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Methane and Coal Dust Problem in Underground Coal Mining and Alternative Ventilation Techniques

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Abstract: Methane and coal dust explosions are among the most important risk factors that cause fatal occupational accidents in underground coal mining. One of the most important reasons for these explosions is inadequate or unfavourable ventilation conditions. In cases where the generally used classical ventilation systems are insufficient, attempts are made to continue ventilation with classical methods instead of some methods that may be considered as alternatives, and these methods often lose their applicability due to high costs. In this study, methods that emphasize their applicability as alternatives in risky situations are proposed and the results of some study examples are evaluated.

Keywords: Methane, coal dust, conventional ventilation, recirculation of air.

Introduction

In underground coal mining, a sufficient amount of clean air must be circulated within the mine to ensure that toxic, suffocating and explosive gases are within safety limits and that the amount of coal dust does not reach dangerous levels. In addition, this sufficient amount of air will positively affect thermal comfort conditions such as temperature and humidity.

In a project carried out in South Africa, in an underground coal mine with six production areas. It was aimed to increase the air flow to the sections without changing the existing ventilation system, and by recirculating 65 m^3/h of air. It was observed that the dust levels in the main entrance and return roadways remained constant, and there was no dangerous situation (Meyer, 1993).

Since the average annual temperature in the coal mines of the Singari Collieries Company (South India) is around 38-42°C and does not cover the cost of expensive air-cooling methods. Controlled recirculation of the mine air has been tried to improve environmental conditions. It was concluded that it can be applied with very little extra equipment (Vijaya et al., 1991; Krishna et al., 1989).

In the Ruttan mine in Manitoba, recirculation of the mine outlet air was tried to reduce heating costs in winter. It was emphasized that the reason for the study to be carried out in potash mines was that there was fewer blasting works in production and the mine outlet air was higher than most metal mines. There was no negative effect on air quality parameters to reduce heating costs. It has also been observed that it can be applied to increase the amount of air (Hall et al., 1989).

In some coal mines in the United Kingdom, in working areas exceeding 10 km, the recirculating ventilation method was tried because sufficient air flow could not be provided by conventional booster fan application, and positive results were obtained in terms of both safety and economy (Lee et al., 1987).

Methane and Coal Dust Explosions

Operating heavy machinery in narrow spaces underground and cutting tons of coal and hauling it to the surface make mining inevitably dangerous. Although explosions occur less frequently than other mining accidents. These are the most feared type of accidents by miners because the energy released is very high and access to the location is very difficult, resulting in multiple deaths (Widodo et al., 2018). While historically it was thought that explosions were caused by the burning of gas, after convincing tests at the Pittsburgh test station in 1908 and 1909, it was seen that coal dust alone could be an explosive element (McIntosh, 1957). In addition, the tendency of coal to spontaneous combustion and the formation of spontaneous combustion conditions should be considered as a situation that increases the risk of explosion (Song et al., 2019; Dmitrienko et al., 2018). It was observed that the most dangerous explosion combination of CH_4 and coal dust mixture made at 1073 K ignition temperature was 9.5%+500 g/m^3, 9.5%+400 g/m^3 and 8.5%+500 g/m^3 (Zhang et al., 2021).

Methane gas, which is much lighter than the mine air, accumulates at the ceiling and its density is 0.716 kg/m^3. Methane, which is flammable and explosive, cannot be separated again when mixed with mine air (Hartman et al., 1997).

The amount of fine dust (-75 μ) in coal dust is important due to its volatile and explosive nature. The surface area of the fine dust in contact with oxygen will be greater and its flammability will increase. Even when there is no methane in the environment, the explosion of coal dust can turn a small-scale methane explosion into a

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large explosion. In addition, the presence of fine coal dust can further lower the explosion limit of the methane-air mixture, and when coal dust takes part in the explosion, a significant amount of CO is included in the combustion residues (McPherson, 1993).

Study of the data of the most common accidents in 108 years of underground coal mining collected by the Mine Safety and Health Administration (MSHA) in the United States by Brnich and Kowalski-Trakofler (2010) revealed that 89.5% of the deaths occurred due to methane gas layering and coal dust explosions during mining (Table 1).

Table 1. Number of workers lost their lives in underground coal mines by type in the United States between 1900 and 2008 (Brnich and Kowalski-Trakofler 2010)

Type of incident	Number of events	Number of fatalities	Percentage
Explosion	420	10390	89,5
Fire	35	727	6,3
Haulage	21	145	1,2
Ground fall/bump	14	92	0,8
Inundation	7	62	0,5
Other	17	199	1,7

When 103 coal dust explosion accidents that occurred in 15 provinces of China between 1949 and 2007 were examined, it was found that 2514 deaths occurred in 49 explosions with methane and 2099 deaths were caused by 54 explosions without methane (Zheng et al., 2009).

Coal mine explosion events that cause serious loss of life and equipment damage generally occur as mixture explosions of methane and coal dust. First of all, there is the methane explosion. Then, the coal dust cloud swirling with the methane explosion will ignite and a more powerful explosion will occur (Lin et al., 2022; Lu et al., 2019).

In the control and prevention of methane/coal dust explosions, the use of inert gases and the construction of water and dust barriers are used to extinguish, and suppress the flame (Jiang et al. 2018; Luo et al. 2017; Zhang et al. 2014).

Classic and Alternative Ventilation

In conditions where classical ventilation methods are inadequate, the applicability of the controlled recirculation of ventilation method as an alternative method is gaining importance day by day. The controlled recirculation of ventilation system to provide cooling in deep underground mines, is known as passing the same air flow from one point more than once (Lawton, 1933).

In the mining industry, controlled recirculation of air is used to save energy during heating or cooling of air in submarine mining (Hannon, 1987), to increase working depths or to ventilate remote areas (Hall et al., 1987; Pritchard, 1995). In order to use the system safely and effectively, it is important that ventilation parameters are measured accurately. Ventilation network modelling is up-to-date, emergency planning scenarios are ready, and an effective monitoring control system is established (Wu, 2011; Longson et al., 1987).

In the study conducted in South Africa's most gold-bearing Witwatersrand deposits, a 66 percent reduction in total fan power requirements was predicted (from 6800 kW to 2300 kW in total) by using a controlled recirculation rate of 42 percent. With the introduction of controlled recirculation of air, significant energy savings have been achieved. The resulting power savings were in the range of 5.7 MW-4.5 MW, while the corresponding cost savings were in the range of USD 1.0-0.8 million per year (Butterworth, 1999).

At a trona mine in Wyoming, pre-test conditions for ventilation were modelled using VnetPC, and a recirculating ventilation system was implemented using Sulphur hexafluoride (SF_6) tracer gas to monitor recirculating air cycles by the U.S. National Institute for Occupational Safety and Health (NIOSH). The data obtained (air velocity, pressure differences, tracer gas arrival times, mine gases and dust levels) showed a good correlation with the model results (Pritchard et al., 2013).

In the Wearmouth coal mine in the United Kingdom, recirculating air in ventilation system was used because the ground connection could not be opened under the North Sea. A 30 percent recirculation rate was applied and it was determined that there was no significant change in the amount of methane in the return airway (Robinson et al., 1988; Pickering et. al., 1984). Similarly, in the Rocanville potassium mine in Canada, part of the return air (18.5 m^3/s) was given to the inlet air through a short circuit. It was observed that the change in the amounts of CO_2, CO, NO_2 and dust was at acceptable levels (Hall et al., 1990).

The first recirculating ventilation system in Turkey was applied at the Middle Anatolian Lignites Enterprise (MALE), in mechanized roadways where blowing auxiliary ventilation was used, and by measuring the dust concentrations in both systems. It was concluded that there would be no increase in dust concentrations with recirculating ventilation (Eyyupoğlu et al., 1995; Saraç et al., 1998).

The dust and gas concentrations that will occur as a result of the recirculating airflow have also been examined mathematically, and it has been concluded that it will not cause any increase in the dust and gas concentrations (Şensöğüt, 1989; Şensöğüt et al., 1990; Lowndes et al., 1990).

The controlled recirculation system in the heading operations, more air than the amount of air given from the blower fan is drawn through the exhaust fan, causing the airflow to short-circuit (Fig. 1a). In the panels, some of the return airflow is added to the inlet air flow with the fan placed on the cross-cut connecting the both roadways (Fig. 1b).

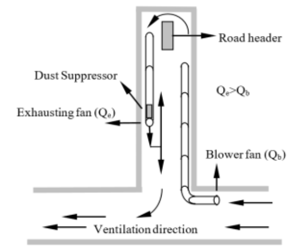

Fig. 1a. Recirculating ventilation system in the heading of main and tailgates

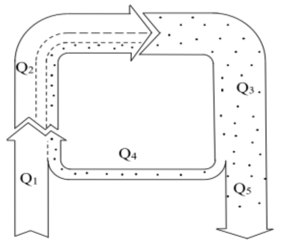

Figure 1b. Air distribution in recirculating ventilation inside the panel

According to Figure 1b, the recirculating ventilation ratio (F) is defined as Q_4/Q_3.

In the first iteration:

$$Q_1 = Q_2 = Q_3$$

$$Q_4 = F.Q_3 = F.Q_1$$

while, when generalized to the nth iteration, it will take the form of

$$Q_2 = Q_3 = Q_1.(1 + F + F^2 + \cdots + F^{n-1}$$

$$Q_2 = Q_1.\frac{1-F^n}{1-F}$$

If $-1<F<+1$, Q_3 value converges towards $Q_1/(1-F)$ value and the system reach equilibrium resulting

$$Q_3 = \frac{Q_1}{1-F}$$

In order to determine the effects of recirculating ventilation, measurement stations were established at the points shown in Figure 2. 7. Different measurement points were determined in order to find out the changes that may occur due to the applied method; blower fan inlet (1), between the blower fan outlet and the heading face (2), exhausting fan inlets and outlets (3 and 5), on the way where the air is recirculated (4), at the heading exit (6), and on the main ventilation roadway (7) was selected (Çınar et al., 2014).

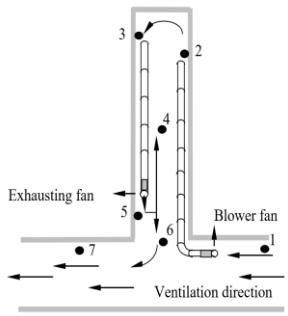

Figure 2. Measuring points

Changes in CO, temperature and dust amounts at these station points are given according to different air recirculating rates (Figure 3a, 3b, 3c).

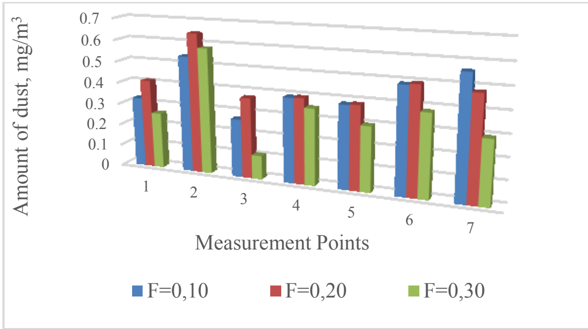

Fig. 3a. Change in dust amount according to different "F" values

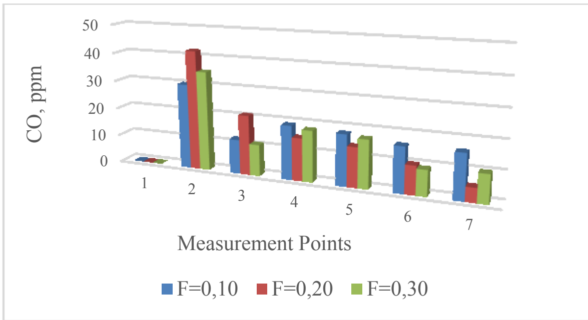

Figure 3b. Change in CO amount according to different "F" values

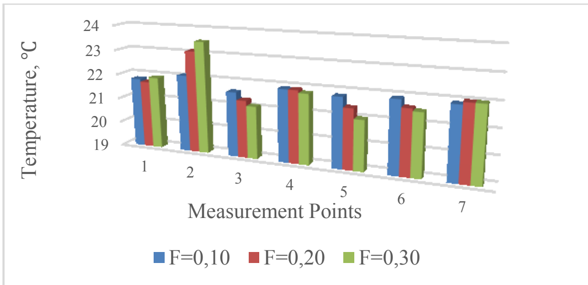

Fig. 3c. Temperature change according to different "F" values

In three separate cases where the studies were conducted; different air flow rates were provided according to the F ratio in air flow amounts. Significant improvements were achieved in the amount of dust, temperature and CO ratios. There was a decrease of 0.26 mg/m^3 in the amount of dust and 18 ppm in the amount of CO, while a decrease of 0.5 °C was achieved in the ambient temperature for a ratio of 0.10. There was a decrease of 0.27 mg/m^3 in the amount of dust and 21 ppm in the content of CO, while a decrease of 1.8 °C was achieved in the ambient temperature for a ratio of 0.20. On the other hand, at the ratio of 0.30, there was a decrease of 0.472 mg/m^3 in the amount of dust and 24 ppm in the content of CO, while a decrease of 2.4 °C was achieved in the ambient temperature.

Results and Discussion

It is extremely important to be able to send sufficient clean air to every space opened in underground coal mines (shaft, roadway, face, etc.) and to keep the amount of air sent under control. As production progresses, the introduction of new levels, the installation of new roadways and the formation of new panels cause the air speed in underground coal mines to change. In addition, a constantly changing ventilation plan is mentioned due to worked out panels or old roadways. Under these conditions, interventions such as air flow direction, air speed, air leakages, control of fan characteristics may be insufficient to deliver the desired amount of air to the desired area.

It is known that methane gas and coal dust cause catastrophic explosions in coal mining due to inadequate ventilation. In this case, as an alternative to classical ventilation systems, recirculating ventilation application will allow the amount of air in the desired area to increase, the methane and coal dust rates to decrease, and the ambient temperature to decrease.

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