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Spontaneous combustion influenced by surface methane drainage and its prediction by rescaled range analysis

Shengqiang Yang [a,b], Xincheng Hu [a,b,c,*], Wei Victor Liu [c], Jiawen Cai [a,b], Xiuhong Zhou [a,b]

[a] School of Safety Engineering, China University of Mining & Technology, Xuzhou 221008, China
[b] Key Laboratory of Gas and Fire Control for Coal Mines, Xuzhou 221008, China
[c] Department of Civil & Environmental Engineering, University of Alberta, Edmonton T6G 2W2, Canada

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ABSTRACT

This study established numerical modeling using COMSOL™ to examine the influence of horizontal location and drainage ability of surface borehole on spontaneous combustion in longwall working face gob. Rescaled Range Analysis (R/S analysis) was employed to investigate the chaos characteristic of N_2/O_2 ratio from a surface borehole in 10416 working face gob, Yangliu Colliery, China. The simulation results show that there is always a circular "dissipation zone" around the drainage borehole and an elliptic "spontaneous combustion zone" in deep gob. Little influence was found on spontaneous combustion zone on the intake side of the gob but the width of spontaneous combustion zone in middle gob is enlarged, while the depth of spontaneous combustion zone near the return side is reduced. The R/S analysis indicates that the influence of surface borehole on spontaneous combustion can be divided into two stages by the chaos feature of N_2/O_2: safety drainage stage and spontaneous combustion initiating stage. It can be concluded that the methane drainage from gob through surface borehole can intervene in the distribution of spontaneous combustion zone in gob and the chaos feature of N_2/O_2 from surface borehole can effectively reflect coal spontaneous combustion condition in gob.

1. Introduction

Coal spontaneous combustion has long been one of the most serious disasters in underground longwall coal mines, especially in the working face next to gob areas [1,2]. In China, about 32% of underground coal mines have both spontaneous combustion and highly gassy (high methane concentration) issues which may cause severe disasters, especially when mining goes increasingly deeper [3].

In highly gassy coal mines, gas or methane drainage must be carried out before or along with mining productions [4]. However, improper methane drainage may induce coal spontaneous combustion, leading to disastrous gas combustion and gas explosion. In spite of long-time research on coal disasters from either coal spontaneous combustion or gas prevention [5–10], only few recent studies addressed the severe threaten from the combined effects of methane and coal spontaneous combustion [11].

Some researchers developed a model with a continuously advancing long-wall face according to the actual long-wall panel operating in the Ostrava-Karvina Coal Mine (OKD, Czech Republic) to simulate the effects of advance speed on gas emission and oxidation process of coal in gob, and the result confirmed that the slower the advancing rate, the higher the maximal temperature and the smaller the depth of the "self-heating" zone in the gob area [12]. Different ventilation schemes were analyzed using the software Fluent™ for the gob area that is mostly prone to coal spontaneous combustion and then optimized its ventilation system under highly gassy conditions [13].

The occurrence of methane explosion caused by coal spontaneous combustion and the role of self-heating during the whole procedure were theoretically analyzed, and high quality three-phase foam containing nitrogen was put forward to prevent such integrated hazards [14]. The crossing of fracture field, CH_4 concentration field, O_2 concentration field and temperature field is the necessary and sufficient condition of symbiotic disaster of methane and coal spontaneous combustion, which increases with mining depth [15,16]. The extraction of methane can raise the risk of self-heating prone coal due to the fact that the drainage itself has the outcomes of more fractures, greater air leakage channels, less compact degree and larger broken grade. These outcomes from drainage make the coal easier to accumulate heat [17]. The formation and variation rule of CO were studied using temperature

* Corresponding author at: School of Safety Engineering, China University of Mining & Technology, Xuzhou 221008, China.
E-mail address: XinchengHu@hotmail.com (X. Hu).

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programmed method and it was found that the initial formation temperature of CO was delayed with the increasing proportion of methane or the declining percentage of oxygen [18,19].

As analyzed above, most research focused on fracture development and gas migration after mining. However, little attention has been paid to the research on coal spontaneous combustion caused by methane drainage. The 10416 working face in Yangliu Colliery, Huaibei, China, was chosen to investigate the influence of methane drainage on coal spontaneous combustion. Field data were collected from one of its surface drainage borehole and then analyzed to develop a prediction method during the extraction process. Moreover, COMSOL™ was adopted to conduct a numerical simulation of different drainage parameters on coal spontaneous combustion in gob. The chaos characteristic of N_2/O_2 indicator series was analyzed using Rescaled Range Analysis (R/S analysis). The risk of coal spontaneous combustion in 10416 working face gob was divided and the corresponding critical values of Hurst index were confirmed in the end.

2. Description of the study working face

Situated at Suixi County, Huaibei, 10416 working face of Yangliu Colliery is the second longwall face in 104 mining district, with the strike length of 1050 m and the dip width of 180 m. The main production coal seam is coal 10 with an average thickness of 2.74 m. According to the field observation of 104 mining district, its maximum absolute gas pressure is up to 2.00 MPa with the coal bed methane content reaching 12.02 m^3/t, which manifests that the seam is prone to coal and gas outburst. Cross-seam boreholes were drilled from the rock roadway beneath the working face and in-seam drainage boreholes were then drilled to reduce the gas content below 8 m^3/t.

The gas pressure of middle coal seams (7_2, 8_1 and 8_2) approximately amounts to 1.70 MPa, with a gas content of about 10.92 m^3/t, which indicates coal and gas outburst proneness. It can be seen from Fig. 1 that coal 10, with an average distance of 81 m and 106 m from 8_1, and 7_2, can serve as the remote protective layer for 7_2, 8_1 and 8_2 coal seams, the thickness of which are 1.22 m, 1.16 m and 1.63 m, respectively. In order to control the gas in middle coal seams, surface drainage boreholes were drained before the advancing of 10416 working face in order to extract gas from overlying relieved gas-bearing strata and the longwall face gob.

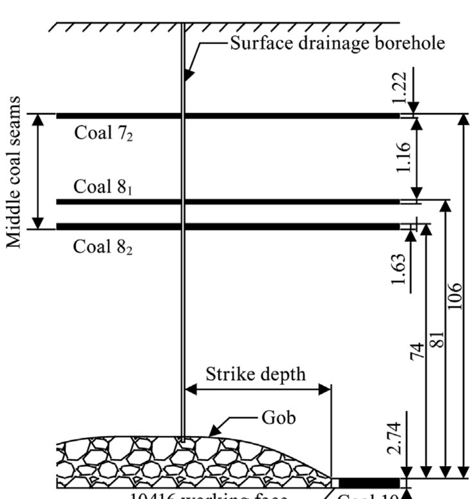

Fig. 1. Section map of surface borehole in 10416 working face along the strike direction (units are in meters).

The surface boreholes were positioned at the middle of working face, 70 m from the return tunnel in dip direction which can be seen in Fig. 2. The surface drainage holes were drilled reaching the caving zone of 10 coal (about 20 m above coal 10), with the opening diameter of 311 mm and the finished diameter of 91 mm. These holes were connected to the ground extraction system to extract methane from both the 10416 working face gob and the relieved middle coal seams. According to the first mined 10414 working face, the surface drainage borehole can take effect when working face was advanced in front of the surface borehole by 10 m–25 m in the horizontal direction, but the drainage effect would drop dramatically when the distance was over 130 m. Thus, to guarantee long-term extraction effect, the surface borehole interval was confirmed as 120 m and the extraction flow 50 m^3/min.

3. Influence of methane drainage on coal spontaneous combustion in the gob

3.1. Modeling of air leakage in working face gob

3.1.1. Geometry of 10416 working face gob

Although the overlying strata can be divided into three zones (i.e., caved zone, fracture zone and bending zone) from bottom to top [20], the 10416 working face gob can be slightly affected by methane that might emitting from middle coal seams because of the long distance to coal 10 [21]. The height of the fractured zone can be confirmed as 35 m according to the empirical formula used by other researchers [22]. Consequently, due to the remoteness of gas-bearing coals, the simulation model of 10416 working face gob can be simplified as a two-dimensional model.

Figs. 2 and 3a give information about the geometry of 10416 working face gob. The dip length of the 10416 gob is 180 m while the strike length is 150 m. The depth of the working face area and supporter area are 4 m and 2 m respectively, with the maingate and tailgate sized the same dimension of 4 m (width) by 10 m (depth).

3.1.2. Porosity distribution and boundary conditions

Even though there are a large amount of simulations have been done to investigate the flow field in gob, most of these deemed the porosity as discrete constants [23]. However, the simplification could not describe the pore distribution in gob. In fact, the porosity in gob varies on the basis of "O-zone theory" [24]. Taking the upper corner behind the supporter area as the origin and the negative of the dip direction as positive *x*-axis direction, the porosity distribution along the strike direction in the middle of the working face gob can be described by [25]:

$$n_x = 0.2e^{-0.0223x} + 0.1 \quad (1)$$

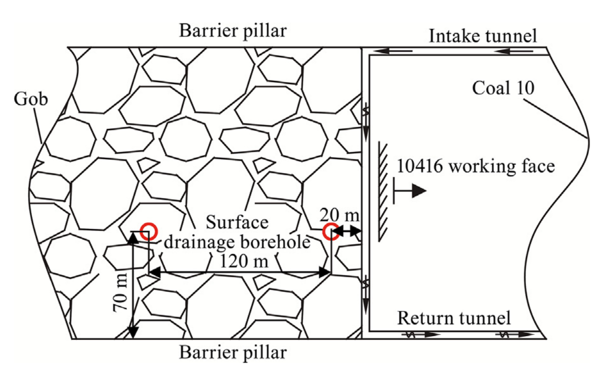

Fig. 2. Tunnel arrangement of 10416 working face, Yangliu Colliery.