Safety Science 50 (2012) 705–708

Contents lists available at SciVerse ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Special Issue Article: The First International Symposium on Mine Safety Science and Engineering

Adequate air volume in working face after mechanical refrigeration ☆

Miao De-jun [a,b,*], Sui Xiu-hua [c], Zhang Sheng-zhu [d]

[a] *Key Laboratory of Mine Hazard Prevention and Control of China Ministry of Education, Shandong University of Science and Technology, Qingdao 266510, China*
[b] *School of Architecture, Tsinghua University, Beijing 100084, China*
[c] *College of Mechanical and Electronic Engineering, Shandong University of Science and Technology, Qingdao 266510, China*
[d] *China University of Mining and Technology, Beijing 100083, China*

ARTICLE INFO

Article history:
Available online 16 September 2011

Keywords:
Mine cooling
Required air volume
Cost
Ansys simulation

ABSTRACT

By analyzing the coal mine working face ventilation and cooling cost after mechanical method is adopted for temperature decrease, the relationship between air volume and ventilation cooling cost was established. And through mathematical analysis and specific applications of the model, the reasonable air volume is determined. With respect to the actual conditions of a coal mine, the air volume is figured out. In order to verify the correctness of the air volume by the new method, the Ansys model of ventilation cooling for the working face is established, and the effect of cooling under the air volume is simulated. The simulation results can meet the mine cooling requirement after being applied in coal mine, the cooling effect and the economic benefit are satisfactory.

1. Introduction

With the increase of mining depth and fully mechanized mining capacity, more and more mines operate in high temperature and are confronted with heat disaster problems. In order to address these problems, some mines achieve cooling by mechanical refrigeration.

For high temperature working face, the required air volume is not the same before and after mechanical cooling is adopted. Before mechanical cooling, the working face will require increased air volume constantly to ensure the requirements of work environment because external environment temperature rises constantly. However, the required air volume will be greatly reduced after adopting mechanical cooling, so the reasonable air volume needs to be determined. The existing method for determining required air volume mainly depends on the necessity of working face cooling (Cheng and Wan, 1992; Wang et al., 1995; Bluhm et al., 1998; Funnell and Sheer, 2001). There are only a few researches on how to determine the required air volume from the perspective of economics and meeting the cooling requirements after adopting the mechanical cooling. This paper mainly researches the reasonable air volume after the mechanical cooling is adopted in high temperature working face.

2. Determining required air volume after high temperature working face being cooled by machine

The existing required air volume calculation for working face is based on "Detailed Rules for Required Air Volume Calculation in Mines". The required air volume calculation of a working face is as follows

$$Q_F = 60 \times V \times S \times K$$

The value V is taken from Table 1, and the value K is taken from Table 2.

The actual required air volume is determined by such parameters as gas, carbon dioxide emission, working face temperature, wind speed, number of people, which take their maximum values.

The existing required air volume is calculated by an empirical formula, which often tends to get a larger air volume. If cooling with the air volume, it would have needed a larger cooling capacity. Actually, the required air volume in working face is determined by maintaining return air temperature below allowed highest temperature, and the wind speed ensuring the essential labor condition. The required air volume after mechanical cooling is

---

☆ The First International Symposium on Mine Safety Science and Engineering (ISMSSE2011) will be held in Beijing on October 26–29, 2011. The symposium is authorized by the State Administration of Work Safety and is sponsored by China Academy of Safety Science & Technology (CASST), China University of Mining & Technology (Beijing) (CUMTB), Datong Coal Mine Group, McGill University (Canada) and University of Wollongong (Australia) with participation from several other universities from round the world, research institutes, professional associations and large enterprises. The topics will focus on mines safety field: theory on mine safety science and engineering technology, coal mine safety science & engineering technology, metal and nonmetal mines safety science & engineering technology, petroleum and natural gas exploitation safety science & engineering technology, mine safety management and safety standardization science & technology, occupational health and safety in mine, emergent rescue engineering technology in mine, etc.

* Corresponding author at: Key Laboratory of Mine Hazard Prevention and Control of China Ministry of Education, Shandong University of Science and Technology, Qingdao 266510, China. Tel./fax: +86 053286057953.

E-mail address: junmdxh@163.com (D.-j. Miao).

0925-7535/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ssci.2011.08.048

Nomenclature

V	appropriate wind speeds in working face, m/s
S	working face effective average ventilation section area (according to the average value of maximum and minimum roof control distance), m^2
K	length adjustment coefficient of working face
C_Z	cooling total cost, yuan
Q_J	required cooling quantity when meeting the allowing inlet air temperature, kW/s
C_J	required expenses of providing the 1 kW cooling quantity, yuan/kW
Q_F	required air volume of working face, m^3/s
C_F	cost of 1 m^3 air volume, yuan/m^3
M	inlet air volume, kg
t	inlet air temperature, °C
t_1	inlet air temperature allowed by the working face, °C
t_2	return air temperature allowed by the working face, °C
t_{gu}	original and average rock temperature, °C
ρ	air density, kg/m^3
φ	relative humidity
U	perimeter of cross-section, m
F	area of cross section, m^2
K_r	unstable heat transfer coefficient between surrounding rock and air flow, W/(m^2 °C)
C_m	specific heat of coal or gangue, kJ/(kg °C)
C_P	air constant pressure quality specific heat, 1.01 kJ/(kg °C)
B	atmospheric pressure, Pa
B, ε', P_m	constant coefficient determined by wind temperature
γ	water gasification latent heat, kJ/kg
T	coal production, t
$\sum Q_M$	sum of heat that release by all sorts of absolute heat source, kW
P_s	saturated vapor pressure, Pa
R	number of people who work in the working face, people
Q_{JI}	installed capacity of the working face, kW

determined not only by ventilation demand but also by the cooling cost, so the reasonable air volume meets demand and the least cooling cost.

$$C_Z = Q_J C_J + Q_F C_F \tag{1}$$

$$\begin{aligned} Q_J &= MC_P dt + Mrdx = MC_P dt + MA\varphi rdt \\ &= Q_F(t - t_1)(\rho C_P + \rho A\varphi r) \end{aligned} \tag{2}$$

Allowable inlet air temperature in working face can be calculated as follows (Sherl Barney, 1982)

$$t_1 = t_2 \exp\left(\frac{N}{1+E\varphi}\right) + \left[1 - \exp\left(\frac{N}{1+E\varphi}\right)\right]\left(t_{gu} + \frac{F}{N}\right)$$

where $F = \frac{\sum Q_M - 1.46\times10^{-4} C_m TL^{0.8}}{MC_P} - E\Delta\varphi\varepsilon'$, $N = \frac{K_r UL + 4.17\times10^{-5} C_m TL^{0.8}}{MC_P}$,

$E = 2.4867A$, $A = 622\frac{b}{B-P_m}$.

Let $A' = K_r UL + 4.17 \times 10^{-5} C_m TL^{0.8}$, $B' = \frac{A'}{\rho C_P(1+E\varphi)}$

$$t_1 = t_{gu} + \frac{F}{N} - \left(t_{gu} + \frac{F}{N} - t_2\right)\exp\frac{B'}{Q_F} \tag{3}$$

Take Formula (3) into Formula (2), and Formula (2) into Formula (1), then

$$C_Z = Q_F\left\{(\rho C_P + \rho A\varphi r)\left[t - t_{gu} - \frac{F}{N} + \left(t_{gu} + \frac{F}{N} - t_2\right)\exp\frac{B'}{Q_F}\right]C_J + C_F\right\} \tag{4}$$

Based on mathematical analysis, the relationship between C_Z and Q_F is shown in Figs. 1–3.$Q_{\min A}$ stands for the minimum air volume that must be satisfied with diluting gas, mine dust, and so on; $Q_{\max A}$ stands for the maximum air volume that must be satisfied with diluting gas, mine dust, and so on.

Table 1
Corresponding table between temperature and wind speed in working face.

Air temperature in working face (°C)	Wind speed in working face (m/s)
15–18	0.8
18–20	0.8–1.0
20–23	1.0–1.3
23–26	1.3–1.6
26–28	1.6–2.0
>28	2.0–2.5

Note: The working face air temperature should be determined in the air in the center of conveyor, and 15 m apart from the return airway.

Table 2
Length adjustment coefficient of working face.

Length of working face (m)	<50	50–100	100–160	160–200	200–260	260–300	>300
K	0.8	0.9	1.0	1.1	1.2	1.3	1.4

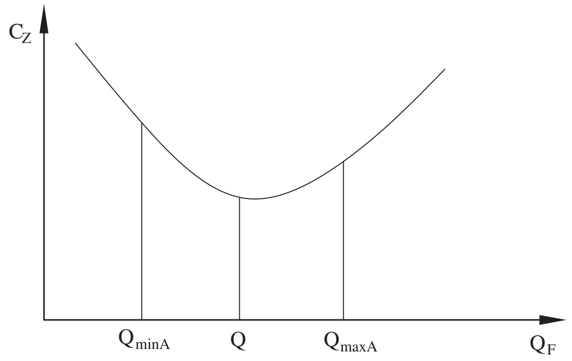


Fig. 1. Relationship between C_Z and Q_F.

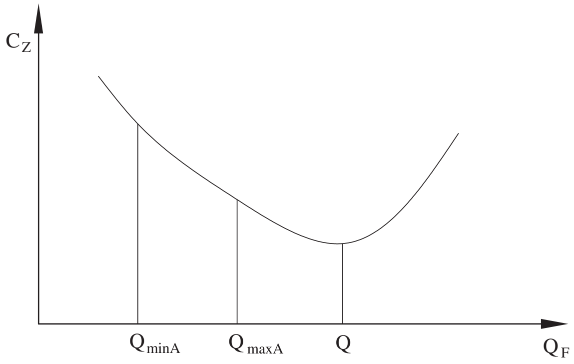


Fig. 2. Relationship between C_Z and Q_F.

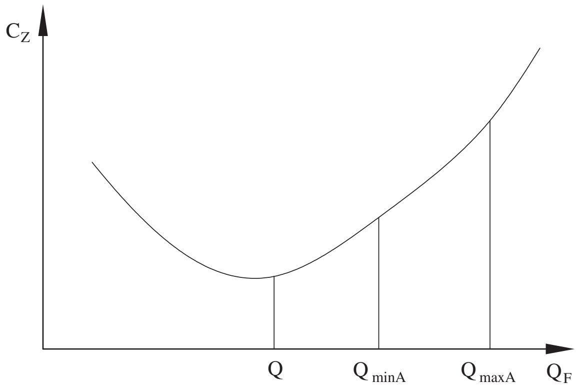


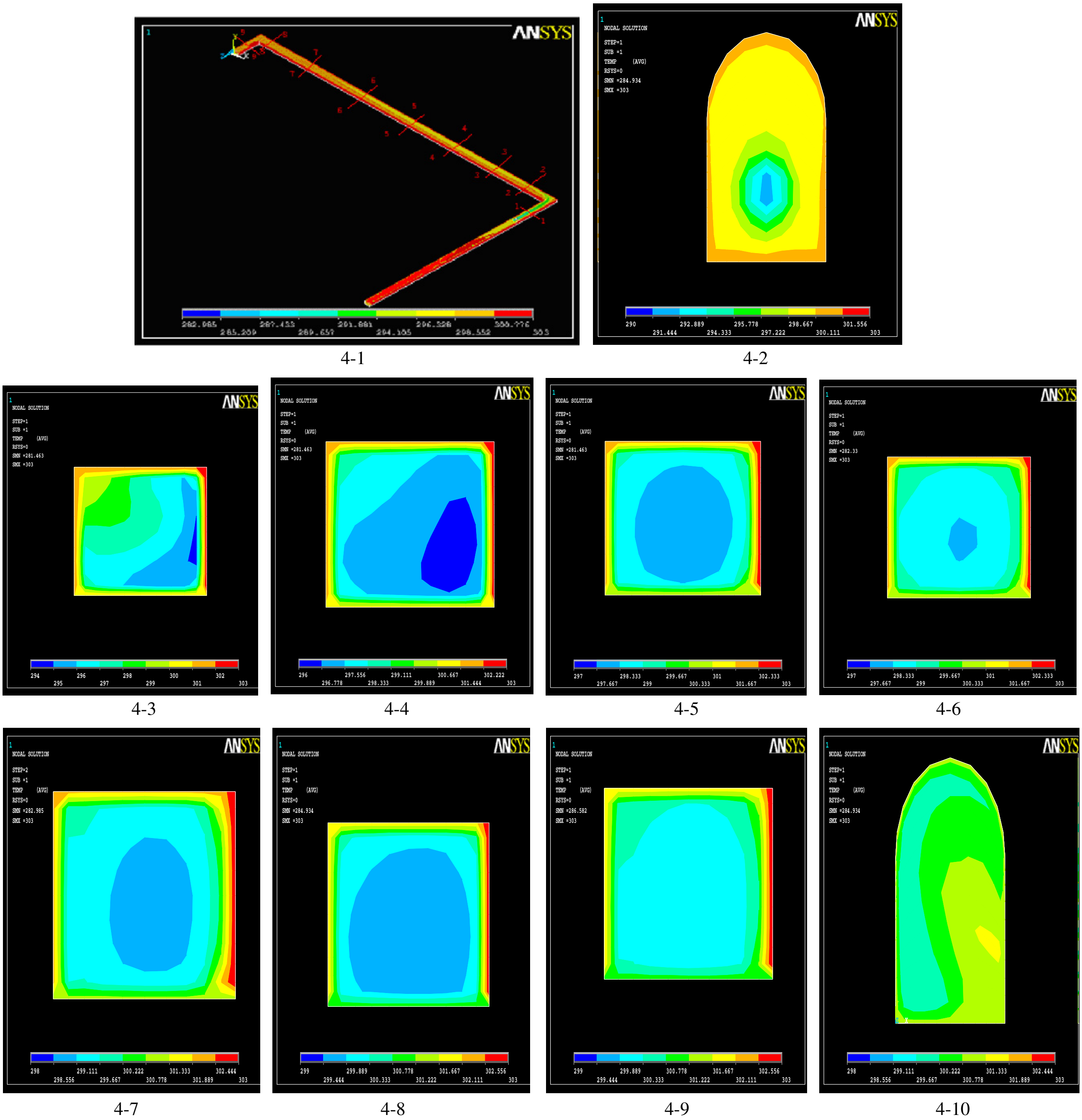
Fig. 3. Relationship between C_Z and Q_F.

Table 3
Correlation parameter of 1302 working face.

Parameter	Value	Parameter	Value	Parameter	Value
ρ	1.13 kg/m^3	C_P	1.01 kJ/kg °C	P_s	42.44×10^{-2} Pa
φ	90%	B	114.34 kPa	t	27.9 °C
t_{gu}	37 °C	t_2	27.5 °C	L	200 m
F	14.9 m^2	U	15.5 m	K_r	5.01×10^{-3} kW/m^2 K
R	25 persons	Q_{JI}	720 kW	T	1200t
C_m	0.84 kJ/kg °C	C_J	1.4 yuan/kW	C_F	0.103 yuan/kW

Table 4
Temperature of each observation point by simulation.

Observation point	1	2	3	4	5	6	7	8	9
Temperature	23.0	23.3	24.1	24.7	25.2	26.0	26.6	27.0	27.3



4-1 4-2

4-3 4-4 4-5 4-6

4-7 4-8 4-9 4-10

Fig. 4. Simulation results.

Table 5
Actual measured temperature of each observation point when the air cooler runs.

Observation point	1	2	3	4	5	6	7	8	9
Temperature	23.0	23.4	24.3	24.9	25.6	26.4	26.9	27.3	27.5

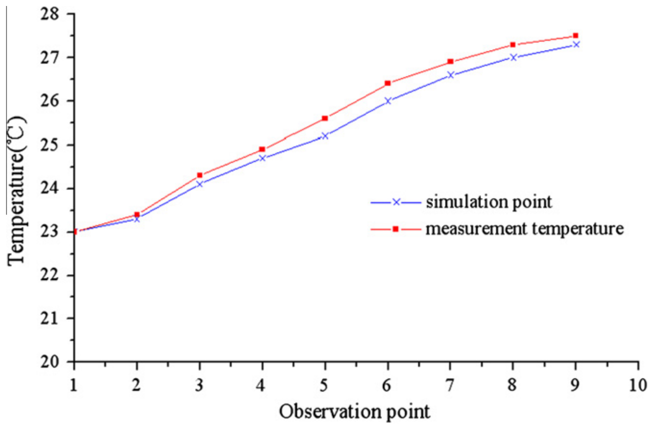


Fig. 5. Temperature comparison diagram between simulation and measurement.

From Fig. 1, it can be concluded that C_Z gets the minimum value at $Q_F = Q$ when $Q_{\min A} < Q_F < Q_{\max A}$. The minimum value can be obtained in Formula (4) by derivation.

From Fig. 2, it can be concluded C_Z gets the minimum value at $Q_F = Q_{\max A}$ when $Q_F > Q_{\max A}$.

From Fig. 3, it can be concluded that C_Z gets the minimum value at $Q_F = Q_{\min A}$ when $Q_F < Q_{\min A}$.

3. Determining required air volume in working face after adopting mechanical cooling in one coal mine

By measuring the related parameters of 1302 working face, the values of parameters are shown in Table 3 (Miao, 2008):

By existing calculation method, $Q_F = 60 \times V \times S \times K = 60 \times 1.6 \times 14.9 \times 1.1 = 1573\ \text{m}^3/\text{min}$.

Taking into consideration the gas, carbon dioxide emission, working face temperature, wind speed, number of people, and so on, the maximum value is 1573 m^3/min.

Because the calculation by Formula (4) is more complex, the computer program is developed to calculate. The result is 1125 m^3/min.

Taking into account the gas, carbon dioxide emission, working face temperature, wind speed, number of people, and so on, the required air volume of 1302 working face is 1125 m^3/min, which is based on the cooling costs and ventilation demand.

4. Ansys simulation and field data test

After adopting mechanical cooling, the required air volume which is based on the cooling cost is 1125 m^3/min and the inlet air temperature is 27.9 °C. In order to understand its cooling effect, it is simulated by Ansys with the above parameters (Tan, 2002). The simulation results are showed in Table 4 and Fig. 4.

The parameter values of airflow in 1302 working face were tested in order to verify the accuracy of theoretical results. The measuring result is showed in Table 5. (Measuring point is near the front column of hydraulic support, apart from goaf about 0.5–1.1 m, 1.3 m high, which is the place where the workers work. Along the working face, one point is placed 25 m apart from the inlet way, the other point is 25 m apart from the return airway. In the middle area, seven points are arranged every 30 m.)

It can be seen from Fig. 4 that in the cross section of the working face, the temperature in surrounding is high, and that in the middle area is low. Fig. 5 indicates that the value of actual measured data is larger than that of the simulation results. However, the error is less than 2%. This can well guide the cooling of the working face.

5. Conclusions

(1) By analyzing the existing calculation method of the working face's required air volume, a new method used to calculate required air volume is put forward based on the ventilation and cooling cost after adopting the mechanical cooling.
(2) The new method has been applied to the 1302 working face. Numerical simulation and field measurement prove that the new air volume calculation method is reasonable.
(3) Comparison of the result by the proposed method with the existing method indicates that the new calculation method after adopting the mechanical cooling has significantly reduced the required air volume by about 448 m^3/min in1302 working face and decreased the ventilation volume and cooling cost.
(4) The Ansys model of the high temperature working face is established. With it, the cooling effect of the 1302 working face is simulated. The difference between the simulation data and field data is less than 2%. The model can be used to guide the mine cooling engineering.

References

Bluhm, S.J., Biffi, M., Wilson, R., 1998. Optimized cooling systems for mining at extreme depths. In: Proceedings of CIM/CMMI/MIGA conference, Canadian Institute of Mining and Metallurgy, Montreal, Canada.

Cheng, Weimin, Wan, Longpping, 1992. Optimal coordination between working face ventilation and cooling air. Shandong Mining College Journal (3), 28–33 (in Chinese).

Funnell, R.C., Sheer, T.J., 2001. Optimisation of cooling resources in deep stopes. In: Proceedings of Seventh International Mine Ventilation Congress, Cracow, Poland.

Miao, Dejun, 2008. Study of thermal safety index and optimization between required air quantity and cooling quantity in working face in high temperature coal mine. Shandong University of Science and Technology (in Chinese).

Sherl Barney, A.H., 1982. Mine Cooling, Guidelines. China Coal Industry Publishing House, Beijing (in Chinese).

Tan, Jianguo, 2002. Finite element analysis with Ansys 6.0. Peking University Press, Beijing, pp. 1–13 (in Chinese).

Wang, Jianxue, Guo, Jinyun, Guo, Xinhe, et al., 1995. Study on the relationship between supply air volume and cooling capacity in high temperature working face. Safety in Coal Mines (5), 32–34, in Chinese.