Experimental Study on Toxic Gas Produced during Pipeline Gas Explosions

JIA Zhi-wei[1,2] XU Sheng-ming[1]

（1.School of Safety Science and Engineering, Henan Polytechnic University, Jiaozuo, 454003, China
2.Central Plains Economic Zone Coal Methane cooperative innovation center in Henan Province， Jiaozuo, 454003, China）

Abstract: *Dangerous gas explosion accidents result in considerable amount of casualties and property damage. Hence, an investigation on the generation of poisonous gases in gas explosions exerts important implications for accident prevention and control and in the decision-making processes of fire rescue. Therefore, a gas explosion piping test system is established in this paper. Experimental research on gas explosion is conducted by selecting methane/air premixed gases with concentrations of 7%, 9%, 11%, 13%, and 15% in the gas explosive range. This research aims to reveal the regularity of CO generation after gas explosion in pipelines. Experimental results showed that when the gas concentration is small (< 9%), 1500–3000 ppm CO will be produced. When the gas concentration is large (> 9%), the CO amount will reach 3000–40000 ppm. The variation trend in CO concentration and the quantity of explosive gas are also obtained.*

Key Words: *gas explosion, piping test system, gas concentration, CO concentration*

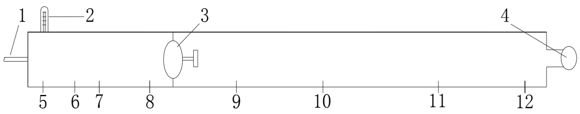
I. Background and significance of the study

Approximately 95% of China's coal is obtained through underground mining, which involves complex geological conditions and relatively adverse working environments. In 2013, the average mining depth of large and medium coal mines is 650 m; the mining depth of Pingdingshan coal mine in Henan Province is 1000 m, which extends downward with an average annual rate of 10 m [1-3]. With the increased coal mining depth, the gas content and pressure in the coal and the gas emission quantity also increase, thereby causing increasingly severe gas explosions and coal and gas outbursts. In recent years, with the gradual increase in the coal mine safety management level and safety investment in China, the death rate per million ton coal decreases annually, and gas disaster has been effectively controlled [4-5]. Nevertheless, in 2013, the death rate per million tons of coal in China remains 10 times that of the United States; additionally, the death rate from gas and coal dust explosions still exceeds 100 each year [6-7]. In the past 10 years, considerable local and international research has been performed about the factors influencing the gas explosion generation and the effects of shape, size, angle, and wall roughness of underground roadway on the generation of flame and wave during gas explosion [8-14]. However, study on the mechanism and propagation law of gas explosion is still limited. In particular, research on the generation and influencing factors of toxic gas during gas explosion lacks a system. Results cannot also provide guidance on disaster relief decision for gas explosion accidents. Major coal dust explosion accidents result in a substantial amount of casualties and property losses, a remarkable psychological trauma to the people, and negative effects on the community. Therefore, research on the generation of shock wave, flame, and toxic gas during gas explosion presents important guiding significance for accident control and disaster relief decision [15]. The generation and propagation of toxic gas, which causes considerable harm, should be investigated. The obtained research results are largely important for estimating the diffusion range of toxic gas in underground tunnel after gas explosion accidents.

II. Experimental study on carbon monoxide produced by gas explosion in pipelines

2.1 Establishment of experimental systems

In this experiment, we used the experimental system with a total length of 20.9 m. The explosion pipeline showed a dimension of 80 mm × 80 mm. The gas explosion concentrations of 7%, 9%, 11%, 13%, and 15% of methane/air premixed gas were selected to produce CO. We concluded that the CO amount in the gas explosion accident is associated with the change in gas concentration. The schematic diagram of the gas explosion experiment system is shown in Fig. 1.



1 - High Energy Ignition Device, 2 - Vacuum Flow Meter, 3 - Spherical Valve, 4 – Poison Gas Collection, 5–8 Front CO Detection Point, 9–12 Rear CO Detection Point

Figure 1 Gas explosion experiment system

Prior to the experiment, the spherical valve was opened. The vacuum pump was picked up at point 4, the pipe was evacuated, the spherical valve was closed, and the gas with different concentrations was injected by the vacuum flow meter. The gas explosion started at the ignition device and continued in the ball valve on the left side of the pipeline. Points 5–8 were used to measure the gas explosion generated by the CO concentration. The distance between points 5–8 and point 1 was 0.25, 1.35, 2.2, and 3.95 m, respectively. The physical model of the experimental gas explosion system is shown in Figs. 2 and 3.

Figure 2 Cavity gas explosion experiment pipe system

Figure 3 Gas explosion experimental

2.2 Experimental data and treatment

Gas explosion with different gas concentrations (30 times) produced six groups of CO. Experimental results are shown in Table 1。

Table 1 Relationship between each measuring point and the gas concentration

CH_4 concentration / %	CO concentration / ppm			
	Measuring point1	Measuring point2	Measuring point3	Measuring point4
7	1550	1600	1550	1400
9	2100	1900	1550	2200
11	16300	15200	17500	10700
13	26750	31050	28350	29500
15	39300	36900	32500	40300
7	1350	1400	1200	1750
9	2200	1350	1400	1700
11	11250	12000	11000	14550
13	27750	28050	29350	30500
15	33300	37000	31500	40500
7	1650	1750	1300	1400
9	2400	2200	2000	2150
11	13250	12050	13050	14550
13	28500	29150	29550	28700
15	39500	43200	44050	39500
7	1850	1300	1650	1400
9	2150	2150	2150	2150
11	11250	14050	11050	10050
13	31750	28350	29650	27850
15	39050	30500	32050	36500
7	1550	1350	2450	1050
9	2100	2050	1800	1350
11	13050	10500	11050	10300
13	31750	29000	30750	31550
15	35050	38050	40450	36750
7	1700	1350	1300	1650
9	2200	1700	1450	2050
11	13300	12500	13200	14300
13	28550	29350	31050	29850
15	33050	39500	27050	37050

The six groups of experimental results were averaged. The relationship between the gas concentration and CO concentration was determined through the gas explosions with different concentrations, as shown in Fig. 4.

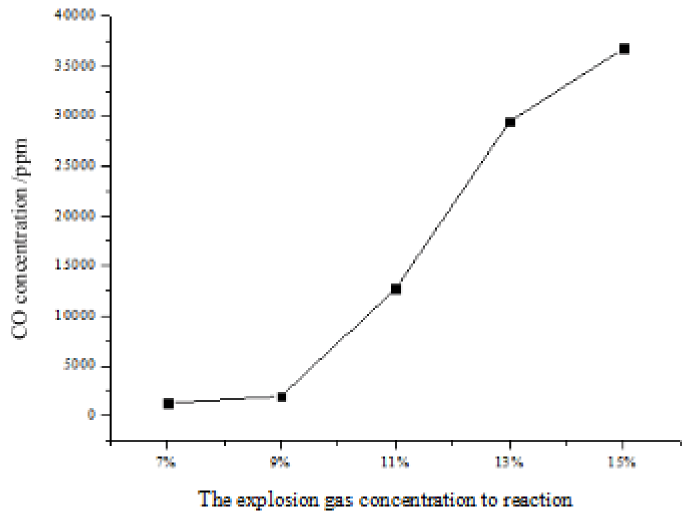


Figure 4 CO concentration with prefilled gas concentration

The relationship between CO and the amount of explosion gas involved in the enclosed confined space was obtained using the following equations:

$$y = 869.88x^{2.32};$$

$$R^2 = 0.9359.$$

III. Data analysis and conclusion

The amount of CO produced after a gas explosion in the pipeline is related to the concentration of the gas during explosion. Therefore, the gas concentration determines the peak density of CO. When the gas concentration exceeds 9%, the CO concentration also increases evidently; high gas concentration results in a large amount of CO produced. This result is attributed to that when the gas concentration is small (< 9%), the amount of oxygen in contact with the gas is relatively abundant. Consequently, methane can be fully reacted. Given that the gas density is less than that of air, a stratified phenomenon occurs in the pipeline mixing process: the gas is in the upper part, and the air is in the lower part. A small amount of gas combustion during explosion is insufficient, thereby producing a small amount of CO. When the gas concentration is relatively large (> 9%), the reaction occurs when the critical point begins to react strongly with a highly representative reaction. Furthermore, the oxygen cannot fully support all methane combustion, and the amount produced by the CO increases rapidly with increased gas concentration.

Experimental data analysis resulted in the following conclusions:

(1) When the gas concentration is small (< 9%), the gas explosion will produce a small amount of CO (1500–3000 ppm). By contrast, when the gas concentration is relatively large (> 9%), the gas explosion will produce a large amount of CO (3000–40000 ppm).

(2) High gas concentration results in large amount of CO produced. The following relation is also obtained: $y = 869.88x^{2.3248}$.

IV. Acknowledgement

This study was supported by Program for National Natural Science Foundation of China (No.51774120).

References:

[1] WANG Hai-yan, ZHOU Xin-quan, QU Zhi-ming. Study on influence and interrelation between shock wave and combustion wave of gas explosion [J]. Coal mine safety, 2008, 39(4): 1-4.

[2] XU Shao-qian, CAI Zhou-quan, LI Jian-xin. Experimental study on dissemination of low concentration gas explosion in pipelines [J]. Mining Safety and Environmental Protection, 2008, 35(2): 22-24

[3] LI Run-zhi. SI Rong-jun, ZHANG Yan-song, etc. Experimental study of low concentration gas explosion dissemination in pipeline [J]. Journal of Shandong University of Science and Technology, 2009, 28(1): 35-39

[4] JIA Zhi-wei, LI Xiao-jun, YANG Shu-zhao. The research progress of gas explosion dissemination in Coal[J]. Mining Safety and Environmental Protection, 2008, 35(6): 73-75.

[5] JIA Zhi-wei. Research on theoretical spreading law of shockwave of gas explosion in general air area[D].Henan Polytechnic University, 2008

[6] TAN Guo-qing, ZHOU Xin-quan, CAO Tao, ZHANG Dai-yue. The new characteristics of serious gas explosion accidents and especially serious gas explosion accidents in the resent years[J]. China Coal, 2009(4)：713

[7] LIU Jian-sheng, WANG Xiao-lei. study on the basic characteristics and occurrence regularity of gas explosion from 2001 to 2013[J]. Zhongzhou Coal, 2014, 9：72-76

[8] JING Guo-xun, YANG Shu-zhao. Experimental study on propagation characteristics of coal dust explosion[J]. Journal of China Coal Society, 2010, 35(4): 605-608.

[9] JING Guo-xun, DUAN Zhen-wei, CEHN Lei, YANG Shu-zhao. Research progressing explosion characteristics and spread law of gas and coal dust[J]. China Safety Science Journal, 2009, (19)4: 67-72.

[10]YANG Shu-zhao, JING Guo-xun, JIA Zhi-wei. Injury study on impact current of gas explosion in coal mine[J]. Journal of China Coal Society, 2009(10): 145-149

[11] JIA Zhi-wei, LIU Yan-wei, JING Guo-xun. Propagation characteristic about shockwave of gas explosion at lane way corner[J]. Journal of China Coal Society, 2011, 36(1): 97-100

[12] JIANG Bing-you, LIN Bai-quan, ZHU Chuan-jie, etc. Influence of uniform electric firld on flame transimission and blast wave in gas explosion[J]. Proceedings of 2010(Shenyang) International Colloquium on Safety Science and Technology，2010: 267-272

[13] LIN Bai-quan, JIAN Cong-guang. Inducement of turbulence and its effect on fire transmission in gas explosion[J]. Journal of China Univ ersity o f Mining and Tech no logy, 2003, 32(2): 108-110.

[14] LIN Bai-quan, GUI Xiao-hong. Computer simulation on the temperature Field of gas explosion and lab measurement for the flame thickness[J]. Journal of Experimental Mechanics, 2002, 17(22): 227-233.