Occupational health and occupational hazard control in coal mines: a comparative study

Xuexiang Deng¹, Yuyuan Zhang²* and Liyuan Cui²

¹Technology Center, Yankuang Group, Jining
²College of Mining and Safety Engineering, Shandong University of Science and Technology, Qingdao
*Corresponding author’s e-mail: hellenzyy@163.com

Abstract. The occupational health efforts within Y Group are examined after analysis on current occupational health and occupational hazard control among coal mines in and outside China, covering a systematic investigation of dust hazard prevention in B Mine and an analytical research of heat hazard in Z Mine. The paper includes an innovative set of studies on the distributions of coal mine workers subject to different occupational hazards and the types of work among pneumoconiosis victims, the distribution of main heat sources underground and measures against heat hazards, as well as the number of dust-exposed workers per ten thousand tons of raw coal. Our findings will provide useful clues for successful occupational health and occupational hazard control in the coal sector.

1. Introduction

Occupational hazards in coal mines represent a great concern associated with the exploitation of coal mine resources. All countries across the globe are challenged by occupational hazards in coal mines and are trying all means to prevent these hazards. An ILO statistics shows that Australia ranks the world’s 7th for occupational accident mortality with over 2000 deaths from work-related accidents—mostly occupational hazards—every year [1–4]; according to the regulations of mine climate conditions, the mine health protection law, and the coordination between coal mining enterprises and labor unions, the German coal mine took the dry ball temperature and the effective temperature as the allowable working time limit standard for each shift, effectively solving the problem of heat damage in coal mine [5,6]; South Africa attaches great importance to occupational health, having set up a Mine Health and Safety Council (MHSC) aimed to eliminate silicosis [7,8]; China, as a large coal producer, has long been exposed to occupational hazards in coal mines, with increasing new cases of occupational diseases every year. Here, dust and noise are among the greatest contributors to occupational hazards in coal mines, especially coal workers’ pneumoconiosis (CWP). According to statistics, 1359 workers in the original key state-owned coal mines died from pneumoconiosis in 2002, which doubled the accident-caused deaths of the year. China highlights corporate occupational health and occupational hazard control, having enacted a succession of laws and acts including the “Labor Law” and the “Regulations on the Prevention and Control of Pneumoconiosis” [9–12] since the 1980s. In the 1990s, following the practices of the United States, the United Kingdom, Australia, and Japan, China drafted trial standards for its own occupational health and safety management system (OHSMS). The aggregate population of detected pneumoconiosis victims is large and has been increasing rapidly year by year. Addressing and improving occupational health in coal mine is of great importance [13].
In view of this situation, we examined the occupational health efforts with respect to two major occupational hazards within Y Group after analysis on current occupational health and occupational hazard control among coal mines in and outside China, covering a systematic investigation of dust hazard prevention in B Mine and an analytical research of heat injuries in Z Mine. We identified the mechanisms underlying occupational hazards and propose preventive measures against these hazards. Our findings are not only helpful for the group's further efforts in occupational health and occupational hazard control, they also pioneer the occupational health system research for coal mining companies and provide useful clues for other coal mining companies in their occupational health and occupational hazard control efforts.

2. Subject of study
Within Y Group, workers are exposed to a wide variety of occupational hazards, covering different branches and types of work. The occupational health and occupational hazard control work is quite complicated. Occupational hazards associated with coal production and washing typically include silica dust, coal dust, cement dust, radiation, noise, heat, vibration, hydrogen sulfide, and carbon monoxide. The B coal mine of Y coal industry co., ltd. is mainly involved in dust hazard, which easily leads to pneumoconiosis of coal miners, while the Z coal mine of Y coal industry co., ltd. is mainly involved in heat hazard.

3. Results

3.1 Dust hazards

1) Pneumoconiosis
In B Mine, there are currently 69 CWP victims, of whom 63 (92%) are in stage I, 5 (7%) are in stage 2, and 1 (1%) is in stage III. Among the 69 CWP victims, 63 are transferred from other mines and the remaining 6 have dust exposure records from other mines. From 1989 to 2008, the annual number of CWP victims has stayed at around 80 with little variation and has been on the fall. New CWP victims are primarily in stage I; stage II victims have not increased significantly and stage III victims have reported zero increase. Control of new CWP victims signifies effective prevention of further development of this disease and suggests successful control and treatment on CWP within the mine.

Among the current CWP victims in B Mine, 47 have retired and 22 are still working. Among the CWP victims that are still working, 9 are driving workers, 6 are mining workers, 6 are mixed workers, and 1 is a signal worker; their age spans from 40 to 78 with an average of 49; their length of services ranges from 10 to 39 with an average of 27. Among the 47 retired CWP victims, 29 were driving workers, 11 were mining workers, 11 were mixed workers, and 1 was a grinding worker; their age spans from 40 to 81 with an average of 74; their length of service ranges from 7 to 45 with an average of 25. Fig. 1 and Fig. 2 compare the types of work between the in-service and retired CWP victims in B Mine.
The current CWP victims in B Mine are mostly aged at 40 to 50, with an average length of service of more than 25. Yet it is 23 years since the mine was put into service, which is lower than the average length of service of the CWP victims. Among the CWP victims, 80% are driving or mining workers. The remainder are mostly mixed workers. In terms of the types of work among the CWP victims, the proportion of in-service driving and mining workers has dropped slightly whereas that of mixed workers has climbed a little when compared with retired workers.

2) Dust exposure in main hazardous locations

In B Mine, dust hazards are typically found on underground mining faces, driving faces, and above-surface washing plants. Fig. 3 shows dust concentrations at different working sites of the mine.
In B Mine, coal mining is carried out by fully-mechanized mining and fully-mechanized caving. Dust produced during production mainly comes from coal cutting, frame removing, coal caving, coal slipping, and coal transport. Fig. 3a shows dust concentrations at dust-producing sites on the mining faces of B Mine from 1996 to 2009. From 1996 to 2009, the coal cutters, coal caving outlets, coal slipping structures, and working face return airways on the mining faces of the mine showed similar dust concentration profiles: from 1996 to 2000, the dust concentration continued to rise, with a maximum of 9.8 mg/m$^3$; from 2000 to 2009, it dropped slowly and but still stayed at around 9 mg/m$^3$. On the coal mining faces, dust hazards were very serious with dust concentration standing at high levels. Although the dust concentrations at all sites were within the specified limits, they were close to the critical points. This means that while dust control measures were well effected, the result was not as good as expected.

Coal driving is carried out by normal driving and fully-mechanized driving. Dust produced during production mainly comes from hole drilling, blasting, shoring, loading, cutting, and transport. The mine has continuously tried new dust management and technical measures during driving process and effectively controlled the dust concentration on the driving faces. Fig. 3b shows dust concentrations at dust-producing sites on the driving faces of B Mine from 1996 to 2009. From 1996 to 2009, the loading, blasing, anchor bolting, and shotcreting sites on the driving faces of B Mine showed roughly the same dust concentration profiles: from 1999 to 2000, the dust concentration climbed slowly, with a maximum of 8.6 mg/m$^3$; from 2000 to 2009, it began to drop, with a minimum of 1.6 mg/m$^3$. Overall, the dust concentration was on a continuous fall.

In B Mine, a proactive dust control procedure spanning from raw coal entry to fine coal delivery is implemented. Fig. 3c shows dust concentrations at dust-producing sites in the washing plant of the mine from 1996 to 2009. From 1996 to 2000, the dust concentration during the coal washing process continued to rise, with a maximum of 6 mg/m$^3$; from 2000 to 2009, it dropped visibly, with a minimum of 2 mg/m$^3$. The average annual reduction was 6.7%. In the case of belt conveyance, for example, dust concentration continued to rise from 1996 to 2000, with a maximum of 8.5 mg/m$^3$, but it began to drop from 2000 to 2009, with a minimum of 1.8 mg/m$^3$. The average annual reduction was 7.9%. Dust control efforts have been paying off since 2000, with dust concentrations at all monitoring sites on the coal mining faces well below the specified limits. Dust concentration has continued to drop every year, demonstrating improved dust control result.

3.2 Heat hazards
Given the complicated production environment in coal mines, rising air temperature underground is attributable to a range of heat sources. Typically, underground heat sources are either physical or chemical or physiological. In Z Mine, heat hazards are a serious problem challenging the development, driving and the return airways. As the return airways involve fewer workers, we will look at the heat sources on the development and driving where people are more concentrated.

1) Development faces
In the case of the return airway downhill of Mine area 1. This site lies to the east of the belt conveyor downhill of Mining area 1, starting from -856.313 m and ending at -927.892 m with a design length of 1507 m. Working is supported by concrete sprayed anchored net and anchorage cable. The workings section is a semicircular arch. As the development workings are driven with smooth bolting and shotcreting where few machines are used and the production has very little impact on the thermal environment of the workings, we did not include the heat from hot water and mechanical devices there. Rather, we calculated the heat dissipations from wallrock, compression, oxidation, human body, blasting, and gangues during transport. Fig. 4 shows the heat dissipations from all above sources. The heat dissipation from wallrock is the highest at 293.82 kW, followed by that from oxidation at 11.16 kW. The heat dissipation from blasting is the lowest at 1.71 kW. Heat exposure is the greatest at wallrocks and protection at these sites must be highlighted.
Fig. 4 Heat dissipations among main heat sources in development workings

2) Driving faces

In the case of the driving of tail entry of Working face 1304 as an example. This driving face lies in the west of Mining area 1, with design tail entry length of 1500 m. The working is supported by rectangular-section bolt meshes. Under regular conditions, bolt meshes are used as support. In situations where the geological structure is abnormal, shed supports are used. From the heat source distribution on the development faces, during blasting operation, ground heat represents the main heat source. Hence, we only included heat from mechanical devices. Inspired by related literature, wallrocks, hot water, electro-mechanical devices, oxidation, human body, and coal or gangue during transport were identified as the main heat sources in the driving workings. Table 1 lists the calculation results.

Table 1 Main heat source calculations on tail entry driving face of Working face 1304 in kW

| Driving Length | Heat from Wallrock | Heat from Hot Water | Heat from Electro-Mechanical Devices | Heat from Oxidation | Heat from Human | Heat from Coal Transport | Total Heat Dissipation |
|---------------|-------------------|---------------------|-------------------------------------|---------------------|-----------------|-------------------------|------------------------|
| 500m          | 279.50            | 99.65               | 95.4                                | 20.07               | 7.05            | 11.14                   | 512.81                 |
| 1000m         | 390.86            | 99.65               | 95.4                                | 40.07               | 7.05            | 19.38                   | 652.41                 |
| 1500m         | 390.86            | 99.65               | 95.4                                | 60.06               | 7.05            | 26.81                   | 679.83                 |

Fig. 5 compares heat dissipations among main heat sources at 1000 m return airway downhill driving of Mining area 1 and at 1000 m tail entry driving of Working face 1304. At both sites, wallrocks contributed the greatest to heat dissipation. However, heat dissipation from wallrocks at 1000 m return airway downhill driving of Mining area 1 was around 40% higher than that from wallrocks at 1000 m tail entry driving of Working area 1304, whereas heat dissipations from human body, electro-mechanical devices and oxidation at 1000 m tail entry driving of Working area 1304 contributed far more greatly than those from the same sources at 1000 m return airway driving of Mining area 1. The heat dissipations at that time were quite uniform.
4. Discussion

China highlights corporate occupational health and occupational hazard control[14]. In order to prevent the occurrence of occupational hazards, Y mining group has adopted corresponding management measures and technical measures. B Mine has set up its own dust management policy and occupational health management standards covering all aspects of dust prevention and control in the mine. In technical terms, the mine implements 13 advanced techniques including hydraulic negative pressure dust control and air curtain closed dust control system for fully-mechanized driving faces. Besides, the mine also applies a number of comprehensive dust control techniques and systems such as ultrasonic atomization, semiclosed dust control, wet vibrating wire dust removal fan. All these efforts have eventually brought down the dust concentration at workplaces by an average of 80% and mitigated the mine workers’ exposure to dust hazards. Z Mine also uses permanent cooling systems for mine construction and transition to control underground heat exposure in the coal mines.

Despite all these achievements, dust hazards on the coal mining faces are still a serious problem pending effective control in Y Group. From 2000 to 2009, the dust concentration dropped slowly but still stayed at around 9 mg/m^3; the number of dust-exposed workers was still large, fluctuating at around 4500 over the past 5 years when the raw coal output did not grow significantly; the proportion of mixed workers in total CWP victims rose a little and became the second most suffered type of work following mining and driving workers. To solve these problems, it would be recommendable that Y Group try more effective means such as ejecting precipitators and automatic spray on coal caving to further mitigate dust exposure and safeguard the operators’ health. They should also invest more efforts in preventing CWP among mixed workers and rearrange jobs to control the total number of dust-exposed operators. Finally, they should further raise the automation level in high-dust areas, expand the dust control coverage to minimize dust exposure, and effect CMP prevention measures to preclude CWP from the source.

5. Conclusions

This study aims at an important aspect of occupational health efforts, the prevention and control of occupational hazards, for the first time. The current occupational hazards within Y Group are examined after analysis on current occupational health and occupational hazard control among coal mines in and outside China, covering current dust and heat hazards, existing management policies and technical measures, and personal protections of the company, as well as the distributions of workers exposed to
different occupational hazards and the types of workers among the CWP victims. Through statistics of occupational hazards present and CWP victims (severity, age, length of service, and type of work) in Y Group and B Mine, we investigated the distribution of workers among different occupations and compared the proportions of the types of work between in-service and retired CWP victims to ensure a higher selectivity for CWP prevention; we quantified heat dissipations on the development, driving, and mining faces of Z Mine and their respective contributions by calculating heat from wallrocks, oxidation and other sources. The results show that wallrocks constitute the main heat source for the development, driving, and mining faces; electro-mechanical devices and hot water constitute the main heat sources for mining faces. We also conducted a comprehensive analysis on the technical measures taken and the cooling result of Z Mine during mine construction, transition and production stages. In our study, we introduced a new index, the “number of dust-exposed workers per ten thousand tons of raw coal”, this index is an innovative index, which can reflect the source control of dust hazards in coal mines and the degree of mechanization in main dust production processes to some extent.

References
[1] Yuyuan Z, Yansong Z, Bo L. (2014) Experimental study on the characteristics of gas explosion in large pipelines and the damage to animals at the ends. Safety in Coal Mines, 33(02): 67-74.
[2] Zhou G, Cheng WM, Tian CQ, et al. (2014) Hazard identification, evaluation and control of mine ventilation system[J]. Journal of shandong university of science and technology (natural science edition.), 33(06): 51-57.
[3] Jia HG, Cao QG, Wang SL, Zhang SM. (2015) Mine big data analysis and workers 'unsafe behavior pre-control research. Journal of shandong university of science and technology (natural science edition). 34(02): 14-18.
[4] Sun YF, Gong X. Transition of resource cities based on life cycle theory (in Chinese). (2010) HLJ Foreign Economic Relations & Trade.; 187(1): 109–110.
[5] Yuyuan Z, Yansong Z, Bo L, Xiangbao M. (2019) Prediction of the length of service at the onset of coal workers' pneumoconiosis based on neural network. Archives of Environmental & Occupational Health. DOI:1080/19338244.2019.1644278
[6] Sun ZP, Wang YY, Li XQ, (2015) Study on comprehensive dust control technology in thin coal seam mining. Journal of shandong university of science and technology (natural science edition). 34(02): 14-18.
[7] De Vuyst P, Camus P. (2000) The past and present of pneumoconiosis. Curr Opin Pulm Med.; 6(2): 151–156. PMID: 10741776
[8] Yansong Z, Yuyuan Z, Gongyan Z. (2019) Risk assessment of explosive dust workplace based on improved interpretative structure model [J]. Industrial Safety and Environmental Protection, 2019, 45(04): 34-38.
[9] Zhou G, Cheng WM, Wang G, Cui XF. (2010) Experiment research of the coupling relationship between dust field and droplet field about fullymechanized and roof caving work face. J China Coal Soc. 2010; 35:1660–1664.
[10] Świątkowska B, HankeW, Szeszenia-Dąbrowska N. (2017) OccupationalDiseases in Poland in 2016. Nofer Institute of Occupational Medicine:Łódź, Poland, 2017.
[11] Świątkowska B, Hanke W. Occupational diseases in Poland in 2016.Med Pr. 2018 pii: 92434. doi: 10.13075/mp.5893.00745 (in Polish).
[12] World Health Organization (WHO) report 2001. Available from www.who.int/quantifying_ehimpacts/global/ebdcountgroup/en/index.html2001. [Last accessed on 2015 Jun 15].
[13] International Labour Organinization. Mining: a hazardous work[Internet]. 2015 [cited 2015 Feb2]. Available from http://www.ilo.org/safework/areasofwork/hazardous-work/WCMS124598/lang–en/index.htm.
[14] Gyekye SA. Workers' perceptions of workplace safety: an Africanperspective. Int J Occup Saf Ergon. 2006; 12: 31e42.