Paper No. 213

Application of an economy comparison model for mine cooling system technology

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ABSTRACT

The existing selection methods for mine cooling schemes are complex and have incomprehensive index values. In order to rectify this problem in the specific circumstance of high temperature mines, this paper puts forwad 13 index values, including the machine power, project investment, operation cost, etc. A comparative model of technical and economic benefit of mine cooling systems is established by using the objective entropy weight and TOPSIS method. Using objective entropy weight, the entropy weight of evaluation index and the weight decision matrix are determined. Using the TOPSIS method, the ideal solution and the negative ideal solution are determined. The optimal scheme can be determined by using the closeness degree calculation for the scheme sort. Optimization calculation and comparisons are carried out for four cooling schemes in a mine. Scheme 4 is found to be the optimal scheme for cooling systems.

KEYWORDS: Mine cooling; Technical and economy model; Scheme optimization

1. INTRODUCTION

With the increase of mining depth and the improvement of comprehensive mechanical mining capacity, high temperature heat damage has become one of the problems that seriously restricts the safe production of mines, and affects the economic benefit of the mine (Qi Yudong et al., 2014). Since the causes of high temperature mine heat damage are different, reasonable solutions should be chosen for each individual mine. Miao Sujun (2010) puts forward a mine cooling system scheme optimization method to aid in choosing a mine cooling scheme. Feng Xiaokai (2009) and Chen Xiaoyou (2013) have researched the economy of cooling projects, the economic benefit of coal mines, and constructed a mine cooling system cost economic evaluation method that focuses on mathematical analysis and scheme comparison. Zhang Hui (2009), Chen Jianmei (2009), Jian Congguang (2008), and Li Hongyang (2010) have optimized the economic and technological indexes of cooling systems and improved the mechanical cooling system evaluation method by comparing the economic costs in multiple dimensions. Of the above schemes, some are very complex, and need more experts to determine the weights. Therefore, it is necessary to build a mine cooling system technology and economic benefit model to improve the effectiveness and practicality of scheme selection.

2. ESTABLISHMENT OF MINE TECHANICAL AND ECONOMIC BENEFIT COMPARATIVE MODEL

In this paper, the mine cooling technical and economic benefit comparison model is based on the objective entropy weight and TOPSIS method. Firstly, target decision matrix are constructed, and normalized processing is carried out. Secondly, the entropy weight of the evaluation index is determined according to the objective entropy weight. The weighted decision matrix is constructed and the ideal solution and the negative ideal solution are determined. Finally, the feasible scheme is determined. The feasible scheme makes the distance between the scheme solution and the ideal solution the smallest, and the distance from the negative ideal solution the largest (Ma Zhipeng et al., 2009).

The decision rule of the scheme is found by comparing the actual feasible solution with the positive ideal solution and the negative ideal solution. The close degree between the scheme and the best scheme can be used as a basis for evaluation of the merits of each program (Yue Chaoyuan, 2003). This can be found by calculating the weighted Euclidean distance between a scheme, the best scheme, and the worst scheme. The calculation steps of the model are as follows:

1) Formation of decision matrix

The decision matrix is formed according to the actual situation of the high temperature mine and the machine-operating power and investment costs. In

the cooling schemes, the corresponding target decision matrix is established. Set multiple target decision scheme set as M= $(M_1, M_2, \ldots, M_m)$, the index set as C= $(C_1, C_2, \ldots, C_n)$, set the project M_j to the index C_i value as x_{ij} (i=1,2,…,m; j =1, 2,…,n), multi-objective decision matrix (A) is:

$$A = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ x_{31} & x_{32} & \cdots & x_{3n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Target decision matrix A is normalized and the normalized judgment matrix B is obtained:

$$b_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}} \quad (2)$$

The value b_{ij} is determined by the superior degree of running power and investment cost index. Specific performance is in the following two aspects:

$$b_{ij} = \frac{x(i, j) - x_{\min}(j)}{x_{\max}(j) - x_{\min}(i, j)} \quad (3)$$

Choice criterion: the bigger the better index

$$b_{ij} = \frac{x_{\max}(j) - x(i, j)}{x_{\max}(j) - x_{\min}(i, j)} \quad (4)$$

Choice criterion: the smaller the better index

Where b_{ij} is normalized value of characteristic value, $x_{\min}(j)$, $x_{\max}(j)$, the j evaluation indexes are the minimum and the maximum.

2) H_j determined by objective entropy weight

According to the definition of entropy, there are m schemes and n evaluation indexes. They can determine the evaluation index of entropy.

$$H_j = \frac{1}{-\ln m}(\sum_{i=1}^{m} f_{ij} \ln f_{ij}) \begin{pmatrix} i = 1,2,\square\cdot,m; \\ j = 1,2,\square\cdot,n \end{pmatrix} \quad (5)$$

In order to make $\ln f_{ij}$ meaningful, it is necessary to modify the f_{ij}. It is defined as:

$$f_{ij} \neq 0, \quad f_{ij} = b_{ij} \Big/ \sum_{i=1}^{m} b_{ij} \quad (6)$$

$$f_{ij} = 0, \quad f_{ij} = \frac{1 + b_{ij}}{\sum_{i=1}^{m}(1 + b_{ij})} \quad (7)$$

3）Establish entropy weight of evaluation index W

$$(8)$$

$$\omega_j = \frac{1 - H_j}{n - \sum_{j=1}^{n} H_j}, W = (\omega_j)_{1 \times n}, \sum_{j=1}^{n} \omega_j = 1$$

4) Constructing the weighted decision matrix

Multiplying the normalized judgment matrix and the weight of each index can obtain the weighted decision matrix:

$$R = (r_{i,j})_{m \times n}, \quad r_{ij} = w_j \cdot b_{ij}$$
$$(i=1, 2, \cdots, m; \quad j=1, 2, \cdots, n) \quad (9)$$

5) Determining the ideal solution and negative ideal solution

The ideal solution S^+ and the negative ideal solution S^- of each scheme can be determined from the weighted decision matrix. The selection of ideal solution and the negative ideal solution can be found via the selection condition of each index in the design scheme.

$$S_j^+ = \begin{cases} \max\{r_{ij}\}, (j = 1,2\ldots,n) \\ 1 \le i \le m \\ \min\{r_{ij}\}, (j = 1,2\ldots,n) \\ 1 \le i \le m \end{cases} \quad (10)$$

$$S_j^- = \begin{cases} \min\{r_{ij}\}, (j = 1,2\ldots,n) \\ 1 \le i \le m \\ \max\{r_{ij}\}, (j = 1,2\ldots,n) \\ 1 \le i \le m \end{cases} \quad (11)$$

6) Distance between the ideal solution and negative ideal solution

The ideal solution S^+ and the negative ideal solution S^- of each scheme can be determined from the weighted decision matrix. The selection of ideal solution and the negative ideal solution can be found via the selection condition of each index in the design scheme

$$S_{d_i}^+ = \sqrt{\sum_{j=1}^{n}(s_j^+ - r_{ij})^2} \quad (12)$$

$$S_{d_i}^- = \sqrt{\sum_{j=1}^{n}(s_j^- - r_{ij})^2} \quad (13)$$

In equations (12) and (13), i=1,2,…,m; j=1,2,…,n

7) Calculation of cooling system close degree and decision

According to the mathematical model, the relative closeness degree ξi can be calculated. Its value is between 0 and 1. The values close to 1 show that the evaluation objects will be closer to the optimal level.

$$U_i = \frac{S_{d_i}^-}{S_{d_i}^- + S_{d_i}^+} \qquad (14)$$

In equation (14), i=1,2,…,m

According to the size of value U_i , they can be sorted. The project will be better if the U_i is closer to the ideal solution.

3. APPLICATION OF TECHNICAL AND ECONOMIC BENEFIT COMPARISON MODEL IN MINE COOLING SYSTEMS

3.1 General Situation of Mine

The average geothermal gradient of a mine is 2.0° /100 m, namely, each 50 m increases by 1° . It belongs to the normal temperature gradient zone. Due to the complexity of the coal bearing strata lithology combination, the general geothermal gradient is higher than that of the non coal measure strata, with an average of 2.2° /100 m. The ground temperature of the recoverable coal seam belongs to the normal gradient (first and second grade high temperature zone), the upper coal seam mostly in the first high temperature zone, and the lower coal seam mostly in second grade high temperature zone. Initial mining was in 3 coal seams. In the north the ground temperature is low, and near the southeast of F2 and F3 is a high temperature zone, belonging to the second grade high temperature zone and the rest belonging to the first grade high-temperature zone.

The level of the mine is about -1000 meters. The inlet air volume is 1200 m³/min. The original rock temperature is 37° . Mechanical equipment in the working face installed capacity is larger. Underground heat damage is very serious in the summer and mechanical cooling should be used at that time.

3.2 Four cooling schemes for high temperature coal mines

According to the specific conditions of the mine, the four cooling schemes are ice cooling, centralization on the ground, centralization underground, dispersion underground and condensation heat centralization.

1) Ice cooling

Cold Source: low temperature water is made from a ground water chiller, transported to the ice making machine, and made into ice.

Cold transportation: ice through the wind is sent to the wellhead while cold water is sent to the underground ice melting pool through the insulation pipe. Melted ice is transported to the required cold place through a pipeline.

Scatter cold: in order to reduce the inlet air temperature of the working face, an air cooler is arranged on the intake airflow roadway. The method of spraying cool. water is used in the working face.

Condensation heat emission: heat is discharged via the cooling tower.

2) Centralization on the ground

Cold source: low temperature cold water is made on the ground by a refrigerator.

Cold transportation: low temperature cold water is sent to the underground high and low pressure heat exchanger through the insulation pipe along the shaft. It is exchanged into low pressure chilled water to the various required cold locations.

Scatter-cold: in order to reduce the inlet air temperature of the working face, the air cooler is arranged on the intake airflow roadway. Small air coolers are arranged on the working face.

Condensation heat emission: it is discharged on the ground through the cooling tower.

3) Centralization underground

Cold source: the cooling chamber can be built in the well and equipped with a refrigeration unit. Cold water is made from a refrigeration machine.

Cold transportation: chilled water is delivered to each required cold locations through insulation pipes.

Scatter cold: in order to reduce inlet air temperature of the working face, an air cooler is arranged on the intake airflow roadway. Small air coolers are arranged on the working face.

Condensation heat emission: it is discharged to the ground through the two pipes of the shaft.

4) Dispersion underground and condensation heat centralization

Cold source: a local refrigeration machine is used to produce the chilled water.

Cold transportation: chilled water is delivered to each required cold location through insulation pipe.

Scatter cold: a large air cooler is arranged on the intake airflow roadway. Mobile cooling is used on the working face.

Condensation heat emission: the cooling water of the refrigerating machine is transported to the bottom of the well through pipelines by a high and low pressure heat exchanger, Heat is discharged to the ground of the cooling tower through the shaft pipeline.

3.3 Comparison of mine cooling schemes

Using the above technical and economic benefit comparison model, the four schemes of mine cooling

and heat energy utilization are compared with 13 indexes, including the choice of power machine, engineering investment, annual operating cost, the length of transmission line, the cold loss ratio, comprehensive utilization of heat energy, the reliability of the system, pressure-bearing, heat emission, expansion capacity, load regulation performance and shaft bottom occupancy space, and the mining influence, as is shown in Table 1.

Table 1: Indexes of four design schemes.

Order number	Index	Index value				Remarks
		Scheme 1：ice cooling	Scheme 2：centralization on the ground	Scheme 3：centralized underground	Scheme 4：dispersion underground and condensation thermal centralization	
1	Installed power（KW）	2374	2250	2180	2140	S
2	Engineering investment (equipment cost, engineering investment)（Thousand yuan）	34700	32800	33500	31200	S
3	Annual operating cost（Thousand yuan）	3500	2800	3000	2600	S
4	Transmission line length（m）	20020	22300	22300	22300	S
5	Cold loss ratio	28%	24%	20%	10%	S
6	Comprehensive utilization of heat energy	3	3	3	7	H
7	System reliability	7	7	7	5	H
8	Pressure bearing property	3	7	7	5	S
9	Heat emission effect	7	7	7	7	H
10	Expansion capacity	5	3	3	7	H
11	Load regulation performance	3	5	5	7	H
12	Bottom space	7	3	5	3	S
13	Mining influence	1	1	1	3	S

In Table 1, S represents the smaller the better; H represents the higher the better.

From the technical and economic benefit model, it is easy to calculate the following values:

$$A = \begin{pmatrix} 2374 & 3470 & 350 & 20020 & 28\% & 3 & 7 & 3 & 7 & 5 & 3 & 7 & 1 \\ 2250 & 3280 & 280 & 22300 & 24\% & 3 & 7 & 7 & 7 & 3 & 5 & 3 & 1 \\ 2180 & 3350 & 300 & 22300 & 20\% & 3 & 7 & 7 & 7 & 3 & 5 & 5 & 1 \\ 2140 & 3120 & 260 & 22300 & 10\% & 7 & 5 & 5 & 7 & 7 & 7 & 3 & 3 \end{pmatrix}$$

$$b_{ij} = \frac{x_{ij} - x_{min}}{x_{max} - x_{min}} = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 0 & 0.5 & 0 & 0 & 1 \\ \frac{124}{234} & \frac{19}{35} & \frac{7}{9} & 0 & \frac{2}{9} & 0 & 1 & 0 & 0 & 0 & 0.5 & 1 & 1 \\ \frac{194}{234} & \frac{12}{35} & \frac{5}{9} & 0 & \frac{4}{9} & 0 & 1 & 0 & 0 & 0 & 0.5 & 0.5 & 1 \\ 1 & 1 & 1 & 0 & 1 & 1 & 0 & 0.5 & 0 & 1 & 1 & 1 & 0 \end{pmatrix}$$

$$H_j = \frac{1}{-\ln m}(\sum_{i=1}^{m} f_{ij} \ln f_{ij}) = (0.9793 \quad 0.9421 \quad 0.9828 \quad 0.6966 \quad 0.8900 \quad 0.6966 \quad 0.9930$$

$$0.9064 \quad 1 \quad 0.9064 \quad 0.9654 \quad 0.9687 \quad 0.9930)$$

$$0 \quad 0.0867 \quad 0.0320 \quad 0.0290 \quad 0.0065)$$

$$w_j = \frac{1 - H_j}{n - \sum_{j=1}^{n} H_j} = (0.0192 \quad 0.0536 \quad 0.0159 \quad 0.2810 \quad 0.1019 \quad 0.2810 \quad 0.0065 \quad 0.0867$$

$$r_{ij} = \begin{pmatrix} 0 & 0 & 0 & 0.2810 & 0 & 0 & 0.0065 \\ 0.0102 & 0.0291 & 0.0124 & 0 & 0.0226 & 0 & 0.0065 \\ 0.0159 & 0.0184 & 0.0088 & 0 & 0.0453 & 0 & 0.0065 \\ 0.0192 & 0.0536 & 0.0159 & 0 & 0.1019 & 0.2810 & 0 \end{pmatrix}$$

$$\begin{pmatrix} 0.0867 & 0 & 0.04335 & 0 & 0 & 0.0065 \\ 0 & 0 & 0 & 0.0160 & 0.0290 & 0.0065 \\ 0 & 0 & 0 & 0.0160 & 0.0145 & 0.0065 \\ 0.04335 & 0 & 0.0867 & 0.0320 & 0.0290 & 0 \end{pmatrix}$$

$$S_j^+ = (0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0.2810 \quad 0.0065 \quad 0 \quad 0 \quad 0.0867 \quad 0.032 \quad 0 \quad 0)$$

$$S_j^- = (0.0192 \quad 0.0536 \quad 0.0159 \quad 0.281 \quad 0.1019 \quad 0 \quad 0 \quad 0.0867 \quad 0 \quad 0 \quad 0 \quad 0.0290 \quad 0.0065)$$

Table 2: Analytic solutions of 4 schemes

Index value	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Ideal solution	0.41034	0.29871	0.29952	0.12896
Negative ideal solution	0.12896	0.30620	0.30247	0.41034
Closeness degree	0.23912	0.50619	0.50245	0.760875

The analytical solutions of the 4 schemes can be obtained from equations (8) to (12), as shown in Table 2.

As can be seen from Table 2：$U_1 < U_3 < U_2 < U_4$

The closeness degree of scheme 4 is the largest, so scheme 4 is optimal. Scheme 4 is chosen by the mine as the mine cooling project.

4. CONCLUSIONS

According to the specific conditions in heat damaged coal mines, 13 index values are determined. A simple and reliable comparison model of mine technical and economic benefits is put forward based on objective entropy weight and the TOPSIS method. The model can be used to optimize the mine cooling scheme.

The mine technical and economic benefit comparison model not only inherits the characteristics of multi-objective decision making, but also can easily and quickly select the best of the designed cooling schemes. The model is preferred to

avoid the serious problem of decision making mistakes.

Calculations and analyses are conducted on four cooling schemes for a high temperature mine and the optimal scheme is determined. The selection of the optimal scheme not only meets the requirements of coal mine safety regulations, but also reduces total investment and saves cooling costs for the mine, which verifies the feasibility and practicality of the model.

5. ACKNOWLEDGEMENT

6. REFERENCES

Chen Xiaoyou. (2013). Research on Cooling Technology And Economics in High Temperature Deep Well. Anhui University Of Science & Technology. pp. 63-70

Chen Jianmei, Zhang Hui, Jian Congguang. (2009). Research on economical operation of the cold-water mine cooling system. Mining & Processing Equipment. Volume 37,No. 24, pp.54-56

Feng Kai. (2009). The Research of the Cooling Technology in High-temperature Mine and Its Economic Analysis. Xi`an University of Science and Technology.pp.42-53

Jian Congguang, Wei Xiujun, Yue Jun. (2008). Ansys on economical operation of the ice refrigeration and air conditioning syetem. Mining Safety & Environmental Protection. Volume 35,No. 4, pp. 33-37

Li Hongyang. (2010). Technical and economic analysis of mine cooling system .Safety in Coal Mines. No. 3, pp. 93-96

Miao Sujun, Xin Song, Peng Peng. (2010). Research and application optimization and decision theory of mine cooling system. Journal of China Coal Society.Volume 35, No. 4, pp. 614-618

Ma Zhipeng, Yuan Jianguo ,Shi Yunyun. (2009). Grey Decision Model for Flood Control of Cascade Reservoirs Based on Stochastic Weight Assignment method. Water Resources and Power,Volume 27, No. 1, pp. 77-80

Qi Yudong, Cheng Weimin, Yu Yanbin. (2014). Status Summarization and Progress of Heat Hazard Control Technology in Coal Mine of China. Safety in Coal Mines. Volume 45, No. 3, pp. 167-174

Yue Chaoyuan. (2003). Decision theory and method . Science Press, 2003

Zhang Hui, Jian Congguang, Zhang Bo. (2009). Econcmical performance of ice refrigeration and air conditioning system in high temperature mine. Journal of Xi'an University of Science and Technology. Volume 29, No. 2, pp. 150-152