Powder Technology 286 (2015) 401–411

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Study of the destruction of ventilation systems in coal mines due to gas explosions

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ARTICLE INFO

Article history:
Received 30 March 2015
Received in revised form 9 July 2015
Accepted 14 August 2015
Available online 22 August 2015

Keywords:
Methane/air explosion
Overpressure wave
Weak panel
Fragment size
Ventilation recovery

ABSTRACT

Gas explosions presented a serious safety threat in the mining industry worldwide. Many coal miners had been killed due to explosions in mining. The malfunction of a ventilation system caused by a gas explosion was the primary reason for casualties in coal mines. In this study, two models were built to simulate ventilation systems in which gas explosions often occur. The models consisted of a pipe incorporating weak panels. Using each model, the propagation of the overpressure shock wave and the distribution on the ventilation system were verified. According to the characteristics of multiple ventilation facilities in a local ventilation system, the combined effects of bends and bifurcations and the destruction of ventilation facilities in the local network model due to an overpressure wave were analyzed. By analyzing the distribution of the methane/air mixture explosion overpressure wave in the pipe models, the effect of a weak panel on the explosion shock wave and the degree of explosion damage were characterized by the statistical results from the sizes of the fragments. The explosion wave peak overpressure in the forward direction was higher than the peak overpressure in the elbow bend direction. After explosion, the production gas was immediately extracted and the composition was analyzed. The destruction order for different ventilation facilities in the local ventilation system was determined according to the pipe model experimental results. The disaster of gas explosion for ventilation network and workers was analyzed, and the spare door was designed to recover the ventilation system after gas explosion.

1. Introduction

In 2009, 157 gas explosions were responsible for 755 fatalities in Chinese coal mines, representing 28.7% of all Chinese coal mine fatalities [1]. On March 21st, 2011, a serious gas explosion in Pakistan's Sorange mine killed 43 miners [2]. A total of two explosions in the Pike River Mine disaster that occurred on November 19th, 2010, in New Zealand killed 29 miners. This accident was ranked as New Zealand's worst mining disaster since 1914, when 43 men died at Ralph's Mine in Huntly [3]. Throughout the coal mining history of the U.S., gas explosions were also considered to be the most dangerous hazard. The Monongah mine disaster of Monongah, West Virginia that occurred on December 6th, 1907, has been described as “the worst mining disaster in American History”. Because of the Sago mine disaster of 2006, the U.S. mining industry became more aware of the composition of sealed atmospheres [4]. Preparations should be made for such accidents. The historic underground coal mine disasters due to gas explosions in the United States from 2001 to 2010 are presented in Table 1. The historic underground coal mine disasters due to gas explosions in China in 2012 are presented in Table 2.

The initial temperature increase of a methane/air mixture can decrease the maximum explosion pressure, the maximum rate of pressure rise and the deflagration index [5,7]. However, with an increase in the initial pressure, the explosion pressure, the maximum rate of pressure rise, and the deflagration index increase [8,9]. The maximum explosion pressure versus the initial temperature of the methane/air mixture can be approximated by a linear function [7], and the linear dependence was also related to the initial pressure [9–11,21]. The flame thickness and the flame stability decreased with an increase in the initial pressure [12]. In the coal mine tunnel, a dust explosion was initiated by the rapid combustion of flammable particulates suspended in the air, thus, a coal dust explosion is usually caused by a gas explosion but was more severe [13,14].

High temperature, blast overpressure and toxic gas in a gas explosion can result in serious casualties [15,16]. Due to the rapid attenuation of overpressure and high temperature, most casualties occur around the explosion source [17–19]. However, extensive data indicated that the irregular smoke plume that still exists after the ventilation system was damaged can result in up to 70% of the casualties. A gas explosion shock wave can destroy the surrounding structures of the ventilation system and lead to large numbers of casualties [10,20–23]. The

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http://dx.doi.org/10.1016/j.powtec.2015.08.020
0032-5910/

Table 1
List of coal mine disasters due to gas explosions in the U.S. from 2001 to 2010 [6].

No.	Year	Day	Mine name, location	Deaths
1	2010	4–5	Upper Big Branch Mine Birchton, WV	29
2	2006	5–20	Darby Mine No. 1 Holmes Mill, KY	5
3	2006	1–2	Sago Mine Tallmansville, WV	12
4	2001	9–23	No. 5 Mine Brookwood, AL	13

explosion flame can ignite combustible materials in the vicinity of the ventilation system, resulting in a larger scale fire. Combustion can also promote the development of an explosion and produce more smoke. High concentration smoke cannot be controlled effectively or diluted quickly by fresh air and thus can cause suffocation. In addition, the explosion smoke plume flow may cause a secondary explosion or even continuous explosions.

Many researchers have thoroughly studied the propagation mechanism of gas explosions. Zhai et al. [24] studied the propagation of explosions using complex pipeline models and observed “T”, “U”, and “Z” patterns. Experimental and numerical simulation results indicated that the angles of roadway bends promoted the overpressure wave, which was further affected by the volume of gas involved in the explosion and the propagation path number. Xu [25] studied the stimulation effect of obstacles in a pipe in the flame zone and in the non-flame zone by numerically simulating the effect of obstacles in a single heading roadway. Lin and Gui et al. [26,27], verified the stimulation effects by experimentally studying the effect of multi-level obstacles on flame acceleration and overpressure propagation. Jiang et al. [28,29] studied the inhibition effect of a vacuum chamber on the propagation of gas explosions and determined the effect of gas concentration on explosion overpressure that was caused by various types of shock waves. Zhu et al. [30–32] quantitatively analyzed the influence of a hedging flame on the propagation of explosive shock waves in a pipe model.

However, few researchers have considered injuries caused by gas explosions in terms of the destruction of the ventilation facilities, the changes in the ventilation network structure, or the variations of the smoke plume flow movement and control methods for smoke dispersion [33]. Gas explosions may occur at any location in underground coal mines, but more than 80% of the explosions occur at mining faces [34]. The primary aim of an emergency rescue was to save lives, as a result, rapid recovery of the ventilation system was very important by studying the destruction of ventilation systems in coal mine gas explosions, the extent of damage caused by shock waves, and the smoke flow path of the movement, this study can provide a basis for the recovery of ventilation systems and the control of smoke flow in coal mine gas explosions.

Table 2
Coal mine disasters due to gas explosions in China in 2012 (http://media.chinasafety.gov.cn:8090/iSystem/shigumain.jsp).

No.	Year	Day	Mine name, location	Place	Deaths
1	2012	2–3	Diao Yutai Coal Mine Shi Chuan	Roadway	13
2	2012	2–14	Xing Da Coal Mine Xin Jiang	Roadway	6
3	2012	3–22	Da Huang Coal Mine Liao Ning	Mining face	5
4	2012	4–23	Xing Ya Coal Mine Nei Menggu	Mining face	9
5	2012	5–15	Zhun Nan Coal Mine Xin Jiang	Roadway	6
6	2012	6–12	Qian Guang Coal Mine Jiang Xi	Mining face	5
7	2012	7–29	Guan Shan Coal Mine Liao Ning	Headings	3
8	2012	8–28	Hong Xing Coal Mine Xin Jiang	Sealed	6
9	2012	8–29	Xiao Jiawan Coal Mine Shi Chuan	Mining face	48
10	2012	9–2	Gao Keng Coal Mine Jiang Xi	Mining face	15
11	2012	12–17	Niu Lanchu Coal Mine Hu Nan	Headings	7

2. Experimental study of gas explosions destroying a ventilation system

Because explosions were influenced by many factors, most of the results regarding the propagation mechanisms of gas explosions were obtained by simulating an explosion in laboratory pipe systems. The aim of the experiment was to determine the distribution of propagation overpressure before and after the destruction of weak panels by gas explosion. The results could be used to determine the priority of the destruction of ventilation facilities at different positions in coal mines.

2.1. Models of a damaged ventilation system caused by gas explosion

According to the statistics regarding gas explosion accidents from the State Administration of Coal Mine Safety in China between 2001 and 2010, 49 gas explosion accidents occurred in the mining face, accounting for 48.5% of the total accidents number, 36 occurred at the tunneling face, accounting for 35.7%, and 16 occurred at the cavern chamber and other locations, accounting for 15.8%. Therefore, the majority of the gas explosions occurred in the mining and tunneling face. According to the mining face layout in a Chinese high-gas coal mine, the local ventilation systems in the mining face where gas explosion frequently occurred is shown in Fig. 1.

The topology method was used to reflect the characteristics of the site model which based on an analysis of local ventilation system. The place where the explosions often occurred, and the key factors influenced the propagation of gas explosions. Gas explosions often occurred near the side of the air-return roadway in underground mine working faces. Due to the mine shields and conveyor belts placed in the mining face, the shock wave propagated along the direction of the track roadway, which would be greatly reduced or even eliminated because of such barriers. Conversely, it is much easier for the shock wave to propagate along the air-return roadway. During the propagation, the shock

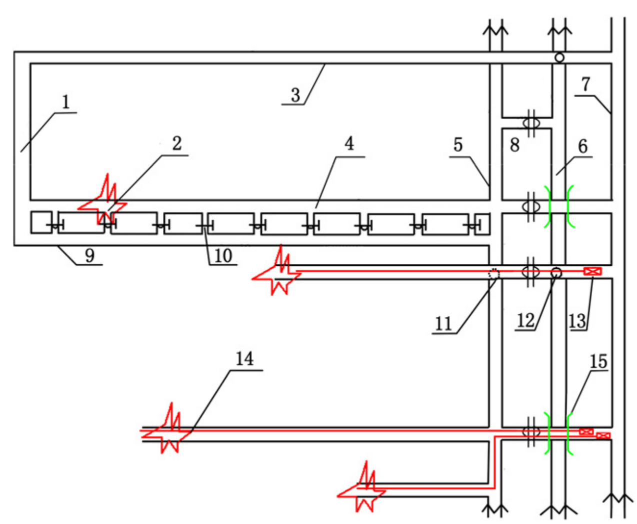

Fig. 1. Gas explosion models in the mining face. 1—Mining face, 2—Gas explosion frequency position, 3—Mining face intake airway, 4—Mining face return airway, 5—Mining area return airway, 6—Mining area transit lane, 7—Mining area track lane, 8—Air doors, 9—Special return airway, 10—Windshield adjustment, 11—Ventilation hole, 12—Milling coal hole, 13—Local fan, 14—Tunneling face, and 15—Air crossing.