Explosion Prevention in United States Coal Mines

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Abstract:

This paper outlines the legal standards and methods for protecting underground coal mines in the United States from explosions of methane gas and coal dust. It will discuss inspection and monitoring of mine atmospheres, dilution of methane through ventilation, methane drainage prior to, during and post-mining, as well as explosion prevention through rock dusting and sealing of mined-out areas.

Recent research findings of the National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory on the magnitude of pressures obtained during methane explosions from modeling and full-scale explosion tests at the NIOSH Lake Lynn Experimental Mine will be presented. This work is currently being applied to modeling the structural response of explosion-proof mine seals to pressures from gas explosions. Also, new research will be presented on the inertization of float coal dust in mines through the addition of inert stone dust and on the application of the Coal Dust Explosibility Meter (CDEM), a handheld device developed by NIOSH to directly measure the explosibility of a coal dust - limestone dust mixture based on optical reflectivity.

1. Introduction

Most coal deposits release significant amounts of methane gas which is flammable when mixed with air in concentrations between 5 and 16%. Coal mine operators need to carefully ventilate underground mine openings to dilute and render harmless concentrations of methane to prevent ignitions and explosions. Krog et al. (2007) document that, between 2000 and 2005, the number of frictional ignitions reported in underground coal mines in the United States numbered between 34 and 60 per year. Although these ignitions are generally small and localized, they have the potential to lead to much larger explosions.

The number of fatalities and injuries resulting from explosions in U.S. coal mines has been considerably reduced since 1980, as Figure 1 shows:

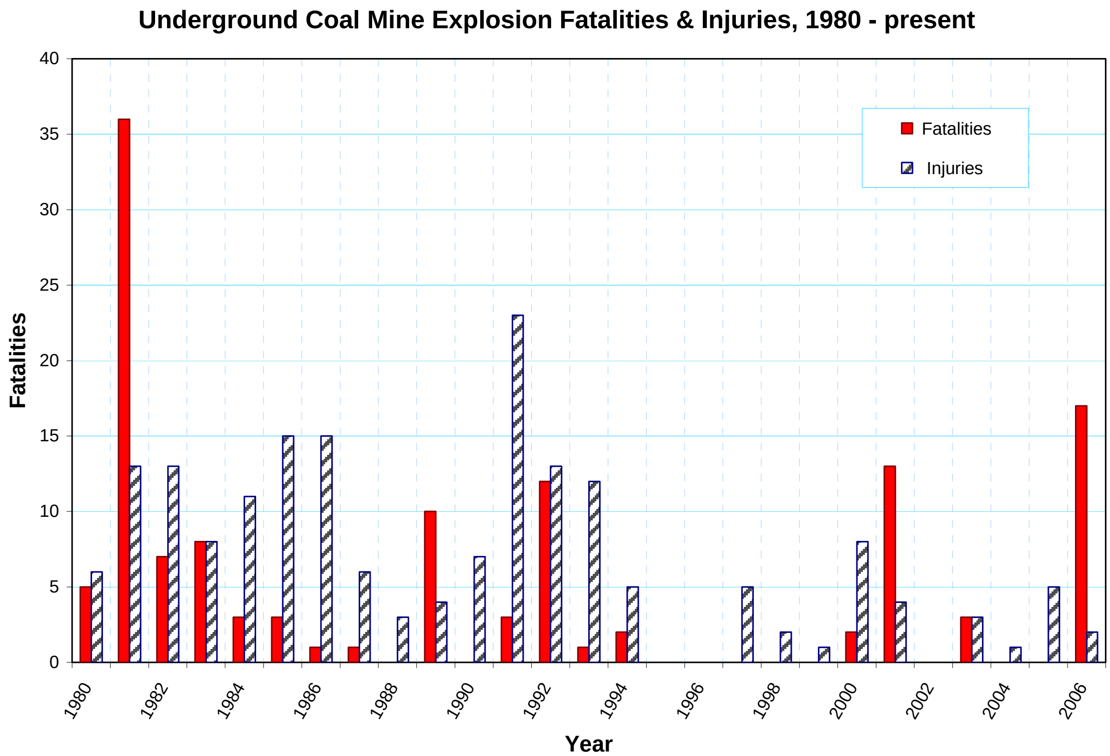

Figure 1: Underground Coal Mine Explosion Fatalities & Injuries, 1980 – present

Still, the recent tragic explosions at the Sago mine (12 fatalities) and at the Darby mine (5 fatalities) in 2006 have demonstrated that methane gas explosions continue to present a significant risk to the coal industry.

Another explosion hazard in underground coal mines is fine coal dust which can be dispersed and ignited by a methane gas ignition. This adds fuel to the ignition, thereby increasing the pressure and heat released by the explosion.

2. Explosion Protection Philosophy

To protect underground mines from methane gas and coal dust explosions, various philosophies can be employed. Basic options are to prevent the occurrence and accumulation of flammable bodies of methane and to eliminate sources of ignition such as open flames, frictional and electrical sparks, heat from spontaneously combusting coal and heat from mining equipment including, but not limited to hot exhaust manifolds and frictional heat (belts, brakes). The following sections discuss these options in detail.

a. Ventilation

Preventing accumulation of flammable gases is mainly achieved through adequate, positive ventilation of all mine openings and through drainage of methane from the coalbed prior to and during mining.

The mine ventilation system must be designed such that all mine openings are ventilated with sufficient quantities of air to dilute all accumulations of methane in intake aircourses to below 1.0% (U.S. Code of Federal Regulations, 30 CFR §75.323). If higher concentrations of methane are detected in intake aircourses, all electrically powered and mechanized equipment must be shut off and the ventilation controls adjusted such that the methane concentration is reduced to a level below 1%. Kissell (2006) points out that a considerable margin of safety below the lower flammable limit (5%) needs to be provided to protect miners from methane explosions

All working areas of the mine (those areas where miners work) must be inspected for proper ventilation within three hours prior to the workers entering these areas. All other active areas of the mine are inspected at least weekly, recording the quantity of ventilation air and any concentrations of methane at specific examination points.

If a given area of the mine is no longer used, it may be sealed by constructing explosion-resistant barriers (seals) in all entries leading to this area. Once an area is sealed, it is no longer ventilated and methane is permitted to accumulate inside the sealed area. Effective May 22, 2007, the United States implemented new regulations requiring seals to have at least a 345 kPa (50 psi) explosion resistance and the atmosphere behind those types of seals to be monitored.

b. Methane Drainage

In addition to diluting methane accumulations by providing fresh air to ventilate the mine entries, methane may also be drained from the active coalbed as well as from adjacent coalbeds above or below the active seam. Methane drainage generally is done prior to mining by drilling boreholes into the coal from the surface or from adjacent mine openings. Draining methane from gobs that are heavily fractured after the coal has been extracted (especially in longwall mining operations) can be an efficient method to prevent methane from coalbeds located above the seam being mined from migrating into the active workings.

c. Preventing Accumulation of Combustible or Explosible Coal Dust

In order to prevent the formation of an explosible coal cloud, rock dust (usually finely ground limestone) is spayed over the coal dust in mine entries to create an inert dust mixture. To render such dust sufficiently inert, U.S regulations require that rock dust be added to the coal dust such that there is a minimum of 65% incombustible matter in all intake entries and 80% incombustible in return airways (Nagy 1981, 30 CFR §75.403). The incombustible matter includes the moisture and ash in the coal, the added rock dust, and any other inert mine dust (such as shale from floor or roof rock). The added rock dust is required to pass at least 70% through a 200-mesh (75 µm) sieve. A higher incombustible content is required in return airways because the coal dust carried by the ventilating air is assumed to be finer in size. This “float coal dust” is defined as dust that passes a 200-mesh (75 µm) sieve.

Reduction of float coal dust can be achieved by using water sprays to prevent the generation of dust and entrainment into the mine ventilation air when cutting and transporting coal. All mining equipment is typically equipped with water sprays. These are typically located next to cutting drums, crushers and conveyor transfer points.

The rock dust acts as a heat sink, and if a sufficient amount is added to the coal dust, it prevents the propagation of a coal dust explosion (Nagy 1981). Rock dust is spread in the mine entries through pneumatic spray dusters as well as trickle dusters that are used in the return entries of longwall and continuous miner sections.

Mine operators and inspectors examine and record the quality of inertization during all ventilation examinations at regular intervals to ensure that appropriate amounts of rock dust are present. The combustible content of rock dust samples is determined by low-temperature (515°C) ashing laboratory analysis. It may take several days or even weeks before the mine operator receives the test results. The recently developed Coal Dust Explosibility Meter (CDEM; Sapko, Verakis 2006) permits an instant assessment of the adequacy of rock dust application through an optical reflectivity analysis. The CDEM is presently in field testing at several mines in the United States and is also undergoing permissibility approval at the U.S. Mine Safety and Health Administration (MSHA) Approval and Certification Center.

d. Elimination of Ignition Sources

The second tier of protection against mine explosions is the elimination of potential sources for ignition. All underground equipment that is used within the face areas where coal is cut must be certified as “permissible” by MSHA. Typically, electrical equipment is rendered permissible through explosion-proof enclosures that prevent an ignition of methane inside electric motors or switchgear from igniting a flammable methane atmosphere outside or through intrinsically safe design where currents inside the electrical equipment are so small that they cannot ignite a flammable methane-air mixture. In addition, mining equipment such as continuous miners and longwall shearers are fitted with methane monitors that are set to warn the equipment operator if methane concentrations above 1% are encountered. At methane concentrations above 1.5%, all electrical face equipment must be disconnected at the power source.

Equipment powered by diesel engines is required to pass rigorous standards with respect to the surface temperature, exhaust gas temperature and exhaust gas quality to be deemed permissible in coal mines (see 30CFR36).

Smoking and open flame are generally prohibited inside underground coal mines. However, if it becomes necessary to work with an open flame for cutting or welding operations, special precautions must be taken to prevent methane ignitions. These precautions include monitoring the atmosphere by a certified mine examiner at the welding site for presence of methane.

If explosives are used in the mining process, they too need to be permissible and approved by MSHA. Permissible explosives typically consist of a sheathed design that prevents detonation if the shot is unconfined and thus can be set off without the risk of igniting a flammable methane atmosphere.

3. Mine Explosions

The explosions in the Sago and Darby mines in 2006 have demonstrated that methane-air mixtures can create violent explosions even without entraining coal dust. This becomes a potential hazard especially if large amounts of such flammable gas-air mixtures are permitted to accumulate inside confined, sealed areas of mines.

a. Explosion Pressures

Ignition of a confined methane-air mix may develop pressures as high as 800 kPa (120 psi) due to the heat of reaction.

Under certain circumstances, it is possible for a methane-air mixture to detonate. An explosion transitions into a detonation when the shock wave that travels ahead of the flame compresses the unburned gas-air mixture to the point where it auto-ignites, causing the flame front to travel faster than the speed of sound relative to the unburned atmosphere ahead of the flame front. Pressures from detonations typically reach the Chapman-Jouguet detonation pressure of 1.76 MPa (256 psi). The transition to detonation may be enhanced and accelerated in mine entries where the gas flows become highly turbulent or where the gas explosion has sufficient run-up length to compress the unburned gas mixture ahead of the flame. If such a detonation wave is reflected from a mine seal, the reflected pressure exerted on the seal may be up to 2.5 times higher, i.e., 4.4 MPa (640 psi).

Explosions resulting from methane-air ignitions inside active workings usually do not create such high pressures, provided that the volume of flammable gas mixture is limited. However, if the mine ventilation system is compromised from an explosion, fire, rock burst, or other event that damages ventilation controls, violent explosions are also possible inside the active working areas of coal mines. The danger of a violent explosion is enhanced by the presence of coal dust, which can add fuel to the explosion if the coal dust is not sufficiently inerted by rock dust.

b. Requirements for Mine Seals

Based on their documentation of possible explosion pressures, Zipf et al. (2007) recommend that mine seals be structurally designed to withstand a 4.4 MPa (640 psi) detonation wave if the sealed area atmosphere is not monitored and if it is unknown whether a flammable gas-air mixture exists behind the seals.

In most coal mines, the methane release by the coal will eventually exceed the upper flammable limit and render the sealed atmosphere fuel-rich inert. Also, slow oxidation processes within the coal itself may reduce the atmospheric oxygen, thereby further reducing the flammability in the sealed atmosphere.

Depending on the methane release rate of the coal, this self-inertization is achieved within a few days to several weeks.

Once the sealed atmosphere has self-inertized, the danger of an explosion is greatly reduced. However, a rise in the barometric pressure will cause fresh air to leak through the seal, providing additional oxygen to the sealed area atmosphere and possibly diluting the gas mixture immediately behind the seal back into the flammable range.

c. Monitoring and Management of Sealed Atmospheres

If the atmosphere behind the seals is monitored and managed such that inert gas is injected behind the seals if a flammable atmosphere is detected, the required seal strength may be reduced to 345 kPa (50 psi) with a safety factor of 2 that accounts for uncertainties in the seal construction process and subsequent damage to the seal from convergence and deterioration. The structural design for the seal must incorporate anchorage along the roof, floor and coal ribs and allow for strains due to convergence of mine entries.

Monitoring behind sealed areas can be accomplished by inserting gas sampling tubes through the seals. Automatic on-line gas analyzers can continuously draw atmospheric sample through these tubes and provide a comprehensive data stream to the mine operator. Computerized alert systems can be connected to the gas analyzer to notify the operator of any hazardous atmospheres inside the sealed areas so that inert gases (typically nitrogen or Tomlinson Boiler exhaust gas) can be injected.

4. Summary and Conclusions

Underground coal mines in the United States rely on a multi-tiered system of protections against explosions of methane-air mixtures. A well-designed and permanently monitored mine ventilation system is used to dilute and render harmless any hazardous concentrations of methane in the air. Mining equipment is designed and certified such that it does not present an ignition hazard. Other potential ignition hazards are reduced by prohibiting smoking underground and by taking special precautions when using flame cutting and welding equipment.

Rock dusting in all active areas of the mines effectively prevents small gas explosions from becoming more violent when coal dust is scoured up, becomes airborne, and is added to a methane explosion flame. A newly developed Coal Dust Explosibility Meter can assess the adequacy of rock dust application instantly.

Recent mine disasters at the Sago and Darby mines in 2006 have demonstrated the need for better protection of miners against explosions within sealed areas of mines. NIOSH has released recommendations for the design of mine seals and for atmospheric monitoring and inertization within sealed areas of mines to prevent such disasters in the future.

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