NIOSH Research in Coal Dust and Explosions

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Abstract: The National Institute for Occupational Safety and Health (NIOSH) mining research program at the Pittsburgh Research Laboratory (PRL), includes the areas of coal mine dust control and monitoring, and explosion prevention. One very important project at PRL is development of a con tinuous recording person-wearable respirable dust monitor. This Personal Dust Monitor (PDM) is a respirable dust sampler and gravimetric -equivalent analysis instrument that is part of a belt-worn mine cap lamp battery unit. Prototypes were successfully t ested in the laboratory and in four underground coal mines. The PDM testing demonstrated that it was convenient to wear and use, robust, and provided accurate and timely data. NIOSH is also conducting research in the program area of coal mine explosion p revention, suppression, and mitigation. Aspects of this research program include: full scale explosion research, laboratory scale research, frictional ignition of methane, mine ventilation seal construction, prediction of coal mine methane emissions, mine monitoring systems, flame cutting and welding operations, spontaneous combustion, and emergency preparedness.

Introduction

In 1996 the U. S. Bureau of Mines (USBM) was closed, however, the mining health and safety research function was absorbed into the National Institute for Occupational Safety and Health (NIOSH). NIOSH has an extensive research program in mining health and safety at the Pittsburgh Research Laboratory (PRL), including coal mine dust and explosion research. The focus in dust research is on the development of dust control and dust monitoring technologies to reduce and measure worker exposure to respirable coal and silica dust. The ultimate goal of this dust research is to eliminate pneumoconiosis in miners. The first part of this paper will discuss the current development of a continuous recording person wearable respirable dust monitor. The remainder of the paper will describe the current NIOSH coal mine explosions research program, which aims to eliminate fatalities from explosions in underground coal mines.

Personal Dust Monitor (PDM)

The PDM is a respirable dust sampler and a gravimetric-equivalent analysis instrument that is integrated in a belt-worn mine cap lamp battery. The main components of the device include a cap lamp, sample inlet located on the end of an umbilical tube, a belt-mounted enclosure containing the respirable dust cyclone, sampling, and mass measurement system, and a charging and communication module used to transmit data between the monitor and a PC while charging its lithium ion batteries for the next shift. Figure 1 illustrates the components typically carried by the miner. The PDM is designed to withstand the harsh conditions found in the mine environment and meets MSHA intrinsic safety type approval requirements.

At the heart of the TEOM mass sensor is a hollow tube called the tapered element that is clamped at its base and is free to oscillate at its narrow end. An exchangeable filter cartridge mounted on its narrow end collects the respirable particles contained in the air stream that passes from the entrance of the mass sensor through the tapered element. Electronic components positioned around the tapered element cause the tube to oscillate at its natural (or resonant) frequency. As additional mass collects on the sample filter, the natural oscillating frequency decreases as a direct result. This approach uses first principles of physics to determine the mass change of the filter, and is not subject to uncertainties related to particle size, color, shape or composition of the collected aerosol.

Fig1: Major components of the PDM.

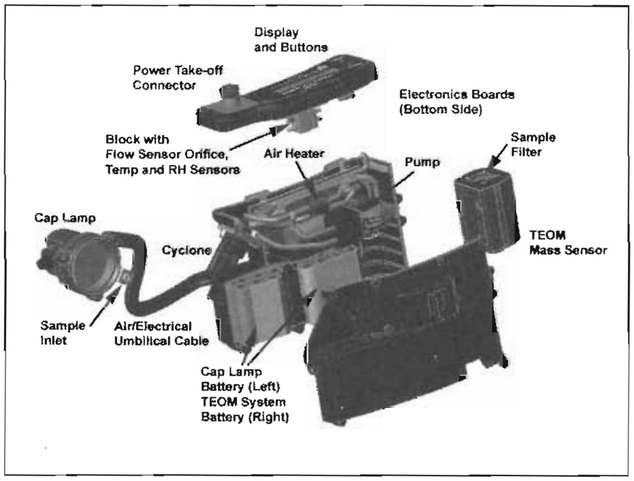

Fig 2: Miner Wearing PDM.

Built-in sample conditioning to remove excess moisture minimizes the PDM response to airborne water droplets. The PDM determines the mass concentration of respirable dust in the mine environment by dividing the mass (as determined by the frequency change) collected on its filter over a given period of time by the volume of the air sample that passed through the system during the same time frame.

Laboratory dust chamber testing was conducted at the PRL. We first determined if the PDM mass measurement was accurate when compared to the filter mass measurement method using a defined accuracy criterion1. We also compared the PDM to the existing personal sampler method of dust measurement using a more complex study design that accounted for the PDM's use of a different cyclone to define the respirable dust fraction2. This bias analysis procedurei was used to determine if the Higgins-Dewell (HD) cyclone used in the PDM had less than or equivalent bias compared to the Dorr –Oliver (DO) cyclone, used with the current sampling system, when using either the Mining Research Establishment (MRE) or International Standards Organization (ISO) definition of respirable dust.

The average mass of 3 individual gravimetric samplers in each time group was used to determine the dust mass during a specific test-time interval. We selected test-time intervals to achieve filter mass target loadings over the range of about 0.5 to 4 mg. As mass loaded onto the samplers with time, groups of gravimetric sampling pumps were turned off at predetermined mass loadings. The mass loading then determined the test-time interval. This procedure resulted in 4 test-time intervals with averaged dust mass that was compared to the measured mass, recorded in each PDM data file. This test was replicated 3 times with various mass loadings to yield a total of 12 measurements. A total of 5 different types or sizes of coal dust were tested in this manner.

A total of 316 laboratory comparisons of PDM to reference samplers were conducted. In addition, 60 laboratory determinations of cyclone bias to ISO and MRE definitions were conducted. Bias, precision, accuracy, and confidence limit calculations for the overall data showed that there is a 95% confidence that the individual PDM measurements were within ±25% of the reference measurement according to Kennedy's method. From the confidence interval data we can predict that 95% of future random samples will be within ±25% of a reference sampler measurement. All laboratory data for various coal types and size distributions are combined in the plot in Figure 3. The linear regression of individual pairs of data supports the accuracy analysis.

The laboratory work specifically assessed the performance of the new dust monitor by comparing the performance to currently used personal samplers in a two-step manner. The first step demonstrated that the PDM accurately measured mass according to accepted criterion. The second step showed that the HD cyclone was better than the DO cyclone in meeting both the ISO and MRE definitions of respirable dust. The combination of these two results leads to the conclusion that the PDM is equivalent or better than the currently used personal sampler in measuring coal dust in the laboratory.

In-mine testing used pair-wise testing to partially take into account the increased variability associated with personal sampling in mining conditions and examined the mine worthiness issues of the instrument when worn by miners performing their normal duties. Limited testing was conducted for 5 shifts in each of four coal mines. This testing compared the end-of-shift gravimetric concentration measured by the PDM to the end-of-shift gravimetric concentration measured with a single reference filter sampler using a HD cyclone and an analytical balance.

Mine testing was conducted in 4 coal mines in different coal producing regions of the U.S. A total of 72 in-mine comparisons of PDM to reference samplers and 40 companion determinations of cyclone bias to ISO and MRE definitions were conducted. While additional shifts of data were successfully measured with the PDM, not all were paired with valid reference comparison samples. Figure 4 shows the regression analysis for the paired data.

An intraclass correlation coefficient (ICC) statistical test for absolute agreement was computed for the overall mine data. The ICC between the PDM and reference sampler was found to be equal to .93 [F-value for two-way mixed effects model = 29.99, $p < .0001$; 95% CI (.90, .96)]. An ICC of .80 is considered good agreement, thus these data demonstrate excellent absolute agreement between the PDM and reference sampler. These results suggest that the two samplers could be considered interchangeable.

The timely PDM dust exposure data provides information that can result in quicker recognition of the failure of engineering dust controls. This type of information enables both miners and management to prevent overexposure to coal mine dust. The information also showed how actions and equipment effect a miner's dust exposure. Miners quickly learn how to better reduce their dust exposures by minimizing certain actions and by better positioning themselves during given activities.

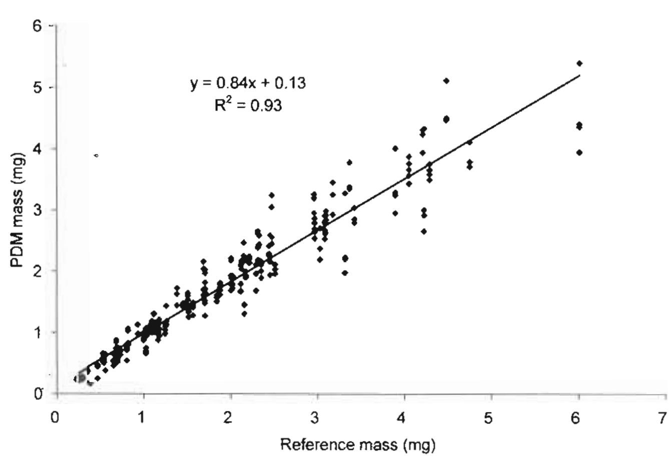

Fig 3. All laboratory data.

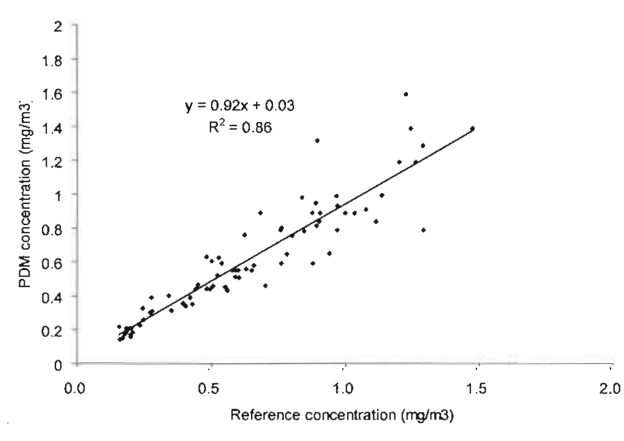

Fig 4. All mine data.

USA Coal Mine Explosion Research at NIOSH

Due in large part to the high number of miner fatalities and incidents of disastrous coal mine explosions early in the twentieth century, the government of the United States formed the U. S. Bureau of Mines (USBM) in 1910. These research findings and implementation of those findings, most notably those related to generalized application of rock dust for explosion suppression, along with the implementation of many explosion prevention practices and enforcement of explosion prevention and suppression laws and regulations by states and later nationally by the Mine Enforcement and Safety Administration (MESA- later the Mine Safety and Health Administration, MSHA), led to the significant decline in incidents and fatalities from coal mine explosions through that century as shown on figure 5. Indeed, near the end of the 20th Century, it had appeared that coal mine explosions had nearly been eradicated from the US coal mining industry (Figure 5).

However, as can also be noted on figure 6, recently there has been an alarming reappearance of deadly coal mine explosions in the U.S. Bracketed around the September 2001 sentinel event of the explosion at Jim Walter Resources (JWR) No. 5 Mine in Alabama (13 fatalities and 3 injuries) was the July 2000 explosion in at the Willow Creek Mine in Utah (2 fatalities and 8 injuries) and the McElroy Coal Mine explosion in West Virginia (3 fatalities and 3 injuries) in January 2003. These events are stark reminders that coal mine explosion incidents still take an unacceptable human toll and clearly demonstrate that not all of the problems that can result in US coal mine explosions have been solved. Equally disconcerting is that a number of events and changes affecting the US coal mining industry that indicate that the risk of mine explosions may increase in the near future. These events/changes include an ongoing high level of frictional ignition incidents (62/yr the last 5 years); the impending exodus of high numbers of highly experienced miners, mining professionals, and mining enforcement personnel; the depletion of "easy-to-mine" reserves and resultant movement into "difficult", deeper reserves with increased amounts of methane; technological and operational changes such as higher mining productivity rates and longer and wider longwall panels that compound methane issues; and the persistence of various potential ignition sources.

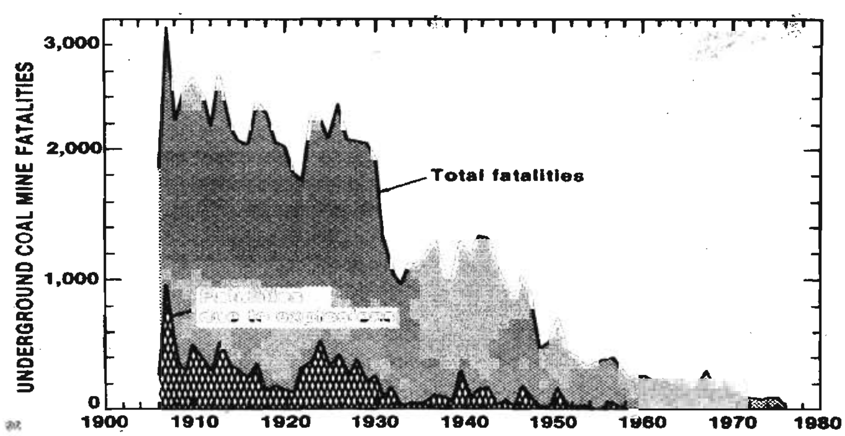

Fig5: Underground U.S. Coal Mining Fatalities 1990-1980

he successful prevention and mitigation of explosions in mines requires highly efficient programs in <u>all</u> of these 7 areas: 1.) prevention of accumulations of flammable gases/dusts; 2.) isolation and elimination of potential ignition sources; 3.) understanding of mine explosion mechanics and parameters; 4.) employment of suppression methods and systems; 5.) foolproof examinations and monitoring of mine conditions; 6.) development of applicable systems to keep pace with industry changes; and 7.) understanding and knowledge of mining industry personnel of all of these factors so that proper actions and reactions are routinely made. The continued occurrence of US coal mine explosion events indicates that the systems currently in place to prevent and mitigate mine explosions in these areas are either not totally adequate, not keeping pace with the evolving changes in the industry, or are disregarded.

To investigate these issues, the Pittsburgh Research Laboratory (PRL) of NIOSH formed a panel of its premier coal mine explosion experts to study the recent mine explosions and identify any areas where the explosion prevention, mitigation, or response systems were non-existent or deemed lacking and to propose research that could address those areas identified. This study focused on the recent fatal mine explosions noted, as well as other non-injury mine explosion and frictional ignition events. The panel examined all aspects of the explosion issue to identify the most important and common thread areas which, if addressed successfully, could provide a systematic, holistic approach to lowering the risk of mine explosions and resultant fatalities. The results of the analyses concluded that, while in retrospect these explosions might not have occurred had certain actions or individual reactions been different, many of the prevention, mitigation and response systems were not robust enough to reduce the risk to the desired near-negligible levels. The specific areas where knowledge or systems were non-existent or lacking were identified and research approaches and methodologies defined to address the problem aspects. These results then formed the basis for current NIOSH research in the program area of coal mine explosion prevention, suppression, and mitigation. Brief descriptions of selected aspects of this current research program area follow.

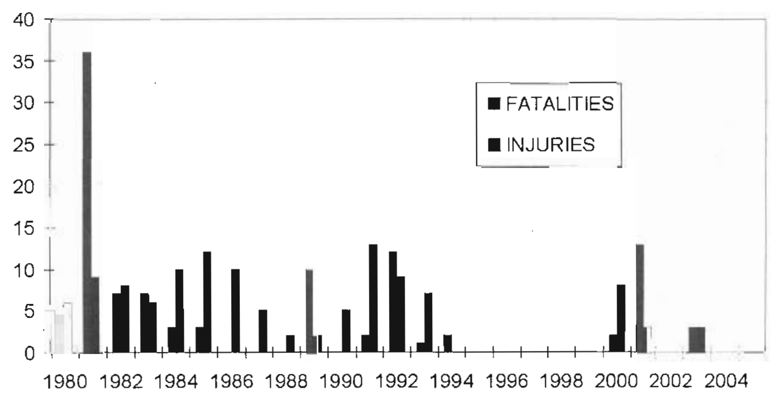

Fig 6: Fatalities and Injuries in U.S. Coal Mines due to Methane Explosions 1980-2004 (YTD)

Full-Scale LLEM Gas/Dust Explosion Research

Full-scale explosion research is conducted by NIOSH at its world class Lake Lynn Experimental Mine (LLEM) located 90 km south of the Pittsburgh Research Laboratory. The LLEM is a former underground limestone mine and surface quarry which has been developed for various mining research activities, but principally for explosion research in typical US coal mining geometries and configurations. Current full scale explosion research is focusing on key parameters that can influence the transition from a small gas explosion near the face to a full-scale propagating dust explosion. Another area of interest is the combustion of large volumes of non-uniformly mixed methane, which may present a different risk than the typical face ignition. These methane volumes may exist in gob (worked-out) areas of mines through a slow accumulation of methane or in working areas due to a more rapid methane outburst. In conjunction with these LLEM full scale explosions tests, various aspects of explosion effects on mine structures and objects are being studied to assist in explosion forensic investigations. Accurate forensics is an important factor for accurate accident interpretation and follow-up recommendations to prevent future occurrences.

Laboratory Explosion Research

To supplement and complement the full scale research at LLEM, laboratory scale research is conducted in 20-liter, 1000-liter, and 1-m^3 explosion chambers. This laboratory research is currently providing a better understanding of the interactions of coal dust as fuel source and rock dust as a suppression agent. These laboratory studies are also further assessing the sizes of coal dust particles that participate in mine dust explosions. The laboratory research investigates a much wider range of coal dust types and sizes than can be studied in the full-scale research.

Frictional Ignition Studies

Frictional heating is the primary cause of methane ignition in coal mines and additional basic research is being conducted to understand some key aspects of this source to reduce its occurrence. Laboratory research is currently centered on the measurement of the hot-spot temperatures (using infrared technology) and surface areas necessary to ignite flammable gases, liquids, dusts, and hybrid mixtures. In addition, the role of adjacent strata in contributing to frictional ignitions is being studied. Samples of adjacent and included rock are undergoing analyses to assess chemical and mineralogical variations and their relative incendivity potential, using a newly developed incendivity apparatus.

Rapid in-situ method to determine the rock dust content and explosibility of coal and rock dust mixtures.

Currently in the US, assessment of the adequacy of rock dusting for explosion preventions is done by sampling which can take weeks for the analysis to return. A portable handheld rock dust meter which is based partly on earlier Bureau of Mines research has been developed to provide on-the-spot assessment of the adequacy or hazard. Reliability assessment and implementation methodologies are being conducted for the potential induction of this device into the US coal industry.

Development of improved methodologies to characterize strength properties of mine seals

Mine seals capable of withstanding explosion overpressures are used in the US to isolate active areas where miners work from abandoned areas of coal mines and the hazard of explosions that may occur in these areas. Being developed are acceptable, performance-based criteria for seal designs and construction methods that will ultimately reduce the potential exposure of US miners to explosion hazards.

Investigations of the interaction between methane and mining induced caving/subsidence

Coal room and pillar retreat mining, as well as longwall mining, cause the ground to cave and subside. This results in increases in permeability of the surrounding rocks and ground and causes fluids, such as methane gas, to flow into coal mines from previously isolated methane sources above, below, and adjacent to the mined coal bed. Caving and subsidence extent and mechanics are being studied via modeling techniques using field data for input parameters and model verification to lead to better predictive methods of coal mine methane emissions and to assist the design of better methane control procedures and techniques.

Improved Ventilation Monitoring Strategies

Recent coal mine explosions in the US have occurred in the large mines, many of which are longwall mines and, as expected, the most gassy. These mines usually employ mine monitoring systems which can assist to monitor for hazardous conditions. Currently, few of these systems fully monitor key ventilation and air quality areas which can provide early warning of system malfunctions. NIOSH is developing monitoring strategies and assessing hardware that will provide the means for a more robust use of these systems to assess these key mine conditions.

Cutting/Welding hazards in underground coal mines:

Flame torch cutting and welding are permitted in US coal mines under certain conditions. Analyses of fires in the US coal mining industry for the period 1990-2002 indicated that 20% (110 fires) of the total number of reported fires (560 fires), resulting in 70 injuries (41% of total reported injuries) and 2 fatalities, were the result of either flame cutting or welding operations. In the recent shaft explosion at the McElroy Mine, flame cutting was the most likely cause of the explosion that resulted in 3 fatalities and 3 injuries. The root causes of the fires and injuries caused by flame cutting or welding operations will be determined and new and improved methodologies and technologies are being evaluated to prevent such fires and explosions.

Spontaneous combustion hazards in gassy mines:

Spontaneous combustion continues to be a problem for many western US mines, as well as several gassy mines in Alabama and the Eastern U.S. Dilution is the principal ventilation control technique to control methane concentrations in US coal mines. Current ventilation dilution techniques can aggravate spontaneous combustion control measures. The specific aim of this research is to develop ventilation methodologies to minimize spontaneous combustion as an ignition source in mines with appreciable methane.

Initial Explosion Response\Multiple Explosion Events

The most recent coal mine explosions were glaring examples of the critical nature of the initial response to an explosion event. In both the JWR #5 and Willow Creek events these initial responses were deemed inadequate by MSHA which contends that these poor responses led to the fatalities. Interventions will be developed and transferred to the industry in the form of training aids and mechanisms to address other issues such as inadequate personal communications at the onset of an emergency, faulty assessment issues, and general emergency preparedness.

Technical Transfer, Education, and Training

It is clear that additional education and training is needed to provide mine inspectors, safety personnel, and underground miners with a better understanding of the factors and conditions contributing to explosion hazards in mines. The large influx of inexperienced personnel into these positions over the next few years in the US dramatically underscores this need. Training materials using various media, as well as workshops and other educational means, are being developed to address this requirement for new and updated explosion hazard and prevention materials and educational methodologies.

Summary

PDM prototype units were successfully tested in the laboratory and in four underground coal mines. Under these specific test conditions the PDM demonstrated that it was convenient to wear, robust, provided accurate data, provided timely data that could be used to prevent overexposure, and was easy to use. Overall successes documented in this work have lead to an early commercial version that promises to correct many of the minor problems identified in the prototype. Further in-mine trials will determine the long term durability, stability and maintenance requirements for this new dust monitor.

The occurrence of an explosion in the underground workplace is in many instances the unfortunate, but preventable coalescence of multiple causative or contributing factors. Current explosion prevention and mitigation research by NIOSH in the US is aimed at providing the research tools that can lead to a systematic and holistic approach to address gaps in the coal mine explosion "safety shield".

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