Instantaneous Coal Outbursts: Mechanism and Prediction

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Summary A new model combining fracture mechanics, gas dynamics and rock mechanics is proposed to elucidate the physical mechanisms leading to instantaneous coal outbursts. This model suggests a domino effect that causes a catastrophic failure of the coal and an instantaneous outburst. The model identifies a critical condition for the onset of an outburst, and it successfully predicts all of the observed phenomena preceding outbursts. The model also predicts a fracture aperture size effect which is confirmed by the existing observation-based fracture classification scheme used to assess outburst proneness.

Introduction

An instantaneous coal outburst is a sudden and violent simultaneous ejection of large amounts of coal and gas from the working coalface during underground mining [1]. Despite the significant hazard it poses, only limited progress has been made over the past 150 years towards the understanding and prediction of such catastrophes. The difficulties of understanding outbursts can be attributed to many factors, including diverse geological structures, anisotropic and heterogeneous coal properties, gas content, *in situ* stress on the coal, and the method of mining [1-3]. Existing theories capture some aspects of the process leading to an outburst, but are incapable of explaining certain phenomena considered as precursors of an outburst, which include: (i) the occurrence of distinct audible noises originating close to the mine opening; (ii) a decrease in the temperature in the solid of the coalface and the nearby atmosphere; (iii) the instability of the coal faces, which usually manifest as a bulge or outward push of a face into the mine opening. Nor can they explain the increased proneness to outbursting with increased rate-of-advance of the coalface. Furthermore, none of the existing models is capable of predicting a failure of explosive and catastrophic nature which characterizes an instantaneous outburst. The new model proposed here, however, is capable of predicting all of these phenomena as shown below.

Model Description

The new coal outburst model I propose is based on a high pressure gas flow through a highly fractured zone in front of the advancing coalface. It has three important elements: the highly fractured zone ahead of the coalface; a high pressure gas flow through the highly fractured zone; and a flow-induced catastrophic failure of the coal.

When a coal bed is mined, the significant reduction in the effective stress in the neighborhood of the excavation face creates a highly fractured zone ahead of the advancing coalface. Observations show that instantaneous outbursts only occur at sites with high frequencies of these mining-induced fractures [1] [4]. This intensive fracturing reduces the effective rigidity of the coal and causes the existing cleats, which are naturally existing opening-mode fractures, to increase their apertures [5]. This creates high conductivity pathways for the gas to flow to the coalface. Gas flow in the highly fractured zone is modeled as a one-dimensional accelerating flow through a porous medium [6]. When a combination of high fracture permeability, large pressure drop and short fractured zone length occurs, gas moving to the coalface through the fractured zone experiences rapid adiabatic expansion and acceleration. When the fractured zone is shortened to a critical length, the flow inside the fractured zone becomes choked; gas flows out of the coalface at sonic speed; and the gas pressure gradient at the coalface becomes unbounded, $dp/dx \to -\infty$. As a result, a large tensile stress develops near the coalface [7], causing a tensile failure of the coal near the coalface.

Mechanism of Outburst

Assume the operation starts from a subcritical, safe condition where the initial length of the fractured zone is longer than the critical length (above the critical length curve in Fig. 1). Also assume the operation is steady, maintaining a constant coalface advancing speed. If the coal porous system is homogeneous, and geological structures and other conditions remain the same, then the newly created fractures from the advance of the coalface will have exactly the same fracture properties as the initial fractures in the fractured zone. The operation will stay safe and no outburst will occur. However, coal is highly heterogeneous and geological conditions can vary significantly along a coal seam. If the coal bulk porosity increases in the coalface advancing direction, then the reduced rigidity increases the resistance of the coal porous system to any fracture growth. Thus, the intensity of the mining-induced fractures ahead of the coalface will be reduced. This in turn decreases cleats opening and shortens the fractured zone. It can make the length of the newly created fractures to fall below the critical length, and the propagation speed of the existing fractures to fall below the coalface advancing speed. When this combination happens, the fractured zone length will be reduced to the critical length within a finite time. At this instant, the flow inside the fractured zone becomes choked. Then the infinitely large gas pressure gradient at the exit of the fractured zone (coalface) creates an extremely large effective tensile stress in the immediate neighborhood of the coalface. It is then certain that the effective tensile stress across some plane in the large tensile stress zone created by the infinitely large gas pressure gradient exceeds the tensile strength of the fracture-weakened coal. This leads to a local tensile failure of the coal just inside the coalface, and a subsequent split and detachment of the coal volume near the coalface from the fractured zone. The loss of the coal shortens the fractured zone further, and this triggers “a domino effect”: gas flow through the fractured zone remains choked; the gas pressure gradient at the new coalface remains unbounded; and the coal near the new coalface experiences a rapid tensile failure, splits from the fractured zone, then flies violently to the open mine with sonic speed gas. Shortening the fractured zone also advances the coalface, and it instantaneously generates new mining-induced fractures, which in turn opens new cleats to keep the fractured zone alive. This process repeats itself rapidly, and more and more solid coals are expelled with sonic gas from the ever fresh coalface. A coal outburst runaway is thus started. This runaway process will not end till the coalface advances to a location where the bulk porosity ahead the coal is so high that no more new mining-induced fractures can be created ahead of the coalface. This is the region predominantly occupied by gas. At this moment, large amounts of stored high pressure gas are released at once to the open mine and the outburst is completed.

Fig. 2 and Fig. 3 show that as the critical fractured zone length for the onset of outburst is approached, the noise level of the gas exiting the coalface increases while the temperature of the exiting gas decreases. These precursor phenomena are explained for the first time by the proposed new model.

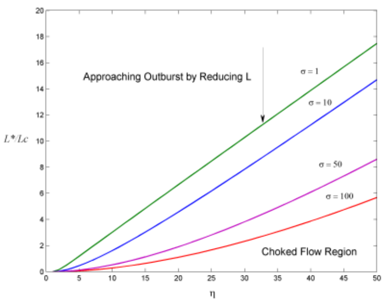

Fig. 1

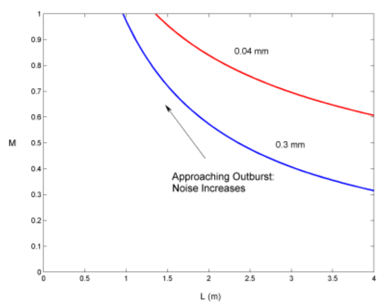

Fig. 2

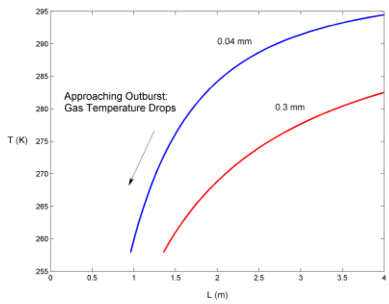

Fig. 3

Fig.1 Dimensionless critical length variation with pressure ratio for various Forchheimer parameters σ. Gas flow in the highly fractured zone ahead of the mining face becomes choked when the fractured zone length is shorter than the critical length. For choked flows, gas pressure gradient at the mining face becomes unbounded.

Fig. 2 Increase in noise levels as the onset of outburst is approached.

Fig.3 Decrease in the temperature of the gas exiting the coalface as the onset of outburst is approached.

Conclusions

The physical mechanism leading to instantaneous outbursts is elucidated in terms of the newly proposed model. This model suggests a domino effect that leads to a catastrophic failure of the coal and an instantaneous outburst. The model identifies a critical condition for the onset of instantaneous outbursts, and it successfully predicts all of the observed phenomena preceding outbursts, most of which are explained for the first time. The model also predicts a fracture aperture size effect which is confirmed by the existing observation-based fracture classification scheme used to assess outburst proneness (not detailed here due to space limitation).

References

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