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An analysis of fatal gas accidents in Chinese coal mines

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ABSTRACT

Although the total death toll due to various accidents in China's coal mining industry has declined in recent years, coal mine gas accidents, which are usually caused by gas explosions and outbursts, are still threatening miners' lives. Fatal gas accidents in Chinese coal mines are quantitatively analyzed using data from 2006 to 2010. Gas accidents account for a significant portion of the death toll in Chinese coal mining. The analysis of gas accident intervals reveals an approximately exponential distribution. The influence of coal mine ownership, gas content in coal and regions of coal mines on safety is determined quantitatively, and the accidents are grouped by cause. Management problems in the coal mining industry are also dissected.

1. Introduction

As China's primary energy supply, coal plays a leading role in supporting the country's energy needs (Andrews-Speed et al., 2003; Burgherr and Hirschberg, 2007; Eliasson and Lee, 2003; Horii, 2001). China is by far the largest coal producer and consumer in the world. With the rapid economic growth from 1990 to 2010, China's raw coal production tripled from 1080 to 3240 million tonnes (Mt), and its proportion to the world total coal production increased from less than one quarter to nearly one half (BP, 2011).

Despite the coal industry's substantial contribution to the economic development of China, it bears the worst safety record in the world. Even with steady safety improvements in recent years, thousands of people are killed in coal mining each year, hundreds of times of the corresponding death toll of the United States (Fig. 1). China's annual coal mining fatality rate (defined by death toll per million tonnes of coal production) is consistently much higher than that of other large coal producers (Fig. 2).

The major accident categories for coal mining in China are gas accidents (primarily gas explosions and outbursts), roof falls, flooding, fire and haulage (SACMS, 2011). Gas accidents constitute an increasing fraction of the fatality list in Chinese coal mining. Table 1 lists the most devastating gas accidents in recent years.

While many publications have analyzed China's general coal mine safety (Burgherr and Hirschberg, 2007; Hirschberg et al., 2003a,b; Kezhi and Courtney, 2009; Liu and Zheng, 2005; Maiti et al., 2009; Wei, 2011; Yu and Zheng, 2005), a focus on fatal gas accidents is rare (Li et al., 2009). Motivated by the severity of coal mine gas accidents, this paper presents an analysis of the fatal coal mine gas accidents in China and attempts to quantitatively identify the various factors affecting safety problems related to coal mine gas. A classic distribution analysis on the coal mine gas accidents of China was performed and some interesting patterns were found, followed by a statistical analysis in term of coal mine ownership, accident type, gas content and coal mine region. Tentative causes of gas accidents were also diagnosed in the final part of the paper. The findings of the paper give an in-depth look at the problems of coal mine gas accidents and are useful for the improvement of the safety conditions of coal mining industry.

2. Background of the analysis

Reports from the State Administration of Coal Mine Safety (SACMS) reveal that within the 26 provinces/autonomous regions/municipalities that produce coal, 15,071 and 12,722 coal mines were in operation in 2007 and 2008, respectively (SACMS, 2008b, 2009). Although the number of mines has declined due to the closure or consolidation of some small mines, these numbers are perhaps the largest among the main coal producers in the world. In China, coal mines have historically been classified into three categories, based on size and operational structure:

- National strategic mines (NSMs), which have the largest production. Of the 12,722 mines in operation in 2008, only 885 were NSMs; however, these mines accounted for approximately

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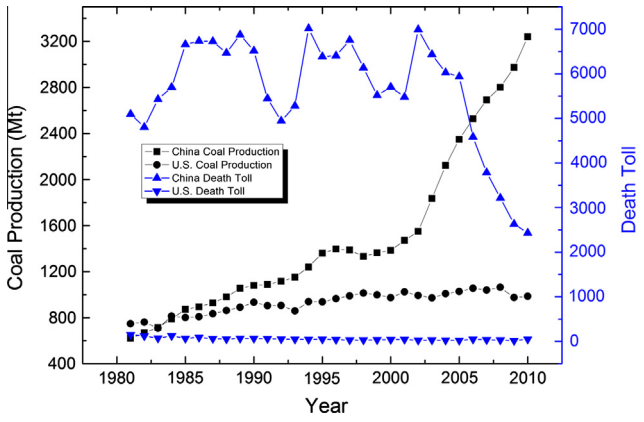

Fig. 1. Annual coal production and death toll from coal mining of China and the United States, 1981–2010. *Footnote*: Sources: data for coal production is from British Petroleum, plc. (BP, 2011); data for death toll in coal mining of China is from the online accident inquiry system of State Administration of Work Safety of China (SAWS, 2011); data for death toll in coal mining of the US is from the US Mine Safety and Health Administration (MSHA, 2011).

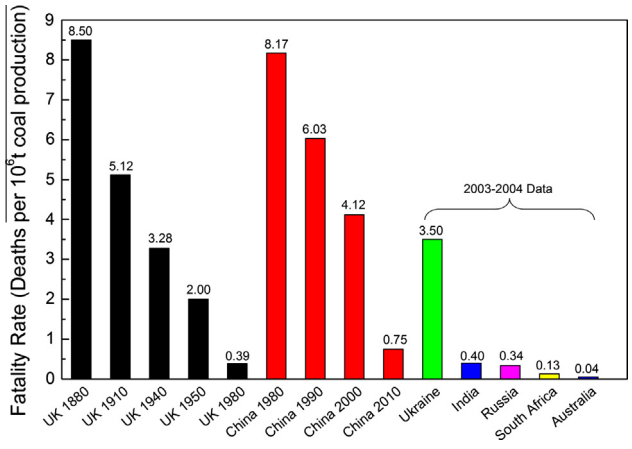

Fig. 2. Fatality rates from underground coal mining in the world's main producers. *Footnote*: Reproduced from Fig. 2.1 of Asian Development Bank's report (ADB, 2009) with additional data for China (BP, 2011; SAWS, 2011). The data of coal production of China is for total coal production (including both underground and surface).

Table 1
Gas accidents each causing more than 100 deaths in Chinese coal mines in recent years.

Location	Date	Deaths	Accident type
Xinxing mine, Heilongjiang	21 November 2009	108	Outburst induced explosion
Yuanxinyao mine, Shanxi	5 December 2007	105	Explosion
Liuguantun mine, Hebei	7 December 2005	108	Explosion
Haizhou mine, Liaoning	14 February 2005	214	Explosion
Chenjiashan mine, Shaanxi	28 November 2004	166	Explosion
Daping mine, Henan	20 October 2004	148	Outburst induced explosion
Chengzihe mine, Heilongjiang	20 June 2002	124	Explosion

half of the national production (SACMS, 2008a, 2009). These large mines are generally equipped with advanced technology and machinery.

- Provincial national mines (PNMs). In 2008, there were 1320 of these provincially administrated mines (SACMS, 2008a, 2009). Most PNMs adopt mining technologies with partial mechanization (Wang, 2000).
- Township mines (TMs). This third category contains primarily mines that are under collective or private ownership. The number of TMs decreased sharply in recent years (Andrews-Speed et al., 2003; Burgherr and Hirschberg, 2007; Horii, 2001; Shen and Andrews-Speed, 2001), although they still represent approximately 10,000 mines, which account for only approximately one third of the total production (SACMS, 2008a, 2009). Due to their low production, they are usually referred as "small mines". The state-owned NSMs and PNMs have notably better safety records than the TMs, which are usually the most dangerous and least regulated mines.

In addition to these three categories, the number of illegal mines, which operate without a permit or safety inspections, is assumed to be large.

As required by the Chinese safety code, *Specification for Identification of Classification of Gassy Mines* (SAWS, 2006), all coal mines in operation in China should be classified with regards to gas hazard. The classification categories based on the gas emission rate are (1) Slightly Gassy Mines (SGMs), (2) Highly Gassy Mines (HGMs) and (3) Outburst-Prone Mines (OPMs). In addition, Unclassified Mines (UCMs) are mines that are under construction or illegal. According to the 2008 coal mine gas hazard specification (SACMS, 2009), NSMs, PNMs and TMs account for 176 (23%), 89 (12%) and 489 (65%), respectively, of the 754 OPMs. Of this total, 609 OPMs (81%) have annual productions of less than 0.3 Mt. The five southern regions (Guizhou, Hunan, Yunnan, Sichuan and Chongqing) contain 590 OPMs, which is 78.3% of the total.

Out of 2433 Chinese coal mine death toll in 2010, 623 (25.6%) were due to gas-related accidents (explosions, outbursts, etc.) (SACMS, 2011). Only roof falls, with 829 deaths, comprised a larger proportion of the total (34.1%). According to the investigation by Burgherr and Hirschberg (2007), over a long period, coal mine gas was responsible for the highest number of accidents and death toll. As shown in Fig. 3, gas accidents often cause the most severe damage.

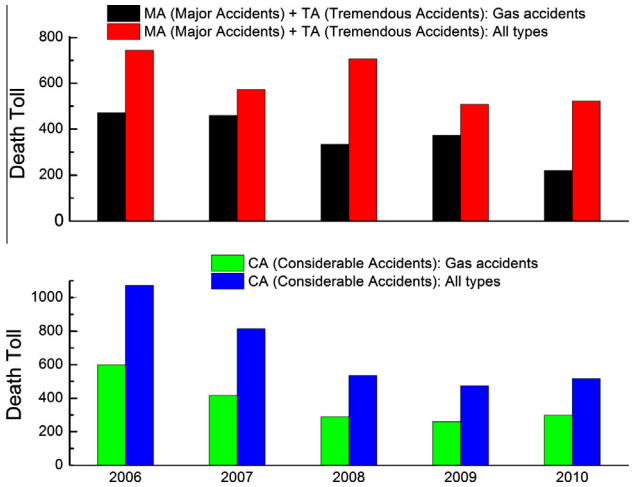

Fig. 3. Comparison of gas accidents with the total coal mine accidents with regard to death toll. *Footnote*: The CA (Considerable Accidents), MA (Major Accidents) and TA (Tremendous Accidents) respectively represent deaths of 30 or more, 10–29 and 3–9 in one single accident, according to the Coal Mine Safety Code of China (SACMS, 2001).

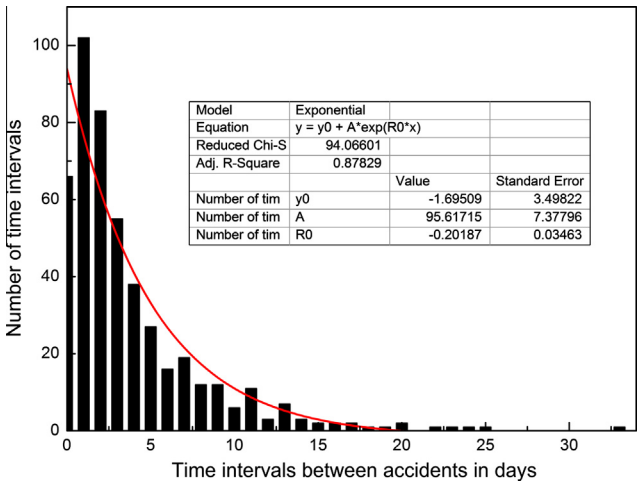

Fig. 4. Histogram of time intervals between gas accidents involving three or more deaths with fitted exponential curve.

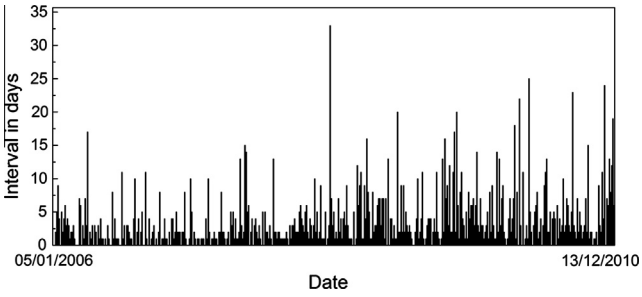

Fig. 5. Time intervals in days between Chinese coal mine gas accidents involving three or more deaths from 5 January 2006 to 13 December 2010.

3. Methodology

Greenwood and Woods (1919) first analyzed industrial accidents based on the frequency of accidents occurring in fixed intervals of time. Other researchers have studied this subject using various sources of mining accident data (Cox and Lewis, 1966; Jarret, 1979; Maguire et al., 1952). More recent researchers, e.g., Loader (1992), Fearnhead (2006) and Zhang et al. (2007) also applied the theories in their work. A similar method is used in this paper to analyze the fatal gas accidents in Chinese coal mines from January 2006 to December 2010.

Whitworth (1901) showed that if the expectation of events per unit time is constant, then the time intervals between events are exponentially distributed. In Fig. 4, these intervals are shown to be approximately exponentially distributed, which supports the accuracy of the data.

4. Results

4.1. Distribution of accident intervals

Fig. 5 gives the time intervals between gas accidents that involved three or more deaths in Chinese coal mines. This figure reveals the high frequency of gas accidents in Chinese coal mines: the longest interval between two accidents was only 33 days while the shortest was 0 (meaning more than one accidents in a single day). The average interval in the five-year period was 3.8 days.

The cumulative number of gas accidents and death toll as a function of time in Chinese coal mines are shown in Fig. 6 and the curves display a slight concavity, which reflects the effect of safer modes of production and better safety practices in recent times.

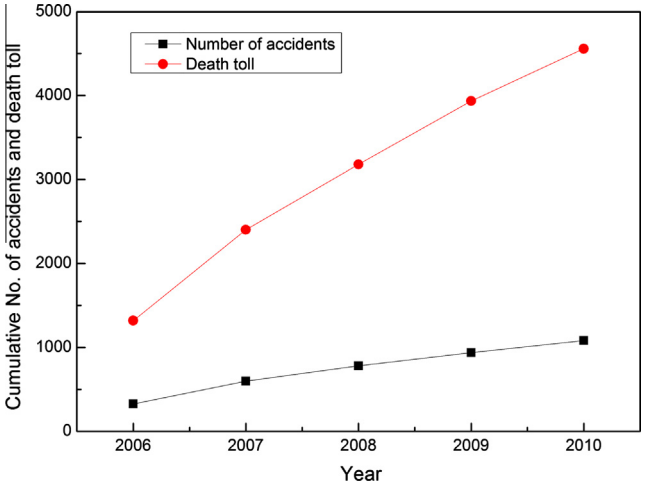

Fig. 6. Cumulative numbers of gas accidents and death toll against date in Chinese coal mines.

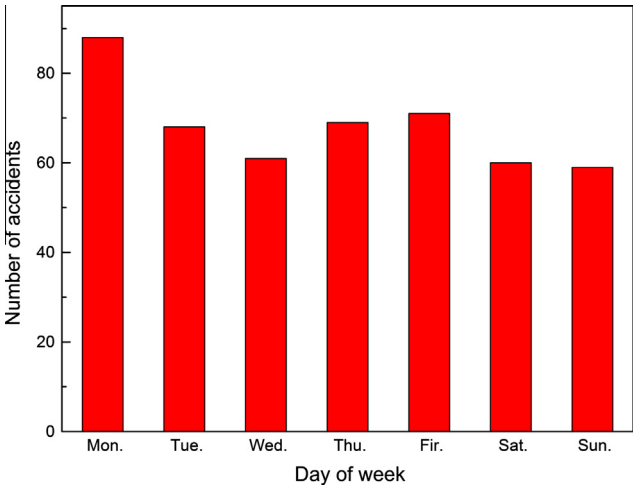

Fig. 7. Distribution of gas accidents over the days of the week.

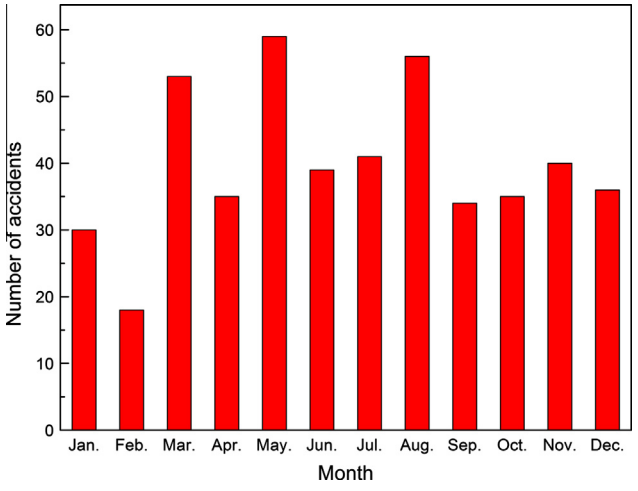

Fig. 8. Distribution of gas accidents over the months of the year.

The distribution of gas accidents over the days of the week and the months of the year is shown in Figs. 7 and 8, respectively. While accidents generally scatter evenly in weekdays and months, more accidents occurred on Mondays and in the summer. While it is difficult to give a plausible reason for the higher accident rate on Mondays, the relatively higher accident rate in the summer can be explained by the heat, which may contribute to worker fatigue in the hot and humid underground environment.

4.2. Statistical analysis

4.2.1. Analysis by coal mine ownership

The relationship between the proportions of NSMs, PNMs and TMs as well as the total number of gas accidents and death toll from 2006 to 2010 is illustrated in Fig. 9. In general, TMs, which account for 36.9% of the total coal production, are responsible for over 70% of the accidents and death toll. Earlier data show that the fatality rate per Mt production of TMs is as much as 8 times that of the NSMs (Yu and Zheng, 2005). Variations in different years are usually due to unusual increases in the number of gas accidents in the NSMs and PNMs. For example, the proportion of death toll for the NSMs increased to 38.3% in 2009 as a result of the unusual rise of gas accidents.

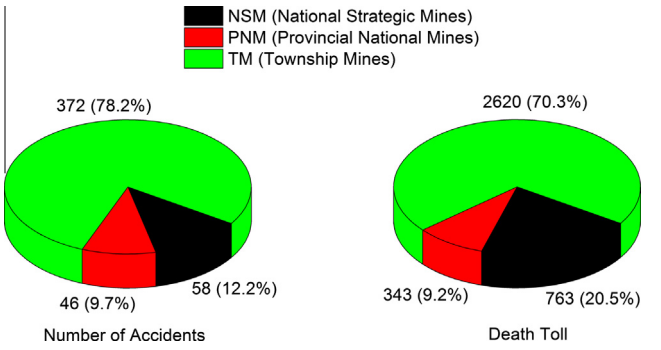

Fig. 9. Proportions of the NSMs, PNMs and TMs on the total number of gas accidents and death toll from 2006 to 2010.

4.2.2. Analysis by accident type

According to China's regulations for investigating coal mine accidents, coal mine gas accidents can be classified into four categories: gas explosion, gas outburst, gas combustion and gas-induced asphyxia. The numbers of accidents and death toll for the gas explosions dominate in the four categories from 2006 to 2010 (Fig. 10). Yearly comparisons show that the number of explosions has been in sharp decline, while the number of outbursts has been steadily increasing. In 2008, the number of accidents and death toll for the outbursts exceeded that of the explosions for the first time, highlighting the severity of the outbursts in Chinese coal mines.

4.2.3. Analysis by gas content

Surprisingly, of the four gassiness classifications, the SGMs have the highest number of accidents and death toll from 2006 to 2010 (Fig. 11), which reveals the inadequacy of this classification and the lack of supervision.

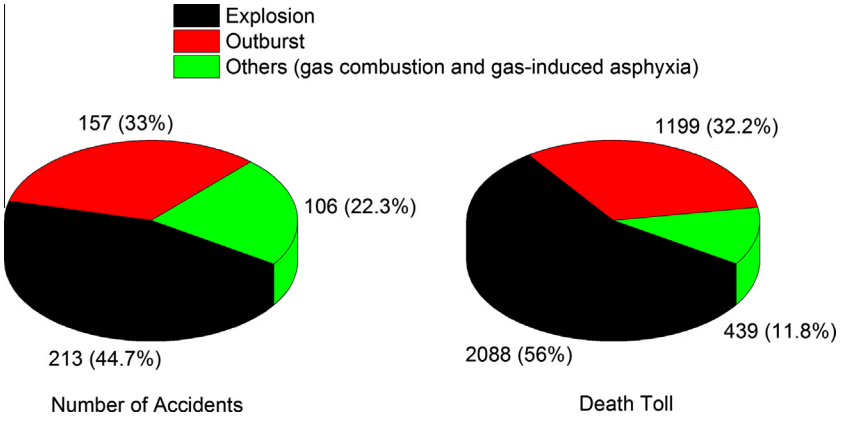

Fig. 10. Proportions of different causes on the total number of gas accidents and death toll from 2006 to 2010.

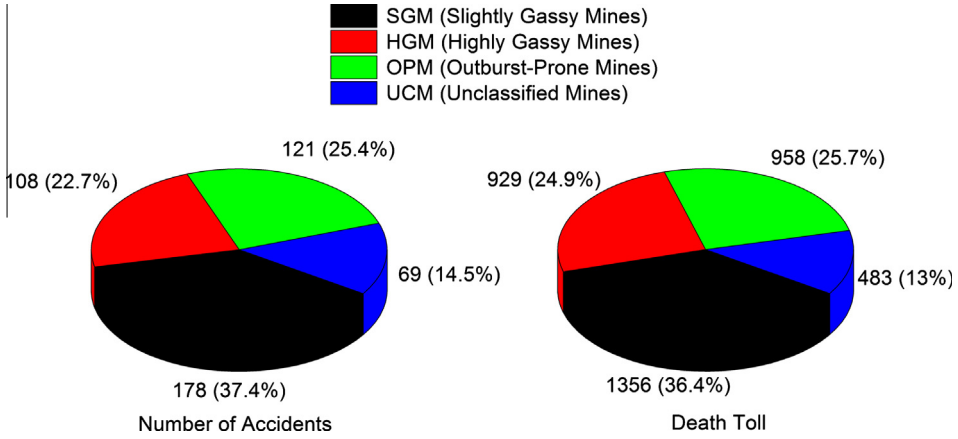

Fig. 11. Proportions of mines with different gas contents on the total number of gas accidents and death toll from 2006 to 2010.

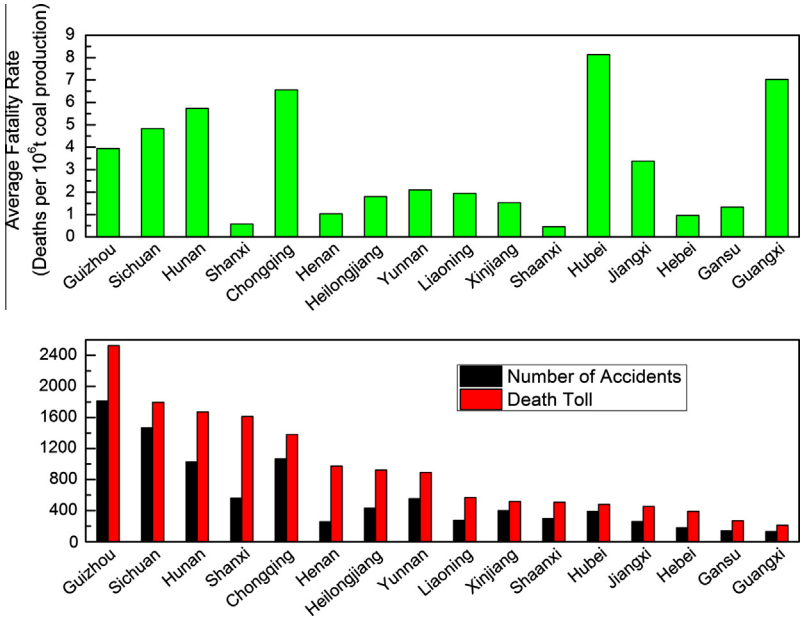

Fig. 12. Regional comparison of on the total number of gas accidents, total death toll and average fatality rate per Mt production from 2006 to 2010.

4.2.4. Analysis by region

Twenty-six Chinese provinces, autonomous regions and municipalities produce coal. According to the data from 2006 to 2010, the regions with the most accidents and largest death toll and fatality rate are generally in southern China (Fig. 12). The five southern regions with the deadliest records, Guizhou, Sichuan, Chongqing, Hunan and Yunan, account for 55.3% and 41.7% of the national total gas accidents and death toll, respectively. However, these regions supply only 13.5% of the total national coal production. The average fatality rate per Mt production of these five regions is 4.63, which is nearly four times the national average. This production-safety imbalance is due to the complicated geological conditions and high gas content in China's southern coal mines.

5. Discussion

Coal mine gas accidents occur more frequently at the faces of roadway development and in the TMs. The causes of gas explosions include missing or improperly installed gas extraction system, insufficient sensors, improper ventilation and illegal blasting. Gas outbursts mostly occur in geologically disturbed areas or where coal seams are subjected to rapid geological changes.

The causes of coal mine gas accidents are also categorized as either direct or indirect. The direct causes involve the technical aspects of the accident, such as gas accumulation and the existence of ignition sources. The indirect causes usually indicate improper management.

In this section, three types of gas accident causes are analyzed: gas explosion, gas outburst and safety mismanagement.

5.1. Gas explosions: a leading threat to miners' safety

Gas explosion accounts for most of the gas accidents. Three necessary conditions are needed for a gas explosion: (1) a 5–16% gas accumulation concentration; (2) an ignition energy greater than 0.28 mJ, temperature higher than 595 °C and ignition lasting for the initiating period for gas explosion; and (3) an oxygen concentration greater than 12% with CO_2 as the inert gas or 9% with N_2

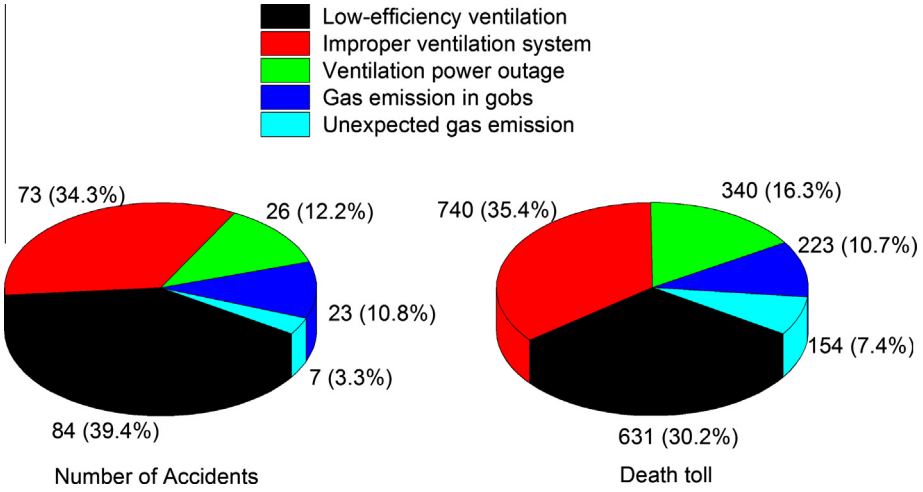

Fig. 13. Causes for the gas accumulation that could result in gas explosion. (Data collected from 2006 to 2010.)

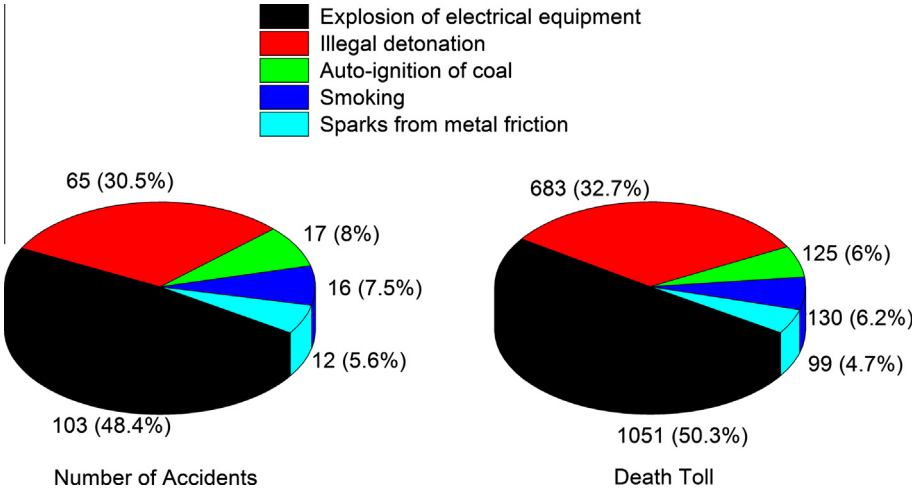

Fig. 14. Causes for the ignition source, a necessary element for gas explosion. (Data collected from 2006 to 2010.)

as the inert gas. As mechanical ventilation is used in underground coal mines, the oxygen concentration is usually greater than the minimum. Therefore, only the gas accumulation and ignition source are analyzed within this paper. The origins of these two factors are illustrated in Figs. 13 and 14.

5.2. Outburst: a deteriorating situation

A gas outburst is the sudden release of gas energy and stress energy in the coal seams, creating a burst of a large amount of coal, rock and gas. The amount of coal and rock could be tens of thousands of tonnes, and the amount of gas could be millions of cubic meters. An outburst could lead to a gas explosion. While most coal producers in the world have abandoned mines with high gas contents, the Chinese coal mining industry is still exploiting dangerous outburst-prone mines due to its energy structure's unusually high dependence on coal.

China's continued dependence on coal production means that the mining operations are mining deeper and that more gassy seams are mined (UN ECE and M2M Partnership, 2010), which increases the methane emissions in the coal mine and could lead to serious outbursts.

The outbursts are often caused by insufficient outburst prevention measures and a lack of proper safeguards during coal mining. These two factors are analyzed below.

5.2.1. Poor implementation of outburst prevention measures

In response to the increasingly serious outburst situation, the Chinese government issued a more rigorous industry code, *Regulations for the Prevention of Coal and Gas Outburst*, based on the original *Guidelines for the Prevention of Coal and Gas Outburst*, which has been effective since 1 August 2009. The new code requires that large-scale outburst prevention measures be adopted to eliminate the outburst risk in outburst-prone seams before mining. However, at present, most OPMs (especially the TMs) are unable to properly implement the new requirements for outburst prevention.

Based on a preliminary estimate, the OPMs with annual outputs of less than 0.3 Mt would not be profitable if these new requirements are strictly implemented. This finding reveals part of the cause of the poor implementation of anti-outburst measures in small mines.

5.2.2. Mining outburst-prone seams

Mining safety in coal mines with high gas contents requires the determination of gas occurrence, outburst prevention design and the construction, validation and testing of outburst prevention measures and safety knowledge. Furthermore, professional and technical personnel, a specialized management department and a specialized construction team are also necessary to prevent outbursts. Many outburst-prone TMs lack these tools and thus are incapable of safely mining outburst-prone seams.

5.3. Poor safety management: an indirect but important factor

Coal mine safety is closely related to the employees' qualifications. Although some NSMs and PNMs may lack specialized personnel, a sound management system as well as education and training systems ensure the improvement of safety in such coal mines. However, most TMs have a limited budget for safety issues and thus lack state-of-art safety equipment and systems. In addition, due to the unsafe conditions and low wages, competent engineers, such as college graduates, are reluctant to work in these mines. The education and training systems, even those required for key positions in some TMs, are usually not available.

In the case of the devastating gas explosion accident on 25 November 2006 in the Changyuan coal mine, Yunnan, which killed 32 miners, the mine's five-person management staff was comprised of one junior high school graduate, three primary school graduates and one illiterate employee.

Currently, the inspection of Chinese coal mines is conducted by SACMS, representing the central government, as well as the Provincial Administration of Coal Mine Safety (PACMS) and the Municipal Administration of Coal Mine Safety (MACMS), representing the local government. As there are more than 10,000 coal mines in China, many regions suffer from a severe shortage of inspection staff. In some of the major mining regions, one supervision department is responsible for the inspection of hundreds of mines. Driven by their own interests, local administrations might overlook the violation of regulations and standards of some TMs. In addition, corruption has also appeared in the safety supervision process.

The coal mine safety regulations in China are not implemented to the same degree for every coal mine ownership. The NSMs and PNMs are strictly required to obey the codes and standards, while the restrictions for the TMs are looser, thus contributing to the high rate of gas accidents. If all coal mines, especially the TMs, meet the requirements of the *Safety Code for Coal Mines* and the *Regulations for the Prevention of Coal and Gas Outburst*, a sharp decrease is expected on the total accidents and the death toll.

Coal mining in China involves a wide distribution of coal mines, varied geological conditions and severe safety hazards. Therefore,

scientific research of coal mine safety should be conducted to determine gas occurrence and mining dangers. Effective gas control techniques and management methods increase the safety of the coal mine. While more of the safety measures based on scientific research are implemented for NSMs, little guidance is provided from the scientific community to address safety for the TMs (Burgherr and Hirschberg, 2007).

6. Conclusions

Although the number of gas accidents and death toll in China's coal mining industry has decreased in recent years, coal mine safety is will remain an important issue in the near future. The following statements summarize the major findings of this study.

- The severity of gas accidents is significant compared to that of other types of coal mine accidents.
- The intervals of gas accidents are approximately exponentially distributed. The cumulative numbers of gas accidents and death toll show an improving safety record.
- Gas explosions and outbursts are the leading types of gas accidents.
- Though categorized as having low gas content, the slightly gassy mines have the largest number of total accidents and death toll.
- China's southern provinces have a worse safety record for coal mining.
- Chinese coal mining management is hindered by poorly qualified employees, inadequate supervision of coal mine safety and an insufficient input of scientific research.

Acknowledgement

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