Inflatable partitions for high-expansion foam generators

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Abstract — *The US Bureau of Mines (USBM) has developed an inflatable feed-tube seal (IFTS) for high-expansion foam generators. The IFTS is a lightweight, portable, rectangular inflatable bag that can be used by firefighters to rapidly seal large openings, such as those in underground mines, and to simultaneously provide a feed-tube for a high-expansion foam generator. Thus allows fire-fighting foam to freely flow to the fire site and control or extinguish the fire. Studies indicated that a high-expansion foam plug will travel 183 m (600 ft) down an entry with a 4.5% rise in elevation, before leakage of foam from around the inflatable partition.*

Introduction

When an underground mine fire cannot be directly combatted due to heat, smoke or hazardous roof conditions, high-expansion foam (HEF) may be one way to remotely quench the fire. Foam is a convenient means of conveying water to a fire (Havener, 1975). It quenches/extinguishes a fire by diluting the oxygen concentration through the production of steam. It blocks air currents to the fire and radiant energy from the fuel (Nagy, Murphy and Mitchell, 1960). Water retention is the most important property of any foam. The more water the foam can retain, the better its fluidity, spread, resistance to bubble collapse and ability to withstand the effects of heat and products of combustion. High water retention also means less foam is required.

As foam moves down an entry, a continuous shrinkage process occurs. A foam bubble cannot exist touching a dry surface. It will collapse, wetting the surface so that the next foam bubble can replace it. As a foam plug advances, there is a constant bubble collapse. This shrinkage is not large and takes place on the leading edge of the foam plug. It is also useful, since the foam wets and cools all dry surfaces, thus controlling or extinguishing the fire.

High-expansion foam cannot control a fire unless the foam plug reaches the fire (Jamison, 1993). Attempts have been made to push foam plugs into the burning entry downwind of the fire. However, the tremendous heat and gases on the downwind side of the fire tend to break the foam and most becomes heated into steam and blown down the entry away from the fire. However, foam pushed into the fire on the upwind side of the fire has a greater chance of reaching and cooling the fire.

Time is critical when dealing with fire. It is imperative that any ventilation change (Mitchell, 1990; Roberts, 1989) be made with caution. High-expansion foam generators may not produce quality foam (bubbles may not form) if the intake air is contaminated with smoke (Jamison, 1993a).

In two recent mine fires, foam was successful in controlling the fire, at least temporarily. In a fire that occurred in a Colorado coal mine (Timko, Derick and Thimons, 1987), miners started fighting the fire with an 11.3 m^3/sec (24,000 cu ft/min) diesel-powered foam generator and 15 208-L (55-gal) drums of foam concentrate. Additional foam concentrate was obtained from several other mines and a local vendor. Unfortunately, there was not enough of foam to quench the fire. As soon as the foam was depleted control of the fire was lost.

At the Montour No. 4 mine fire (Jamison, 1993b) in Pennsylvania, foam was made for most of three days. More than 15.1 kL (4000 gal) of foam concentrate and 1 ML (270,000 gal) of water were depleted during that period. It was stated that "The foam took over successfully at a critical time and reduced one of the largest mine fires on record to a safe sealing operation (Jamison, 1993b)."

To effectively use the foam method for remotely fighting fires in underground mine entries, it may be necessary to construct — some distance from the fire site — a partition or seal in fresh air. This is done to separate the foam generator and its operators from smoke and toxic fire products. In addition to limiting exposure to smoke and toxicity, if a partition is not constructed, foam could flow back over the foam generator, rendering the fire attack futile. The problem is especially acute when the fire is located uphill on a sloping entry.

In past practice, concrete block, wood, plastic sheeting, brattice or similar materials have been used for such partitioning (Fig. 1). However, mine entries often have irregular dimensions that the partition must conform to to avoid leakage around the periphery. Building these partitions can be time consuming. In addition, after the partition is made, a hole must be cut to allow passage of the high-expansion foam from the foam generator to the fire site. This can be labor-intensive and time-consuming. It may also be danger-

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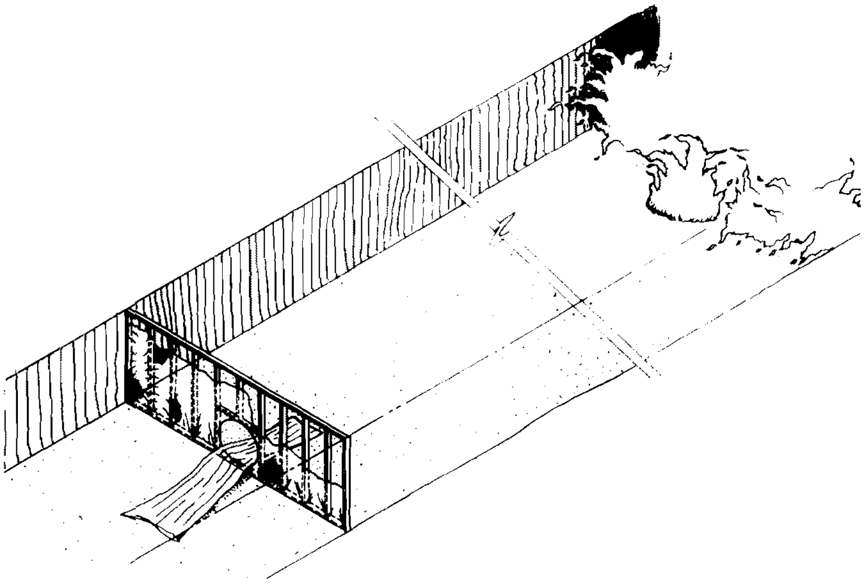

Fig. 1 — Partition for high-expansion foam generators.

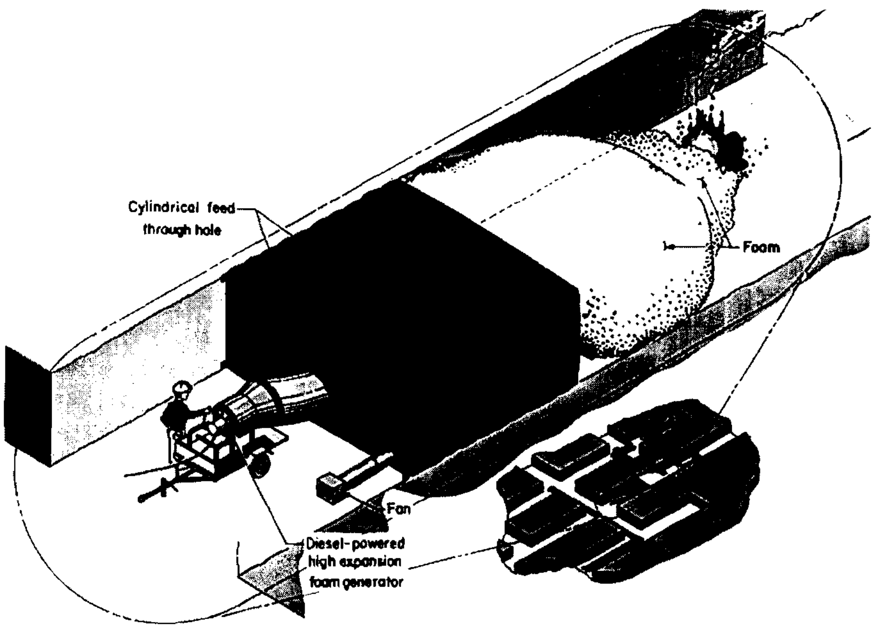

Fig. 2 — Inflatable partition for high-expansion foam generators.

ous, depending on fire conditions (the accumulation of flammable gases on the other side of the partition). The through-hole in an improperly sealed partition often results in a substantial leakage around the high-expansion foam feed tube due to the backpressure of the advancing foam plug.

The erection of any partition reduces the ventilated airflow and can cause the fire to burn fuel-rich. This can be hazardous if the unburned volatiles are ignited. Due to this potential explosion hazard, advance planning is essential, as is training and preassemblage of correct materials (foam generator and concentrate, water supply, partition, etc.). To minimize this hazard, the use of the foam generator should occur immediately following the erection of the partition.

Earlier tests conducted by the USBM (Nagy, Murphy and Mitchell, 1960) using foam to control and extinguish experimental underground coal, wood and oil fires indicated that a foam plug could travel 488 m (1600 ft) in a level entry (2 m high by 2.9 m wide or 6.5 x 9.5 ft). Several limitations of using the foam plug method included:

- The time required to assemble the equipment near the fire location.
- The limited distance foam can be transported, including up and down sloping passageways.
- Electrical power requirements (fan motor used to produce foam) near the fire area and the effect of the foam plug on ventilation.

Despite these limitations, the underground experiments indicated that foam was effective in controlling or extinguishing the fires.

Additional information on fire-fighting resources and fire preparedness for underground coal mines can be found in reference (Conti, 1994).

Inflatable feed-tube seal

To address the problem of reconstructing a partition, the inflatable feed-tube seal (IFTS) was developed by the USBM (Conti and Lazzara, 1994). The IFTS is a lightweight, portable, rectangular inflatable bag that is used in conjunction with high-expansion foam generators. It rapidly seals large openings, such as those in underground mines (Fig. 2). The IFTS can be deployed in several minutes to simultaneously seal the entry and provide a feed-tube for a high-expansion foam generator.

The portable IFTS is easily transported to a burning mine passageway and inflated by an air blower or other source of compressed gas. The IFTS seal is made from a water- and heat-resistant, lightweight fabric (0.076 mm or 0.003 in. thick), such as chemically treated, rip-stop nylon. The shape and size depend on the passageway dimensions. For example, for a mine entry 2.1 m high by 5.8 m wide (7 x 19 ft), the seal would take the shape of a slightly oversized rectangular bag about 2.6 m high by 6.1 m wide and 3.1 m long (8.5 x 20 x 10 ft), weighing 8.2 kg (18 lbs).

Traversing the seal is a collapsible cylindrical aperture lined with the fabric of the bag. A collapsible plastic feed-tube is passed through the aperture to convey foam from one side of the seal to the other. The pressure of the foam in the tube will exceed the pressure of air in the seal. This keeps the aperture open. When the foam generator is turned off, the aperture collapses.

Figure 3 shows the inflatable feed-tube seal while being deployed in a mine entry to contain a fire. The seal is air inflated (to about 0.14 kPa or 0.02 psi) by a fan attached to the seal with an air tube. When inflated, the seal blocks the entry (Fig. 4).

A collapsible plastic feed-tube extends through the aper-

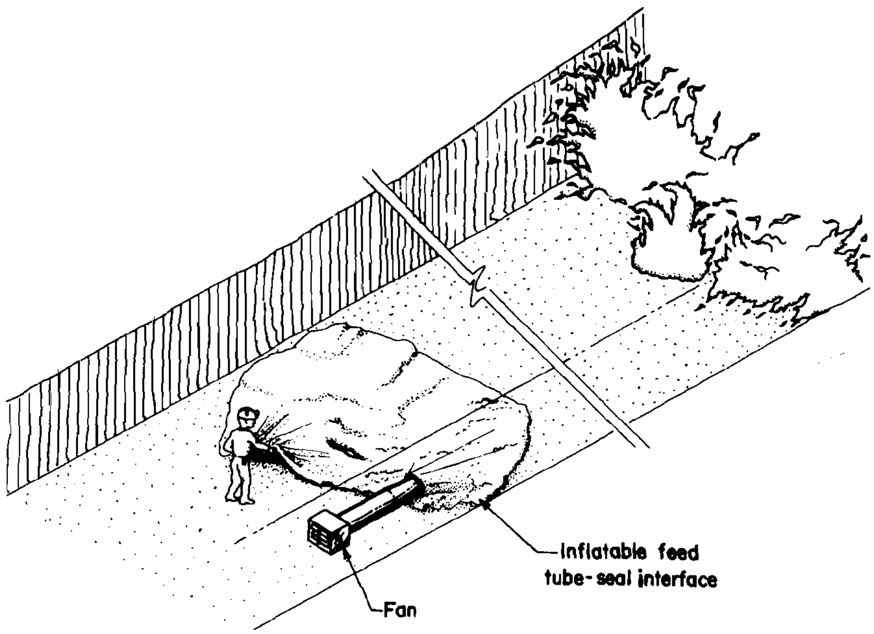

Fig. 3 — Inflating the feed-tube seal with fan.

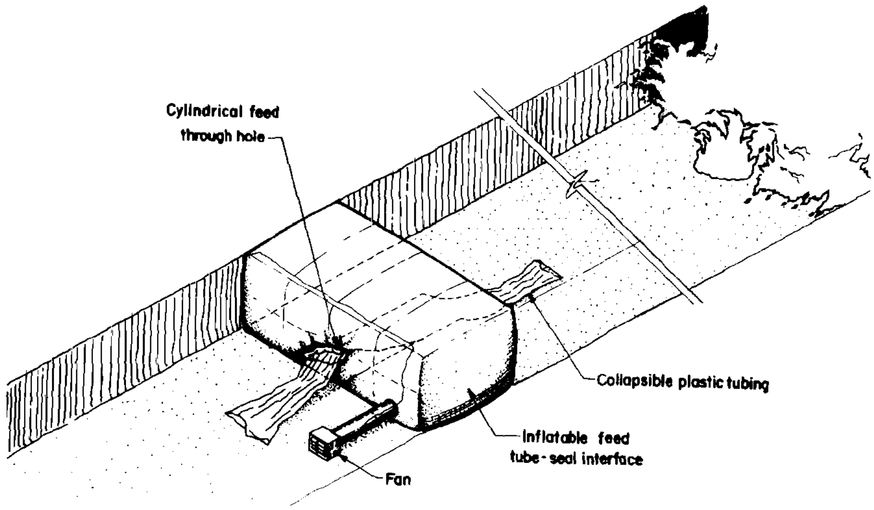

Fig. 4 — Inflated feed-tube seal.

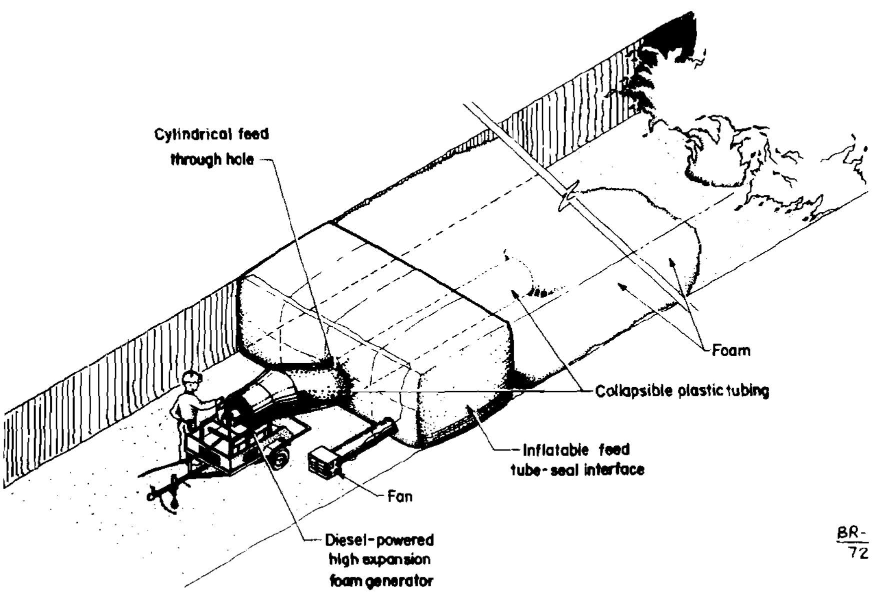

Fig. 5 — Inflated feed-tube seal coupled to the foam generator.

ture (about 3.1 m or 10 ft long). At this stage, the aperture is collapsed, closing the aperture and the feed-tube. Air pressure in the seal is maintained by the fan and air tube. One end of the collapsible plastic feed-tube is then connected to the high-expansion foam generator (Fig. 5). The generator expands the feed-tube due to the pressure of the generator's fan. This allows the high-expansion foam to freely flow through the seal, down the entry to the fire site.

Experimental section

Experiments with high-expansion foam and the IFTS were conducted at the USBM's Lake Lynn laboratory experimental mine (Mattes, Bacho and Wade, 1983; Triebsch and Sapko, 1990). This is a former limestone mine converted to a multipurpose mining research facility for fire and explosion prevention research. The entry dimensions of the underground mine range from 1.8 to 2.4 m high (6 to 8 ft) and from 5.3 to 6.7 m wide (17 to 22 ft). The average cross-sectional area is 12 m^2 (129 sq ft).

High-expansion foam tests. Tests conducted in the Lake Lynn experimental mine showed the required foam concentrate necessary to produce sufficient high-expansion foam to fill a mine entry. The tests used a 2.8-m^3/sec (6000 cu ft/min) diesel-powered, high-expansion foam generator with a 2% foam concentrate solution (expansion ratio is 850:1). The operating parameters were set at 3.15 L/sec (50 gpm) of water and 0.551 MPa (80 psi) water pressure at the eductor. It required 2.2 minutes to fill 30.5 m (100 ft) of a 5.8 m wide by 2.1 m high (19 x 7 ft) entry, (372 m^3 or 13,300 cu ft). Therefore, in 1 hour, 11,356 L (3000 gal) of water and 227 L (60 gal) of foam concentrate would be used with this foam generator.

Tests in the Lake Lynn experimental mine also showed that a high-expansion foam plug traveled down and completely filled an entry (with a 4.5% rise in elevation). This included a crosscut with the above dimensions. The foam plug also traversed corners and obstacles, such as wood cribs.

Using a plywood partition, the foam spread 207 m (680 ft) before the partition failed (the failure criterion was foam leakage from the foam feed tube hole or around the partition, that rolled back over the foam generator). Parti-

Fig. 6 — Photo of inflatable feed-tube seal at the Lake Lynn experimental mine.

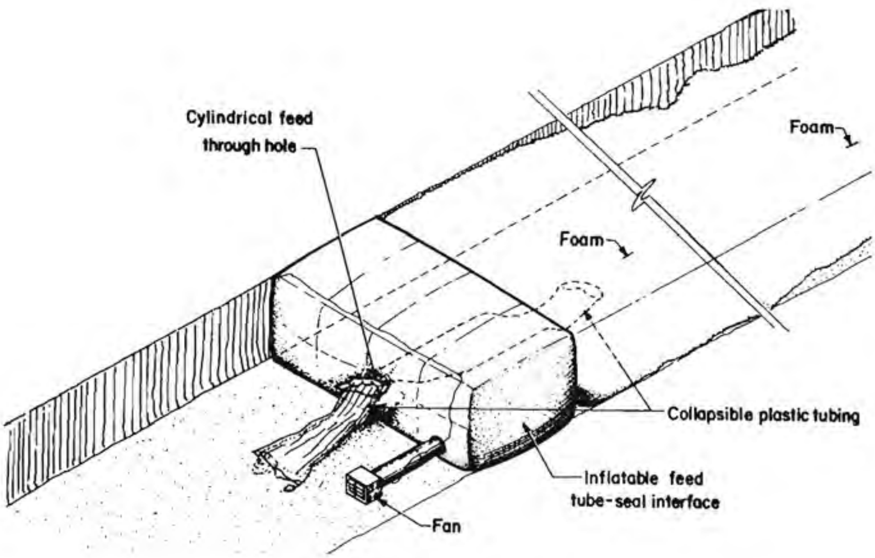

Fig. 7 — Sealed feed tube.

tion failure depends on how well a partition is constructed. During the above test, the advance rate of foam for the first 30.5 m (100 ft) was 11.7 m/min (38 fpm). This gradually decreased to 1.74 m/min (6 fpm) when the foam reached 207 m (680 ft). The amount of foam concentrate used in this test was 182 L (48 gal).

Additional tests indicated that the advance rate of the foam plug over the first 30.5 m (100 ft) was 12% slower in a dry entry than in a wet entry (the entry was wetted before the test). It also required 38% more foam concentrate to completely fill 30.5 m (100 ft) of entry in dry conditions with high-expansion foam compared to a wet entry. The foam shrunk 0.31 m (1 ft) from the roof over the first 24 hours. It continued to shrink an additional 0.46 m (1.5 ft) over the next 96 hours.

Tests with inflatable feed-tube seal, first prototype. The IFTS was developed and tested to improve the time required to erect partitions during a mine fire near the fire location. In an experiment in the Lake Lynn experimental mine (Fig. 6), an IFTS (2.6 m high by 6.1 m wide and 3.1 m long or 8.5 x 20 x 10 ft) was inflated in an entry, 2.1 m high by 5.8 m wide (7 x 19 ft), to evaluate propagation distance. The diesel-powered high-expansion foam generator produced foam that propagated up the entry (4.5% rise) 92 m (300 ft), including filling of a crosscut. After the foam generator was turned off, the feed-through tube sealed itself (Fig. 7).

Another experiment was conducted with the IFTS in a 2.1-m high by 5.9-m wide (7- x 19-ft) entry. This was done to determine the rate of advance of a high-expansion foam plug and the distance the foam plug would travel in dry entry conditions before IFTS failure. The failure criterion was foam leakage that rolls back over the foam generator.

The advance rate of the foam for the first 30.5 m (100 ft) was 7.2 m/min (23 fpm), decreasing to 6 m/min (20-fpm) when the foam reached 92 m (300 ft). The advance rate was significantly slower than the 11.7 m/min (38 fpm) advance rate of the tests performed with the plywood partition. This was attributed to the restriction offered by the diameter of the aperture.

At 92 m (300 ft) the test was terminated because the IFTS started leaking foam around both ribs. It is possible that such leakage could be mitigated by increasing the size of the IFTS with respect to the entry dimensions.

Additional tests included inserting a 1170-mm-diam (46-in.-diam) rigid tube through the feed-tube hole. This increased the advance rate to 10.2 m/min (33 fpm) for the first 30.5 m (100 ft). The initial experiments on the first prototype showed that the IFTS concept had merit and additional experimentation was warranted.

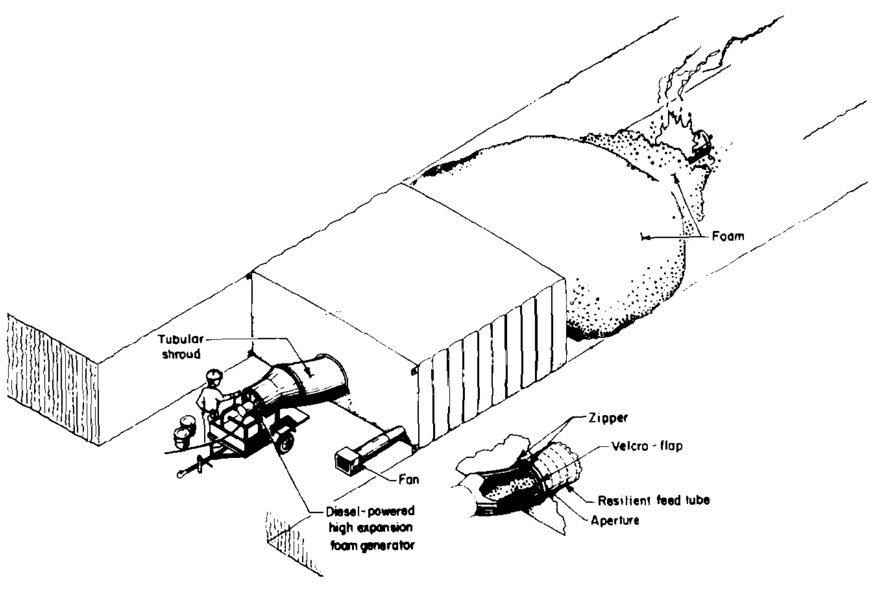

Fig. 8 — Second prototype inflatable feed-tube seal, showing the resilient feed-tube.

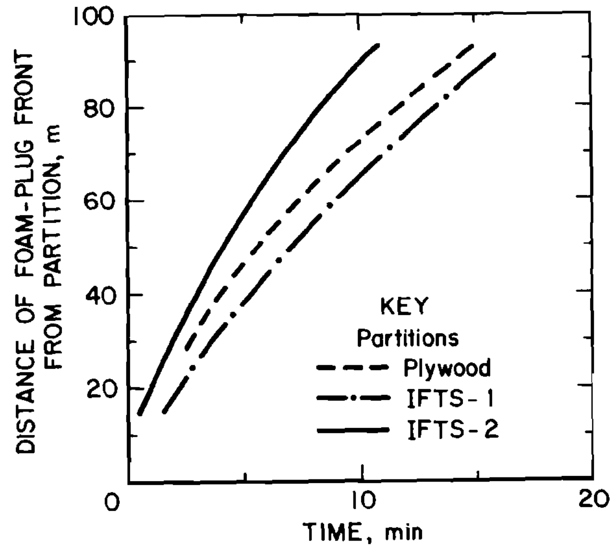

Fig. 9 — Distance traveled with respect to time of foam plug fronts for three partitions.

Tests with inflatable feed-tube seal, second prototype. In a subsequent version of the IFTS (Fig. 8), a tubular shroud was used to convey high-expansion foam from the foam generator to a resilient feed-tube. The overall dimensions of the IFTS were also increased to enhance the distance a foam plug can travel before the device fails and to allow deployment in larger or irregular shaped entries.

The 1370-mm-diam (54-in.-diam) resilient feed-tube incorporated a helical metal wire that extended the length of the aperture. A wire-stay prevented the aperture from collapsing due to the air pressure in the seal. This helped to maintain the unrestricted propagation of the foam from the generator through the partition.

A tubular shroud was attached to the front side of the seal with a zipper and Velcro.* The shroud replaced the collapsible plastic feed-tube used in the previous IFTS. The shroud was designed to collapse when the foam generator is turned off. This prevents flow of high-expansion foam back toward the foam generator. The total weight of the bag, excluding the blower assembly, was 39 kg (86 lbs).

Experiments with the second prototype IFTS were conducted in the Lake Lynn experimental mine. The amount of foam concentrate used in the test was 90 L (24 gal). The average advance rate of the foam plug for the first 30.5 m (100 ft) was 14.4 m/min (47 ft), decreasing to 9 m/min (30 ft) when the foam reached 92 m (300 ft). At 183 m (600 ft), the test was terminated because the IFTS started to leak foam near the corner of the roof. Such leakage can probably be mitigated by anchoring the four corners of the exiting foam side of the IFTS to the ribs.

The distance-time relationships for transport of the foam plug for 90 m (295 ft) for all three partitions are shown in Fig. 9. The data for all partitions indicate that the advance rate decreases with distance travelled. This is due to the resistance of foam plug (as the foam plug propagates further away from the foam generator) and to the constant driving force of the foam generator. The driving force is constant for this foam generator. But it can vary depending on the type of foam generator.

In addition, and more importantly, the second IFTS prototype (IFTS-2) showed a significant increase in the advance rate of the foam plug, compared to the earlier version of the IFTS and the plywood partition. Even though the distance that the foam plug had travelled was less with the IFTS-2 compared to the plywood partition at partition breaching, the foam-producing efficiency was increased. This improved efficiency (the distance the foam-plug front traveled from the partition with respect to time) was mainly due to the enlarged diameter of the resilient feed-tube.

Future studies. Additional experiments are planned to evaluate the maximum distance a foam plug can travel in an entry before the device fails (by anchoring the four corners of

* Reference to specific products does not imply endorsement by the US Bureau of Mines.

the exiting foam side of the IFTS to the ribs). Also, tests will be conducted to determine the effects of entry airflow on the inflation process and stability of the IFTS in the entry. This will include whether the dynamic force of the entry airflow against the IFTS would be counterbalanced by the opposite force exerted on the IFTS by the foam plug.

In addition, an evaluation will be made of foam generators with larger driving forces interfaced to the IFTS to determine the advance rate of the foam plug. Fabricating the IFTS from other materials, such as Mylar, is also being considered. The use of other nonporous materials may eliminate the need for a continuous air supply after the bag is inflated. Tests will also be conducted to evaluate the extinguishment of experimental mine fires.

Summary

The IFTS was developed for use during an underground mine fire to rapidly isolate the fire while providing a feed-tube for a high-expansion foam generator. The first prototype validated the IFTS concept, providing a portable (lightweight and easily transported), rapidly deployed (five to eight minutes), partition with an integral aperture for passage of a feed-tube from a high-expansion foam generator.

The second prototype IFTS included a wire insert to maintain aperture opening. It also included an enlarged aperture diameter that increased foam production efficiency. The foam plug travel distance and rate were also significantly improved.

The inflatable feed-tube seal offers a potential tool for firefighters to rapidly fight fires in passageways with high-expansion foam. As always, a fully implemented emergency and preparedness plan is critical in dealing with and reducing the probability of a mine fire. ♦

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