

Computational fluid dynamics modeling of a methane gas explosion in a full-scale, underground longwall coal mine

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Special Extended Abstract

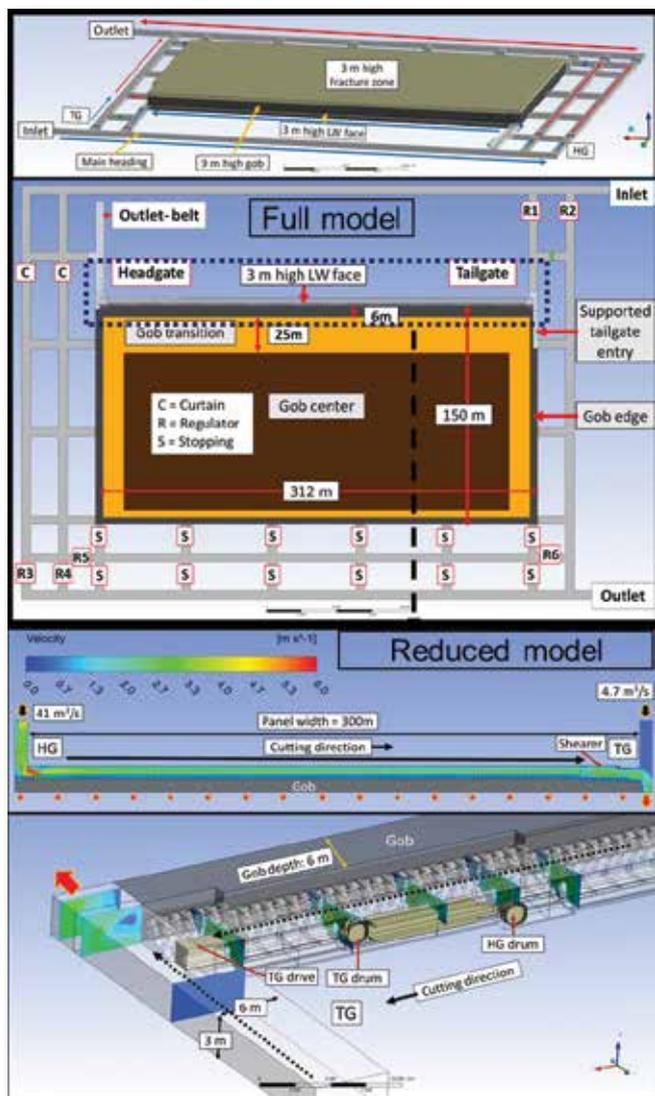


Fig. 1 Longwall bleeder model geometry (top) and flow distribution in the longwall face (bottom).

Methane gas explosions are a major risk in underground coal mining operations. The severity of such explosions can range from local area damage to massive loss of miners' lives along with significant damage to mine infrastructure and ventilation controls that may lead to mine closure and loss of the entire operation. This study demonstrates the viability of integrating a computational fluid dynamics (CFD) combustion model into a longwall mine ventilation model to simulate methane gas explosions in the longwall face area. The resulting 3D methane gas explosion simulation can provide better understanding of the fundamental physics and the potential impact of an explosion in an underground longwall coal mine.

Introduction

CFD modeling can be used to analyze airflow patterns and hazardous gas mixtures formation in the longwall face. Full integration of a CFD combustion model into a full-scale longwall ventilation model is difficult due to computational time and resource requirements. This study demonstrates the viability of modeling a methane gas explosion in a full-scale longwall face model, and the capability of predicting the impact of an explosion, by reducing the model coverage to only include the area of interest and utilizing data interpolation. An improved understanding of methane gas explosions will aid in developing more reliable methane monitoring practices and explosion mitigation strategies to improve safety in longwall coal mining operations.

Modeling methods

ANSYS Fluent version 18.2 was used for the CFD simulations. First, a bleeder ventilation model was modeled, consisting of a single longwall panel and its surrounding bleeder entries. To simulate ignition and methane flame propagation in the longwall face area, the model was then reduced to only contain the longwall face, a portion of the gob behind the shields, and a portion of the headgate and tailgate bleeder entries. To maintain computational accuracy, pressure profiles obtained from the full-scale, steady-state bleeder model were used as boundary conditions. Limiting the model to this smaller section of the mine al-

lows for improved cell allocation by refining the mesh around the simulated ignition location.

The modeled longwall face includes a simplified model of 152 shields support, longwall shearer and other support components such the armored face conveyor (AFC), headgate and tailgate drives, and face curtain. To simulate the airflow interaction between the longwall face and the gob, each shield includes a 0.28-m² opening on the back of the shield. The gob is modeled as a porous medium and divided into three zones with different porosities ranging from 40 percent to 14 percent, and viscous resistances, calculated as the inverse of permeability, ranging from $1.5 \times 10^5 \text{ m}^{-2}$ to $5.0 \times 10^6 \text{ m}^{-2}$, based on findings by Marts et al. [1]. Figure 1 shows the full bleeder ventilation model and the resulting reduced ventilation model, along with the simulation result showing airflow distribution inside the longwall face.

For the chosen bleeder ventilation setup, the tailgate corner provides a back return where the return air is coursed through the first crosscut in by the tailgate. The shearer is located close to the tailgate corner, between shield number 140 and 146, and cutting toward the tailgate. Fresh air enters the longwall face from the headgate side at a rate of 41 m³/s. Some of this face air leaks into the gob, leaving only 16 m³/s of airflow by the time it reaches the tailgate corner. The tailgate entries out by the face is set to supply 4.7 m³/s of fresh air.

In this study, only methane emanating from uncut coal face is simulated. The uncut coal is modeled as a porous medium with thickness of 20 cm. The source term method is used to supply pure methane gas, simulating methane flowing from the cleats in the uncut coal around the shearer drums. Coal face methane inflow was 0.14 m³/s.

After steady-state simulation of the ventilation conditions, the model settings are changed to simulate a transient combustion event. In this scenario, an ignition occurs at the coal face, near the roof, while the tailgate drum is cutting the coal face. Ignition was initiated using ANSYS Fluent Spark Model version 18.2 with spark duration of 1 ms, spark kernel radius of 2 cm, ignition energy of 60 mJ and the laminar flame speed model.

Modeling results and discussion

Figure 2 shows the simulation results. The snapshot at 40 ms shows that the overpressure from the explosion is sufficient to divert face airflow into the gob area where it can mix with additional available methane, creating new or expanding explosive mixtures inside the gob area. Diverting the flow from the shearer drums also reduces the available fresh air to dilute the methane around the drums, potentially creating an environment that can lead to secondary explosions. The snapshot at 60 ms shows that the supplied fresh air is no longer reaching the tailgate corner of the longwall face.

Conclusions and future work

This modeling effort successfully demonstrates the viability of integrating a methane combustion model into a full-scale, 3D longwall bleeder ventilation CFD model. From these results, we conclude that even small ignitions can ini-

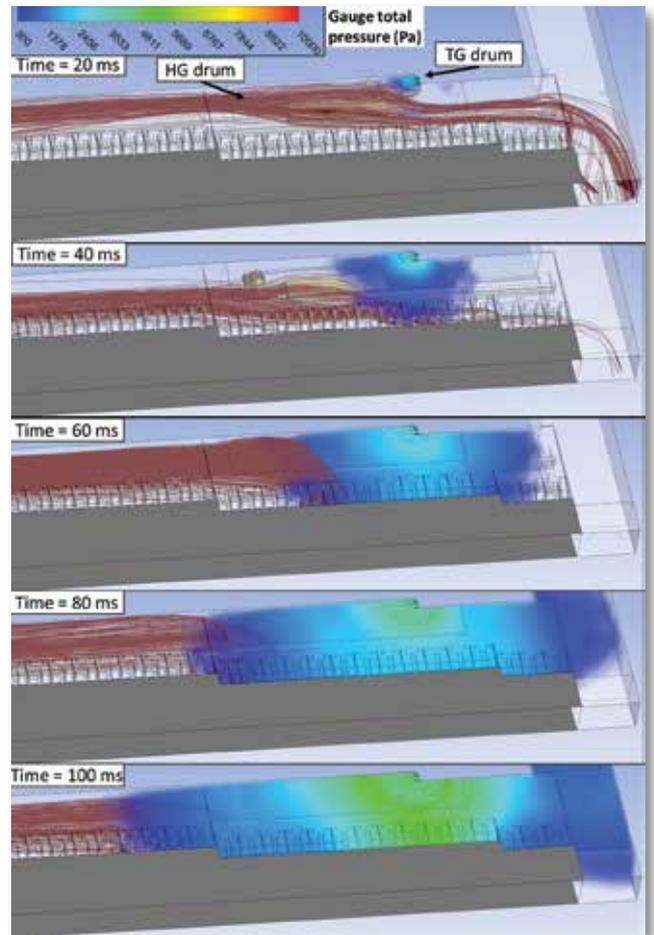


Fig. 2 Volume rendering of gauge total pressure showing explosion overpressure shifting the airflow (brown streamlines) in the longwall face for 0.14 m³/s methane inflow from the coal face.

tiate major explosions underground. The pressure from an explosion can divert airflow away from the face and tailgate, creating more explosive mixtures near the face or potentially transition into coal dust explosions.

Three-dimensional, full-scale CFD modeling can provide a better understanding of the fundamental physics and the potential impact of an explosion in an underground longwall coal mine. Expanding this study has potential for future research, including:

- Expansion and impact of methane explosions for different ventilation scenarios and ignition locations.
- Evaluation of explosion prevention and mitigation strategies, including explosion barriers.
- Improvements in ventilation layout.
- Structural design of ventilation control, such as mine seals. ■

Selected reference

1. Marts JA, Gilmore RC, Brune JF, Bogin Jr GE, Grubb JW, Saki, SA (2014) Dynamic gob response and reservoir properties for active longwall coal mines. *Trans Soc Min Metall Explo* 2015 Englewood, CO 336:129–136

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