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Research Article

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Economic Optimization Analysis of Mine Roadway Section Based on Ventsim

ZHU Xu-dong

School of Safety Science and Engineering, Henan Polytechnic University, Henan Jiaozuo, 454000, China

Abstract In order to comprehensively consider the technical, safety and economic aspects in the optimization of mine ventilation system, taking the Sucun coal mine as an example, the Ventimim software is used to establish the mine three-dimensional ventilation simulation model and the roadway section optimization model, and the mine measured data is input and analyzed. The main problems in the mine ventilation system are the large resistance of the return air section and the excessive wind speed of the concentrated return airway. Starting from the economic factors, the total cost of the wind cycle, the total cost of the ventilation network cycle, the concentrated return air volume, and the ventilation network are selected. According to several reference indicators such as total air volume, the best economic section of the concentrated return airway is 3.5m×3.5m. At this time, the total air volume of the mine increases by 258 m^3/min, the negative pressure drops by 223Pa, and the power decreases by 8.1KW. Not only does the total cost of the use period not increase, but also saves 32,000 yuan of electricity during the annual festival, so as to achieve the purpose of energy saving and consumption reduction, so as to provide reference for more optimization of mine ventilation system.

Keywords Ventsim, ventilation system optimization, economy, mine roadway section

1. Introduction

The research on mine ventilation system has been nearly 80 years old. Scholars and practitioners from all over the world have simplified tools from the beginning, the basic theory is still not perfect, and the problems encountered during the simple period of ventilation and ventilation are simplified, and the experience is judged to the electronic computer. The continuous popularization, the maturity of basic disciplines and the improvement of practical technology have made remarkable achievements in the optimization of mine ventilation systems. Mine ventilation systems have undergone profound changes in many aspects, from empirical design to optimized design, from empirical management to expert decision-support management, from basic theory to computer numerical simulation and adjustment optimization, from qualitative evaluation to quantitative evaluation. It has become an extremely important branch of the mining safety field. At present, domestic and foreign experts and scholars in the field of mine ventilation system research mainly focus on: mine ventilation network solution, mine ventilation system simulation, mine ventilation system optimization and other aspects.

Mine ventilation system consists of ventilation power and device, ventilation network, ventilation flow monitoring and control facilities. The quality of a mine ventilation system should be evaluated from three aspects of technology, safety and economy [1-2]. The optimization of mine ventilation system is the general name of a series of work from the analysis of ventilation system to the optimization of ventilation system [3]. At present, the research direction of mine ventilation optimization mainly focuses on the rational distribution of air volume, the improvement of fan efficiency and the optimization of cross-section of mine and roadway [4-6]. Considering the technology and safety, most of them neglect the economic factors. Blindly opening up the alleys, increasing ventilation and regulating facilities, and increasing the power of motor have become the optimal adjustment schemes of most mines. While effectively and accurately adjusting to improve the mine ventilation system, achieving the goal of reducing ventilation cost and energy saving and emission reduction has become the research direction of many scholars.

Ventsim software, which was developed by Chasm (Rift Valley) Mining Consulting Company in Australia in 1993, is one of the most popular ventilation simulation software in the world today [7-9]. Ventilation Design, VENTGRAPH, VUMA and other ventilation software developed by the United States, Poland and the United Kingdom, as well as domestic MVSS, virtual mine ventilation system ventilation, CFIRE and other ventilation software in compatibility, interaction, visualization and so on, still have a certain gap with Ventsim software [10-17]. Ventsim software uses Hardy-Cross iteration method to solve ventilation network. The calculation of ventilation network is based on the law of air volume balance (1), the law of air pressure balance (2), and the law of resistance (3):

$$\sum_{j=1}^{n} Q_{ij} = 0 \tag{1}$$

Where: Q_{ij} is the air volume of the branch j associated with the i-node; n is the number of branches associated with the point.

$$\sum_{j=1}^{n} h_{ij} = 0 \tag{2}$$

Where: h_{ij} is the resistance of the jth branch belonging to the i loop; n is the number of branches in the loop.

$$h = R\,Q^2 \tag{3}$$

Where: R is the equivalent wind resistance of the wind network wind resistance; Q is the total air volume passed by the wind network.

Ventilation costs run through the entire life cycle of the mine, and we should consider the economic costs of ventilation in the future. These include: considering unplanned ventilation and excavation requirements; considering the case where the total cost is similar, prefer to choose a larger cross-section airway; consider the mine's development and extension costs; consider the future energy cost increase; consider the future possible payment Investing in the implementation of ventilation regulations and management regulations. Only through comprehensive system model analysis can we help the mine operation to save ventilation costs, improve safety, and optimize production management efficiency. This study uses Ventsim software to build a mine ventilation system model to optimize the economics of the roadway section, and provide reference for the optimization analysis of ventilation networks in more mines.

2. Construction of mine model and analysis of current situation

2.1. Construction of mine model

In the mine CAD drawing, draw the center line, generate the DXF file, import it into the Ventsim software, generate the wind network, input the basic data such as coordinates, build the model framework, and then input the main fan, the local fan and other data to form the fan data. At the end, the actual data collected such as air volume, wind pressure, and roadway section data are input into the model, and the closed, air duct and other facilities are arranged to form a three-dimensional ventilation simulation model of the mine. For the convenience of analysis, take the Sucun coal mine as an example to establish a three-dimensional ventilation simulation model, as shown in Figure 1. In order to facilitate the intuitive understanding, a map of the mine ventilation network is also drawn, as shown in Figure 2.

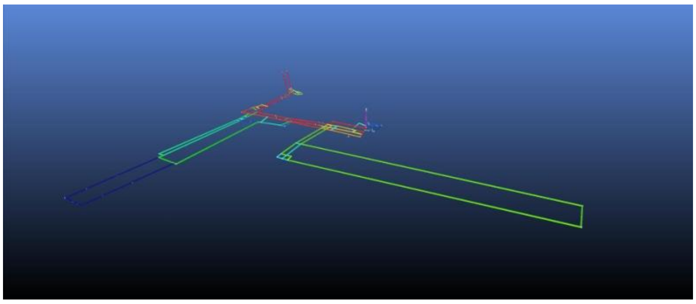

Figure 1: 3D model of mine ventilation in Zhangcun Mine

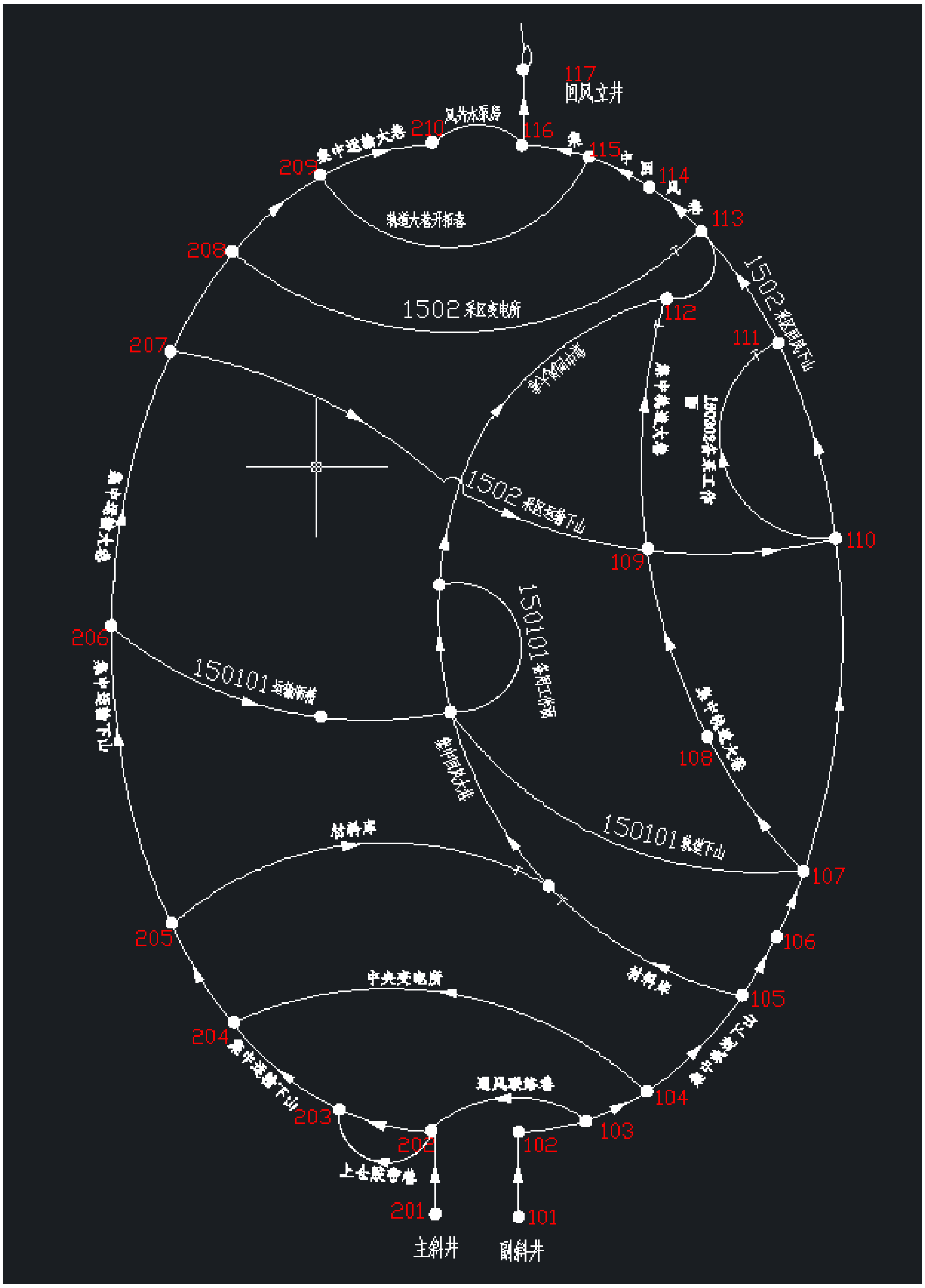

Figure 2: Mine ventilation network diagram

2.2. Analysis of mine ventilation status

Shanxi Lingchuan Chong'an Sucun Coal Industry Co., Ltd. is located in the west side of Liyi Town, Lingchuan County, mining No. 15 coal seam, with an annual mining capacity of 1.8 million tons. The coal dust is non-explosive. It belongs to Class III non-self-igniting coal seam and has low gas content. Approved as a gas mine. The coal mining method is one-time mining full-wall mining method, the coal mining technology is comprehensive mining, and the mine ventilation method is mechanical extraction type. The mine now has three wellbores, of which the main inclined shaft and the auxiliary inclined shaft enter the wind. The wind shaft has a wellbore return air. The ventilation method is mechanical extraction type. The main ventilator model of the return air well is FBCDZ-8-No22B. The working surface adopts a single U back ventilation system. According to the actual measurement, the total air intake of the mine is 4676m3. /min, mine ventilation resistance: 1094.68Pa, mine total wind resistance: 0.1803N·S2/m8, mine effective air volume rate: 88%, mine external air leakage rate: 2.22%, mine's equal hole: 2.80m2, is easy to ventilate mine. See Table 1 for the distribution of mine ventilation resistance.

Table 1: Ventilation system resistance distribution

Section	**Point number division**	**length/m**	**Resistance/Pa**	**Total of resistance/%**	**100 meter resistance value/Pa**
Inlet section	1-19	1322.5	243.48	22.24	18.41
Wind section	19-22	1621	125.46	11.46	7.74
Return section	22-6	2280.6	725.75	66.30	31.82
Total		5224.1	1094.68	100	20.95

From the above calculation and analysis, the resistance of the inlet section accounts for 22.24% of the total resistance, the resistance of the wind section accounts for 11.46% of the total resistance, the resistance of the return section accounts for 66.30% of the total resistance, and the resistance of the return stroke section is relatively large. In addition, the section of the concentrated return air main road is too small, so that the wind speed of some places in the concentrated return airway is more than 8m/s, as shown in Figure 3.

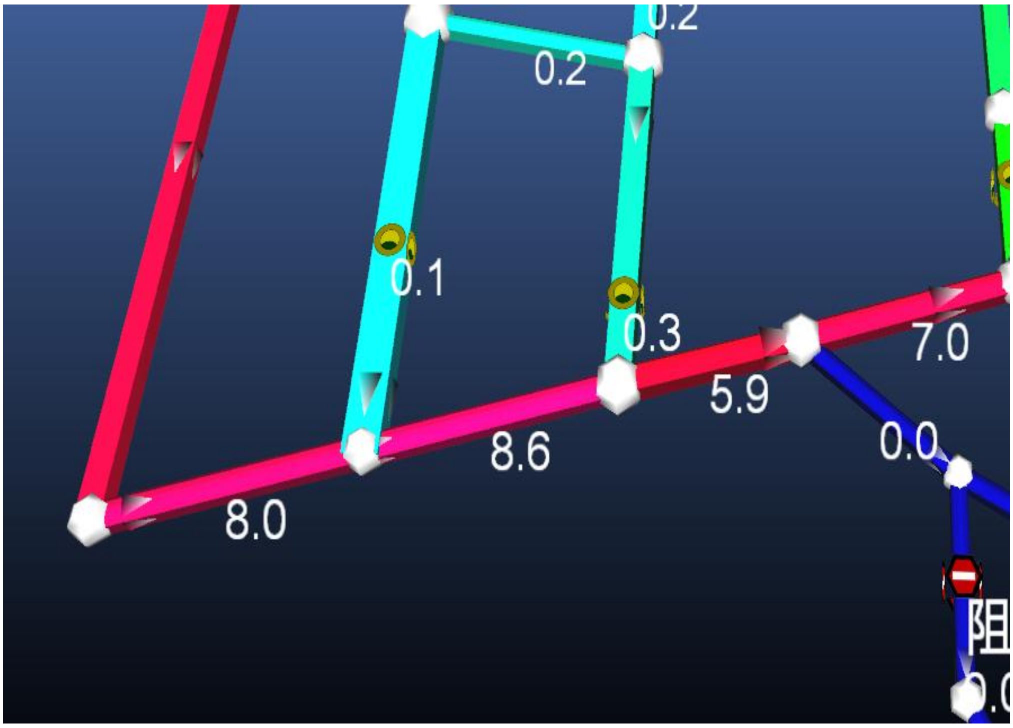

Figure 3: Schematic diagram of wind speed exceeding standard in concentrated return air roadway

3. Establishment and application of optimization model for roadway section

3.1. Establishment of roadway section optimization model

The network method is used to optimize the mine roadway section. Considering the sum of the direct cost, auxiliary cost, construction management fee, maintenance fee and ventilation electricity cost of the roadway is the optimal objective function. Using the overall static thinking, combined with the research status at home and abroad [18-20], the optimal well section must be technically, technically reasonable, and easy to construct, so that the comprehensive cost of tunneling, maintenance and ventilation is minimized. Therefore, the following model (4) was established.

Objective function:

$$\begin{aligned}\min f(S) = & \sum_{i=1}^{n} C_{Ji}(S_i)L_i k_{1i} + \sum_{i=1}^{n} C_{ui}(S_i)L_i k_{2i} + \\ & 1.15\sum_{p=1}^{n_f}\left\{\frac{1}{\eta_p}\left[\max_{j\in l_p}(\sum_{i=1}^{n} l_{ji}h_i)\right]\bullet q_p e k_{2p}\right\} + \\ & \sum_{p=1}^{n_f}\frac{8.76 r_{Lp}(P_{Lp}q_p)^3 e}{\eta_p}k_{2p}\end{aligned} \tag{4}$$

Restrictions:

$$\begin{aligned} & v_{i,\min} \le v_i \le v_{i,\max}, \quad i = 1,2,\cdots n_1 \\ & S_{i,\min} \le S_i \le S_{i,\max}, \quad i = 1,2,\cdots n_1 \\ & \max_{j\in l_p}\left\{\sum_{i=1}^{n} l_{ji}h_i\right\} \le H_P, \ i = 1,2,\cdots n_1 \end{aligned} \tag{5}$$

Where:

e –is the actual cost per kWh, yuan / (kW · h);

r_{Lp} - is the external wind leakage resistance value of the main ventilator of the p-stage of the mine, $N\cdot s^2/m^8$;

P_{Lp} -is the average external air leakage rate of the main ventilator of the mine in the service period, %;

n_f -is the number of wind shafts installed in the main ventilation system of the mine ventilation system, that is, the number of mine ventilation subsystems;

q_p -is the total return air volume of the p-subsystem, m^3/s;

n -is the number of network branches;

n_1 -is the number of branches of different lane sections to be optimized in the network;

S_i -ventilation net cross-sectional area, m^2;

$S_{i,\max}$ -is the maximum cross-sectional area that the air duct i may reach according to the driving construction factors, m^2;

$S_{i,\min}$ -is the minimum cross-sectional area of the air duct i according to the layout of the transport equipment, m^2;

H_p -is the maximum wind pressure limit allowed in the design and management of the pth subsystem, Pa;

l_{ji} -independent path matrix elements;

l_p -a set of independent paths in the pth subsystem;

h_i -is the i-th branch ventilation resistance value, Pa;

$v_{i,\max}, v_{i,\min}$ -is the maximum and minimum wind speed limit of the roadway specified in the "Safety Regulations for Coal Mines", m/s;

1.15 - A factor multiplied by the local ventilation resistance of the mine and the resistance value of the wind ventilation.

The first item in the objective function is the tunneling fee for the air duct in the ventilation network, the second item is the maintenance cost of the air duct, the third item is the ventilation electricity fee, and the fourth item is the ventilation electricity cost consumed by the air leakage outside the mine. The variable tolerance method is used in the calculation. In the process of searching towards the planning problem, the near-feasibility limit is gradually strengthened until the feasible sectional area S vector and the total system ventilation in the optimization model (4) in the limit case. The pressure is accepted.

3.2. Ventsim application in roadway section optimization

Taking the wind speed overrun of the concentrated return road in the Sucun coal mine as an example, according to the service period of the roadway for ten years, the relevant parameters in the roadway section optimization model (4) are set, see Table 2, and input into the Ventsim software. Using the economic simulation module in Ventsim software, the total cost of the selected wind path cycle (ventilation + tunneling) and the selected wind road section size relationship, the total cost of the ventilation network cycle (ventilation + mining) and the selected wind path are plotted. Cross-sectional size relationship diagram, relationship between air volume and selected wind path section size, network total air volume and selected wind path section size relationship.

Table 2: Economic optimization basic parameter list

Roadway support type	**width /m**	**High /m**	**Cost /\$/m**	**Total cost of mining/\$**	**Wind tunnel annual ventilation cost/\$**	**Fan cost /\$**	**Total cost of the wind cycle/\$**	**Wind path /m^3/min**	**Wind network annual ventilation cost/\$**	**Network fan purchase cost/\$**
Anchor spray	2.5	2.5	1625	288418	61074	10597	674286	3815	869648	198550
Anchor spray	3.0	3.0	1900	337227	28481	4942	517170	3911	861596	196711
Anchor spray	3.5	3.5	2225	394911	14560	2526	486901	3951	858310	195961
Anchor spray	4.0	4.0	2600	461469	8081	1402	512528	3969	856811	195619
Anchor spray	4.5	4.5	3025	536901	4801	833	567234	3978	856058	195447
Anchor spray	5.0	5.0	3500	621208	3015	523	640255	3983	855650	195354
Anchor spray	5.5	5.5	4025	714389	1981	344	726906	3986	855415	195300
Anchor spray	6.0	6.0	4600	816444	1352	235	824988	3988	855272	195268
Anchor spray	6.5	6.5	5225	927374	953	165	933394	3989	855181	195247
Anchor spray	7.0	7.0	5900	1047179	690	120	1051536	3989	855121	195233

From the above simulation analysis, it is known that when considering the total cost of the total return airway cycle wind path, after the concentrated return air main road is expanded to 3.5m×3.5m, the ventilation cost is the lowest; considering the total cost of the total return airway ventilation network : After the concentrated return airway is expanded to 3.5m×3.5m, the total ventilation cost starts to increase obviously; considering the air volume and the total return airway expansion section size: after the concentrated return airway is expanded to 3.5m×3.5m, the roadway The increase of air volume is not obvious; considering the total air volume of the mine and the size of the cross-section of the total return airway: after the concentrated return airway is expanded to 3.5m×3.5m, the total air volume increase of the mine is not obvious; considering the construction quality and other factors, the return air is concentrated. After the main road is expanded to the best economic section of 3.5m×3.5m, the total air volume of the mine increases by 258m^3/min, the negative pressure drops by 223Pa, the power decreases by 8.1KW, and the annual electricity cost is 32,000 yuan.

4. Conclusion

(1) Using the three-dimensional simulation model established by Ventsim, not only has a three-dimensional multi-window graphical interface, but also convenient and quick input and output of various ventilation parameters. In terms of compatibility, the DXF file of the domestic mainstream design software AutoCAD can be directly converted into the Ventsim ventilation network. Compared with other ventilation software, the model also has the functions of ventilation cost and ventilation network economic optimization analysis, pollutant dynamic simulation, real-time monitoring, ventilation inspection file, etc., and the reliability of optimized simulation data is higher.

(2) When optimizing the mine ventilation network, it is necessary to consider not only the indicators of safety, reliability, and resilience, but also the economic factors to enable the mine ventilation system to achieve and

maintain optimal operation conditions, not only to meet the mine ventilation requirements, but also to meet the mine ventilation requirements. To prevent "big horses," it is necessary not only to achieve "system is simple, safe and reliable", but also to reduce ventilation costs, energy saving and emission reduction.

(3) Taking the Sucun coal mine as an example, the simulation analysis shows that for the problem of excessive resistance in the return air section and excessive wind speed in the concentrated return airway, the optimal economic model after the expansion is determined by using the optimized model and using Ventsim software. It is 3.5m×3.5m. At this time, the total air volume of the mine increases by 258m^3/min, the negative pressure drops by 223Pa, and the power decreases by 8.1KW. The total cost is not increased in the service life, and the annual electricity saving fee is 32,000 yuan.

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