Study and practice of the controlling technique on heat-harm during the tunneling in Zhaolou mine

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Abstract: This paper proposes the cooling system type and cooling equipment type which are deep mine with high temperature during the construction, and presents auxiliary cooling measures making up duct temperature rise since compression and heat transfer temperature rise. The cooling system designed against Zhaolou mine's ground temperature and weather conditions, with its sprinkler room handling an average temperature difference up to 19.5 ~ 23.8 ℃, and the average enthalpy difference could reach 48.4 ~ 60.7 kJ/kg. At the same time, it gets a series of basic data used for mine construction during the cooling system design and equipment selection according to the measured results; using the analysis software Matlab, it obtains the change relations between the temperature of sprinkler room and fan export supply air temperature, wind casing temperature rise and fan export supply air temperature, working face temperature and supply air temperature, used for the mine cooling which has the similar conditions.

Key words: deep mine with high temperature; mine development tunneling; cooling

1 The profiles of mine's rock temperature and work space temperature

The Heze Energy and Chemical Company Limited of Yanzhou Coal, the thickness of topsoil of the Zhaolou mine is about 400 ~ 750 m. It mainly exploits No.3 (3_{top}) coal bed. Some of the coal early exploited is buried at 900 m, the level of the bottom yard is 905 m. The average geothermal gradient is 2.02 ℃ per 100 m, and the average geothermal gradient of non-coal strata is 2.76 ℃ per 100 m. Most of the original rock block's ground of the initial mining area and the gushing water temperature is 37 ~ 45 ℃.

When the Zhaolou mine's main well reaches 890 m in depth, the local air temperature is 30 ℃, side-wall's spraying water temperature is 43 ℃. The air volume reached at work space is about 450 m^3/min, the actual measured heading temperature of tunneling work space is 38 ℃. Shaft sinking platform space temperature of low-story is 34 ℃, the middle-story's is 36 ℃, and the top's is 37 ℃.

2 The cooling parameters of tunneling work space of Zhaolou mine's shaft and main roadway

According to Zhaolou mine's rock temperature conditions and the local climate conditions, the parameters of the entered the cooling device are: dry-bulb temperature is 35 ℃, relative humidity is 80 %. The design air parameters of the tunneling work space's are: dry-bulb temperature is 28 ℃, relative humidity is 90 %; the amount of the handled air is 3 500 m^3/min.

By calculation, the cooling system installing cooling load during Zhaolou mine well's construction and the preparatory stage before reclamation: 6 700 kW.

3 The selection of the cooling system program and cooling device during the well's construction

3.1 Scheme determination of cooling system

Wide view the mine cooling technology used at home and abroad, it can be classified into increasing air volume cooling technology, artificial refrigerating water cooling technology and artificial ice making cool-

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ing technology.

Increasing air volume is an easy cooling method, but its temperature drop range is limited and it is influenced by the inlet air temperature and the surrounding-rock temperature. The Academician A. H. Serban of former Soviet Union Ukraine Academy of Sciences, Japanese doctor Pinsonliangxion and professor Foose in aide academe of the former West Germany proposed the model of the airflow temperature in mine prediction, which can reflect the trend with the use of increasing air cooling, and it proves that increasing air is useful to cooling in theory[1-3]. Also, it was proved it had a good effect with many field experiments, it can cool down the work space with 1 ~ 4 ℃[1,4,5].

Although, increasing air has no effect on the cooling when the surrounding-rock temperature reaches a height in a sense. Mei Fuding in WuHan Coal Design Institute got the message with the comparison between horizontal rock temperature and the work space air temperature: it has no effect to cooling when the horizontal rock temperature reaches 35 ℃[6]. Federal Republic of Germany scholars once discussed the relation between the effective temperature of coal face and the rock temperature by use of U-type ventilation, and they got: it can't use the measure of increasing air when the rock temperature reaches 40 ℃[6]. M. J. Miferxun who come from south Africa also have the thought, it must reduce the air ventilation, and increase the air cooling degree when the original rock temperature is over 40 ℃[6].

The type of artificial refrigerating water cooling is mainly by means of using evaporative type chiller to prepare frozen water (3 ~ 7 ℃) that can cool the underground airflow. The artificial refrigerating water cooling technology was already on the rise when it is 1930s, it had a rapid development in 1970s, and it became the main mine cooling method. This mine cooling method has some main forms: underground centralized type, ground centralized type, underground combined with ground centralized type and dispersed type; but these are mainly used to production mine, hardly used to the mine construction.

The differences between ice cooling and water cooling: a. ice cooling system mainly makes use of the ice melting latent heat, when it comes the same cooling capacity, the ice capacity is just as 1/4 ~ 1/5 times as the water capacity that the water cooling system needs. b. ice cooling system uses ice to contact with water directly, which can get cold water about 1 ℃[4]. But the ice generator's efficiency is worse than water chiller's and it needs more equipment, larger volume and greater investment.

Zhaolou mine is a newly built mine and it is the very moment to exploit the shaft and large roadway. Its cooling system has the characteristics that it is temporary and short-time using. It proposes 4 kinds of possible cooling scheme with the field practical conditions[1,7,8]: wind increase with evaporative cooling program; using existed freeze well-side's ammonia refrigeration plant program; using cold water chilling unit; using ice for cooling. After a detailed technical and economic comparison, it selects the program of using existed freeze well's ammonia refrigeration plant. This system has the outstanding advantages: small newly added investment, saving much time of manufacturing refrigeration equipments and supplying goods, short installing cycle.

This cooling program mainly contains ammonia refrigeration compressor, plate-type heat exchanger, freeze pump and terminal cooling equipment. Ammonia refrigeration compressor and evaporative compressor use the existed freeze well's cooling equipment, which saves lots of system initial investment. This chilled water system can supply chilled water for the cooling equipment, the lowest temperature is 3 ℃.

3.2 The choice of cooling equipments of air treatment terminal

Air treatment terminal used in mine—air cooler is mainly classified into two kinds: surface-type and direct-contact type (spraying water chamber). The surface-type cooler is compact, with a small volume, good adaptability and it can use in every kinds of sites; but the surface-type cooler has a worse efficiency than the spraying water chamber, it needs lower water when they get the same air terminal parameter; the resistance when airflow through it is much greater than it happens in the spraying water chamber. The airflow resistance in the spraying water chamber is mainly decided by the resistance in the pre- and post-eliminator, about 120 Pa, but airflow resistance in the surface-type cooler with 8 rows is over 270 Pa, and the resistance will double increase if they are used in series[9]. Make an exception, the spraying water has the advantage of purifying airflow, it will not be affected by the surrounding environment.

According to the practice conditions and the local weather conditions while Zhaolou mine's construction, the design can deal with large air volume, large enthalpy drop and temperature drop. It should several coolers series use or parallel use if use the surface-type air cooler; and it is heavy, water pipes with complex connection, with high resistance of airflow (about 1 000 Pa). Finally, because the cooling equipment just should be laid on the ground and the cold air should be long-range transported, it chooses the spraying water chamber to deal with the airflow. The cooling system is showed in Fig. 1.

4 The selection of auxiliary cooling measures

As the limitation of the specific conditions during the construction of the mine, the sprinkler room will be installed on the ground near the well's top. The cold air at low temperature handled by sprinkler room supplied to the underground tunneling head along the wind tube connected with the fan, with long distance, there is self-compression temperature rise and heat transfer temperature rise between wind tube internal and external along the way. It decides to adopt the auxiliary cooling measures, which ensure the cooling effect of work space. It proposes two kinds of auxiliary cooling measures: the first one, install evaporative cooling equipment in a certain position in pre-export of the wind tube[10], lowering the wind tube export supply air temperature again; the second one, load with surface-cooling equipment again in the vicinity of wind tube. Evaporative cooling auxiliary cooling measure is using the normal temperature water or underground water to spray to the airflow of the wind-tube export, water evaporating and then it is endothermic, reduce the airflow temperature much more. This measure has a small resistance to the airflow, it needn't frozen water, easily operating. If use the additional surface cooling equipment, it should be supplied low temperature frozen water, hard to realize and it is going with high airflow resistance. So it decides to use the first auxiliary cooling measure.

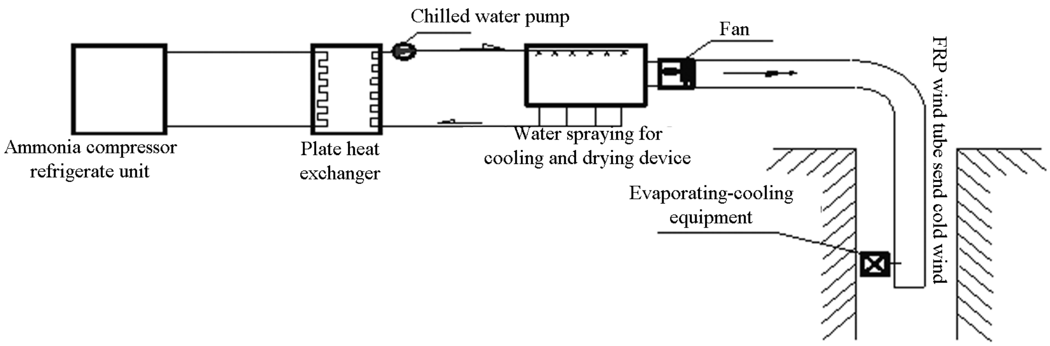

Fig. 1 Schematic of cooling system for shaft tunneling face of Zhaolou coal mine

5 The test and summary of the cooling system's cooling effect

5.1 Measuring instrument

VelociCalcPLUS series multiparameter airing instrument, temperature accuracy ±0.1 ℃, wind velocity accuracy ±0.01 m/s, standard mercury thermometer, accuracy ±0.01 ℃, alcohol thermometer, accuracy ±0.1 ℃, fan psychromerter, accuracy ±0.1 ℃ alcohol psychrometer, accuracy ±0.1 ℃.

5.2 Summing up cooling effect

5.2.1 The basic situation of tunneling work face of each well tube serviced by the sprinkler room

No. 1 sprinkler room services the auxiliary shaft, driving about 740 m in depth, send cold wind to tornado fan with 2 ×22 kW, wide-open two stages, using 800 mm diameter wind tube made of FRP above well tube over 600 m, and using 800 mm diameter wind tube made of canvas near the work face, well-side with serious spraying water.

No. 2 sprinkler room services the tunneling work face of east tunnel of main shaft's bottom roadway, which drives about 50 m, the main shaft is 905 m in depth, the roadway is dry, no spraying water. Send cold wind to tornado fan with 2 ×30 kW, just open one stage, using 800 mm diameter wind tube made of canvas.

No. 3 sprinkler room services the tunneling work face of west tunnel of main shaft's bottom roadway, which drives about 10 m. As it meets confined water, the work face stop working; roadway is dry, no spraying water. Send cold wind to tornado fan with 2 ×45 kW, just open one stage, using 800 mm diameter wind tube made of canvas.

No. 4 sprinkler room services the tunneling of the wind well, driving 880 m in depth, well-side with serious spraying water. Send cold wind to tornado fan with 2 ×45 kW, wide-open two stages, using 800 mm diameter wind tube made of canvas.

5.2.2 Summing up cooling effect

1) The sprinkler room handling an average temperature difference up to 19.5 ~23.8 ℃, and the aver-

age enthalpy difference could reach 48.4 ~ 60.7 kJ/kg.

Table 1 The temperature drop, enthalpy drop case of each sprinkler room

Sprinkler room number	1#	2#	3#	4#
The average temperature of spraying water /℃	6.7	7.1	8.0	7.1
Temperature drop/℃	22.1	19.8	19.5	3.8
Enthalpy drop/($kJ \cdot kg^{-1}$)	59.7	51.0	48.4	60.7

2) The airflow temperature of the export of work face and wind tube, the airflow temperature of the import and export of the fan, which of these basically aren't effected by the change of ground air temperature.

3) The change of spraying water temperature has a rather great impact to the temperature of the import and export of the fan, with small effect on the temperature of the wind tube's export and work space, but the change trend basically matches with the change of water temperature

4) The average temperature rise of fan is about 3.1 ~5.3 ℃. The No.1 sprinkler room's temperature rise of fan is about 2.0 ~ 4.0 ℃, the average is 3.1 ℃; the No.2 sprinkler room's temperature rise of fan is about 3.6 ~4.7 ℃, the average is 3.6 ℃; the No.3 sprinkler room's temperature rise of fan is about 3.3 ~7.7 ℃, the average is 5.1 ℃; the No.4 sprinkler room's temperature rise of fan is about 4.0 ~ 7.0 ℃, the average is 5.3 ℃.

5) The average temperature rise per 100 m of the wind tube is about 1.3 ~1.7 ℃, average heat transfer temperature rise per 100 m is about 0.4 ~0.81 ℃.

Table 2 The wind casing temperature rise case of the supply air of each sprinkler room ℃

Sprinkler room number	1#	2#	3#	4#
Comprehensive average temperature rise	11.2	17.1	15.0	11.6
Temperature rise per 100 m	1.4	1.7	1.6	1.3
Average heat transfer temperature rise	4.2	8.1	6	3.6
Average heat transfer temperature rise per 100 m	0.53	0.81	0.63	0.4

6) The air humidity of the wind tube export and work space is affected by the spraying water of well-side or tunnel.

The No. 1 and No. 4 sprinkler room's service well-side have great spraying water. The wind tube dry-bulb temperature closes to the wet-bulb temperature, and the air humidity comes close to saturation.

The east and west yard tunnels serviced by No.2, No.3 sprinkler room are dry; the wind flow of wind tube export and work space is dry. The average is 41.6 %; it's generally about 50 % ~55 % at the work space, the average is 51.6 %. The measured dry-bulb temperature is rather high, but the staff do not feel very hot. The relative humidity of No.3 wind tube export is 68.8 % ~82.2 %, the average is 73.7 %. The cause of getting high humidity of the export wind possibly is that the well-side spraying water enters into the wind tube.

6 The regression analysis of determination parameters

To sum up the regularity of the cooling during the well tube tunneling, obtain the related basic data of the well tube cooling, get more precise quantitative numerical relation among the relevant operating parameters of the cooling system, the analysis software Matlab is used to analyze the measurement results of relevant parameters with statistical regression, which is used for the mine cooling which has the similar conditions.

6.1 The relationship between the water temperature of the sprinkler room and supply wind temperature of fan export

With regression analysis, the fan export temperature almost linear change with spraying water temperature. The fan export temperature linear increases with the spraying water rise. The regression function:

$$T_{SF} = 0.92T_{PS} + 5.9 \quad (1)$$

T_{SF}, fan export air temperature, ℃; T_{PS}, sprinkler room spraying water temperature, ℃.

6.2 The relationship between wind duct temperature rise and fan export supply wind temperature

It exists temperature rise when the cold air is sent to the well bottom along the wind tube. This temperature rise is mainly caused by two kinds of aspects: The first one is wind flow's self-compression temperature rise, the second one is heat transfer temperature rise. At the adiabatic condition, the self-compression is 1 ℃ per 100 m. But the heat transfer temperature rise is effected by many factors, such as: wind tube diameter, heat transfer coefficient of wind duct material, the temperature difference between inside and outside, supply air volume, the air humidification degree of the wind tube.

The change relationship between FRP wind tube export air temperature and fan export air temperature can fit to:

$$T_{FT} = 0.49T_{FJ} + 19 \quad (2)$$

T_{FT}, wind tube export air temperature, ℃; T_{FJ}, fan export air temperature, ℃.

The change relationship between FRP wind tube heat transfer temperature rise and fan export air temperature can fit to:

$$T_{CS} = -0.51T_{FJ} + 13 \quad (3)$$

T_{CS} ,wind tube heat transfer temperature rise,℃.

The change relationship between FRP wind tube heat transfer per 100 m temperature rise and supply air temperature can fit to:

$$\delta T_{100} = -0.085T_{FJ} + 2.2 \quad (4)$$

δT_{100} ,wind tube heat transfer per 100 m temperature rise,℃; T_{FJ} ,supply air temperature,℃.

6.3 The relationship between work face temperature and supply air temperature

According to the measured data, the change relationship between work face temperature and fan export supply air temperature:

$$T_{WS} = 0.47T_{FJ} + 21 \quad (5)$$

T_{WS} ,work face temperature,℃; T_{FJ} ,supply air temperature,℃.

7 Conclusions

1) A set of temporary cooling system which is suitable for high temperature deep well during construction is successively designed;

2) The design makes a water spraying chamber with large enthalpy drop and large temperature drop;

3) The innovation makes the evaporation cooling technology as an auxiliary measure applied to the mine cooling system;

4) The measured data and regression analysis results can be used by the other high temperature mine to cooling.

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