INFLATABLE DEVICES FOR COMBATING UNDERGROUND MINE FIRES

RS Conti and ES Weiss

Supervisory General Engineer and Mining Engineer, USA

National Institute for Occupational Safety and Health

ABSTRACT

The National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, conducted full-scale studies in the Lake Lynn Experimental Mine with lightweight inflatable devices that can be used for rapidly isolating underground mine fires. These inflatable devices can stop airflows of up to 1,100m^3/min and allow for fire suppression and/or personnel escape. One device, a remotely-installed bag, was designed to isolate the fire zone and to then serve, as an explosion resistant seal when remotely injected with low-density organic or inorganic foams (never actually tested against explosions).

The inflatable feed-tube partition (IFTP) is a lightweight, rectangular inflatable bag that can be used by fire-fighters to rapidly (within 15 min) close large openings, such as those in underground mines, and to simultaneously provide a feed-tube for high expansion foam generators. This allows fire fighting foam to freely flow to the fire site and control or extinguish the fire. Results showed that a 2,800-L/s diesel-powered, high expansion foam generator with the IFTP cold push a foam plug 245m through an entry 2.1m high by 5.8m wide a 4.3 pct rise in elevation, before the foam generator failed to push the foam plug further.

A third device, the positive-pressure, inflatable walk-through escape device with its "pass-through" feature, allows extra time for personnel evacuation by isolating a smoke-filled entry from fresh air. This escape device would be strategically placed in a mine entry, and then be either manually or remotely deployed during a mine fire. This device successfully isolated smoke-filled entries from fresh air, and mine personnel effectively passed through the device to fresh air or back into the smoke-filled entries. These inflatable devices have shown merit in providing a relatively rapid method for isolation of a mine fire and for use with a foam generator for fire suppression, or for personnel escape.

INTRODUCTION

Fires are an unfortunate but all too common occurrence during underground mining operations. Mine Health and Safety Administration (MSHA) statistics indicate that 91 underground fires occurred in coal and metal/non-metal mines from 1992 to 1997 in the United States. Historically, mine fires have caused fatalities, injuries, and economic losses totalling hundreds of million dollars. One of the major objectives of the National Institute for Occupational Safety and Health's (NIOSH) Pittsburgh Research Laboratory (PRL) is to enhance the safety of the mine personnel by preventing disasters, such as fire and explosions.

The success of safely controlling and extinguishing an incipient mine fire depends on several factors, such as an awareness of the fire hazards, early detection, availability of effective fire fighting equipment, quick response time and trained fire-fighters. When a mine fire is detected in its early stages, a small window of opportunity exists for the fire-fighters to directly attack the fire. When mine fires can no longer be fought directly due to heat, smoke or hazardous roof conditions, high expansion foam may be one way to remotely quench the fire. Another fire fighting procedure is to construct air-tight seals in mine passages leading to the fire zone so that the oxygen supply to the fire can be cut off. The more rapidly the seals are constructed, the more successful they are in containing the fire. Conventional methods of sealing passageways surrounding the fire zone are not only time-consuming but also dangerous because of the presence of potentially toxic combustion products and explosive gases. Sometimes mine crews have the opportunity to construct explosion-resistant ventilation seals along access ways to the fire zone. However, the final sealing has to be completed at a safe location.Typical ventilation seals (*1,2*) require considerable time to erect and are not conducive to fighting fires in the early stages of the fire when suppression is significantly easier to accomplish. Therefore, there is a compelling need for a rapid sealing system which can be deployed relatively close to the fire zone for the early isolation of underground mine fires. By necessity, these rapid sealing techniques and/or devices must be able to stop or redirect the air supply (oxygen) away from the fire zone and, in some cases, to withstand methane and/or coal dust explosions which may occur prior to the extinguishment of the fire or the installation of the final permanent seals. Fires generate smoke or gases which can spread through mine passageways and make evacuation difficult and dangerous. During an examination of mine fire preparedness at four mines (*3*), mine personnel stressed the importance of smoke-free escapeways. This report highlights PRL's research on developing inflatable devices for isolating and combating underground mine fires. Discussed are the in-mine and remotely deployed inflatable flow restrictor (IFR) for isolating mine entries and controlling ventilation airflows (*4*), an IFTP for use with a high-expansion foam generator for delivering suppressant foam to the fire zone (*5*), and a positive-pressure inflatable escape device (IED) for aiding personnel to evacuate the mine.

INFLATABLE FLOW RESTRICTOR

The IFR, shown in figure 1 is a lightweight inflatable bag. The IFR was designed to be cylindrical in shape, to overcome orientation difficulties encountered when lowering the IFR through deep boreholes, and oversized for the mine entry in which it will be deployed. Over sizing the device results in a large surface contact area with the mine walls when inflated. This large contact area enhances the frictional resistance between the IFR and the mine entry, thereby reducing the internal pressure required for the inflated device to withstand the ventilation flow while still maintaining a relatively air-tight restriction. In order to be remotely deployed from the ground surface, the IFR has to be fabricated from lightweight material so that the entire package could be lowered through typically-sized boreholes ranging from 15-20 cm diameter.

Full-scale tests with IFR were conducted in the entries of the PRL's Lake Lynn Experimental Mine (LLEM) (*6*). This former limestone mine now serves as one of the world's foremost multipurpose mining laboratories for conducting health and safety research, particularly in the area of fire and explosion prevention. The entry dimensions of the underground mine are approximately 2m high by 6m wide.The average cross-sectional area is $12m^2$. The first full-scale tests were conducted with the in-mine version of the IFR.A 3m high by 9.1m diameter IFR (oversized cylindrical bag) was fabricated using a lightweight, waterproof, rip-stop nylon fabric (same material used for the other inflatable devices). Other fabrics could be substituted during actual in-mine applications for increased fire resistance and durability. A 40 cm diameter axial fan with a delivery rate of $74m^3$/min. When using this device in entries with higher air velocities, nylon netting was secured to roof bolt plates across the entry room 6m downstream of the deflated IFR and fan assembly and then extended along the entry floor and under the device. This prevented movement of the IFR during the initial inflation process in ventilation flows as high as, $1,100m^3$/min.

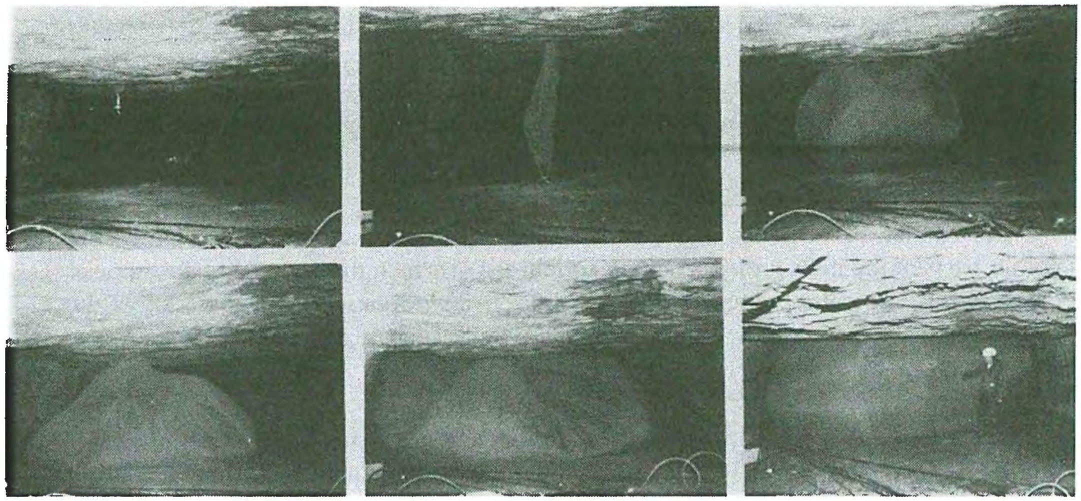

Figure 1 - Installed process of the inflatable flow restrictor as it was remotely deployed from the surface through a borehole into the mine entry.

If direct underground fire fighting methods fail, other sealing techniques are attempted to isolate and suppress the fire. Often, the portals into the mine are sealed to starve the fire of oxygen. This technique has resulted in long-term and/or permanent shutdowns of many mines. However, generally before this technique is employed, many mines will drill boreholes into the entries surrounding the fire and then stow materials into these entries in an attempt to seal the fire zone. This requires massive amounts of materials for stowing and very rarely achieves the desired results. For this reason, full-scale experimental trials were conducted with a slightly modified version of the IFR by remotely deploying it from the ground surface through a 60-m-deep by 20-cm-diameter, polyvinyl chloride-lined borehole into the LLEM entry. One end of a 2.5-cm-diameter air hose was secured to the inside of the deflated bag; the other end was attached to a portable air compressor on the surface. To aid in monitoring the inflation pressure, a length of 0.6-cm-diameter plastic tubing was secured alongside the air hose with one end near the bottom, inside of the bag. The bag was lowered down the borehole using a diesel powered winch until 3.7 m of the bag extended into the entry (lowering distances were premarked on the winch's wire rope), leaving the remainder of the bag/hose assembly in the borehole. The bag was then partially inflated until the pressure gauge, which was attached to the surface end of the plastic tubing, indicated a pressure rise within the bag. The air delivery was then temporarily turned off which resulted in a pressure drop within the bag. An additional 2.4 m of bag/hose was then lowered into the entry and the air inflation was resumed until the internal pressure of the bag once again began to increase. This inflation and lowering process was repeated until all 9.1 m of the bag was inside of the entry. Less than 30 min was required to deploy the bag down the borehole and fully inflate it within the entry. Obstructions within the mine, such as timbers and cribbing for roof support, track, etc., appear to have little effect on the deployment of the IFR (the IFR wraps around these obstacles during inflation).

Although the remotely deployed IFR, when filled with air, offers a means of controlling ventilation to and from a fire, it would be unable to withstand the pressures generated from a methane and/or coal dust explosion within the fire zone area. However, if the air in the IFR were replaced by a relatively quick-setting material, it might be possible to obtain a seal capable of withstanding these explosions over pressures. In several quarter-scale bench tests, two liquid polyurethane components were pre-mixed and rapidly injected in less than 2 min into the pre-inflated IFR. The manufacturer slowed the reaction time of the materials to allow for the complete transfer of material into the IFR prior to any expansion. The polyurethane then expanded from the simulated entry floor to completely fill the entry. The IFR served as a containment vessel for the expanding polyurethane and successfully limited the amount of material required to fill the cross-section of the simulated entry. The intended use of the IFR filled with a rigid material (full-scale trials have yet to be conducted) was that it would serve as a temporary seal until the fire was extinguished or permanent seals could be installed at a safer location.

Deployment of IFR's as described above would alter the existing mine ventilation. Care must be exercised that this does not create a greater hazard (*7*), for example, by reducing ventilation in other parts of the mine and/or creating conditions in which toxic or flammable gases behind ventilation seals could be forced into the active workings due to a lowering of the pressures in the active workings relative to that in the sealed areas.

INFLATABLE FEED-TUBE PARTITION

When mine fires can no longer be fought directly due to heat, smoke or hazardous roof conditions, high expansion foam (HEF) may be one way to remotely quench the fire. The fire fighting personnel and HEF generator can be located away from the immediate vicinity of the fire at a less hazardous underground location. The HEF is a convenient means of conveying water to a fire. It quenches or extinguishes a fire by diluting the oxygen concentration through the production of steam, obstructing the air currents to the fire, and blocking the radiant energy from the burning fuel to other combustibles.

To effectively use the foam method for remotely fighting fires in underground mine entries, it is often necessary to construct, at some distance from the fire site, a partition or stopping in fresh air to separate the foam generator and its operators from the smoke and toxic fire products. If this is not done, the HEF could flow back over the foam generator, rendering the fire attack futile. This problem is especially acute when the fire is found uphill in a sloping entry. Concrete block, wood, plastic sheeting, mine brattice cloth or similar materials have been used for such partitions. Often, mine entries have irregular dimensions to which the partition must conform to avoid leakage around the periphery. Construction of such partitions can be time-consuming process. After the partition is constructed, a hole must be cut through it to allow passage of the high expansion foam from the foam generator to the fire site. During a recent underground simulation for mine rescue teams and fire brigades in an operating coal mine, it required 77 min to construct a partition from wood, metal and brattice curtain, and start the foam propagating up the mine entry.

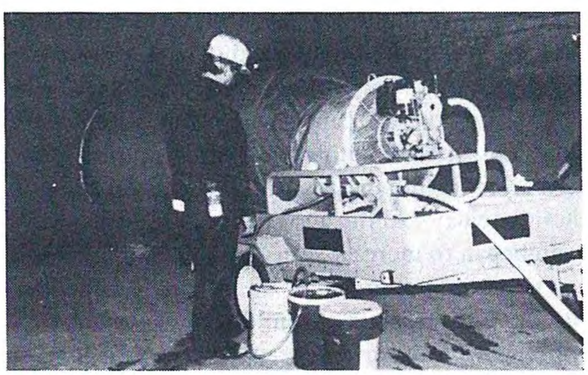

Figure 2 - Inflatable feed-tube partition in the Lake Lynn Experimental Mine

To address the drawbacks of constructing a partition for HEF generators, the IFTP (*8*) was developed. The IFTP, shown in figure 2, is a lightweight, inflatable rectangular bag. The device can rapidly (within 15 min) block large openings, such as those in underground mines, and simultaneously provide a feed-tube for high expansion foam. This allows fire fighting foam to freely flow to the fire site and control or extinguish the fire.

The portable IFTP can be easily transported to a mine passageway leading to a fire area and then be inflated by a permissible fan/air blower or a compressed air source (air source must be kept on to compensate for leakage). The shape and size of the IFTP depend on the passageway dimensions in which it may be used. For example, for a mine entry 2.1-m-high by 5.8-m-wide, the IFTP would take the shape of a slightly oversized rectangular bag approximately 2.6-m-high by 6.1-m-wide and 3.1-m-long. Experiments in the LLEM showed that a 2,800-L/s diesel pow ered (fixed driving force), high-expansion foam generator with the IFTP could push a foam plug 245-m through an entry 2.1-m high by 5.8-wide with a 4.3 pct rise in elevation, before the foam generator failed to push the foam plug further. Additional information on the use of foam and partitions can be found in reference 5.

POSITIVE-PRESSURE INFLATABLE ESCAPE DEVICE

Another conceptual use of an inflatable bag is the IED shown in figure 3. This rapidly deployed device, with its "pass through" feature, allows extra time for personnel evacuation by isolating a smoke-filled entry from fresh air. The IED would be strategically placed in a mine entry, and then be either manually or remotely deployed during a mine fire. Mine personnel escaping from the fire area would enter the bag from the smoke-filled side, and exit into fresh air. Since the bag is under positive pressure, it would be impervious to outside contaminates, such as smoke and gaseous combustion products. If the inflating air was clean compressed air, the bag could be used as a temporary shelter. The use of fan for inflation, however, would require that the fan remain in fresh air or that filters be installed on the fan to cleanse the mine air of any contaminants.

Figure 3 - Mine personnel entering the positive-pressure inflatable escape device

Another potential use for this device could be realised during mine recovery operations following a fire or explosion; the IED could be rapidly advanced as mine recovery continued. The IED has also been very effective during mine rescue simulations conducted at Lake Lynn Laboratory and an operating coal mine. The IED was used as an airlock system during rescue and exploration exercises by mine rescue teams. This device successfully isolated smoke-filled entries from fresh air, and team members effectively passed through the device to the fresh air base or back into the smoke-filled entries (*9*).

SUMMARY

Experiments in the LLEM have shown the portable in-mine IFR can be deployed in 3 min and effectively stopped airflows of up to 1,100m^3/min in a 12m2 entry. Tests have also shown the successful blockage, in less than 30 min, of a 1.8-m-high by 6-m-wide entry with the IFR which was remotely deployed through boreholes up to 60m deep. The IFR has shown promise as a means to isolate a mine fire area. It has to be realised that it would take a number of these devices to seal off a mine area, considering U.S. mine layouts. Such a device, whether deployed remotely from the ground surface through a borehole or from within the mine, may provide a greater degree of protection for the mine personnel involved in fire fighting or final mine sealing activities.

Both the IFTP and IED have shown merit in providing a relatively rapid method for isolation of a mine fire and for use with a foam generator for fire suppression, or for personnel escape and rescue. The IFTP can rapidly block large openings, such as those in underground mines, and simultaneously provide a feed-tube for high expansion foam. The IED could be used as an airlock system during exploration by mine rescue teams and rapidly advanced as mine recovery operations continued.

REFERENCES

1. Mitchell, D.W. Explosion-Proof Bulkheads: Present Practices. USBM RI 7581, 1971, 16pp.
2. Weiss, E.S., N.B. Greninger, C.R. Stephan, and J.R. Lipscomb. Strength Characteristics and Air-Leakage Determinations for Alternate Mine Seal Designs. USBM RI 9477, 1993 21pp.
3. Conti, R.S. Fire Fighting Resources and Fire Preparedness for Underground Coal Mines. USBM IC 9410, 1994 23 pp.
4. Weiss, E.S., R.S. Conti, E.M. Bazala, and R.W. Pro. Inflatable Devices for Use in combating Mine Fires. USBM RI 9614, 1996, 18 pp.
5. Conti, R.S. Inflatable Partitions for High Expansion Foam Generators. Mining Engineering, vol. 47, No. 6, June 1995, pp. 561-566.
6. Mattes, R.H., A. Bacho, and L.V. Wade. Lake Lynn Laboratory: Construction, Physical Description, and Capability. USBM IC 8911, 1983, 40 pp.
7. Mitchell, D.W. Mines Fire. Maclean Hunter Publishing Company, 1996, 178 pp., Section on Fuel and Ventilation, pp. 5-26.
8. Conti, R.S., and C.P. Lazzara. Inflatable Partition for Fighting Mine Fires, U.S. Patent No. 5,469,920 November 28, 1995.
9. Baldwin, G.L. "Inflatable Portable Refuge Structure," U.S. Patent No. 5, 537,784, July 23, 1996.

INFLATABLE DEVICES FOR COMBATING UNDERGROUND MINE FIRES

BY

Ronald S. Conti and Eric S. Weiss

Proceedings

MINESAFE International 1998

An International Conference on Occupational Health and Safety in the Mining Industry

28 September to 2 October 1998

Sun City, South Africa

pp. 388 - 393