Paper No. 175

ISMS 2016

Development and realization of a coal and gas outburst simulation device

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ABSTRACT

Similar coal and gas outburst simulation devices both at home and abroad are analyzed and their advantages and disadvantages are examined. A large size experimental device of coal and gas outburst simulation is developed based on the congeneric testing device. This device consists of coal and a gas outburst model system, gas injection system, loading system, stress measurement system, gas pressure measurement system, temperature measurement system, electromagnetic radiation testing system, and high-speed photography system. The functions of the device are as follows: (1) to study the laws of roof break development and stress evolution during outburst process by simulating coal seam, roof and floor with similar material, (2) to simulate stress distribution of a roof at high strength springs of different sizes, (3) to realize the uniform adsorption in coal by 3 gas injection pipes that are pre-buried, (4) to induce coal and gas outburst at predetermined gas pressure by blasting bursting disc instantly that set on the outburst hole, (5) to observe and record fracture and migration process of coal in the cavity during outburst that is achieved by a visual glass window on the side of cavity.

KEYWORDS：coal and gas outburst; testing device; similar simulation; gas pressure; ground pressur**e**

1. INTRODUCTION

Coal and gas outburst is a kind of complicated dynamic instability tbat occurs in underground coal mines (Hu Qianting et al., 2007). Most researchers study the mechanism of coal and gas outburst through laboratory simulation because of the danger involved in tracking studies of real coal and gas outburst occurring in coal mines. The one dimensional outburst simulation tests were conducted firstly in Soviet Union in the 1950s (Аируни, 1955). The results showed that the coal can be broken and thrown only under conditions of great gas pressure gradient. In the beginning of the 1960s, Japanese scholars conducted a simulation test of the ejection of coal through a shock tube (SHI Ping, 1985). In the test, ice crystals of carbon dioxide, rosin, cement, and coal particles were used to make a model. Driving was also simulated. Adsorption performance of the model varied wildly from the coal. Researchers believe that the degree of metamorphism, the diffusion coefficient, permeability, and porosity are closed related with coal and gas outburst, as shown through experiments and theoretical analysis (Beamish BB, Crosdale PJ., 1998, Sobczyk J., 2011). Norbert Skoczylas conducted an externally induced outburst test and the results showed that the intensity of outburst is affected by unloading time (Norbert Skoczylas, 2012).

In China, many universities and research institutes such as Shenyang Branch of China Coal Research Institute, Institute of mechanics of China Academy of Sciences, China University of Mining and Technology, Henan Polytechnic University, and Chongqing University furthered the research of coal and gas outburst by developing different simulation test devices. Deng Quanfeng et al. (1989) simulated the coal and gas outburst of Ⅳ, Ⅴ coal induced by rock cross-cut coal uncovering, and the coal model was conducted without any additive agent. Jiang Chenglin (1994; 2003) simulated the coal and gas outburst of Ⅳ, Ⅴ coal induced by rock cross-cut coal uncovering with a one dimensional outburst simulation test. Meng Xiangyue et al. (1996) conducted many tests using a two-dimensional simulation test device, and the results showed that the destruction of coal exists with “dehiscence” and “outburst”. Cai Chenggong (2004) designed a three dimensional simulation test device based on the similarity theory and mechanical model. A mathematical model of the relationship between the intensity of outburst and gas pressure, coal forming strength, three dimensional stress, and gas pressure was established. The simulation condition between briquette outburst and real coal seam outburst was put forward and dimensionless parameter criterion of outburst was established based on the comprehensive function hypothesis of outburst and similarity theory by Zhang Jianguo (Zhang Jianguo and Wei Fengqing, 2002). The change trend of temperature in the process of outburst was analyzed by Guo Liwen (Guo Liwen et al., 2000). The research team of Yin Guangzhi and Xu Jiang developed a comprehensive simulation device. In this device, different forming stress, different loading stress, different loading form and different diameter of outburst

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can be simulated for coal and gas outburst simulation tests. The cusp catastrophe instability model of creep fracture of coal containing gas based on testing machine and specimen system was established (Xu Jiang et al., 2008; Wang Dengke, 2009; Tao Yunqi, 2009; Ying Guangzhi et al., 2009). Wei Chunfu et al. (2014) studied the gas pressure effect in coal and gas outburst through a self-designed coal-rock gas dynamic disaster simulation test system. Wang Zhirong et al. (2014) discussed the mechanism of delayed outburst in “three soft” mining area through establishing nonlinear viscoelas to plastic rheological model of soft coal containing gas. Wang Gang et al. (2015) established a model of energy conditions for outburst and a prediction model for outburst intensity.

2. THE DEVELOPMENT IDEA AND PURPOSE

2.1 The development idea

In the light of deficiency of current coal and gas outburst devices, the development ideas of the simulation test device are as follows:

(1) The simulation test device is a large size device. The roof and floor of coal seam can be simulated by sand, quartz sand, gypsum and other aggregate, from which development of cracks in the roof and evolution of stress after and during the process of coal and gas outburst can be analyzed.

(2) The change of various physical parameters is very important for the research of outburst. Physical parameters such as coal temperature, gas pressure, stress, strain, and acoustic signal need to be collected in the test. This function will be realized by a variety of sensors and enameled wire.

(3) The simulation of real roof stress distribution of coal in front of mining face is always a difficult point in simulation tests. In this device, a series of springs are installed between the loading piston and the top of the roof. And the size and specifications of springs need to be calculated by real roof stress distribution of coal in front of mining face.

(4) This device should simulate coal and gas outburst under different condition such as different stress, different gas pressure, different loading form, and different diameter of outburst. In addition, the process of outburst can be record by high-speed camera. So the observation windows need to be installed at the device for the recording of the high-speed camera.

(5) The gas can be aerated and adsorbed evenly in the coal sample. To insure the gas can be aerated and adsorbed evenly in the coal sample, three inflatable tubes will be curried evenly in the coal sample in the process of coal forming. Some small holes will be drilled at the inflatable tubes for the inflow of gas into the coal sample.

(6) Blasting sheet and clamping device need to be installed at the outburst hole. Coal and gas outburst can be induced through fast blasting of blasting sheet at a prescribed gas pressure.

The design idea of a coal and gas outburst simulation device is shown in Figure1.

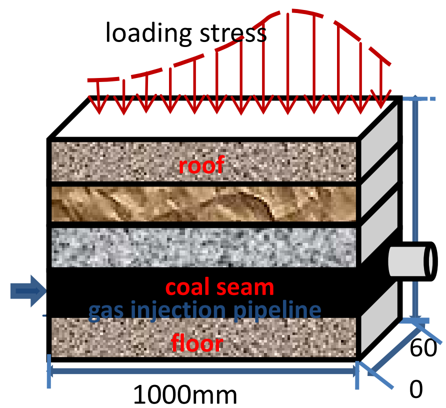


Figure 1: The design idea of a simulation device.

2.2 The development purpose

This test device is designed to simulate coal and gas outburst. Outburst process under conditions such as different forming stress, loading stress, gas pressure, loading form, thickness of coal seam, roof and floor conditions, and diameter of outburst is researched using this device. The stress, temperature, roof strain, gas pressure, acoustic parameters in the process and migration law, size classification, and distribution characteristics of the coal sample after outburst are studied in order to study the mutual coupling effect of stress, gas pressure, and the physical and mechanical properties of coal and its comprehensive mechanism for outburst. The coal and gas outburst mechanism can be revealed based on a comprehensive mechanism (Wang Jiren et al., 2008, Zhang Yugui et al., 2007).

3. THE DESIGN OF THE SIMULATION DEVICE

The outburst simulation device consists of the outburst model system, vacuum pumping and gas injection system, stress loading system, stress testing system, gas pressure testing system, temperature testing system, the electromagnetic and radiation measurement system, high speed photography system ,and the data acquisition, control and processing system. A system diagram of the coal and gas outburst simulation device is shown in Figure 2.

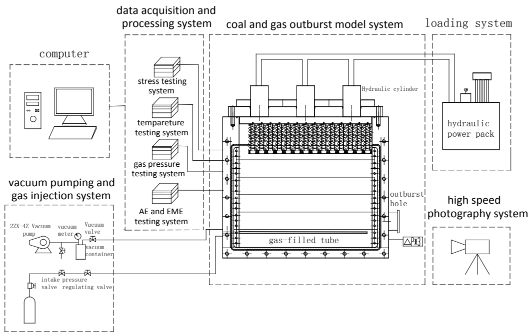
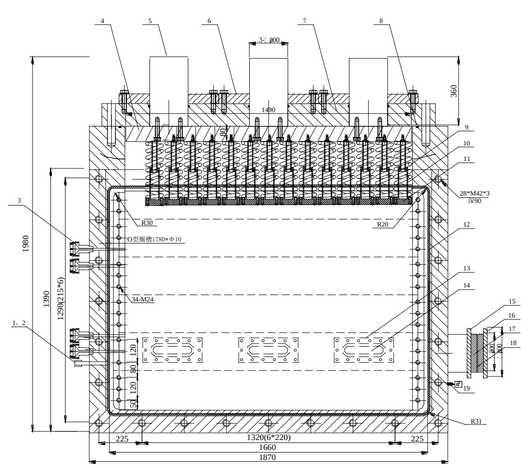


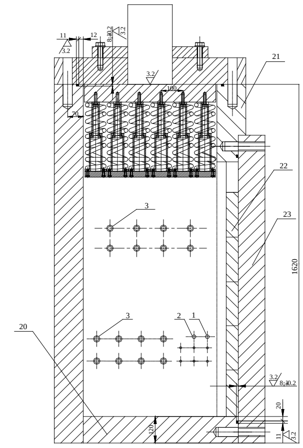
Figure 2: System diagram of simulation device.

The cavity size of outburst model system is 1500 mm x 600 mm x 1000 mm. The various physical parameters are tested through sensors such as temperature, gas pressure, stress cell, electromagnetic radiation, and acoustic emission and so on. The roof and floor of the coal seam can be simulated using similarity material. A series of springs are installed between the loading piston and the top of the roof to simulate the real roof stress distribution of coal in front of mining face. The front cover plates consist of two layer cover plates. The outboard plate is used for sealing. The inboard plates consist of five small plates, which are used for compression molding of coal, roof, and floor. The height of the small plate is 20 cm. Blasting sheet and clamping devices need to be installed at the outburst hole. Coal and gas outburst can be induced through fast blasting of the blasting sheet at a prescribed gas pressure. Three observation windows are installed on the device for the recording of the high-speed camera. Three inflatable tubes are be curried evenly in the coal sample in the process of coal forming. A structure diagram and physical diagram of the coal and gas outburst simulation device are shown in Figure 3 and 4.

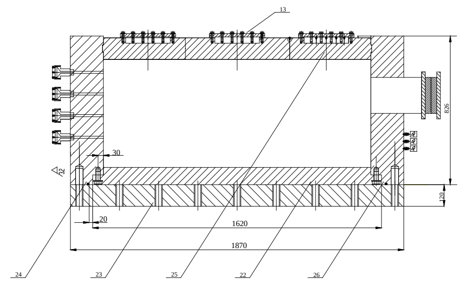


(a)

Front view of simulation test device



(b) Side view of simulation test device



(c)Top view of simulation test device

1-vacuum interface 2-charging port 3-patch board 4-big press plate 5-hydraulic piston 6-piston base 7-upper cover plate 8-sealing ring of upper cover plate 9-spring group 10-guiding mechanism of spring 11-small press plate 12-sealing ring of front cover plate 13-fixing mechanism of observing window 14-glass observing window 15-inner flange of outburst hole 16-outer flange of outburst hole 17-clamping device of blasting sheet 18-blasting sheet 19-differential pressure sensor 20-floor 21-front supporting plate 22-inner front cover plate 23-outer front cover plate 24-the left side plate 25-the rear side plate 26-the right side plate

Figure 3: Structure diagram of coal and gas outburst simulation device.

4. THE TEST CASE

Two successful tests were conducted through coal and gas outburst simulation test device. The coal samples were from 2# coal seam in Zhenxing Er coal mine and 2# coal seam Dashucun coal mine. The coal samples were crushed into a 1mm particle size, in the laboratory. The floor was laid by similarity material. The molding stress was 20 MPa, and the loading stress was sustained for 30 min. The crushed coal sample was placed into the cavity layer by layer. The molding stress is 20 MPa, and the loading stress was sustained for 30 min. The roof was laid by similarity material. The molding stress was 20 MPa, and the loading stress was sustained for 30 min. In the two tests, the weights of the coal sample and similarity material are 1109 Kg and 1186 Kg, respectively. After the model was completed, it was dried for fifteen days. After leakage detection was successful, the cavity was vacuumed. Carbon dioxide with 99.99% concentration was aerated into the cavity, and adsorption equilibrium was ensured. Adsorption equilibrium pressure was 0.4 MPa and 0.6 MPa, respectively. The time for adsorption equilibrium was 7 days and 13 days. The blasting pressure of the blasting sheet was 0.5 MPa and 0.74 MPa. After adsorption equilibrium, gas was aerated to the blasting pressure continuously and blasting sheet bursts and the outburst occurred. The state diagram during the coal and gas outburst experiment and the distribution of the coal sample after coal and gas outburst are as shown in Figures 5 and 6.

Figure 5: The state diagram during coal and gas outburst experiment.

Figure 6: the distribution map of coal sample after outburst.

The results were as follows:

(1) The weight of coal sample and rock sample that was ejected outside the cavity was 369.9 Kg and 373.6 Kg respectively in the two tests.

(2) The shape of the outburst hole was pear-shaped with a small opening and big cavity.

(3) The coal sample and rock sample that were ejected outside the cavity present obvious sorting features. The sample with big particles was near the outburst hole and the sample with small particle was far from the outburst hole.

(4) The sample which was ejected outside showed axisymmetric fan-shaped distribution and the center line of the outburst hole was the symmetry axis. The farthest ejection distance of sample from the outburst hole was 41.4 m and 49.5 m, respectively.

5. CONCLUSIONS

Development, purpose, ideas, and scheme design of a coal and gas outburst similar simulation device were introduced in detail based on similar devices at home and abroad. The functions are as follows:

(1) To study the laws of roof break development and stress evolution during outburst process by simulating coal seam, roof and floor with similar material. (2) To simulate stress distribution of a roof at high strength springs of different sizes. (3) To realize the uniform adsorption in coal by three gas injection pipes that were pre-buried. (4) To induce coal and gas outburst at a predetermined gas pressure. (5) To observe and record the fracture and migration process of coal in the cavity during outburst, achieved using a visual glass window on the side of the cavity.

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