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Early fire detection for underground diesel fuel storage areas

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ABSTRACT

With the increased use of mobile diesel-powered equipment in underground mines, the fire risk posed by underground diesel fuel storage areas is a concern. To reduce the risk associated with the storage and transfer of large quantities of diesel fuel in permanent underground mine storage areas, an experimental study was conducted to investigate the responses of different sensors for early detection of diesel fuel fires in a storage area. Fire sensors tested in this study were four carbon monoxide (CO) sensors, two smoke sensors, and one flame sensor. A series of fire tests were conducted in the NIOSH Safety Research Coal Mine, Bruceton, PA, using various fire sizes at different ventilation airflow velocities and fire locations. Response times for different sensors were analyzed, and the results suggest that the flame sensor and smoke sensors resulted in shorter response times in most tests compared to the CO sensors. Based on the test results, the appropriate sensor locations for early fire detection in a diesel fuel storage area were identified. The results of this study can help mining companies to select appropriate fire sensors for underground diesel fuel storage areas and improve the deployment of these sensors to ensure the safety of underground miners.

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1. Introduction

Diesel-powered equipment is commonly used in underground coal mines across the United States. Diesel equipment in underground coal mines poses a risk of fire or explosion, as a result of the introduction of an ignition source (the diesel engine) into an environment that may contain methane gas. Improper fuel handling and fuel transfer procedures underground present significant fire hazards. Because of the methane gas and coal dust present in the underground coal mining environment, any fire presents a significant risk of loss of life.

The U.S. Code of Federal Regulations, Title 30, Part 75.1903 requires that a permanent underground diesel fuel storage area facility be constructed of noncombustible materials and ventilated with intake air. The regulations state that the area must be equipped with an automatic fire suppression system. 30 CFR Part 75.1912 sets forth the requirements for automatic fire detection using fire sensors to activate an automatic fire suppression system for permanent underground fuel storage areas. However, the regulations do not specify what kind of fire sensors should be used nor where the fire sensors should be installed in the area. This information is critical for effective early detection and extinguishing of the fire and to prevent a small diesel fuel fire incident from causing a major explosion.

A considerable amount of research has been done on the hazard characterization of diesel fuel pool fires in other structures and facilities. Wang et al. (2009) studied diesel oil pool fire characteristic under natural ventilation conditions in tunnels with roof openings. Li et al. (2010) researched the ignition of the leaked diesel on a heated horizontal surface. Sahu et al. (2017) conducted full-scale experimental and numerical studies on the effect of ventilation in an enclosure diesel pool fire. Yuan and Lazzara (2004) investigated the effects of ventilation and preburn time on water mist extinguishing of diesel pool fires in underground diesel fuel storage areas. De Rosa and Litton (2010) studied the rapid detection and suppression of mining equipment cab fires with diesel fuel as the fire source. However, no research has been conducted on the early detection of fires in an underground diesel fuel storage area, which poses specialized fire prevention challenges. In these areas, the diesel fuel may be spilled on the floor or may leak on to the floor during the fuel handling and transfer process. The spilled or leaked fuel may become ignited by a heat source such as a hot engine exhaust pipe or engine surface.

Early fire detection is vital to reducing both the damage and injury the fire may cause. Carbon monoxide (CO) sensors have been commonly used in underground coal mines for fire detection in conveyor belt entries, diesel fuel storage areas, and battery charg-

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Fig. 1. Fire test chamber in the NIOSH Safety Research Coal Mine.

Fig. 2. Diesel fuel fire test setup.

ing stations (Smith and Litton, 2015). Appropriate smoke sensors, if and when they become available, could be used in parallel with the CO sensors or as replacements because of their early warning capability (Perera and Litton, 2012). Edwards and Friel (1996) conducted an in-mine evaluation of CO and smoke sensors in a mine entry. They recommended that smoke sensors be used whenever possible as part of a mine atmospheric monitoring system as they would give greater flexibility for setting alarm values for fire detection at low smoke levels. Litton and Perera (2015) evaluated different fire sensors for mine fire detection in a mine entry using an atmospheric monitoring system, but with mixed results. In the current study, to further add to this body of research and develop guidelines for placement of sensors for early fire detection, a series of experiments were conducted in the NIOSH Safety Research Coal Mine (SRCM) using various diesel fuel fire sizes at different ventilation airflow velocities to evaluate the responses of CO sensors, smoke sensors, and a flame sensor for early fire detection in a diesel fuel storage area. A novel approach was used in this study to make comprehensive comparisons of sensor response between CO sensors and smoke sensors, between CO sensors and a flame sensor, and between CO sensors and a fire suppression system detector for the early detection of diesel fuel fires. To authors' knowledge, no such research has been done before. The results of this study provide unique and practical solutions on optimizing fire detection systems for the diesel fuel storage areas. These results are not available before and can greatly improve the effectiveness of fire detection systems to ensure the safety of workers.

2. Experimental

A diesel fuel fire test chamber simulating a diesel fuel storage area was constructed in the SRCM. The test chamber was located in a crosscut in the mine with dimensions of 153 in long, 87 in wide, and 70 in high, as shown in Fig. 1. A regulator with dimensions of 24 in by 24 in was located in the rear of the chamber with a door in the front of the chamber. Four CO sensors and two smoke sensors were installed under the roof of the chamber along the centerline parallel to the regulator. One flame detector was installed on the roof near the front door per manufacturer instructions.

Diesel fuel pool fires were used as the fire source and were located on the floor of the chamber, as shown in Fig. 2. Two round fire pans with diameters of 6 in and 4 in were utilized to generate a large fire and a small fire, respectively.

Before each test, all CO sensors were calibrated using standard calibration gas, and the smoke sensors and flame sensor were calibrated based on the manufacturers' recommendations. The airflow rate was adjusted using brattices and a desired air velocity was achieved at the regulator. During each test, diesel fuel in the fire pan was ignited using a propane torch, and the signal outputs from all sensors and airflow velocities at the regulator were collected using a data acquisition system. The duration of diesel fuel burning was also recorded to estimate the heat release rate of the fire. In the tests, the diesel fuel fire was placed at three locations—the center of the chamber, two feet from the front door, and two feet from the regulator—to examine the effect of the fire location on the sensor responses. In each location, the fire pan was placed along the centerline perpendicular to the regulator. To determine the appropriate placement of CO sensors, ten fire tests were conducted with only one CO sensor installed at different locations as detailed in the Results and Discussion.

The sensors tested in this study were four CO sensors from different manufacturers: Rel-Tek, AMR, Conspec, Pyott-Boone (designated as PB); two smoke sensors—Conspec and Rel-Tek; and one flame sensor—Honeywell. All CO sensors have their alarm levels set at 10 ppm. The Conspec smoke sensor has on/off alarm at a preset smoke density level, while the Rel-Tek smoke sensor responds to optical obscuration of air due to smoke particles with a linear output over the 0%–10% optical density range. The alarm was set at 1% per meter obscuration level. The Honeywell flame sensor is the multi-spectrum triple infrared fire and flame detector and has the fire detection performance combined with optimal false alarm rejection. All the CO sensors and smoke sensors are approved by the Mine Safety and Health Administration (MSHA) for use in underground coal mines, while the flame sensor is not MSHA-approved.

3. Results and discussion

A total of 27 tests were conducted to examine the responses of different sensors to the diesel fuel fires. Because the focus of this study is on early fire detection, during which time the heat release rate of the fire is usually small, the diesel fires generated from two fire pans proved to be sufficient for the sensor response tests. Fig. 3 shows the typical responses of CO sensors to both large and small diesel fires. For the large fire, the Rel-Tek and PB CO sensors had a maximum CO reading of 60 ppm, and the maximum CO readings for the AMR and Conspec were over 80 and 90 ppm, respectively. Because a 10-ppm CO concentration is commonly used as the threshold value for alarming in mine fire detection systems, this value was used as the criterion for determining the sensor response time.

The Rel-Tek sensor had the longest response time and the AMR sensor the shortest. For the small diesel fire, all CO sensors had much lower maximum readings compared to the large fire. How-