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Study on local temperature controlling technology and equipment in heat disaster coal well

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ABSTRACT

Along with the continuous increase of coal resource mining depth, high temperature and heat disaster is becoming more and more serious. The health of workers under coal wells can be threatened at any time and the safe mining of coal resources is seriously impacted. In order to eliminate coal well heat disasters, scholars at home and abroad have inputted a lot of time and energy. They have researched the controlling theory of coal well heat disasters. They developed cooling equipment for high temperatures and have achieved some results. However, the equipment is too large and as a result it is hard to move. The power of the equipment is high so it costs a large amount of electric power. Maintenance costs are huge, and therefore the application of this technology is not ideal.

Based on this, the present study firstly analyzed the influence factors of coal well heat disaster. Then, the calculation method of cooling load in coal wells was researched. The authors put forward the technology for controlling local high temperatures. The ZLS-90 movable cooling equipment was developed successfully which includes a refrigeration compressor, evaporator, water cooling condenser, and expansion valve. The property of the compressor plays an important part in the cooling effect of the whole system. After comparing, the GEA bock compressor was chosen. The enthalpy difference comprehensive testing system was used to test the performance of the equipment. Test results showed that all performance indexes comply with the design requirements. The property is also stable.

This paper also proposes discharging heat with a heat-rod to deal with the heat of condensation as well as using the heat synthetically. Effective cooling can be carried out by means of local temperature controlling technology and equipment. In that case, the working environment under coal wells would be guaranteed and the safe production of coal wells would be guaranteed. It would realize efficiency, conservation, and the environmental protection of resources.

KEYWORDS: heat disaster; temperature controlling technology; enthalpy difference; heat-rod

1. INTRODUCTION

Coal is the main energy source for our country and world. It occupies an irreplaceable position in the primary energy consumption structure (Yang D D, 2013). With the increasing mineral resources exploitation level and gradual enhancing of degree of mechanization, shallow buried coal resources are draining off and deep mining is gradually dominating (Cao X L, 2010). In recent years, countries around the world have entered deep mining areas (Singh et al., 2003). The mining depth of some coal in Germany and Russia has amounted to 1400-1500 m (Nimaje and Tripathy, 2010). The depth of Kariton Vere gold mine in South Africa is 3800 m underground and its upright shaft is about 4500 m deep (Gangopadhyay and Dutt-Lahiri, 2005). Some metal mines in India and Brazil are more than 2000 m (Li H J, 2009). There are more than 30 mines that exceed 1000 m deep in Canada and more than 10 mines in America (Abdelaziz et al., 2003). At present in our country's proven reserves, 1000-2000 m deep coal reserves accounted for 53.2% of total reserves (Wu J T et al., 2010). Dozens of mines are more than 1000 m deep (Feng D Q et al., 2013). Currently, the mining depth is rising at a rate of 8 to 16 m/a in China (Feng X L and Chen R H, 2005). Deep mining of coal will be the main problem we face in the future.

With the increase of mining depth, temperature of the surrounding rock is rising constantly (Vosloo et al., 2012). Electromechanical devices, people, hot water, coal, and gangue all emit heat. All of these cause severe environments of high temperature and high humidity which lower the working efficiency and affect equipment operation (Hughes et al., 2006). It seriously hinders the normal construction and efficient production of mines. Even worse, it gives rise to worker’s sunstroke and dehydration, or even death. Besides water, fire, gas and roof, deep well heat disaster has been one of the major disasters that restricts the development of the coal industry (Xin S et al., 2012). In order to control deep well heat

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disasters, scholars at home and abroad have done a lot of research from the aspects of theory, technique, and equipment. The scholars have developed a series of cooling equipment. However, there are still many problems such as a lack of theoretical research, large and hard to move cooling equipment, expensive to maintain, and difficult to let out the heat of condensation (Cao Q K et al., 2010). It is necessary to carry out research on cooling technology and equipment of deep coal well heat disasters.

2. DISTRIBUTION CHARACTERISTICS AND INFLUENCING FACTORS ANALYSIS OF HEAT DISASTER COAL WELL

By 2014, there are more than 150 heat disaster coal wells which mainly distribute in the east of China (Figure 1). Among these heat coal wells, 20 wells represented by Pingdingshan, Fengcheng and Xuchang are distributed in Central China. More than 40 wells represented by Yanzhou, Xinwen, Xuzhou (including Datun), Juye, Huainan and Huaibei are distributed in East China. In Northeast and North China, there are more than 30 heat disaster coal wells represented by Fengfeng (Handan), Xingtai, Datong, Kailuan, Tiefa, Beipiao, Fushun, Liaoyuan and Jixi (Zhang L et al., 2009). The rest are scattered in Hunan, Gansu, Guangxi, etc.

Figure 1: Distribution of heat disaster coal wells.

According to the survey, heat sources that cause deep coal heat disasters are the changes of surface atmospheric state, temperature rise of air self-compression, heat emitting from surrounding rock, heat emitting from electromechanical device, heat releasing from transport of coal and gangue, heat of hot water, and other heat sources. Take typical heat disaster coal wells, Panxi mine, Jining 3# mine, Pingdingshan 5# mine, Tangkou mine, Dongtan mine etc. for example. We analyzed the proportion of all these influence factors in heat disaster. The research shows that heat emitting from surrounding rock, electromechanical devices, and hot water are the main factors of heat disaster, as shown in Table 1 and Figure 2.

Table 1: factors incidence of part heat disaster coal wells.

heat sources	surrounding rock	electromechanical device	terrestrial heat	hot water	oxidation	air compression	transportation process	human body	lack of air	surface climate
Dongguashan copper mine	√	√√	√√	√	√	√				
Panxi coal well	√√	√		√√	√	√	√	√		
Jining 3# coal well	√√	√√			√√	√	√			
Pingdingshan 5# coal well	√√	√√		√√	√	√	√		√	
Qishan coal well	√	√	√√		√	√				
Chengjiao coal well	√√	√		√√	√	√	√		√	
Sanhejian coal well	√√	√√			√	√				√
Baiji coal well	√√	√			√	√			√	
Pingdingshan 8# coal well	√√	√		√√	√	√		√		
Dongtan coal well	√√	√	√√	√√	√	√				

Annotation: "√√" represents main reasons. "√" represents general reasons.

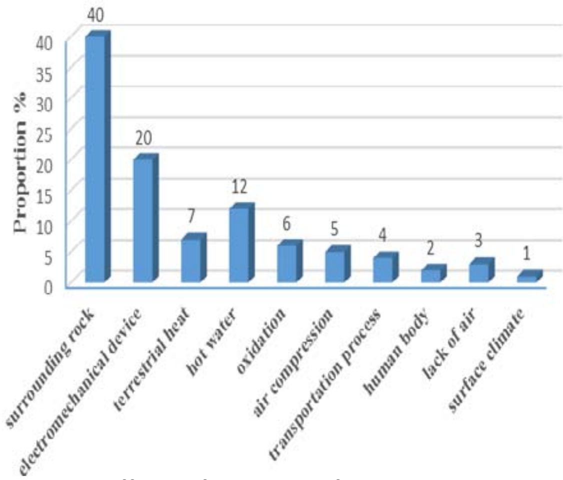

Figure 2: Affecting factors ratio of heat disaster coal wells.

3. COOLING LOAD COMPUTING METHOD OF COAL WELL TEMPERATURE DECREASING

There are multiple methods for the cooling load calculation of heat disaster coal well temperature decreasing. Some are based on the heat sources of the coal well, some are based on the air enthalpy of the air intake and air outlet, while others are based on the refrigeration station (Xin S et al., 2011). Computed results belied with the actual cooling load needed. Therefore, it is not scientific to confirm the refrigerating capacity of cooling equipment. Resource utilization is low and the cooling effect is not ideal. Based on this, the current study puts forward the correction cooling load calculation method of coal well temperature decrease. The computational formula is:

$$Q_{cold} = k\,(Q_{emit} - \Delta Q) = k\,(Q_w + Q_j + Q_r + Q_m + Q_k + Q_c + Q_y + Q_s - \Delta Q)$$

In the formula: Q_{cold} -refrigerating capacity needed, kW; k-correction factor, 1.05; Q_{emit} -emiting heat of heat sources, kW; ΔQ -absorption heat of roadway air, kW; Q_w -emiting heat of surrounding rock, kW; Q_j -emiting heat of electromechanical device, kW; Q_r -emiting heat of people, kW; Q_m -emiting heat of coal and gangue, kW; Q_k -emiting heat of air self compression, kW; Q_c -emiting heat of air leak from goaf, kW; Q_y -emiting heat of oxidization, kW; Q_s -emiting heat of hot water, kW.

4. LOCAL TEMPERATURE CONTROLLING TECHNOLOGY AND EQUIPMENT IN HEAT DISASTER COAL WELLS

Aiming at numerous problems in preventing and treating coal well heat disaster, such as temperature decreasing equipment being bulky in volume, high in energy consumption, expensive to maintain, difficult to move and so on, we present local temperature controlling technology and movable equipment. By means of the technology and equipment, we can cool the local thermal environment of working-face in exploiting and mining. It not only reduces the energy consumption of the equipment, but also meets the requirements for local temperature controlling.

4.1 Develop movable cooling equipment

Aiming for local thermal environment cooling only, the refrigerating capacity of the equipment can lower suitably. According to the air supply situation of the exploiting and mining working-face in most coal wells, we chose 90kW as the effective refrigeration capacity of the equipment (nominal working conditions: dry-bulb temperature of inlet air 30℃, relative humidity 85%, temperature of air-out 25℃, air capacity 300 m^3/min). It can guarantee that the temperature of air transmitted to the working-face is lower than 26℃. The relationship between air capacity disposed and inlet air temperature is shown in Figure 3.

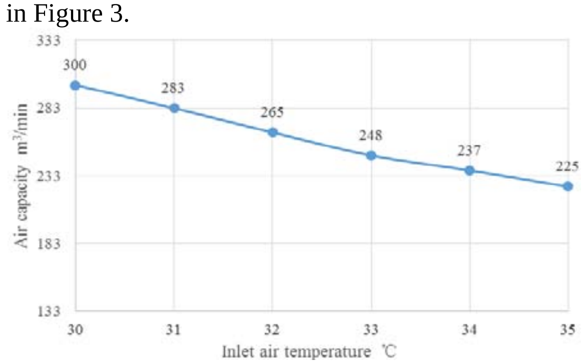

Figure 3: Relationship between air capacity disposed and inlet air temperature (air-out temperature 25℃).

The movable cooling equipment is comprised of a compressor, condenser, evaporator, electronic control system, and so on. In order to accord with explosion-proof requirements, we chose a BOCK (FX14/1366) piston open-type compressor equipped with an explosion-proof electric machine. The power source of the electric machine is a three-phase four-wire system, quaternary. A thermostatic expansion valve was used in the throttle mechanism. Performance parameters of the compressor are shown in Table 2.

Either an evaporative condenser or shell-and-tube condenser can be chosen. These two types of condenser each have their own merits and demerits. The ultimate length of the refrigerating fluid connecting hose should firstly be considered (Figure 4). The W type represents the single biggest length of connecting hose 1 and connecting hose 2. The evaporator is lower than the compressor in the right side while higher in the left side. N type represents the single biggest length of connecting hose 3 and connecting hose 4. The condenser is higher than the compressor in the right side while lower in the left side. L_v/L is the ratio of the connecting hose height difference value and single tube length. $L_v/L \approx 0$ in coal wells. Analysis conclusion: the biggest connecting hose length of the condenser is about 60 m and the biggest connecting hose length of the evaporator is about 22 m. Based on the above analysis, the shell-and-tube condenser was selected. R407C was chosen as the refrigerating fluid and water as the cooling medium.

Table 2: Performance parameters of the compressor.

Condensation temperature T_c/℃	Evaporation temperature T_o/℃									
		15	10	5	0	-5	-10	-15	-20	-25
30	Cold capacity/W	168000	140000	116000	95000	77300	62200	49400	38600	29600
	Power /kW	15.7	17.3	18.1	18.1	17.6	16.6	15.3	13.9	12.4
35	Cold capacity/W	159000	133000	110000	89700	72800	58400	46200	35900	27200
	Power /kW	19.6	20.6	20.8	20.3	19.3	18.0	16.4	14.8	13.2
40	Cold capacity/W	150000	125000	103000	84200	68200	54500	43000	33200	24800
	Power /kW	23.3	23.6	23.2	22.3	20.9	19.2	17.4	15.6	13.9
45	Cold capacity/W	141000	117000	96300	78600	63500	50600	39700	30400	22500
	Power /kW	26.7	26.4	25.5	24.1	22.4	20.4	18.4	16.5	14.7
50	Cold capacity/W	132000	110000	89700	73000	58700	46600	36400	27600	20100
	Power /kW	29.9	29.0	27.7	25.9	23.8	21.6	19.4	17.3	15.6

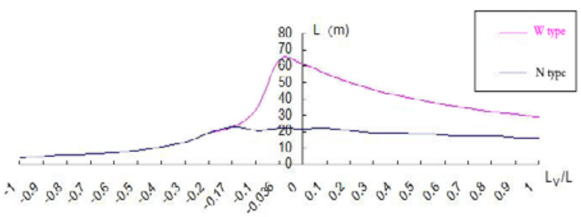

Figure 4: Ultimate length analysis of refrigerating fluid connecting hose.

The evaporator is an important component of the refrigeration system. It is a sort of dividing wall type heat exchanger. Direct evaporative cooling was designed. Floating air temperature outside the coiled tube is reduced by the evaporation of refrigerating fluid in the coiled tube. In order to decrease the influence of dust under the well on heat transfer of the heat exchanger, slick coil pipes were used for the evaporator. This type of pipe is convenient to rinse. Calculating parameters of the evaporator are as follows: air supply volume 300 m^3/min, dry-bulb temperature/wet bulb temperature of inlet air 30/28℃, the temperature of air-out 25℃. Slick copper pipes (φ16×1.2) were bent to an 800 mm single length. There are 36 pathways with 342 pipes. The air resistance is about 900 Pa.

As a kind of movable cooling equipment used in coal wells, its electronic control system should automatically monitor the main technical parameters and running status of the equipment. It should also adjust automatically according to actual situation. The electronic control system should show air-out temperature, air-out humidity, air suck, and exhaust pressure of the compressor. The electronic control system is the key of equipment operation and automatic control. So, it should have the function of being explosion-proof as well as have air exhaust pressure protection, over temperature protection, overload protection and so on. After systematic design and manufacturing, the movable cooling equipment was named ZLS-90 mine explosion-proof refrigeration unit.

4.2 Performance testing of the cooling equipment

The comprehensive enthalpy difference method was used to test the performance of the cooling equipment. The enthalpy difference test system adopts the testing philosophy of air enthalpy-difference method or means of liquid secondary refrigerant in the primary side and water heat meter method in the subordinate side. The system can test air blast capacity, refrigerating capacity, consumed power, electric current, EER (energy efficiency ratio) and other technical parameters of cooling equipment accurately. Using the programmable controller as the core, running equipment can adjust test conditions automatically during the testing process. Data collecting, processing, and saving are carried out by a computer. It can also generate testing reports and analyze the results by itself. Testing principles of the system are shown in Figure 5.

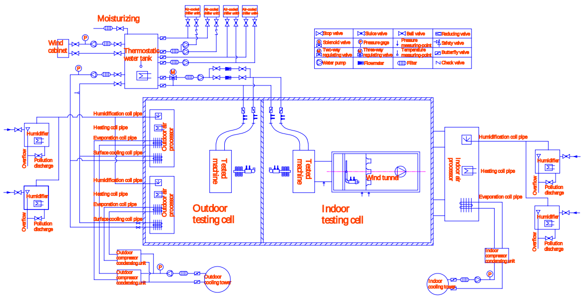

Figure 5: Testing principle of the enthalpy difference test system.

In accordance with the relevant procedures, performance testing of the refrigerating equipment was carried out. Calculating data and results are shown in Table 3 and Figure 6.

As shown in Table 3 and Figure 6, refrigerating capacity and other performance indexes of the cooling equipment all satisfy the design values. The performance is good and stable. The cooling equipment is portable, so it can be moved easily and quickly with the help of a mine platform lorry. This can save a lot of time because it is not necessary to add refrigerating fluid repeatedly after each move. With this equipment, we can implement effective cooling to mining and driving work face and other local thermal environments.

Table 3: Calculating data and results of ZLS-90 mine explosion-proof refrigeration unit.

items	unit	NO1	NO2	NO3	NO4	NO5	NO6	NO7	result
air quantity	m^3/h	18065.330	18063.747	18071.212	18076.135	18074.847	18072.565	18081.917	18072.251
heat exchange of air side	kW	112.884	111.136	112.282	112.801	112.185	112.539	113.016	112.406
heat exchange of water side	kW	121.733	121.712	121.850	121.592	122.080	122.169	122.121	121.894
input power	kW	30.106	30.094	30.097	30.093	30.098	30.080	30.094	30.095
COP	kW/kW	8.771	8.683	8.744	8.775	8.739	8.768	8.787	8.752
deviation	%	7.904	9.561	8.578	7.850	8.855	8.710	8.087	8.506
water resistance	kPa	26.047	26.070	26.103	26.074	26.054	26.057	26.127	26.076
sensible heat	kW	37.906	37.120	37.580	37.218	36.674	37.150	36.355	37.143
latent heat	kW	74.979	74.015	74.702	75.583	75.511	75.388	76.661	75.263
inlet air enthalpy	kJ/kg	91.039	90.832	91.116	91.224	91.535	91.618	91.847	91.316
outlet air enthalpy	kJ/kg	70.919	71.019	71.107	71.128	71.537	71.555	71.707	71.282

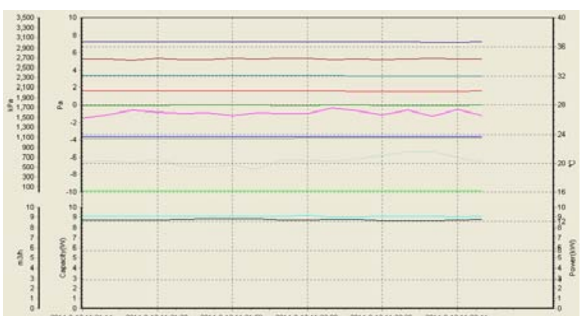

Figure 6: Performance test curves of ZLS-90 mine explosion-proof refrigeration unit.

5. MINE CONDENSING HEAT EMISSIONS TECHNOLOGY

There are currently three primary types of mine condensing heat emissions to local cooling under wells: heat discharging by water, heat discharging by water and fresh air, and heat discharging by water and ventilation air methane (Zhou T et al., 2012). There are some problems, such as being difficult to discharge or having a high failure rate of the discharging device. In view of this, we proposed to discharge condensation heat by heat-rod technology. The heat collector is connected to the discharging port of the movable refrigeration unit. The evaporation zone of the heat-rod is inserted into the heat collector. In that case, the condensation heat in the heat collector can be discharged to the upper space or surface by the heat-rod. Finally, the heat can be used synthetically.

6. CONCLUSION

Through the above research, we can come to the following conclusions:

(1) Heat disaster coal wells are mainly distributed in Central China, East China, Northeast and North China. The rest are scattered in West and South China.

(2) For most of the mines, heat emitting from surrounding rock, electromechanical devices, and hot water are the main factors that cause heat disaster.

(3) The ZLS-90 mine explosion-proof refrigeration unit was designed to cool local high temperature environments. It is the ideal equipment to improve local thermal environments and has the advantage of being lightweight to move, having low energy consumption, stable properties, good cooling

effects and it is not necessary to add refrigerating fluid repeatedly after each move.

(4) Using heat-rod technology to discharge mine condensing heat, it is simple in craft, convenient, swift, long in service life, and good in its discharging effect.

7. ACKNOWLEDGEMENT

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8. REFERENCES

Abdelaziz EA, Saidur R, Mekhilef S. (2011) A review on energy saving strategies in industrial sector. Renew Sust Energy Rev. Volume 15, pp. 150-168.

Cao Q K, Zhang S H, Yang W. (2010) Deep mine cooling and geothermal resource utilization. Journal of Liaoning Technical University(Natural Science). Volume 29, Supp 1, pp. 40-42.

Cao X L. (2010). Deep mine high temperature heat hazard resourceful utilization technology in Sanhejian coal well. BeiJing, China University of Mining and Technology.

Feng D Q, Zhao X D, Chen Z. (2013) Application of local cooling technology in deep mining of Xuzhuang Coal well. Industry and Mine Automation. Volume 39, No. 3, pp. 92-97.

Feng X L, Chen R H. (2005) Research and Development on Air-cooling in Deep High-temperature Mines at Home and Abroad. Yunnan Metallurgy. Volume 34, No. 1, pp. 7-10.

Gangopadhyay, P. K., Dutt-Lahiri, K. (2005) Detecting Coal Fires with Remote Sensing: A Comparative Study of Selected Countries , Resource Management in Asia-Pacific Region (RMAP) Working Paper No. 58, RMAP Program, Research School of Pacific and Asian Studies. The Australian National University, Canberra, ISSN- 1444.

Hughes A, Howells MI, Trikam A, Kenny AR, van Es D. (2006) A study of demand-side management potential in South African industries. In: Proceedings: Industrial and commercial use of energy (ICUE) conference, August, Cape Town.

Li H J. (2009) Technology for Air Control in Coal well Cooling. Warm Circulating and Air Control. No. 6, pp. 43-45.

Nimaje D. S., Tripathy D. P. (2010) Thermal Studies on Spontaneous Heating of Coal. The Indian Mining & Engineering Journal. p. 10.

Singh, R. V. K., Singh, V. K. (2009) Status of Mine Fire of Jharia Coalfield and Suggestions for Prevention and Control. National Seminar on Reinventing Jharia Coalfield, MGMI, Dhanbad Chapter.

Vosloo J, Liebenberg L, Velleman D. (2012) Case study: energy savings for a deep-mine water reticulation system. Apply Energy. Volume 92, pp.328-35.

Wu J T, Chen X M, Xia J. (2010) Research and Application of Mobile Refrigerator to Deep Mine Temperature Reduction. Coal Science and Technology. Volume 38, No. 10, pp. 86-88.

Xin S etc. (2011) Prevention and Cure of Heat Disaster in Coal Wells. Beijing, Coal Industry Publishing House, 216 p.

Xin S, Fu H L, Yan X Y. (2012) New Designing Idea of Centralized Cooling System for Coal Well. Safety in Coal Wells. Volume 43, No. 3, pp. 60-63.

Yang D D. (2013) Research on feature of thermal disaster and the control effect in zhuji coal well. An Hui, AnHui University of Science and Technology.

Zhang L, Chen S, Yu F. (2009) Several mine cooling technologies. Shandong Coal Science and Technology. No. 3, pp. 152-153.

Zhou T, Xiang D, Chen Y H, etc. (2012) Engineering practice and discussion on condensing heat emission during local cooling engineering. China Coal. Volume 38, No. 12, pp. 90-94.