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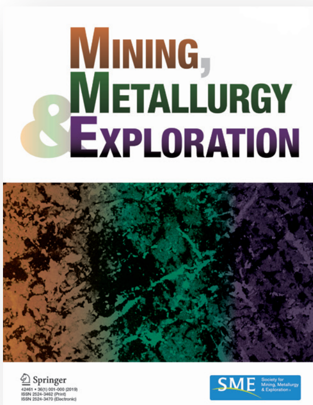

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Collection on Mine Ventilation

Investigation of explosion hazard in longwall coal mines by combining CFD with a 1/40th-scale physical model

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Keywords: Longwall, Coal mining, Mine ventilation, Computational fluid dynamics, Scaled modeling

To evaluate methane explosion hazards in underground longwall coal mines, researchers at the Colorado School of Mines developed a computational fluid dynamics (CFD) model along with a 1/40th-scale, optically accessible, physical model of a longwall mining section. In this project, CFD models assisted in the design of the physical model to ensure specifications were met to accurately represent the scaling physics as well as to assist in narrowing the experimental matrix and identifying key locations for sensor placement to measure velocity, pressure and gas concentrations. This research will help develop strategies for methane monitoring to prevent methane ignitions and explosions in longwall coal operations.

Introduction

Adequate ventilation and a mine-wide atmospheric monitoring system are keys to preventing explosions in underground coal operations. The use of point-type methane sensors to detect explosion risks relies heavily on sensor placement. In addition, methane monitoring within the gob area is difficult as the caved area is inaccessible. To evaluate the flow patterns and gas mixtures in these critical areas, a 1/40th-scale physical model of a longwall coal mine panel was built [1,2]. To complement and guide the development and testing with this model, CFD modeling is used to help identify critical ventilation parameters, such as flow dynamic and kinematic scaling, gas mixture distribution, and sensor placement. The goal of this project is to develop early detection methods to improve methane explosion prevention and mitigation strategies in longwall coal operations.

Method

Physical model overview. The dimensions of the 1/40thscale physical model are length of 7 m, width of 6 m and height of 0.61 m, equivalent to a section of a longwall mine that is 280 m long, 240 m wide and 24 m high. The modeled active longwall panel includes the longwall face, gob area and surrounding mine entries as well as the ventilation control required to simulate different ventilation scenarios. The scaled version has optical access on the sides and tops to visually observe the airflow patterns by injecting a visible tracer gas. Flow-velocity and gas-concentration sensors are installed in critical areas to validate the flow distribution and gas mixtures inside the gob area and surrounding mine entries. The dimensions of the mine entry are width of 145 mm and height of 72.4 mm, equivalent to full-scale width of 5.8 m and height of 2.9 m, which is typical for many longwall mines.

The length of the longwall face is 5.5 m, equivalent to 220 m in full scale, and it is separated into 11 face segments or carts, consisting of 10 shields per cart. These face carts (FCs) can be advanced individually to simulate different face advance positions and shearer cutting scenarios.

Each gob cart is 0.6 m long, 0.5 m wide and 0.61 m high. The model can accommodate up to six rows of gob carts, equivalent to face advances of 24, 48, and so on, up to 144 m. The gob carts can be filled with objects of different geometries and sizes to simulate the varying gob porosities and permeability distributions observed in real longwall gobs.

Surrogate methane gas inflow into the model occurs through two main injection systems, allowing independent control of flow rates to the face and gob regions. Due to safety concerns, methane is substituted with a mix of 70 percent helium (He)/30 percent carbon dioxide (CO_2), which has similar molecular weight and transport properties, providing comparable mixing characteristics to methane. In addition, CO_2 is easily detectable in low concentrations, allowing accurate gas concentration measurements throughout the gob, face and mine entries.

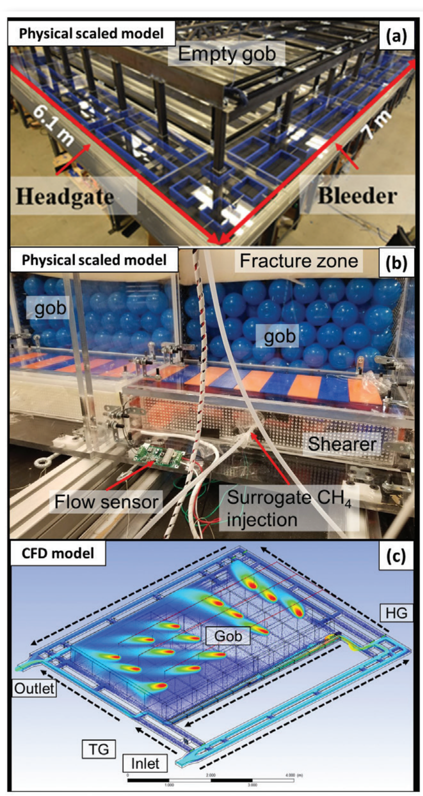

Fig. 1 (a) Overview of assembled physical scaled longwall model, (b) close-up view of physical model longwall face, (c) overview of the corresponding CFD model.

CFD model. ANSYS Fluent v.18.2 software is used for the CFD simulation. The CFD model represents the physical model dimensions, features and ventilation controls. The model is separated into multiple segments, such as the mine entries, face carts, gob carts and methane injection system. These segments are meshed separately before combining them in the ANSYS Fluent software for the simulation. For the gob resistance, the gob fringe resistance is assigned a viscous resistance value of 6.5×10^6 /m^2, while a viscous resistance value of 1.05×10^7 /m^2 is assigned to the five rows of center gob. These viscous resistance values are based on flow resistance tests with 58 mm- and 38 mm-diameter plastic spheres packed randomly in the gob. The rider coal bed at the top of the gob is represented by foam material having a viscous resistance of 1×10^8 /m^2.

Figure 1 shows images of the physical scaled model and the corresponding CFD model.

Results and discussion

The results of the scaled physical experiments are compared with results from the CFD model. The modeled ventilation scenario is a bleeder system, with the main fan set to supply 100 L/s of fresh air to the mains and 3.0 L/s of methane surrogate (the helium and CO_2 mix) injected into the model (1.5 L/s to the longwall face and 1.5 L/s to the gob area). Figure 2 shows a comparison of airflow velocity and surrogate-methane profile across the longwall face between experimental results and CFD prediction. The measured CO_2 concentration is converted into an equivalent methane concentration. The shearer is located at face cart number 11, near the tailgate.

The results in Fig. 2 show that the CFD and scaled physical models show overall good agreement in the velocity and methane concentration profile across the face. Velocities near the headgate side show greater discrepancies due to flow separation and reattachment as the airflow makes a right-angle turn from the headgate into the face, creating turbulence. The predicted methane concentration at the face sensors located at 1 m and 3 m away from headgate are within 0.5 percent methane equivalent, while the predictions at the sensor located 5 m away from headgate agree within 1 percent methane equivalent. Both models also confirm that the methane-equivalent concentration in the face increases toward the tailgate side.

Conclusions and future work

A CFD model is used to aid in the design and development of a 1/40th-scaled physical model of a longwall coal mine.

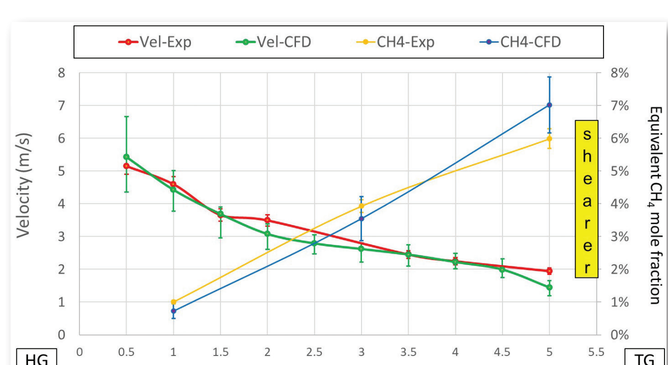

Fig. 2 Comparison of airflow velocity and methane equivalent across the longwall face between experimental results and CFD prediction.

Data from the scaled physical model, such as airflow patterns, leakage rate and methane-equivalent distribution are used to validate the CFD model. Comparison of experimental and CFD simulation results shows overall good agreement in terms of flow patterns and gas distribution in the longwall face and gob regions. This confirms the viability and advantages of this coupled modeling approach, which can be used to develop more-robust, full-scale longwall coal mine CFD models to aid in the design and improvement of ventilation and air-quality monitoring practices to reduce the risk of longwall mine explosions. For future work, the CFD model will be used to simulate different ignition scenarios, such as longwall face ignitions during shearer cutting operation and in-gob ignitions. ■

Selected references

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2. Pinheiro H, Juganda A, Sandoval N, Wilson F, Gallagher K, Bogin G, Brune J (2021) Scaling and flow similarity considerations to develop a 1/40th scaled aerodynamic model of a longwall coal mine for methane hazards investigation. Proceedings of the 18th North American Mine Ventilation Symposium (virtual event)

TGA kinetic analyses of zinc ferrite reduction with H_2

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Zinc ferrite is considered an integral phase of zinc residues as their presence can render the processing of zinc and critical metals difficult. It is a refractory phase, formed at high temperature in the presence of zinc (Zn) and iron (Fe) during oxidative roasting in zinc processing plants. Because it is refractory to efficient leaching, unreacted zinc ferrite gets concentrated in the final zinc residue, making it a viable source of zinc and indium extraction. The refractory nature of zinc ferrite makes the extraction of associated critical metals difficult. In order to explore a potential economic and carbon-neutral zinc ferrite processing technique, our previous study proposed the partial reduction of zinc ferrite followed by sulfuric acid leaching of the roasting product [1-3]. As demonstrated in our previous studies, partial reduction of zinc ferrite results in a mixture of ZnO, Fe_3O_4 and FeO, which can be further subjected to leaching for efficient extraction of zinc and critical metals such as gallium and indium.

Background

This study explores the kinetic parameters and reaction controlling mechanism in a specific set of conditions — 10 to 30 percent hydrogen (H_2) gas concentration and temperature in the range of 300 to 700 °C — using the isoconversional method of kinetic analysis to analyze the thermogravimetric analysis (TGA) data. TGA kinetic data were fitted into selected isoconversional kinetic models to determine the reaction controlling mechanism and calculate kinetic parameters.

Materials and methods

The 99 percent-pure zinc ferrite used for TGA experiments was bought from alfa-aesar. Isothermal reductions of zinc ferrite in the presence of H_2 and nitrogen (N_2) were performed on a NETZSCH STA 449F3 thermal analyzer. Isothermal reduction experiments were conducted at 300, 400, 500, 600 and 700 °C with 10 percent H_2 and at 400, 500 and 700 °C with 30 percent H_2. The total flowrate of reducing gas was maintained at 100 mL/min. The solids were characterized with scanning electron microscopy (SEM).

Results and discussion

The extent of conversion was found to increase with temperature and H_2 concentration (Fig. 1). With increasing temperature, some of the reactions, such as volatilization of zinc as vapor and further reduction of magnetite to wustite, are thermodynamically possible, and consequentially, relatively higher mass loss can be observed. Increase in H_2 concentration enhances the mass transfer and thus increases the reaction kinetics.

With 10 percent H_2 concentration, the maximum extent of conversion (0.723) was obtained at 700 °C, whereas at

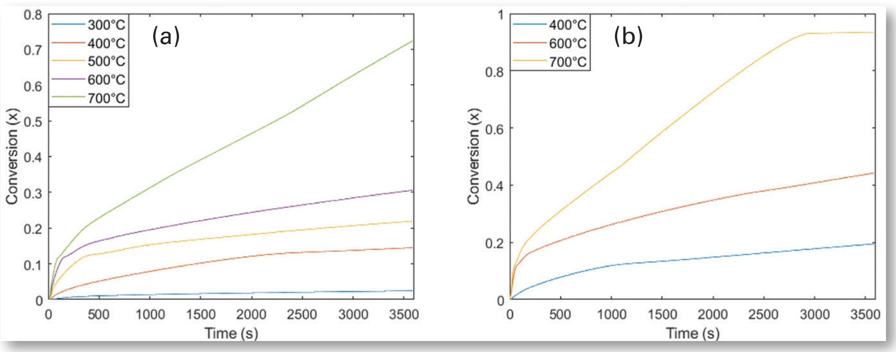

Fig. 1 Extent of conversion of zinc ferrite reduction with (a) 10 and (b) 30 percent H_2 concentration.