Analysis of Heat Hazard and Exploration of Comprehensive Utilization Technology in Deep Buried Thick Coal——Taking Ningzheng Mining Area as an Example

Lan Yu1*, Rili Yang1, Chao Zheng1, Fengfeng Yang1, Ruiqing Su1
1School of Energy Engineering, Longdong University, Qingyang, Gansu, 745000, China
*Corresponding author's e-mail: 418187657@qq.com

Abstract. At present, 53% of reserves buried under 1 kilometers in China and the amount of green coal resources is less than 500 billion tons. Ningzheng Mining Area is a newly developed large-scale coal mining area in Western China, and is the main succession area of coal resources in Gansu Province in the future. The coal seams are generally buried more than 1 kilometres. Taking the newly built mines in Ningzheng Mining Area as an example, this paper carried out a geological analysis of thermal environment and analysis of the main influencing factors of thermal hazards, established the model of mine production system, and explored several comprehensive utilization technologies of thermal hazards such as HEMS (High Temperature Exchange Machinery System) cooling technology model and gas, the cooling modes of power generation combined heat, power and cooling system and the artificial ice-making. The cooling technology can effectively guide the development of new mines in Western China in mines and the efficient utilization of resources.

1. Introduction
Coal resources have been exploited for many years in China and shallow buried resources with good conditions is gradually decreasing. With the development of science and technology, deep coal unqualified for exploitation is gradually exploited[1]. According to statistics the exploited coal mines are being extended at the speed of 10-25 m/a, the average extension speed is 8-12 m/year in China, and the depth of first mining face has approached and exceeded 1 kilometer. It is predicted that it will cause serious occupational hazards and restrict the safe, efficient and friendly mining[3]. Prevention and control of heat hazard in deep well is also listed as one of the key projects in the "13th Five-Year Plan" coal mine science and technology[2], we neglected the fact that heat hazard is also a kind of heat energy resource. We concern how to eliminate heat hazards rather than to utilize them cleanly and efficiently, and Cause to waste heat resources. Ningzheng mining area is a newly built Western mining area. The overburden depth of the first coal seam in the mining area is more than 800 meters, which is a typical high-temperature and heat hazard mine. The construction plan of the mining area fully reflects the development ideas of the "three major", namely, the development of large enterprise groups, the construction of large coal mine bases, and the construction of large modern coal mines. Therefore, how to mitigate heat hazard and comprehensively utilize thermal energy is a problem worthy of exploring in the new mines in the west[4].
2. Geological analysis of Thermal environment in Ningzheng mining area

Xinzhuang mine is the main construction mine of ningzheng mining area, and other mines under construction are similar to this mine. This paper uses the relevant data of Xinzhuang mine for geological analysis of thermal environment. The coal seams including coal 2, coal 5-1, coal 5-2, and coal 8 are the Middle Jurassic Yan'an Formation, of which coal 5-1 and coal 5-2 are mostly recoverable. The 8th layer of coal is the most stable coal seam in the whole area. There is mainly non-caking coal with high calorific value, and a small amount weak caking coal Mine. The first mining area consist of 5 blocks with the coal 8 as a panel. The coal seam is categorized as thick coal seam with an inclination angle of 4~5°, the recoverable thickness of 0.88~27.41m and an average thickness of 9.71m. The thickness of coal seam is not uniform[5]. Coal mine stage geological temperature conditions are as follows: The average temperature of the eight layer plate is 31.9 °C ~ 45.5 °C, The highest measured temperature at the bottom of the hole, 1270 m from the surface, is 40.6 °C; In the shallowest well of 758 meters, the measured temperature at the bottom of the hole is 39.5 °C; The highest measured temperature at the bottom of hole, 1261m from the surface, is 46.8 °C. It is located in the syncline axis downhole regions and exceed the standard level of thermal hazard zone. More than two-thirds belong to secondary heat hazard zone, which mainly located in the southwest and west mining field. The geothermal gradient is about 2.53 °C / 100 meters without abnormal heat hazard.

3. Main impacting factors of heat hazard

The main impacting factors of heat hazard in Ningzheng mining area are the following aspects:

(1) The coal seam is deeply buried. The virgin rock temperature is high. The air self-compression heat temperature is obvious[6]. The deep hole thermometry was used to measure temperatures at different depth. The temperature 500 meters underground ranges from 0 to 35.5 °C. Some of the rock temperatures exceed 31°C, which is Level one heat hazard zone; Ground temperature increases with the increase of depth. the temperatures of the bottom hole near the coal mining face are higher than 40 °C, which falls into level two heat hazard zone(second-grade thermal hazard zones: 37). the heat problem at the mining working faces is very serious.

According to the design of Xinzhuang Mine, the main inlet shaft (auxiliary shaft) has a depth of 1025 meters, the return well has a depth of 967 meters, and the mining depth of the mining face exceeds 1000 meters. The air density is measured at 1.05kg/m³. The temperature raise caused by the air self-compression process can reach 10°C based on adiabatic compression calculation. Therefore, the virgin rock temperature and air self-compression have a great impact on the wind temperature of the mine.

(2) The heat is generated in the modern mine production process. The planned mines in Ningzheng Mining Area are all modern large-scale mines. Large-size coal mining machines, transport machines, and other mechanical and electrical equipment may release a large amount of heat during production process. The heat generated by the oxidation of coal and explosives cannot be ignored either.

(3) The aquifer hot water temperature has an effect on the mine temperature. The biggest threat to coal mining in Ningzheng mining area is the roof confined water located in Luohu formation. The water-conducting fissure zone generated after coal mining will become the mine water-filled fissure through the porous fissure channels of roof conglomerate and sandstone. Preliminary exploration does not see any geothermal anomaly area. according to the groundwater in the preliminary forecast horizon for 400 ~ 800 meters the temperature of aquifer water was preliminarily predicted as roughly 26 ~ 36 °C as the groundwater locates mainly at 400-800 meters underground. In addition, heat transfer of surrounding rock through the fissure water convection is also a means of heat conduction[7].

(4) Typical geological formations have a certain impact on the heat hazard distribution area. The Xinzhuang Minefield in Ningzheng Mining Area is located in the northern margin of the fault-stricken east wing of the Weibe, and is located in the southern part of the Qingyang monoclinal in the eastern wing of the Tianhuan. It is generally located in the south of the Qingyang monoclinal. It is a compound monoclinal structure with a gentle slope in the northwest direction. The undulations are mainly caused by the Dengjia anticline. The two sides of the anticline are developed with two backs and synclines.
arranged in the same direction with a spacing of 2 to 3.5 km. The geothermal temperature is closely related to the tectonic trend. The ground temperature is slightly lower along the anticline portion (the paleo-uplift region), and the ground temperature is higher at the oblique axis portion (the depression).

4. Mine airflow heat exchange and wind temperature prediction

Based on the survey of the mine ventilation system, the following air temperature calculation model (see figure 1) was established. The airflow route of the coal mining face: from the auxiliary shaft -- 2210 auxiliary transport lane -- 22106 air inlet drift -- 22106 stope -- 22106 air return drift -- air return shaft. Airflow route at the development faces: From the auxiliary shaft - 2210 auxiliary transport entry - 22107 to the development roadway. The mining depth of the intake shaft is 1000m, and the shaft circumference is 30m. The auxiliary transport roadway is 3000m long and basically extends horizontally. The length of 22106 air entry roadway is 1500m, closing to the horizontal roadway. The working face of 22106 is 300m long, and the return air roadway of 22106 is 1500m long closing to the horizontal roadway. The developing roadway of 22107 is 1500m long, close to the horizontal roadway. 2210 return air roadway is 3000m long, which is a gently inclined roadway. The depth of the return air shaft is 1000m. Figure 1 shows the thermal calculation model of a kilometer deep shaft in Xinzhuang Minefield.

Fig 1. Calculation model of wind temperature in deep wells in Ningzheng mining area

| Working place | 1  | 2  | 3  | 4  | 5  |
|---------------|----|----|----|----|----|
|℃             | 24.05| 29.01| 31.45| 37.5| 31.45|

According to the above analysis, the mine must implement effective cooling measures to the workface. A fully mechanized workface in the coal 8 area is arranged in the initial stage of the mine production (and a preparatory working surface is arranged for gas pre-draining); a longwall fully mechanized workface is arranged in the coal 5 panel; 5 integrated mechanized development faces and 1 rock digging face are provided. It is calculated that the cooling capacity of the two coal mining faces is below the 26℃ is 4323.25kW, and the cooling capacity of the six development faces are 3502.7kW. According to the actual mine situation, the factor of cooling loss and reserve is 1.15, and the total cooling capacity is 9000 kW.

5. Technical measures for prevention and control of heat hazard
The general technical measures for mine cooling are: selecting a reasonable mine ventilation system, optimizing the mine mining system and roof management method, increasing the air volume of the ventilator, and effective personal protection for the miner. The first mining seam in Ningzheng Mining Area has serious heat hazard. It is necessary to adopt mechanical cooling and other cooling technologies (such as ice cooling, water-cooled mine air-conditioning technology)\(^8\). Mechanical cooling technology can meet the cooling requirements of the working face. However, due to large capital input, low energy efficiency, and large sized equipment\(^9\), most of the technical methods fail to fully consider the recycling and reuse of condensation heat, geothermal and hot water resources. Therefore, it results in high heat loss\(^10\). This paper fully investigates domestic and foreign thermal hazard prevention and resource utilization technologies, and recommends several comprehensive utilization technical measures.

5.1 **HEMS cooling technology**

HEMS cooling technology was proposed by Professor He Manchao of China University of Mining and Technology\(^{11}\). The HEMS cooling system is composed of underground and ground parts. The underground part is composed of pressure conversion workstation, heat exchange workstation, refrigeration workstation, and cooling workstation, while the ground part is composed of regulating pool, heat exchange workstation and heat utilization workstation to realize full utilization of heat energy\(^{12}\). The well is connected to the well through a pump station.

It can be used in many mines extending to deep mining in the east and south, such as Xuzhou Sanjianhe Mine, Shandong New Grave Suncun Mine, Hunan Zhouyanshan Mine, etc. The average temperature is lowered by 8~10 °C\(^{13}\), which has the significant advantages of cooling and recycling of heat energy. The method uses the HEMS cooling system to extract the cooling capacity from the gushing water source of the underground mining face, exchanges heat with the hot air of the mining face to cool the cooling air, and then uses the mine drainage as a medium to transport the working surface thermal energy to the well instead of bathrooms, boilers, and building and domestic water heating to achieve a change\(^{14}\).

5.2 **Gas power generation and cogeneration system cooling technology**

The system integrates the centralized cooling system, gas extraction system and waste heat utilization system of the mine, and has the characteristics of comprehensive prevention and utilization of heat and gas disasters and resource utilization. The principle of gas power generation and cogeneration system is as follows: The mine gas drainage system transports the high-concentration gas extracted from the gas to the gas storage tank\(^{14}\). The ground pretreatment system is used to filter, dehydrate and supercharge the gas in the gas storage tank, and then send it to the generator set for power generation. The high temperature flue gas discharged from the power generation process is used as the mine cooling heat source, and is used as the refrigeration unit power of the mine centralized cooling system\(^{15}\). The electricity generated by the gas generator set can supply power to the mine mechanical cooling system, and the rest of electricity can be used as underground power generation.

The system can adjust the peak according to the change of electricity consumption in winter and summer. When the cooling capacity is large in summer, the waste heat of the boiler is used for refrigeration. The waste heat in winter can be partially used for refrigeration, and the rest can be used as ground heating. At the same time, the system plans a mine gas power plant or a coal gangue pit power plant, which is very consistent with the concept of high-grade recycling of coal resources by large coal mines.

5.3 **Ground buried tubular downhole centralized cooling**

This is a Centralized refrigeration cooling system. Its cooling water circulation can be realized by drilling holes on the ground. The cooling refrigeration system can be placed in the cooling load center by selecting the location of drilling holes to reduce the loss of cooling water in the process of transportation. The water supply temperature of the terminal air cooler equipment is low and can be lowered to more than 8 degrees Celsius.
This method is to drill two holes from the ground to the underground (generally in the vicinity of the mining area), and two cold water pipes are buried in the borehole to realize the cooling of the concentrated cooling water in the underground. At the same time, the buried drilling hole is used to circulate the cooling water back to the ground, and the residual heat is utilized, and then cooled by the cooling tower and then returned to the underground for recycling. The system is mainly for the problem that the condensation heat is difficult to be discharged in the underground centralized cooling system. The cooling water of the refrigeration unit is set down in the well, and the cold water is used as the refrigerant to be transported to the underground working place to realize the cooling and cooling. The refrigerating unit chamber is generally arranged near the parking lot of the underground mining area, and a cooling machine room is arranged on the ground, and the condensing heat is discharged through the ground cool technology.

The system is a waste heat utilization system. The thermal water resources are used for staff heating and domestic hot water to realize the effective and full utilization of thermal energy in winter. The hot water is returned to the cooling tower for cooling, which saves part of the energy. The method is recycling value.

5.4 Mine artificial ice cooling technology
For the deep mining exceeding 1 kilometers, the cold load is very large, the ground refrigeration unit is used to make ice cubes, and the ice is sent to the portal through the ice transport system. Then the ice relies on its self-gravity and inertial flow ice-melting device. In the ice-melting device, the ice and the water are exchanged with sufficient heat, and melted into cold water of about 0 °C and sent to the well-excavation work place. Using the mine artificial ice making technology, to obtain the same cooling capacity, the required ice volume is less than one quarter of the water, and the energy efficiency is higher, which is convenient for solving the problem of mine humidity and water pressure conversion for one kilometer mine. The advantage of using artificial ice making technology is very obvious. Of course, the obvious drawback of the artificial ice-cooling system is that the solid ice transported intends to block the pipeline. It can learn from the Israeli ice storage technology to use muddy ice or de-granulated ice to reduce the blockage of the pipeline.

5.5 Formation cold storage technology
This is an emerging and innovative technology that uses a portion of the air's own cooling capacity to cool the mine during the winter, and then store most of the cold air in the underground aquifer. The cold air stored in the aquifer is extracted during the summer or other seasons to achieve a well temperature drop. The technology is not yet fully developed and needs further research.

6. Conclusion
Xinzhuang Coal Mine is a newly built mine in Ningzheng Mining Area. A refrigeration station is set up in the industrial site of auxiliary well. There are Nine sets of X180T ice-making equipment which is 1000kW capacity, the total refrigeration capacity is 9000KW. It is the best method that Combines “Gas power generation and cogeneration system cooling technology” with “evaporation cooling technology” by comprehensive analysising and comparing.

In short, Ningzheng Mining Area, as a large-scale modern coal production base built by the western region, has deep burial of coal seams and significant heat hazard. During constructions, it should fully consider the prevention and utilization of heat hazard and comprehensive utilization technology. It is a subject worth exploring. The construction and development of mining areas should form their own methods and prevention modes, strengthen the promotion of new technologies and new processes, combine international advanced cooling technology, promote innovation, focus on resource utilization, and form their own unique style.

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