -510m ramp	7:10
3	1’’	-460m middle section to -510m ramp	14.71	0.81	11.91	Air inlet to -510m ramp	7:13

4	1’’’	-460m middle section to auxiliary shaft	9.74	0.97	9.44	Auxiliary shaft to -460 ramp	7:15
5	1’’’’	-460m ramp to -460m middle section	12.53	0.72	9.00	Air inlet to middle section	7:20
6	2’	-510m ramp to auxiliary shaft	10.98	0.41	4.46	Air inlet to auxiliary shaft	7:10
7	2’’	-400m ramp to -510m ramp	17.86	1.00	17.79	Air inlet to -510m ramp	7:13
8	2’’’	-510m ramp to large equipment road	14.60	1.00	14.56	Air inlet to -510m ramp	7:14
9	2’’’’	-510m ramp to -510m middle section	11.56	1.75	20.23	Air inlet to middle section	7:15
10	3’	-510m large equipment road	14.39	1.41	20.23	Auxiliary shaft to large-scale road	7:17
11	3’’	-510m large equipment road to -580 ramp	15.40	0.34	5.27	Air inlet to -580m ramp	7:20
12	3’’’	-510m large equipment road to -510m ramp	14.1	1.00	14.30	Air inlet to -510m ramp	7:16
13	4’	-580m middle section 1# ore body to -580m Matoushan ramp	21.36	1.44	30.70	To Matoushan ore body	7:14
14	4’’	-580m Matoushan ramp to Matoushan return air shaft	8.15	1.16	9.44	Middle section to Matoushan return air shaft	7:15
15	4’’’	-580m Matoushan ramp to -510 Matoushan ramp	12.12	1.14	13.82	To -510m	7:17

Table 4: Actual measured data of each measuring point after the reverse wind test

No.	Measurement point	Measurement location	Cross-sectional area (m^2)	Average Wind speed (m/s)	Average wind volume (m^3/s)	Wind direction	Measurement time
1	1’	In the surface wind tunnel of the west wind shaft	9.62	15.30	139.41	Air intake	7:30
2	1’	Ramp to -460m middle section	12.61	0.39	4.91	Air intake to -460m ramp	7:40
3	1’’	-460m middle section to -510m ramp	14.33	0.36	5.14	Air intake to -510m ramp	7:43
4	1’’’	-460m middle section to auxiliary shaft	9.36	2.1	19.65	Air intake to auxiliary shaft	7:45
5	1’’’’	-460m ramp to -460m middle section	11.83	1.65	19.52	Air intake to	7:50

						-460m ramp	
6	2’	-510m ramp to auxiliary shaft	10.09	2.19	22.15	Air intake to auxiliary shaft	7:40
7	2’’	-400m ramp to -510m ramp	14.92	0.51	7.57	Air intake to -510 ramp	7:43
8	2’’’	-510m ramp to large equipment road	13.35	0.56	7.51	Air intake to -large-piece road	7:44
9	2’’’’	-510m ramp to -510m middle section	12.50	2.15	26.91	Air intake to -510m ramp	7:45
10	3’	-510m large equipment road	14.02	0.32	4.45	Air intake to large-piece road from auxiliary shaft	7:47
11	3’’	-510m large equipment road to -580 ramp	13.52	0.79	10.70	Air intake to -580m ramp	7:50
12	3’’’	-510m large equipment road to -510m ramp	13.33	0.55	7.50	Air intake to -580m ramp	7:48
13	4’	-580m middle section 1# ore body to -580m Matoushan ramp	21.36	0.76	16.25	To 1# ore body in the middle section of -580m	7:40
14	4’’	-580m Matoushan ramp to Matoushan return air shaft	8.15	0.66	5.36	To -510 ramp	7:45
15	4’’’	-580m Matoushan ramp to -510 Matoushan ramp	12.12	1.80	21.83	To 1# ore body in the middle section of -580m	7:50

It can be seen from Table 3 and Table 4 that the total return air volume of the mine under normal ventilation is 202.6m3/s, the total air intake of the mine during the reverse wind test is 139.4m3/s, the reverse air volume of the main fan of the ventilation system is 68.8% of the normal operating air volume, and the average ratio of the reverse air volume of the three middle sections -460m, -510m, and -580m underground to the air intake volume during normal operation is 70.5%. Therefore, the total reverse air volume of the mine and the proportion of the reverse air volume of the four middle sections to the normal operating air volume are both greater than 60%, which meets the requirements of the "Safety Regulations for Metal and Non-metal Mines" and "Technical Specifications for Ventilation of Metal and Non-metal Underground Mines-Ventilation System" that "when using axial flow fans to reverse the wind, the reverse air volume should reach more than 60% of the normal operating air volume".

5. Conclusion

After a field investigation of the ventilation system of Anqing Copper Mine, this paper established a three-dimensional ventilation network model based on Ventsim and modeled the ventilation system of Anqing Copper Mine in real time. After the model was built, ventilation simulation was carried out. The results of the wind path simulation were verified according to the actual ventilation data measured on site. The verification results showed that the constructed model met the use requirements. By changing the fan parameters in the model, the ventilation conditions after the mine was reversed were simulated in advance, laying the foundation for the subsequent mine reverse wind tasks. According to the design requirements of the on-site reverse wind scheme, an on-site reverse wind test was carried out on Anqing Copper Mine, and the wind was measured at the pre-planned measuring points. The results showed that the reverse wind volume of each measuring point accounted for more than 60% of the normal operation wind volume, which met the task requirements of the reverse wind test. According to the reverse wind time and reverse wind volume of the mine wind flow, this reverse wind test achieved the expected effect, which was in line with the expected flow direction of the wind flow when the fire area occurred in the hypothetical area, and effectively tested the reliability and practicality of the mine ventilation system reverse wind.

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