Spontaneous combustion prediction and remediation techniques

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Methods for predicting spontaneous combustion include examining coal properties and observing coal-oxygen interactions. Accurate predictions in mines are difficult because of variations encountered in actual conditions which change coal behavior considerably. The most common remediation techniques for control of spontaneous combustion are isolation and inertization, and pressure balancing. When isolation and inertization are used, there can be considerable leakage of air from stoppings, which can dilute the whole process and increase nitrogen consumption. The pressure balancing approach can provide a solution that is not so susceptible to leakage problems.

A series of experiments were conducted at University of Utah mine ventilation laboratory to ascertain the variation of pressure across a simulated mine gob with an adjacent pressure chamber. Experiments were conducted at different conditions, including variations in the pressure build-up and decay rates at the chamber, in an attempt to reduce the ingress of air to the gob. Results of these experiments arte reported in this paper.

Keywords: Spontaneous combustion, Inertization, Pressure balancing

1. Introduction

Certain materials such as coal and pyrites have the characteristics of self-heating upon interaction with the mine air. If the heat liberated is greater than the rate of dissipation, it may result in a chain reaction known as spontaneous combustion or endogenous fire. The risk from such fires may accrue at a temperature much lower than the corresponding ignition temperature of the material, depending on extraneous conditions such as coal quality, geological conditions, and mining practice.

Seals used to separate the working areas from the gob are not airtight, and they tend to "breathe in and breathe out" with changes in barometric pressure. In mines ventilated by a U-tube exhaust system, the gob is often kept under negative pressure. Under these circumstances, an increase in barometric pressure may cause an influx of fresh air into the gob. This quantity may be sufficient to start the self-heating of coal.

1.1 Factors influencing spontaneous combustion

The interaction of coal with oxygen is an exothermic process. Some of the important factors that contribute to the generation of heat are coal properties, geological conditions, and mining method. A number of different estimation and prediction methods are available to predict the propensity of coal for spontaneous combustion. Different methods used to predict the heating of coal on the basis of coal-oxygen interactions include crossing point temperature, differential thermal analysis, and adiabatic calorimetry technique [1, 2]. Adiabatic calorimetry is used to simulate conditions close to those that occur during mining, and is based on the fact that spontaneous combustion is an adiabatic phenomena. Each method has its own limitations, and accurate prediction of spontaneous combustion with any of them is difficult.

Moreover, the interaction of each of the key factors to generate spontaneous combustion is complex. Control measures in the form of remediation techniques should be practiced to prevent any spontaneous combustion and unwanted subsequent events.

1.2 Remediation techniques

The techniques used to control spontaneous combustion include caved area inertization and pressure balancing. Inertization refers to injection of an inert gas into the gob atmosphere to reduce the concentration of oxygen and render the atmosphere inert in relation to methane content. Inertization also helps reduce the oxygen concentration in and around the heated area, and to reduce the intensity and spread of secondary combustion. Pressure balancing is a technique in which the pressure across the gob area is minimized to control the ingress of air. There are two types of pressure balancing techniques which can be used: passive and active techniques.

1.2.1 Passive pressure balancing:

Using this method, pressure balancing is achieved by adjusting the flow in the affected area using regulators and fans, or by judicious adjustment of the air flow rate. The adjustment takes place first through the different branches of primary ventilation network, and second

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through pipes and pressure chambers designed for the purpose [3]. A pressure chamber is constructed by first building an isolation stopping in front of the isolation seal and then equipping it with a set of air sampling and flow control devices. Two pipes are laid out connecting the pressure chamber to the main intake and return airways. Air sampling pipes through the isolation stoppings are used to measure the pressure differential across the stoppings. When the pressure differential across the isolation stopping is greater than an allowable value, this is balanced by adjusting the airflow rates through these pipes.

Figure. 1 shows a schematic of a passive pressure balancing arrangement. The seals used to isolate the gob are not usually airtight and the pressure differential between the intake and gob side can be high enough to cause an ingress of air in the gob. A passive pressure chamber can be installed by making another seal adjacent to the original seal and connecting it to the intake and return airway using pipes. Once these connections are made, the air flowing in the mine is used to pressurize the chambers using control valves. These valves regulate the quantity of air that enters the chamber, to attain the desired pressure. Once the pressure inside the chamber equals that of the gob, pressure balancing is said to be achieved.

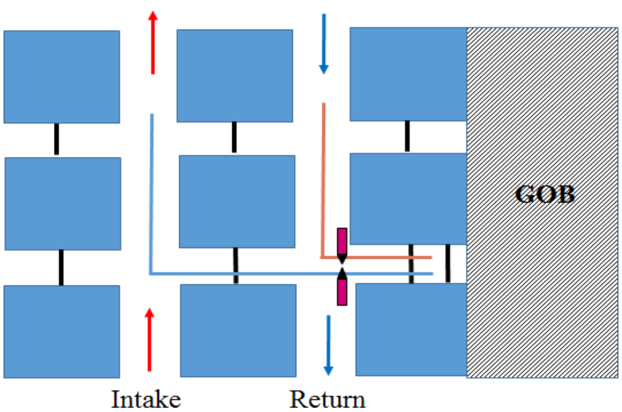

Fig. 1. Schematic of passive pressure balancing arrangement.

1.2.2 Active pressure balancing:

This is a preferred choice when passive pressure balancing is difficult to implement. In this method pressure chambers are built in a manner similar to the previous method, except that here the chamber is connected to a source of inert gas. The chamber is equipped with a differential pressure sensor and a microprocessor, which are the active components of a control loop that ensures an adequate flow of inert gas to the chamber [6].

When the chamber is pressurized and maintained at a pressure slightly higher than that of the gob area, minimal leakage of inert gas (usually nitrogen) occurs from the chamber to the gob side. Inert gas leakage from chamber to the gob does not affect its atmosphere. In this way the ingress of oxygen can be contained and spontaneous combustion can be mitigated. In additional, gob air is prevented from flowing towards the face when barometric pressure variations occur. There are several sources of inert gas that can be used with this method, depending on local conditions and quantity requirements.

Figure. 2 shows a schematic of an active pressure balancing chamber. The chamber is isolated from mine openings by two seals. Placing a more substantial seal on the outer end of the chamber will ensure that the leakage from the gob to the workings is reduced when the pressure differential across the seal is positive [4, 5].

A central pipeline carrying inert gas is used to pressurize the chamber. Differential pressure sensors are used to monitor the gage pressures in the chamber and the gob. If the pressure in the gob is higher than the mine side, a microprocessor controller will open the valves and pressurize the chamber. The chamber is pressurized so that its pressure is slightly higher than the gob pressure.

2. University of Utah mine ventilation model

Laboratory models are helpful in simulating real life problems. Experiments can be performed to come up with meaningful conclusions, which may not be possible in active mines. The University of Utah laboratory ventilation model (Figure 3) is constructed of 0.15-m (5.75-in.) diameter pipe and equipped with two fans and an atmospheric monitoring system.

The pipes are configured in a standard U-shaped ventilation network with one intake and two return airways. Crosscuts are constructed of 0.06-m (2.5-in.) diameter pipes, which act as leakage paths between the intake and the return airways. Two airways, one each designated as continuous miner face and longwall face, are used to simulate two active workings. The model is equipped with a main blower fan and a bleeder fan. Each fan is equipped with a variable frequency drive to allow changing the fan duty for different experimental conditions.

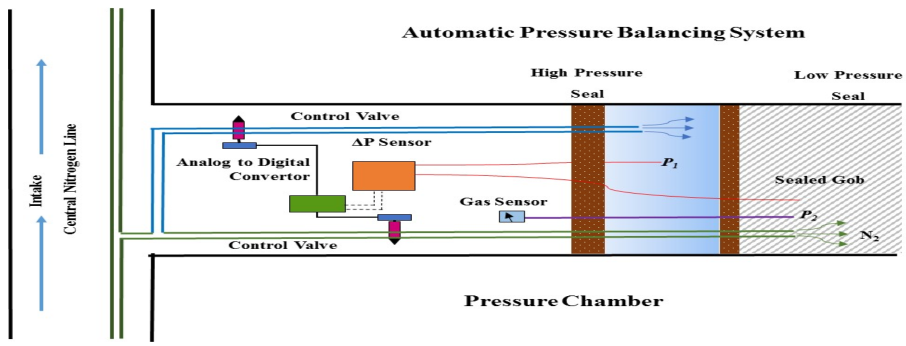

Fig. 2. Schematic of active pressure balancing chamber

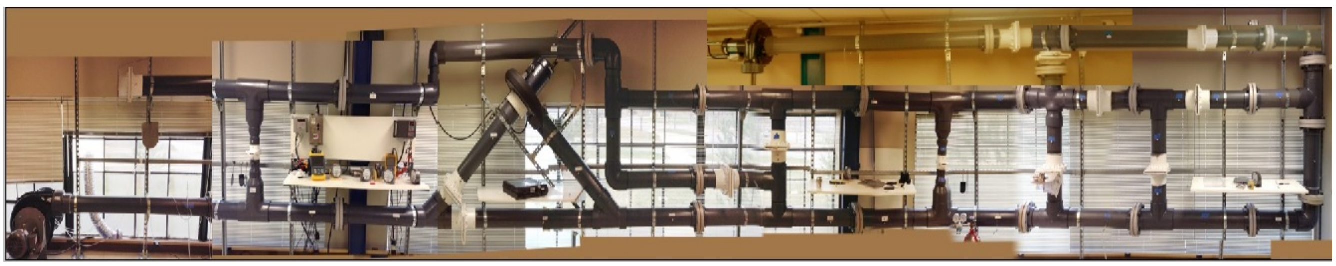

Fig.3 University of Utah laboratory model

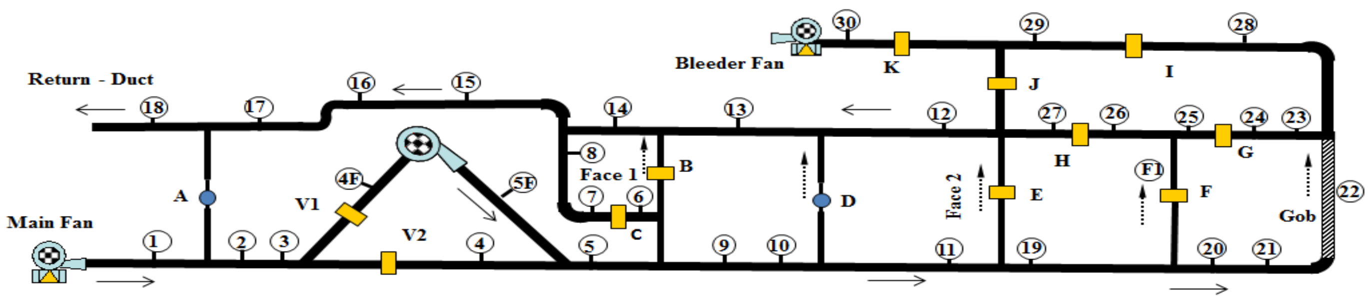

Fig. 4. Schematic of laboratory model

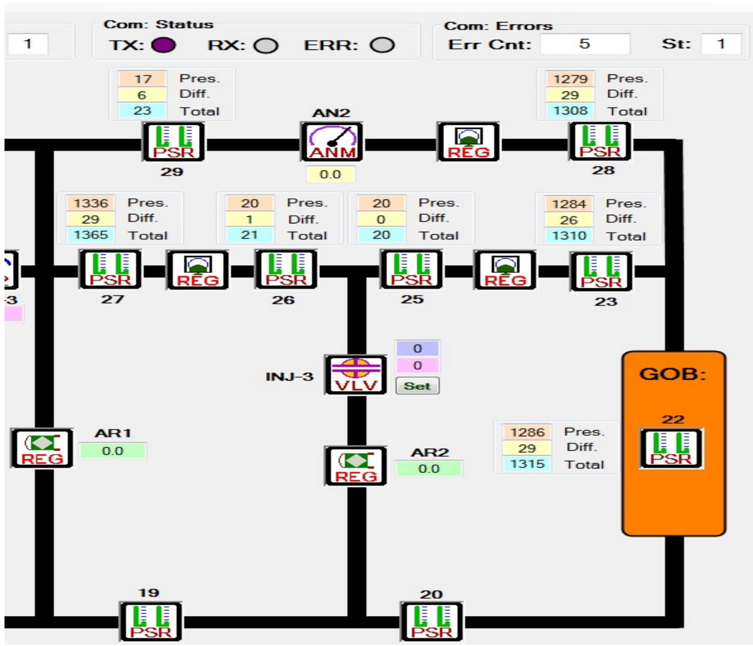

Fig. 5. Gob section of University of Utah atmospheric monitoring and control system

Figure. 4 is a schematic of the laboratory model showing the intake and return airways, the simulated workings (Faces 1 and 2), and the locations of fans, regulators, and pressure-quantity measuring stations.

The model was used to conduct several pressure balancing experiments. In each experiment, the main fan was used as the pressure source. Perforated gate valves of variable resistances were used as regulators to control the flow of air and achieve the desired quantities at the simulated working faces. A container, filled with broken rock (shaded area in Figure 4) was used to simulate the mine gob. This section was equipped with a bleeder fan and a set of regulators to allow simulation of different gob ventilation scenarios.

Figure 5 shows gob section of the model. The pressure recorded by these transducers are mentioned against them .Each transducer is equipped with its own microprocessor controlled by a host PC. Typical functions performed by the microprocessor include scaling, averaging, filtering, and verification of signals throughout the system. All communication in the system uses RS 485 standard interface hardware. Each module draws a small amount of power (~ 30 milliamps) from 12-V DC bus for its internal digital and analog circuitry. Each module has a unique address and responds to control and query commands sent across the network.

Following is a summary of the components currently used with this system:

- Pressure transducers are used to monitor the static, velocity, and total pressure across the system. In total 25 pressure transducers are installed.

3. Continuous monitoring system

The University of Utah laboratory model is equipped with a micro-processor based atmospheric monitoring and control system. The monitoring system consists of a host PC attached to a communication network and a set of air velocity and pressure transducers and a CO_2 gas injection-system.

- CO_2 gas injection and sampling system is used to control the flow of carbon dioxide in the model and to determine its concentration at three strategic locations.
- Fan control devices are used to change the fan speeds for different experimental conditions.

This system was used to continuously monitor and record data for a set of laboratory tests. The data was recorded every second and stored in an Excel file. The data in this file was processed to analyze and evaluate the effect of variations of fan pressures and regulator resistances on airflow distribution across the gob.

4. Laboratory experiments

Three experimental conditions were set up by changing the main fan duty and regulator resistances in the model. Two of these were set up for passive pressure balancing, and one for active pressure balancing.

4.1 Experiment 1

The aim of this experiment was to minimize the pressure differentials across the gob by changing regulator resistances in the model.

Two gob ventilation scenarios were set up, one for a punch-out bleeder ventilation system, the other for wrap-around ventilation system. For the former, the regulator in the punch-out airway (regulator K in Figure 6) was partially blocked so that only 28% of its total area was open. This allowed a fraction of the gas generated in the gob to be vented to the surface. For the latter, this regulator was fully closed and regulator J was partially open. In each case, the blower fan was the only source of pressure for the system. The initial conditions and the results of each test are presented below.

Case 1- Punch-out bleeder system

<u>Initial conditions</u>. These are given by:

- Main fan pressure: 1635 Pa.
- Regulator settings: regulators A, B, and D, with 5% total open area, represent high quality stoppings with almost zero leakage flow , and the other regulators (C at 28% open area, F at 50%, G at 8%, H at 28%, J at 8 %, and K at 28%) represent leakage paths.

<u>Results</u>. Air pressure–quantity measurements were taken using a barometer, manometers, Pitot tubes, and a thermometer. Pressure differentials were measured using micro-manometers. The results of these measurements were used to determine the fan duty and plot pressure gradients. Figure. 7(a) shows the static pressure profile for this model. In this case, the blower fan supplied 0.45 m^3/s of air at 1635 Pa of static pressure. In this Figure, the blue line indicates pressure profile in the intake airway and the red line, the pressure profile in the return side. Under these conditions, the differential pressure across the gob area was about 100 Pa.

Case 2. Wrap-around bleeder system

In this case, the mine gob was ventilated by a set of airways arranged in a wrap-around ventilation system. The pressure differentials across the gob were controlled using regulators placed between the cross-cuts and the simulated mine gob. The system imitates a longwall section in which the regulator in the bleeder entry (regulator K in Figure 7) is fully closed, and the regulator in the inby cross-cut (J) is partially open. This arrangement was used to minimize the pressure differential across the gob.

The initial conditions and the results achieved are presented below.

<u>Initial condition</u>. These are given by:

- Main fan pressure: 1740 Pa.
- Regulator settings: the regulator in bleeder entry (K) was fully closed, and the regulator in the in-by cross-cut (J), partially open. Settings of other regulators were the same as in case 1.

<u>Results</u>. Figure 7(b) shows the static pressure profile for this case. The pressure generated by the main fan was 1740 Pa, slightly higher than that recorded in the previous case. This pressure decreased as the air moved towards the longwall face. The pressure differentials across the gob were practically nil, indicating that the gob air was stagnant. This can be observed by comparing the pressure profiles around the simulated mine gob, indicated in Figures 7(a) and 7(b) by the dashed vertical lines.

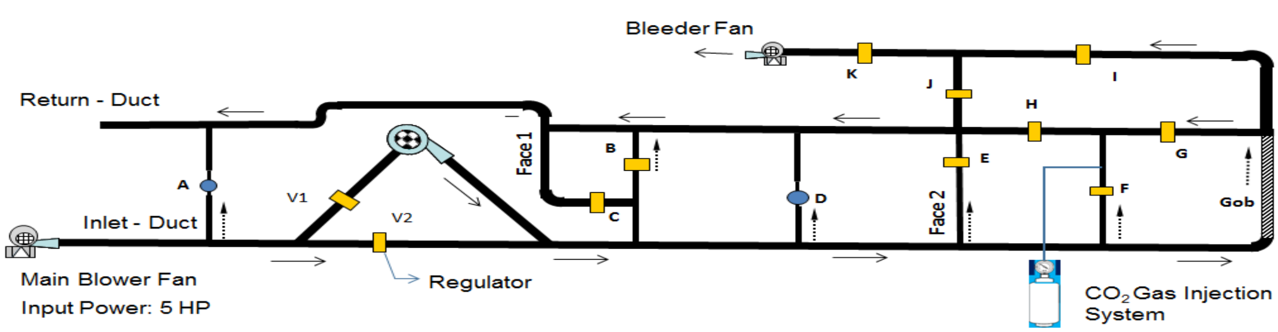

Fig. 6. Schematic of model and corresponding pressure profile

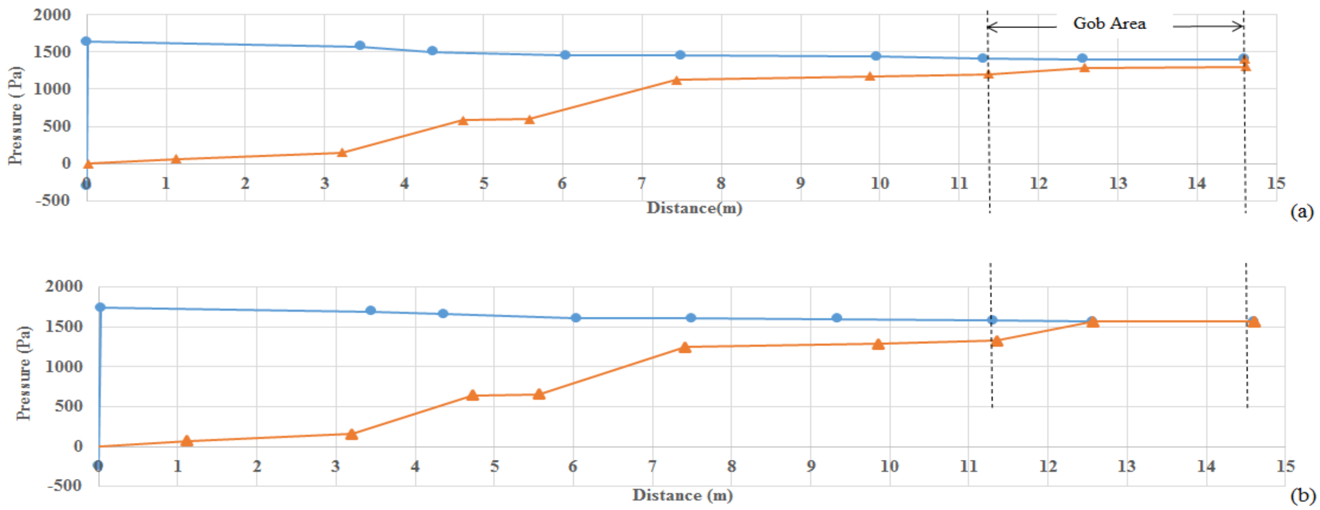

Fig. 7. Pressure profiles for two longwall bleeder ventilation systems: (a) Punch-out system, and (b) wrap-around system.

4.2 Experiment 2

The aim of this experiment was to test a passive pressure balancing system in the simulated gob model. The University of Utah ventilation model was modified to include a pressure chamber and two flow control pipes, connecting the chamber to the main intake and return airways (Figure 8).The chamber was built by isolating a section of the gob using three fully-closed stoppings, F, G and H. Tubing were used such that the existing airflow in the intake and return can be used to raise the pressure in chamber. Two 3-mm-diameter silicon tubes were used to connect the chamber to the intake and return airways. These tubes were equipped with pressure gages and flow control valves.

A test was conducted under the following conditions:

- Main fan pressure: 1620 Pa.
- Regulator settings: Regulators A, D, I, and J were partially closed, with 5 % of total area open; regulators C and K had 28% of total area.

During the experiment the pressure differential between the chamber and the gob was monitored continuously. When this difference was deemed to be significant, the pressure in the chamber was balanced by manually opening one of the flow control valves (C1 or C2), depending upon the relative pressure in the chamber. Figure. 9. shows the pressure profile obtained before and after the opening the control valve C2, used to balance the pressure in the chamber.

A comparison of the pressure profiles shown in Figure 9 (a) and (b) shows that when the control valve C2 was opened, the pressure difference across the regulator G, which separates the intake and gob, dropped from 545 Pa to 55 Pa. Based on these results it was concluded that a pressure chamber equipped with flow control pipes can be used to reduce or balance the pressure across the gob, thus reducing the possibility of a spontaneous combustion event.

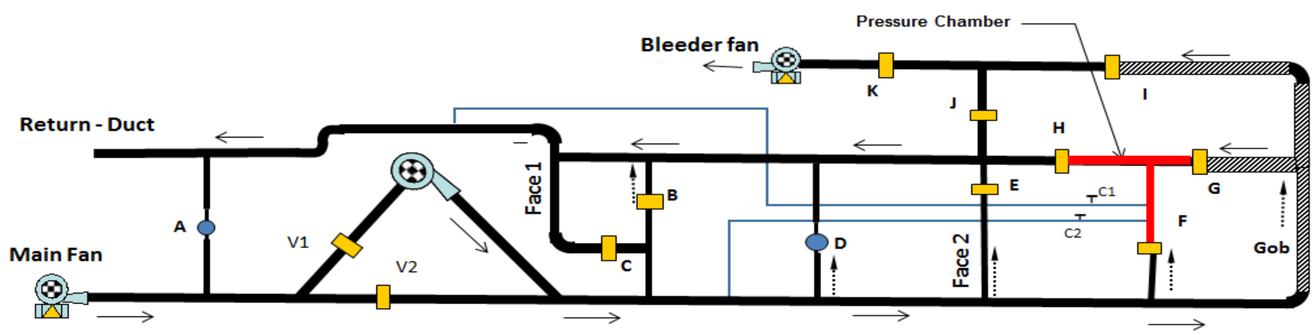

Fig. 8. Schematic of the model for passive pressure balancing system

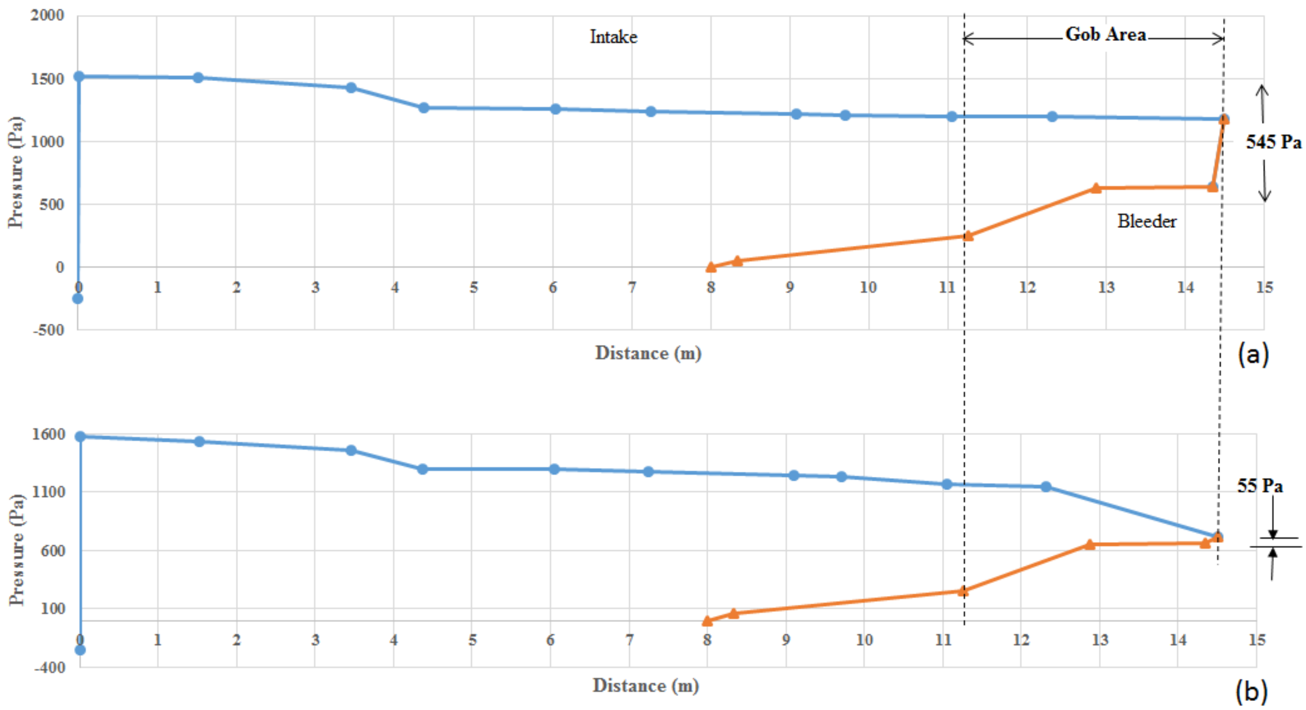

Fig. 9. Pressure profiles with pressure chamber in place; (a) when control valves C1 and C2 were both closed, and (b) after control valve C2 was open.

4.3 Experiment 3

This section describes an active pressure balancing experiment carried out with the University of Utah ventilation model. The aim of this experiment was to use an external automated CO_2 injection system to pressurize the chamber. Pressure transducers and gas sampling monitors were used to monitor pressure differentials across the gob and gas concentrations in the return airway.

As in the previous experiment, the pressure chamber was established by using three regulators (G, F and H), of which two were fully closed and the third (G) had 0.05 % of its total area open. The chamber volume was 0.03 m^3 (1.2 ft^3). Two pressure transducers (PS 26 and PS 23 in Figure 10) were used to monitor pressure differentials across and around the gob.

The experiment was initiated by operating the main fan at full speed and monitoring the gage pressures along the ductwork and pressure differentials around the simulated gob (stage 1). The gas injection system was then opened to reach a pre-established flowrate, held for few seconds, and shut off (stage 2). This caused the chamber to be pressurized and a new steady- state level reached. When the gas injection system was shut off, the chamber pressure returned to its initial level due to reverse leakage from the chamber to the gob.

When the chamber is pressurized the leakage from the intake towards the gob can be reduced or eliminated. This process was repeated to observe the variations of pressure build up and decay. The initial conditions and the results achieved are presented below.

<u>Initial conditions</u>:

- Main fan duty: Pressure 1790 Pa, quantity 0.4 m^3/sec and frequency 60 Hz.
- Regulator settings: Regulators B, F, G and K fully closed; H, 0.05 % open, and the rest as in experiment 1.

<u>Results</u>. When the experiment was initiated (stage 1), the differential pressure across the stopping separating the chamber from the gob (regulator G in Figure 8) was –150 Pa. This was created by the back pressure caused by closing the regulator K and using a wrap-around ventilation system. Under this condition, the chamber was held under negative pressure. This pressure difference is sufficient to cause the ingress of gob gas into the face. To mitigate the problem, carbon dioxide was injected to the chamber at the rate of 10 L/min (stage 2).

This inflow of gas pressurized the chamber to a maximum of 1,860 Pa, and reversed the pressure difference across the stopping (regulator G) from –150 Pa to 450 Pa, causing part of the pressurized gas to migrate from the chamber into the gob. This flow reversal was sustained as long as the gas injection rate was kept constant. When the gas injection was stopped, the pressure in the chamber returned to its initial level. Figure 11 shows the pressure differences between the chamber and the gob for the two conditions, without and with gas injection into the chamber. Based on these results it was concluded that the pressure chamber can be used to stop the gas flow from the gob into the face.

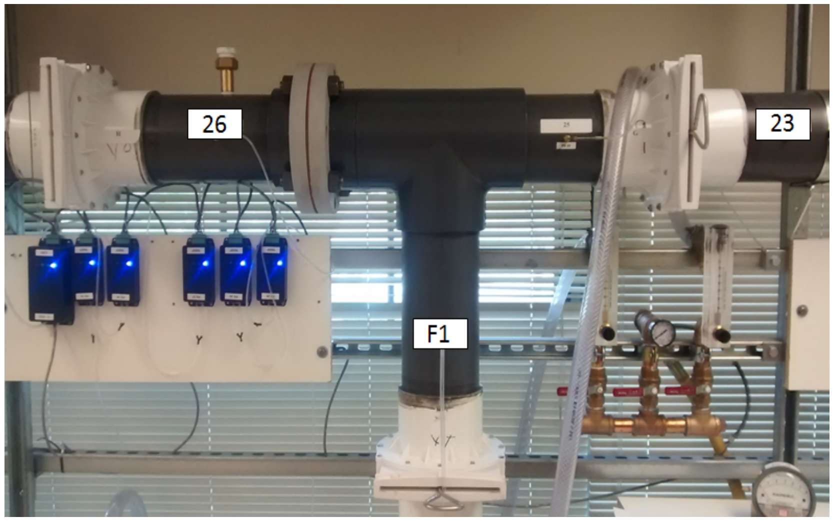

Fig. 10. Automated pressure transducers for monitoring pressure at the chamber and gob.

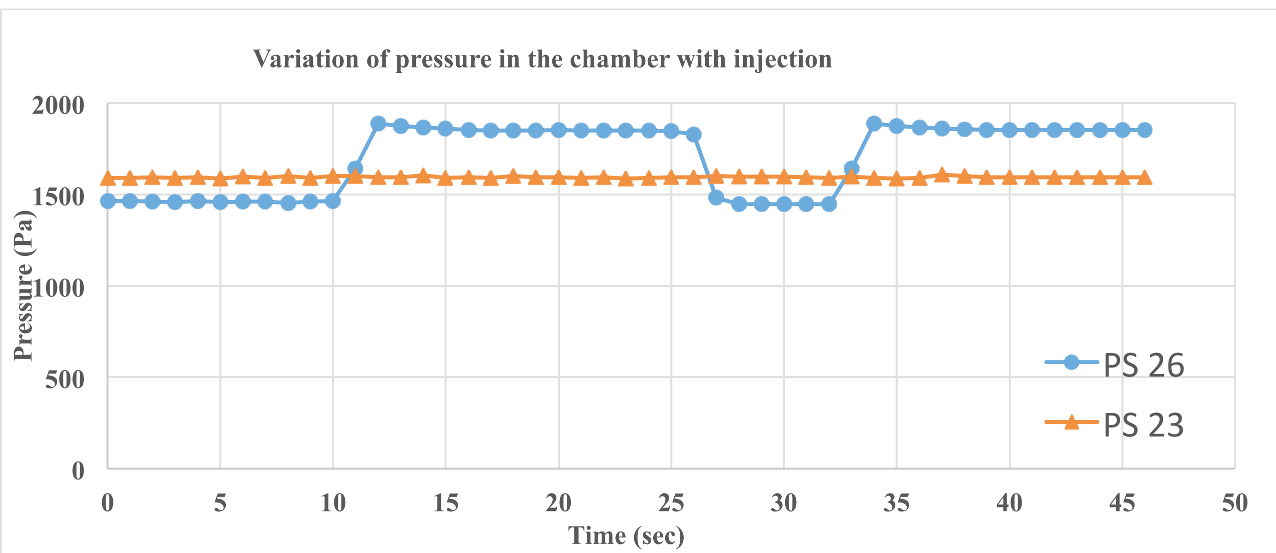

Fig. 11. Pressure build-up and decay in the chamber with changes in gas injection rate

5. Conclusions

Pressure balancing is an effective technique to control spontaneous combustion in underground coal mines. There are two types: passive and active. Passive pressure balancing is used when large pressure differences across the gob are expected. It is desirable because it does not require any external pressure source. Active pressure balancing requires an external pressure source. It can be used where passive pressure balancing is not effective.

The University of Utah's ventilation laboratory model was upgraded to include a longwall section, a pressure chamber, and a bleeder ventilation system. Three experimental conditions were set up in this model, two to investigate the effects of passive pressure balancing on the flow distribution in the gob, and one for active pressure balancing.

When a longwall gob is ventilated by bleeder entries, the wrap-around system is more effective in controlling the pressure differential across the gob than the punch-out system. The results of experiment 1 demonstrated this fact.

A pressure chamber together with two flow control pipes connecting the chamber to the main intake or return airways can be used to minimize the pressure difference across the gob. Experiment 2 showed that when the intake pipe flow control valve was opened, the pressure difference across the gob dropped from 545 Pa to 55 Pa, thus reducing the ingress of air to the simulated gob.

In experiment 3, a pressure chamber was created near the gob by isolating a crosscut using three gate valves, two that were fully closed and one that had a pinhole to a simulate leakage path. The fan was operated at 1,790 Pa and the CO_2 gas injected to the chamber at fixed rate (10 L/min). This action allowed the pressure build-up in the chamber. Once the targeted pressure was reached, the gas control valve was switched off and the chamber depressurized. This experiment demonstrated that an external, automated CO_2 injection system could be used to pressurize the chamber and control gas flow into the gob.

Disclosure

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