CDC NIOSH Workplace Safety and Health
Technology News
No. 530 Milestones in Mining Safety and Health Technology March 2008

Frictional Ignition of Methane-Air in the Presence of Liquid Hydrocarbons

Background

Frictional ignitions continue to be a problem facing the U.S. underground coal mining industry. Many methane ignitions are associated with the impact of mining machine cutter bits on quartzitic material (e.g., sandstone) during the coal-cutting process. Most ignitions result in small methane-air fireballs often only a few feet in size and limited to the cutter head location. However, under certain conditions, frictional ignitions can lead to larger methane explosions and/or fires with the potential for causing serious injury or death to the mining machine operator and other nearby miners. The requirements for a frictional ignition are a flammable volume of methane-air and an ignition source. This source is usually the hot streak caused by the frictional impact of the mining bit on hard rock, and the frequency of occurrence increases with increased bit wear. Another possible ignition source is the frictional impact of rock on rock during a roof fall.

In addition to flammable methane gas, some underground coal mines encounter heavier molecular weight liquid hydrocarbons that can generate flammable vapors. For example, a coal mine in Utah experienced significant inflows of liquid hydrocarbons, with approximately 1,200 gal being pumped from the mine per day. The Mine Safety and Health Administration (MSHA) reported that this mine experienced several ignitions, including one in 1998 that led to a significant fire. MSHA listed liquid hydrocarbons as contributing to this fire [Elkins et al. 2001]. On July 31-August 1, 2000, there were multiple explosions and a fire at the same mine, resulting in 2 fatalities and 12 injuries. The MSHA investigation report listed methane and liquid hydrocarbons as contributing to the explosions and fire [McKinney et al. 2001].

Approach

The National Institute for Occupational Safety and Health's (NIOSH) Pittsburgh Research Laboratory conducted a series of experiments to investigate the effect of added hydrocarbon liquids on the frictional ignition potential from the impact of mining bits on sandstone. The experiments were conducted in a laboratory test apparatus (Figure 1) where a single miner bit on a cutter drum struck a sandstone block. The bit was worn so that the shank steel was exposed. A 100-ft^3 mixture of flammable methane-air was enclosed by a plastic diaphragm that broke and vented the explosion after ignition. The relative ease of ignition was measured by the number of strikes necessary to cause ignition. Tests were conducted with flammable methane-air mixtures and with added liquid hydrocarbons on the sandstone block.

Figure 1.—Frictional ignition of methane in experimental test apparatus.

The first series of tests was conducted to determine the number of strikes of the bit on the sandstone block necessary to ignite a flammable mixture of methane-air. With the cutter drum rotating, the sandstone block was moved horizontally in front of the cutter bit so that there would be a fresh surface for each strike of the bit. Additional tests were done with hydrocarbon liquid sprayed on the sandstone just before each test. Since hydrocarbon liquid samples

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from actual mines were not available for this study, a liquid hydrocarbon simulant was mixed based on the MSHA analyses of the hydrocarbons at the Utah mine [Elkins et al. 2001]. MSHA reported that "the hydrocarbons were tested and were determined to be chemically similar to a mixture of 15% gasoline, 35% diesel fuel, and 50% motor oil" [Elkins et al. 2001].

Results

Using a worn bit, five tests were conducted with only methane-air in the test chamber. The mixture did not ignite in any of the five tests, with an average of greater than 90 strikes per test. An additional five tests were conducted with added liquid hydrocarbon simulant on the sandstone. The methane-air mixture ignited in each of these five tests, with an average of about 30 strikes to ignition. The explanation may be that the liquid hydrocarbon ignites more easily than methane, and then it forms a pilot flame that ignites the methane. The hydrocarbon vapors can ignite at significantly lower temperatures than the methane.

Based on these results, NIOSH researchers determined that the presence of a hydrocarbon liquid in the mining environment has the potential to increase the ignition hazard associated with the frictional heating from impact of steel on sandstone.

Recommendations

Improving the ventilation airflow should be the main method for reducing any flammable gas volume, thereby limiting the extent of flame propagation if a frictional ignition should occur. The frictional ignition probability decreases with new sharp bits. Replacing worn bits on a regular basis and using adequate back-mounted water sprays (that cool the frictional hot spots) have been shown to reduce the frictional ignition probability of methane when used on longwall and continuous mining machines.

The increased fire and explosion hazard associated with the presence of heavy hydrocarbons can be estimated by collecting and measuring the flash point of the fresh hydrocarbon liquid. If the flash point is at or below the ambient mine temperature, the liquid can ignite and burn even without methane. If the flash point is above ambient temperature, the liquid hydrocarbon can enhance the ignition probability of methane.

When using a handheld methanometer in the presence of heavier hydrocarbons, the instrument needs to be calibrated with gas mixtures that reflect the presence of the heavier hydrocarbon vapors. The instrument manufacturer should be contacted for advice on calibration procedures that will ensure accurate measurement of potentially flammable mixtures.

In summary, extra precautions to prevent fires and explosions must be taken when heavier molecular weight liquid hydrocarbons are present in addition to methane in an underground coal mine.

For More Information

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DHHS (NIOSH) Publication No. 2008–124