International Journal of Mining Science and Technology 25 (2015) 773–778

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

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

Flow characteristics of three-phase foam in mine gob and its application

Shi Guoqing *, Liu Maoxi, Kong Jia, Wang Deming

School of Safety Engineering, China University of Mining & Technology, Xuzhou 221116, China

ARTICLE INFO

Article history:
Received 26 December 2014
Received in revised form 20 January 2015
Accepted 18 March 2015
Available online 24 August 2015

Keywords:
Three-phase foam
Gob area
Seepage
Diffusion range
Numerical simulation

ABSTRACT

To study the flow characteristics of three-phase foam in gob area, different perfusion experiments in coal mine gob were designed and put forward in the paper. Through the observation of flow range, flow characteristics of three phase foam were analyzed with different flow rates. And, unsteady seepage process of three-phase foam was simulated with CFD software. Base on experiment and numerical simulation results, flow characteristics of three-phase foam and its major influence factors are discussed, and the optimal arrangement distribution of mine fire control drills is also determined. Research results show that the flow range and stacking height of three-phase foam in gob are significantly influenced by gravity. The vertical stacking height and horizontal diffusion distance of three-phase foam are also directly related to the flow volume of foam perfusion, the larger flow single hole perfusion volume, the higher stacking height and the longer diffusion distance could be obtained.

1. Introduction

Coal fires are a global catastrophe for valuable coal resources, the environment, human health and safety. Fire-fighting activities are the approach to limit these catastrophic influences and to extinguish active coal fires [1,2]. Three-phase foam is one of the popular technologies for fire controlling, it is generated by yellow mud, water and gas (nitrogen or air) through physical foaming, which not only possesses the advantages of general grout injection, inert gas foam injection, nitrogen injection and other fire controlling technologies but also overcomes the drawbacks of these technologies. It is characterized by high stacking, wide coverage and long stable duration so that it has been widely used for fire controlling in coal mines [3–7]. At present, little attention has been paid to the flow characteristics of three-phase foam in the gob area. Therefore, its flowing diffusion range, stacking height and influence factors have not been well understood which causes its blind application in fire controlling [7–11]. To deal with this problem and provide basis for the design parameters of three-phase foam, this paper put forward a perfusion experiment of three-phase foam in a large gob area in Antaibao Open Pit Mine. This paper also comprehensively analyzed the seepage range characteristics of foam in the gob area by numerical simulation, and the research results would be used to guide the optimized design of the arrangement distance of coal fire controlling boreholes.

2. Profile of the experiment site

The experiment site is in an old gob area of a small coal mine, and it is exposed within Antaibao Strip Mine. Antaibao Open Pit Mine is located in Suozhou city, Shanxi province, which is one of China largest open pit mines. Its minable seams are Nos. 4, 9 and 11 coal seams, with an average thickness of 70 m in the surface layer and a stripping ratio of 1:5. When No. 9 was mined, Antaibao Strip Mine once suffered from large-scale fire in No. 9 mine gob area of the small Jingyang Coal Mine due to spontaneous combustion. After 1330 platform was bulldozed, the caving zone of No. 9 gob area was completely exposed to the open area, and the 9 m deep gob area provides a suitable experiment platform for the seepage experiment of three-phase foam, as shown in the left part of Fig. 1.

In the strip coal mine, it is difficult to specify the gob area only by observing surface geologic features. Hence, this paper used Ground Penetrating Radar (GPR) produced by Sweden Geoscience company to conduct a geologic detection for the small mine gob area. From GPR detection data, loose area could be obtained, and the following perfusion experiment would be put forward in these areas. To ensure the drilling and observing drills in every experiment be located in a gob area, YTJ20 Drilling Rock Recorder was used to observe the conformation inside the drill. Fig. 2 shows

* Corresponding author. Tel.: +86 13505219747.
E-mail address: shiguoqing2001@163.com (G. Shi).

http://dx.doi.org/10.1016/j.ijmst.2015.07.012
2095-2686/

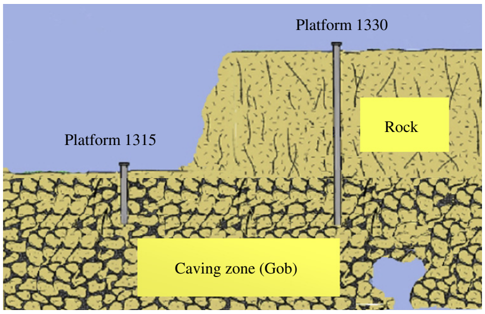

Fig. 1. Diagrammatic cross-section of geologic features at experiment site.

the image features of the drill wall in experiment area obtained by this equipment.

3. Technological process of the experiment

According to Fig. 3, the foam seepage experiment system has been established. In this system there are some main equipments and devices, including slurry tank, XAS186 air compressor, foam generator, grout flowmeter, seconds counter and gas flowmeter. The major materials used in this experiment including KSF-II foaming agent, industrial sewage from underground, coal fly ash produced by the power plant of Antaibao strip mine. The initial slurry was composed of water and fly ash, and prepared in the slurry-mixing tank. Volume ratio between water and coal fly ash is 4:1. Foam agent was added to the tank. Then, prepared slurry was pumped into the grouting pipes where the foaming agent was introduced by volumetric screw pump in the proper proportion. The slurry and foaming agent was fully mixed and then delivered into the foaming generator. Air gas was added into the foaming generator through a rubber pipe from air compressor, and three-phase foam was formed following the interaction between the gas and slurry. Gravity and pumping delivered the three-phase foam to the gob zone through borehole.

4. Experimental process and result analysis

4.1. Stacking height of foam

(1) Arrangement of the experiment

There are five drills in this experiment; drill 0# was used as a perfusion drilling with a depth of 5 m. To avoid the negative influence on the experiment caused by seepage of three-phase foam from the drilling wall, we adopted Φ108 mm steel tube to conduct a complete hole sealing for the drill, which was also conducted to ensure the foam diffuse with a point-source style. Four observing drills are located at a distance of 1 m away from drill 0#, they are 1#, 2#, 3# and 4# drills. The layout of drills arrangement is shown in Fig. 4. In order to observe the stacking height of three-phase foam accurately through these four drills, different depths were designed for these drills, and the corresponding depth of drill 1#, 2#, 3#, 4# are 2, 3.5, 3, 4 m.

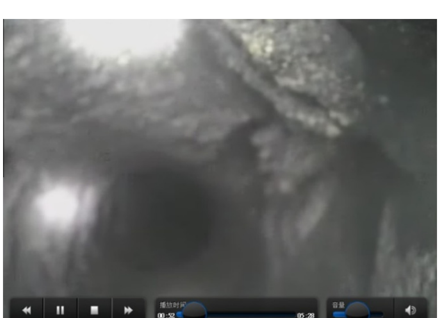

Fig. 2. Image of drilling interior.

(2) Experiment procedure

Firstly, these main devices were connected by high pressure hoses. And then, the valves of the mud pump were opened and adjusted, and air compressor was used to control the flow rate of three phase foam. Flow rates of foam are 120, 150, 180, 240, 300 and 360 m^3/h in every perfusion experiment, and each experiment lasted about half an hour. The times when three-phase foam overflows out of the drills were observed and recorded. If foam overflowed out from the drill during experiment procedure, cement sandbag was used to block it off, and then perfusion experiment continued.

(3) Experiment results and analysis

Table 1 shows experiment results. From the experiment we found that there was no three-phase foam overflowing from the drill when the perfusion experiments were conducted with flow rate of 120, 150, 180 m^3/h, so the upward stacking height of three-phase foam did not exceed 1 m. While the flow rate increased up to 240 and 300 m^3/h, three-phase foam overflowing from observing drill 4#, which indicated that the upward stacking height of three-phase foam was between 1 and 1.5 m. While we conducted the perfusion experiment with flow rate of 360 m^3/h, three-phase foam overflowed out from observing drill 2#, 3# and 4#, except drill 1#. It indicated that under this perfusion volume condition, the upward stacking height of three-phase foam was within 2–3 m. All of these experimental results suggest that the upward stacking height of three-phase foam is closely related to the perfusion flow rate, the larger the single drill perfusion volume, the higher the upward stacking.

4.2. Diffusion range

Without the influence by the boundary of perfusion area, the starting pressure gradient will be the determining factor for the diffusion range of three-phase foam, which means that when perfusion dynamic gradient cannot overcome the starting pressure gradient, three-phase foam can reach its calculated extreme diffusion range [12,13]. However, when three-phase foam is transfusing in the gob area, the starting pressure gradient is so small that it is very difficult to reach the final calculated diffusion range according to starting pressure gradient [14]. Therefore, in this paper, the diffusion range in the experiment refers to the foam transitory diffusion distance in the same horizontal level with exit of the perfusion drill.

(1) Experimental arrangement

Fig. 5 shows the layout of experiment drills. There are five vertical drills in this experiment, and No. 0# drill was used as a perfusion drill. And Nos. 1#, 2#, 3#, 4# drills are used for observing, and the respective horizontal distances from each observing drills to perfusion drill (0# drill) are 1, 2, 3 and 4 m. Both perfusion drill and observing drill were 5 m deep.

(2) Experimental procedure

Firstly, 0# drill which is a perfusion drill was connected with the foam generator by pipeline. And then, the valves of mud pump