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Full Length Article

Multi-physics coupling model of coal spontaneous combustion in longwall gob area based on moving coordinates

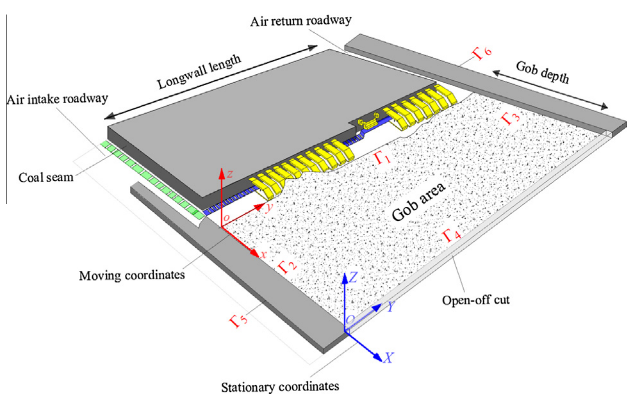
Wei Liu *, Yueping Qin

College of Resources & Safety Engineering, China University of Mining & Technology (Beijing), Beijing 100083, China

HIGHLIGHTS

- Moving coordinates is introduced to fix computational region of longwall gob.
- *COMBUSS-3D* is programmed to predict coal spontaneous combustion in longwall gob.
- Key influence factors are evaluated to suppress spontaneous combustion in gob.

GRAPHICAL ABSTRACT



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ABSTRACT

The spontaneous combustion of coal in gob area that is caused by longwall mining techniques results from the coupling effect of air seepage, oxygen transport, heat transfer and exothermic reaction. Previous researches are neither able to systematically address the whole process of spontaneous combustion in longwall gob nor model the continuous expansion of gob area perfectly well. In this paper, the mechanism of multi-physics coupling of spontaneous combustion in longwall gob is illustrated in detail, and a technique of moving coordinates is introduced to convert the expanding gob area into a relatively fixed region to simplify solving. On this basis, a time-independent model of multi-physics coupling of spontaneous combustion in gob is established, which is discretized by a new algorithm based on tetrahedral mesh. A software system of *COMBUSS-3D* is developed independently to solve the discretized model. This model is verified by matching the field measurement. Thus, this software can be served as a crucial tool to predict spontaneous combustion and locate high temperature zone in longwall gob areas.

The influence factors of spontaneous combustion in gob, such as longwall advance rate, thickness of crushed coal and ventilation flux, are also analyzed quantitatively through the software. The results reveal that (i) the high temperature zone of spontaneous combustion locates in the windward side of gob; (ii) increasing the advance rate, reducing the crushed coal and decreasing the ventilation flux are all able to effectively reduce the risks of spontaneous combustion of gob; (iii) the minimum advance rate, the maximum thickness of coal and the maximum ventilation flux are obtained as the technical targets to suggest how to suppress or even eliminate the spontaneous combustion through regulating on-site mining technology. These results are beneficial for preventing spontaneous combustion of coal in longwall gob areas.

* Corresponding author.
E-mail address: liuwei7230@sina.com (W. Liu).

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1. Introduction

China is the biggest coal-producing and consuming country in the world. By statistics, China has produced about 4.2 billion tons in 2014, and 90% comes from the longwall mining underground [1]. However, there are still five major hazards threatening the safety in production underground, and spontaneous combustion of coal is one of them [2,3]. The majority of spontaneous combustion occurs in longwall gob area. Due to the extensity and inaccessibility of gob area, once occurred, the spontaneous combustion is difficult to be extinguished within a short time. Meanwhile, a large amount of toxic gases are produced to harm the workers' health. The worst thing is that the spontaneous combustion may cause gas explosion underground [4]. In March 2013, two successive gas explosions occurred at Babao Coal Mine in Jilin province of China and killed 53 people. The root cause was that the spontaneous combustion of coal ignited ambient methane in a failure obturation of gob. According to incomplete statistics from 2001 to 2014 in China, 32 cases of fire or gas explosion underground resulting from coal self-ignition had occurred, and 614 mining workers were killed. Therefore, the governments and scholars both put more efforts on understanding and preventing the coal self-ignition in longwall gob [5–7].

There have been many predictive studies focused on spontaneous combustion in coal storage/stockpile [8–13] or underground coal seams [14–16]. However, the spontaneous combustion in longwall gob area is more complex, because the mined-out area is continuously expanding when longwall face advances forward. This characteristic not only creates difficulties in physical similarity experiment in lab but also in field observation in gob area. Therefore, numerical simulation is a promising approach to evaluate the evolution of spontaneous combustion of coal in gob. Taraba et al. used software of FLUENT to simulate the process of coal self-heating in longwall gob, but ignored the heat transfer between air and the caved rock-coal particles [17,18]. Yuan and Smith established a three-dimensional model based on the FLUENT to predict the coal spontaneous heating in gob, but the longwall face was stationary [19]. Recently, scholars have recognized that the spontaneous combustion in gob is the result of interaction of multi-physical fields, involving gas seepage, oxygen dispersion, and heat transfer. Xia et al. proposed a hydro-thermo-mechanical model to simulate the coal self-ignition in longwall gob by using COMSOL software, but it was a two-dimensional model without considering the influence of thickness of coal left in gob [20]. Other studies identified a risk area of spontaneous combustion in gob, but the divided "oxidation zone" was too huge to provide a target zone for prevention [21–23]. To summarize, previous studies using commercial simulation software can't involve the multi-physics coupling of spontaneous combustion in gob perfectly well. Moreover, the growing gob area induced by longwall face movement is still a big challenge for simulating spontaneous combustion in gob. Thus, the main objectives of our study are to address the coupling of multi-physics and to simulate the simultaneous process of evolution of spontaneous combustion in gob with longwall face advancing.

In this paper, a technique of moving coordinates is proposed to fix the computational region of gob. On this basis, a time-independent model of multi-physics coupling is established, and then a solving software system is programmed to investigate the evolution of spontaneous combustion in longwall gob. The key influence factors like longwall advance rate, thickness of crushed coal and ventilation flux are also evaluated quantitatively how to suppress the spontaneous combustion in the gob.

2. Multi-physic coupling of spontaneous combustion in longwall gob

2.1. Moving coordinates of gob

In longwall mining, the roof of coal seam is supported by special hydraulic shields. When the hydraulic shields are artificially operated to move forward, the roof rock subsequently collapses. This process makes the mined-out area enlarge continuously. If a stationary coordinates (X, Y, Z) is set at the open-off cut of longwall district, shown in Fig. 1, the boundary Γ_1 of gob that is close to the hydraulic shields will move forward as the longwall face advances. The mathematical model of spontaneous combustion of gob under the stationary coordinates will be a set of partial differential equations with unsteady in time and space, which is too complicated to be solved. A technique of moving coordinates is presented to simplify the model, also in Fig. 1. The y axis is set at the boundary Γ_1, the x axis along the depth of gob, and the origin o is set at air intake corner of gob. The new coordinates (x, y, z) moves forward in the same speed with the longwall face advancing. In this way, anywhere in gob is settled under stationary coordinates but moves along the positive direction of x axis relative to the longwall face under the moving coordinates. The

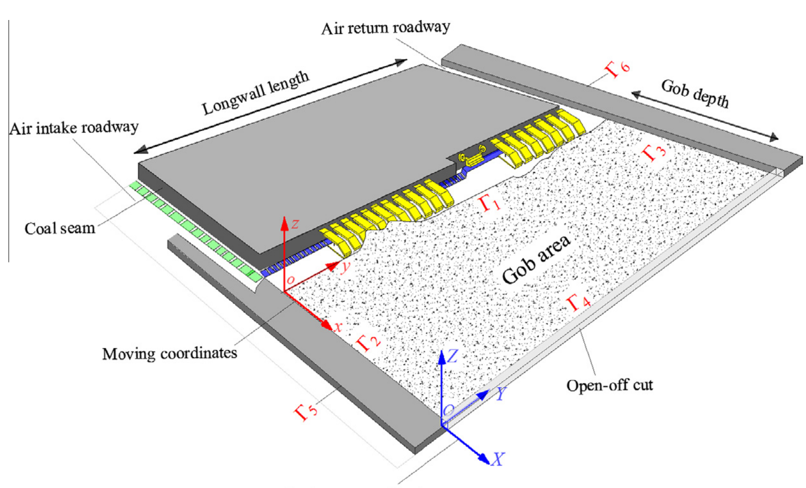

Fig. 1. Moving coordinates of gob with U-ventilation, where Γ_1, Γ_2, Γ_3, Γ_4 is boundaries of computational region of gob area.