EVALUATION OF GAS-ENHANCED FOAM FOR SUPPRESSING COAL MINE FIRES

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ABSTRACT

Improvements in remote fire fighting technology are needed to reduce miner exposure to the dangers of fires and possibly save the lives of those who may become trapped. The National Institute for Occupational Safety and Health, in cooperation with U.S. Foam Technologies, Inc[1]., conducted a series of experiments at the NIOSH Lake Lynn Experimental Mine to study the stability, transport, control and fire extinguishing effectiveness of nitrogen-enhanced foam technology. This paper presents a description of the mine test configurations and experimental results.

INTRODUCTION

The objective of this study was to evaluate the stability, transport, and fire suppression effectiveness of a nitrogen-enhanced foam system for coal mine fire control and extinguishment. Mine fires constitute one of the greatest threats to the health and safety of those working in an underground mine. Although fatalities due to mine fires are rare, each event has the potential for disastrous consequences due to the presence of methane and the limited means of egress from the mine. One only needs to be reminded of the Sunshine mine fire in Idaho in 1972, where 92 miners lost their lives, or the Wilberg Mine fire in Utah in 1984, where 24 miners succumbed to a raging mine fire. It was reported that from 1990 – 1999 there were 81 coal mine fires in the United States [DeRosa, 2004]. Since 2000, a total of 19 coal mine fires have occurred in the U. S., most recently at mines in Virginia and Kentucky. These statistics suggest that mine fires are occurring with alarming frequency. Improvements in remote fire fighting technology are critically needed to reduce miner exposure to the dangers of fires and possibly save the lives of those who may be trapped.

During the initial stages of a mine fire, it is common practice to try to extinguish the fire underground for as long as possible, thus exposing those fighting the fire to the dangers of smoke inhalation and the possibility of an explosion. If reliable, proven remote fire fighting technology was available, then it would be possible to more quickly evacuate the mine and address the fire remotely, thus removing miners from danger.

Fire fighting foam technology has been available for many years, and has been used extensively to fight flammable and combustible liquid fires on the surface [Colletti, 1992, Brackin, 1992, Oman, 1993]. The application of fire fighting foam in underground mines was developed in the 1950's [Hartman, 1958, Nagy, 1960]. Its use has been mostly limited to direct fire fighting using a high-expansion foam generator located underground to push the foam to the fire area [Scott, 1968, Banerjee, 1986, Conti, 1995, Conti, 1998]. Other applications include the pumping of

[1] Mention of a company name or trade product name does not imply endorsement by NIOSH.

nitrogen-enhanced high expansion foam into gob areas to control spontaneous combustion [Komai, 1989, Voracek, 1993].

More recently, the methods that employ compressed gas foams have been developed, resulting in smaller, more uniform bubbles [Grady, 1994]. These compressed gas foams expand water to between five and fifteen times its original volume. Foam suppression of a fire works through the evaporation of the contained water and cooling through energy removal. As the foam collapses, the water is released and increases in temperature by absorbing heat. Eventually the water turns into steam. Water is released from foam either through bubble rupture or through the effect of gravity, which distorts and bursts the bubble walls. Because this process takes time, the foam can act as a water reservoir, releasing water at a rate that allows absorption into the fuel, rather than running off the surface. If nitrogen is used as the enhancing gas, in addition to removing heat from the fire, it can also take away a second leg of the fire triangle by the removal or displacement of oxygen.

The use of remotely-applied foam from the surface through boreholes is relatively new. Because of the lack of experience with this new technology, there are uncertainties with respect to the foam's ability to maintain its composition when pumped under pressure through deep boreholes and its ability to move away from the down hole location. In order to quantify these and other parameters, a series of full-scale experiments was conducted in NIOSH's Lake Lynn Experimental Mine (LLEM). The foam was injected remotely from the surface through a borehole into the mine cavity and the foam's stability, flow speed and flow length was determined. In addition, the ability of the foam to flow through non-linear configurations, through and around obstructions, and over pooled water was evaluated. Its suppression effectiveness was measured against a deep-seated coal fire and a diesel pool fire. Lastly, its ability to flow up dip was determined.

Description of Experiments

Foam delivery system

The above ground foam injection system consisted of water, nitrogen, foam concentrate supplies, a water pump, and a foam injection metering pump. The water, foam, and nitrogen was mixed and delivered to the mine borehole through three U.S. Foam Technology Hellfighter™ apparatuses. A schematic of the foam system is shown in figure 1.

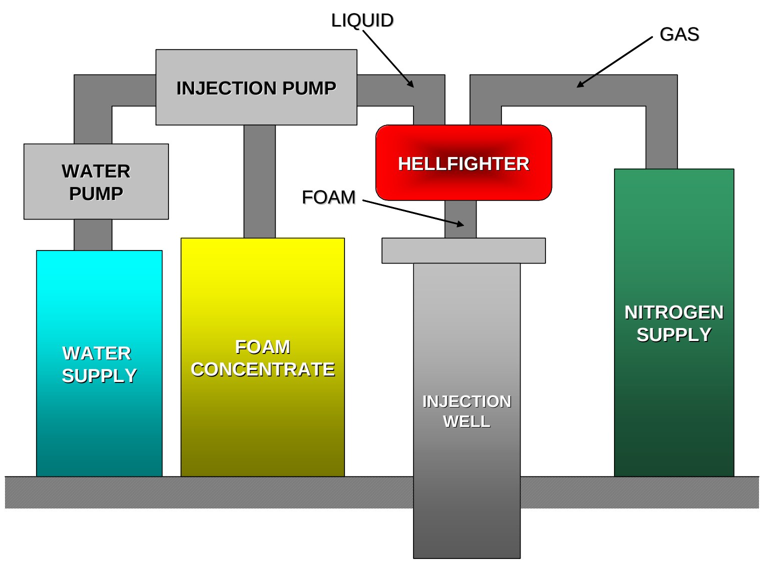

Figure 1. Schematic of surface foam injection system.

For these experiments, the water was stored in a 10,000 gallon tank and a fire engine pump was used to pump the water. The foam concentrate was supplied in 250 gallon plastic containers. A foam injection pump was used to meter the foam concentration into the water stream. The percentage of foam concentrate can be adjusted to vary the density of the foam depending on the application. The water and foam concentrate supplies and water and foam injection pumps are shown in figure 2.

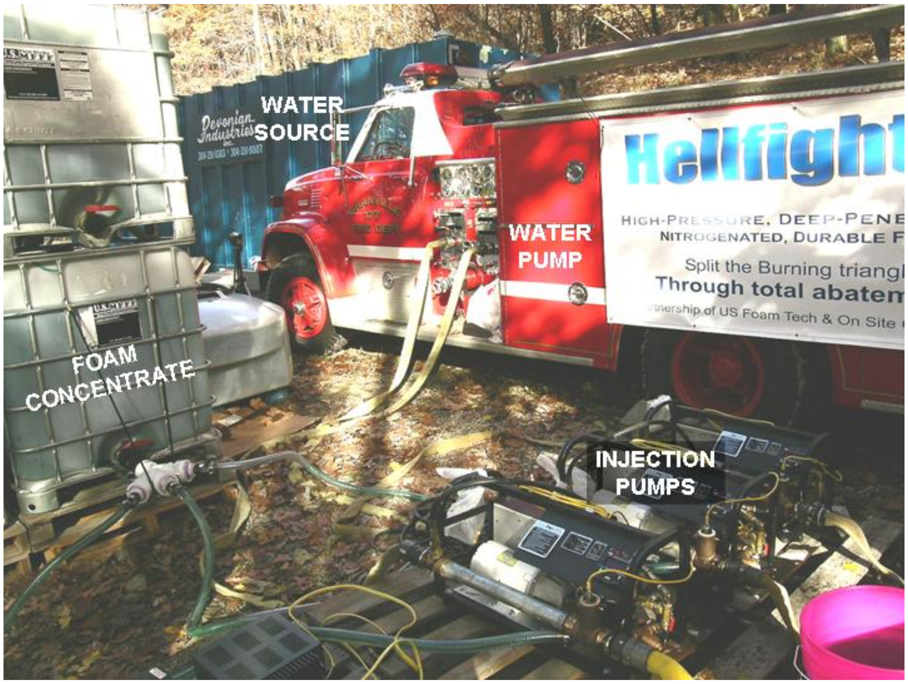

Figure 2. Surface foam injection site.

The nitrogen was supplied by a 1,000 ft^3/min membrane separation plant, shown in figure 3. The Hellfighters^{TM}, attached to the borehole injection well, are shown in figure 4. The injection borehole into the mine entry was 197 ft in depth, terminating at the mine roof.

Figure 3. Nitrogen membrane separation plant.

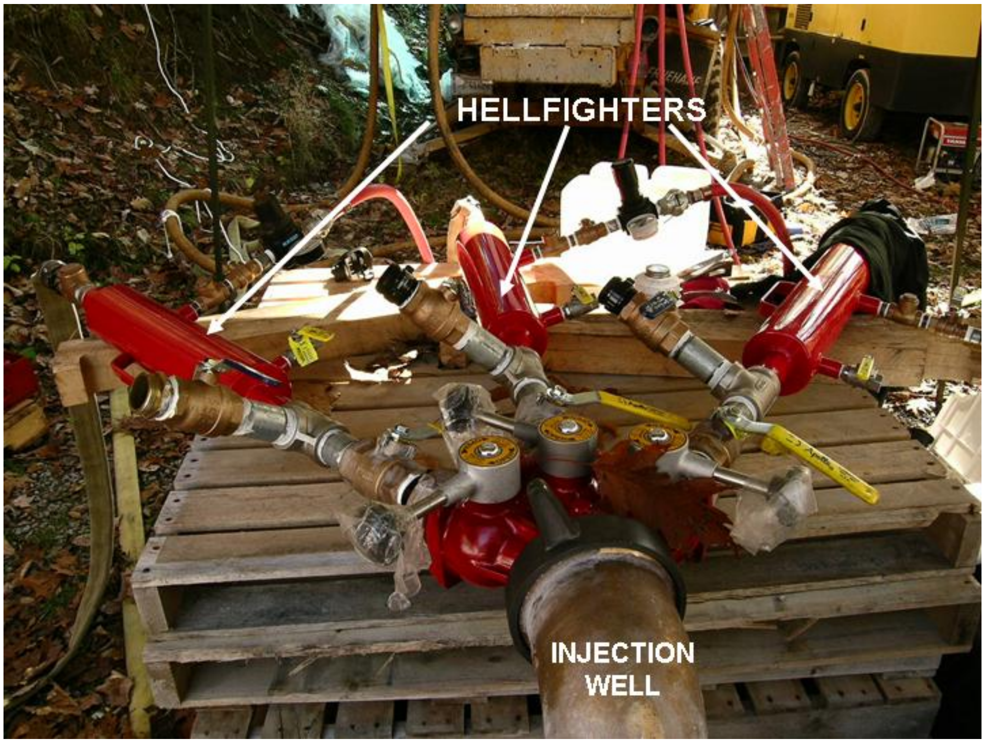

Figure 4. Hellfighter™ foam injection apparatuses connected to borehole coupling elbow.

Lake Lynn ExperimentalMine

Experiments were conducted in the NIOSH Lake Lynn Experimental Mine (LLEM). A schematic of the LLEM is shown in figure 5.

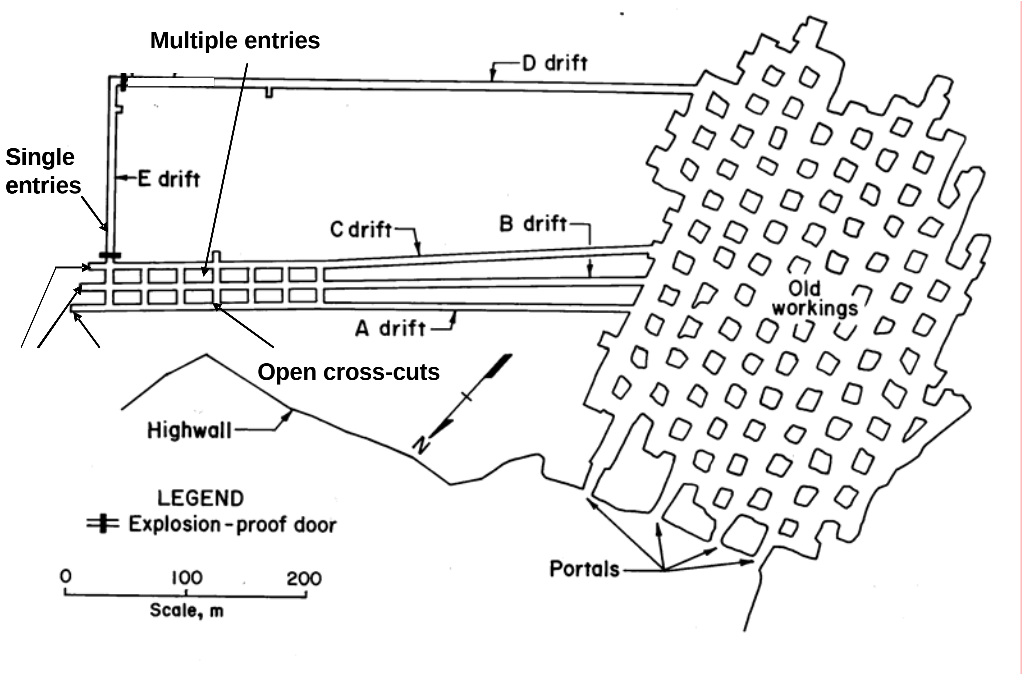

Figure 5. Schematic of Lake Lynn Experimental Mine.

The underground mine entries were developed adjacent to an abandoned commercial limestone quarry and underground limestone mine. The entries of the abandoned limestone mine, labeled as the old workings, are approximately 50 ft wide by 27 ft high. The LLEM contains 5 drifts, shown in figure 5 as A, B, C, D, and E. These entries were developed to approximate the size of a typical Pittsburgh seam coal mine, about 20 ft wide by 6 ft high, and range from 500 to 1500 ft in length. The entries, in conjunction with the use of two explosion-proof bulkhead doors that can be positioned to open or close an entry, can be made to simulate room-and-pillar and longwall mine configurations.

EXPERIMENT 1

The first experiment was designed to evaluate the physical characteristics and flow behavior of the foam. Air was used as the gas in this experiment so that researchers could visually observe the foam movement without the need for self-contained breathing apparatuses. The parameters studied in this experiment included measuring the condition and volumetric changes in the foam as it was pumped into the borehole and entered the mine, the foam's stability, flow speed, length of flow, stacking characteristics, movement through and around obstructions, movement over a pool of water, and flow through non-linear configurations. To accomplish this, the multiple entry section of the mine was configured as shown in figure 6.

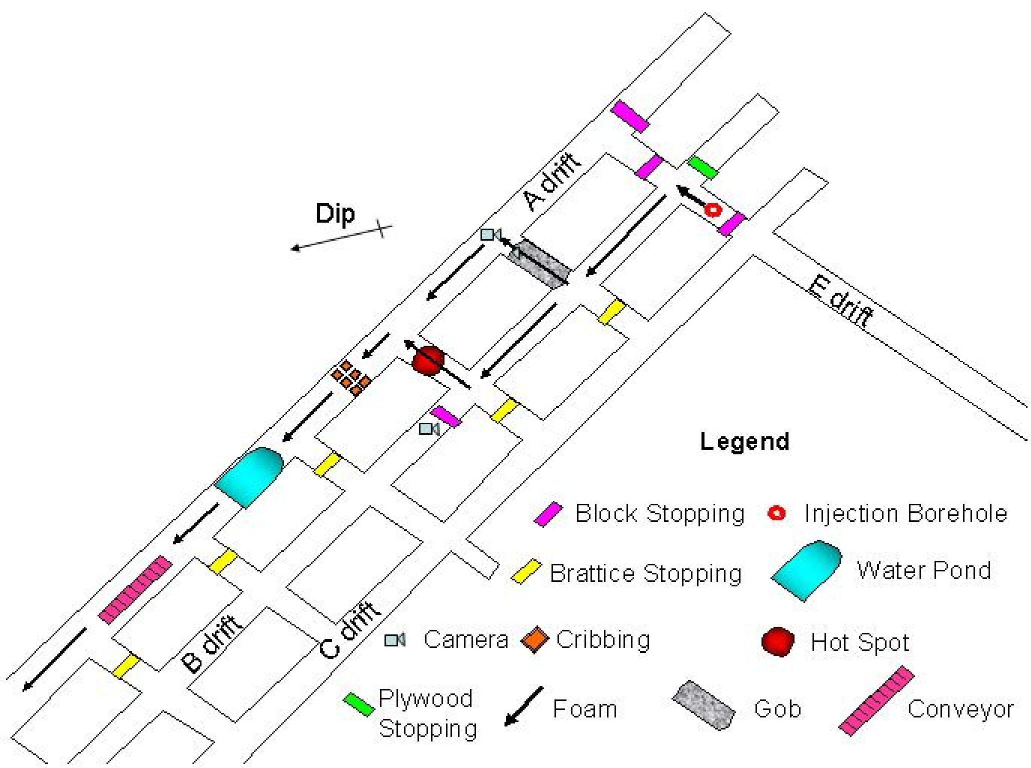

Figure 6. Schematic of Lake Lynn Experimental Mine setup for first foam experiment.

The injection borehole intercepts the mine workings in the crosscut closest to the face between B and C drifts. The borehole is completed to the mine opening with 6-in diameter casing. At the location of the borehole, the mine opening is 7 ft high and slopes towards B drift on a 1.13 percent gradient.

To evaluate the long-term stability of the foam under environmental temperature and humidity conditions typical in a mine, a 5.5-ft high concrete block stopping was construct in the closed end of the A drift to create an isolated area that could be filled with foam. This area is 92-ft-long by 20-ft-wide. To transport the foam to this area, a flexible hose was attached to the bottom of the injection borehole and extended to this enclosure. The enclosure volume was then filled with foam.

A combination of block, plywood, and brattice stoppings was used to direct the foam as it exited the borehole. A plywood stopping at the outby end of the B drift stub and concrete block stoppings in the first crosscut between A and B drift were installed to direct the foam down B drift. The second crosscut between A and B drift was filled from wall to wall and floor to roof with broken rock to simulate compacted gob material. This was used to determine if the foam would penetrate the broken rock or if the rock only served to block the flow path. Another block stopping was placed in B drift just outby the third crosscut. One block was replaced with a window and a camera was located behind the stopping window to record the foam movement. Brattice stoppings were placed in the second and third crosscuts between B and C drift and in the fourth, fifth, and sixth crosscuts between A and B drift. Because of the dip of the mine floor, this combination of stoppings directed the foam flow across a broken rock zone in crosscut 3 between A and B drifts. This rock zone was approximately 3 feet high and spanned the width of the opening. Three electric resistance heating elements were buried at the center of this rock pile to simulate a deep-seated hot spot, to determine if the foam could infiltrate the broken rock and reduce the temperature of the hot spot.

Eight crib block structures were constructed in A drift between the third and fourth crosscuts and a 26 foot long conveyor belt structure was placed in the middle of A drift between the fifth and sixth crosscuts to observe the behavior of the foam as it flows through or around mine structures. Lastly, a pool of water was created in A drift between the fourth and fifth crosscuts to determine whether the foam moves over a body of pooled mine water or if the pool creates a barrier to the water flow or degrades the foam. The water pool was created by constructing a watertight 2-foot high block stopping across the width of A drift to act as a water dam. Because of the slope of the mine floor, this allowed a pool approximately 50 feet long to form in A drift.

The initial attempts to deliver high quality foam to the mine entry required some adjustment to the foam concentrate ratio. This is typical of foam use and is usually done on the surface by the equipment operator. In this case, the adjustment was made through communications between in-mine personnel and personnel on the surface at the pump site. After adjustment, a foam having a shaving cream-like consistency was achieved at the bottom of the borehole. The foam moved down and around the corner of the first crosscut into B drift, as shown in figure 7. The foam reached a height of 3 to 4 feet through B drift as it moved down dip away from the borehole.

Figure 7. Movement of foam around first crosscut in B drift during experiment 1.

The first obstacle encountered in B drift was the rock pile in the second crosscut between A and B drift. The camera mounted on the A drift side of the rock pile showed that no foam moved through the rock. Water, however, apparently from foam degradation that settled out, was observed running through the bottom of the rock pile due to the slope of the mine entry.

The mine stopping configuration then caused the foam to turn into the third crosscut between A and B drift, where the foam encountered the three-ft-high rock pile with the heating elements simulating a deep-seated hot spot. Figure 8 shows the temperature profiles of the thermocouples attached to the four heating elements located in the rock pile.

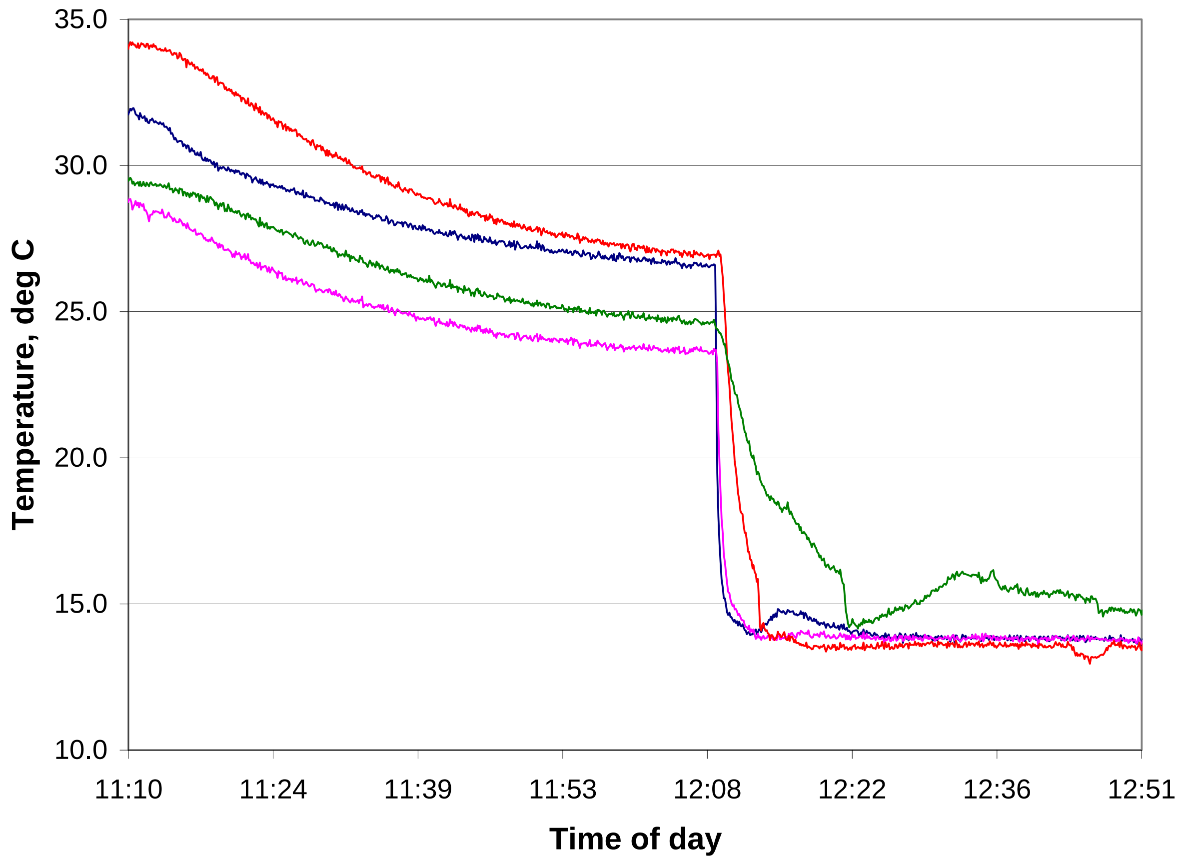

Figure 8. Plot of temperature versus time in rock pile between A and B drift.

Unfortunately, the heating elements burned out after reaching temperatures ranging from 28º to 34º C, just 15º to 20º C above ambient temperature. The heating elements were not on long enough to raise the rock temperature any appreciable amount to measure the effect of the foam on the rock temperature and are not shown. However, it is clearly obvious that the foam quickly infiltrated the rock pile and cooled the heating elements within minutes.

After turning the corner into A drift, the foam moved down dip until it ran up against the crib blocks. Figure 9 shows that the crib blocks formed an effective barrier to the foam, causing it to build up to roof height behind the crib blocks. Past the crib blocks, the foam height in the entry was reduced to about 2 ft.

Figure 9. Foam behavior at crib blocks in A drift.

The foam then approached the water pool in A drift, constructed to evaluate the effect of the water on the foam stability and movement. The water had no apparent effect on the foam as it moved over it without any apparent affect on foam quality. A photo of the foam moving over the water, viewed from inby the water pool is shown in figure 10.

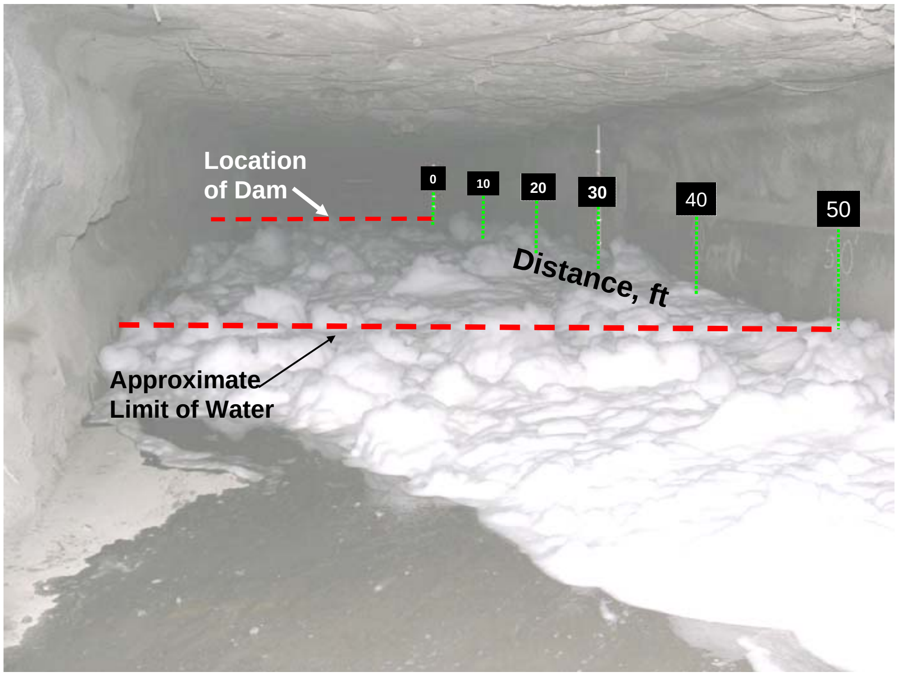

Figure 10. Foam moving over a pool of water in A drift.

Finally, the foam encountered the conveyor belt structure, shown in figure 11. The structure acted much like the crib block in A drift, causing the foam to build up to it upstream of the structure. Since the structure only occupied about 6 ft of the width of the entry, the foam moved through the unobstructed part of the entry similarly to the way it moved through the B drift.

Figure 11. Conveyor belt structure in A drift.

Foam stability: To measure the stability of the foam under static conditions, the closed end of A drift up dip of the first crosscut was filled with foam to a height of 5.5 feet. Figure 12 shows the foam just after filling the enclosed area and figure 13 shows the rate of decay of the foam volume versus time. The foam lasted for 9 days and the rate of decay was linear over the 9 day period at about 900 ft^3. It should be noted that this area was not exposed to mine ventilation flow and was strictly a measure of the rate of foam degradation.

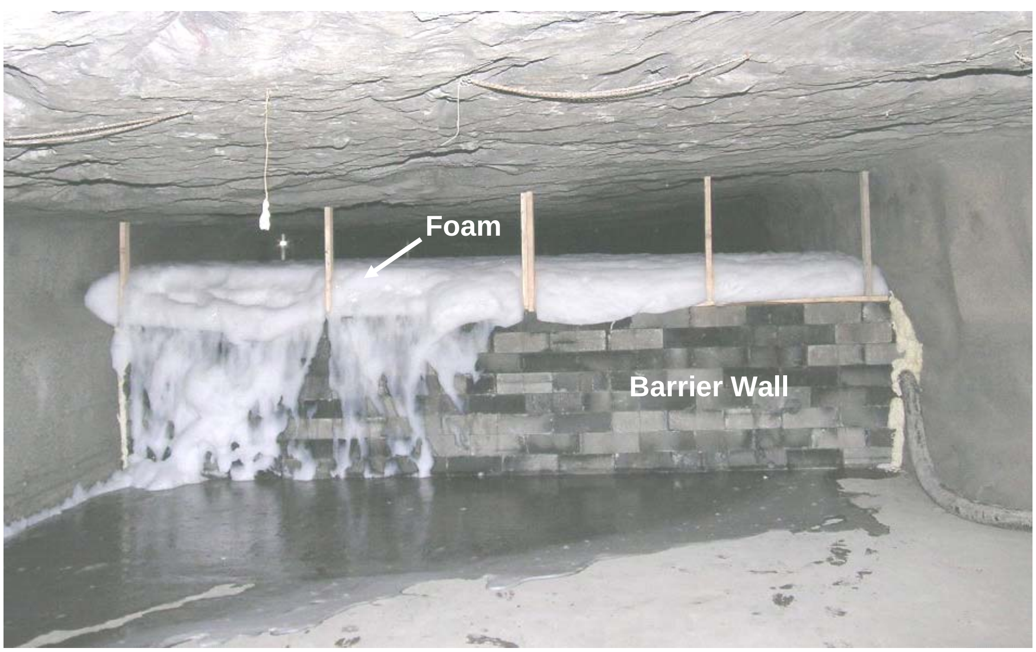

Figure 12. Foam stability test in A drift.

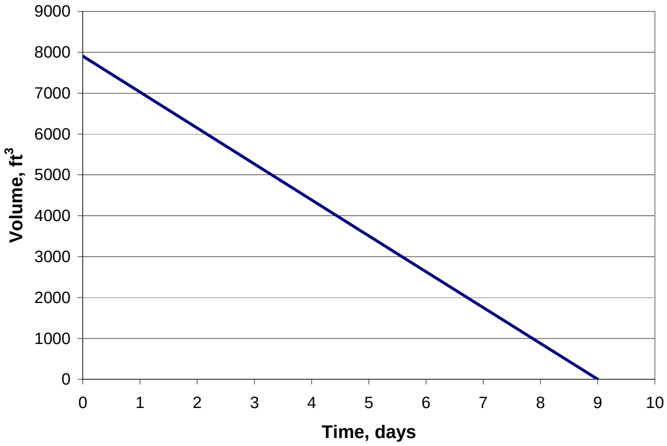

Figure 13. Rate of decay of foam versus time in foam stability test.

EXPERIMENT 2

Experiment 2 was designed to evaluate the fire fighting effectiveness of the foam against a deep-seated coal fire and a flammable liquid (diesel fuel) pool fire. In this experiment, nitrogen was used as the gas. The mine configuration to direct the flow of the foam was the same as in experiment 1. The obstructions in A drift were removed since the purpose of this experiment was to evaluate the efficacy of the foam to extinguish the test fires. A concrete block stopping was placed in the third crosscut to contain the foam to B drift. Because of this configuration, B drift was not ventilated. The diesel fuel fire was located in the center of the third crosscut in B drift. Five gallons of diesel fuel was floated on a 1-in water layer in a 3 ft by 3ft square metal tray. This fire was ignited just prior to the arrival of the foam front. The size of fire was approximately 600 kW. The deep-seated coal fire was placed just up dip of the diesel fuel fire in the center of the mine entry. To create the coal fire, approximately 250 lb of coal was placed on top of 25 lb of commercial cooking charcoal in a 3 ft by 3 ft square metal tray. This fire was ignited approximately 60 minutes before the foam flow was initiated. Figure 14 shows a schematic of the mine for experiment 2.

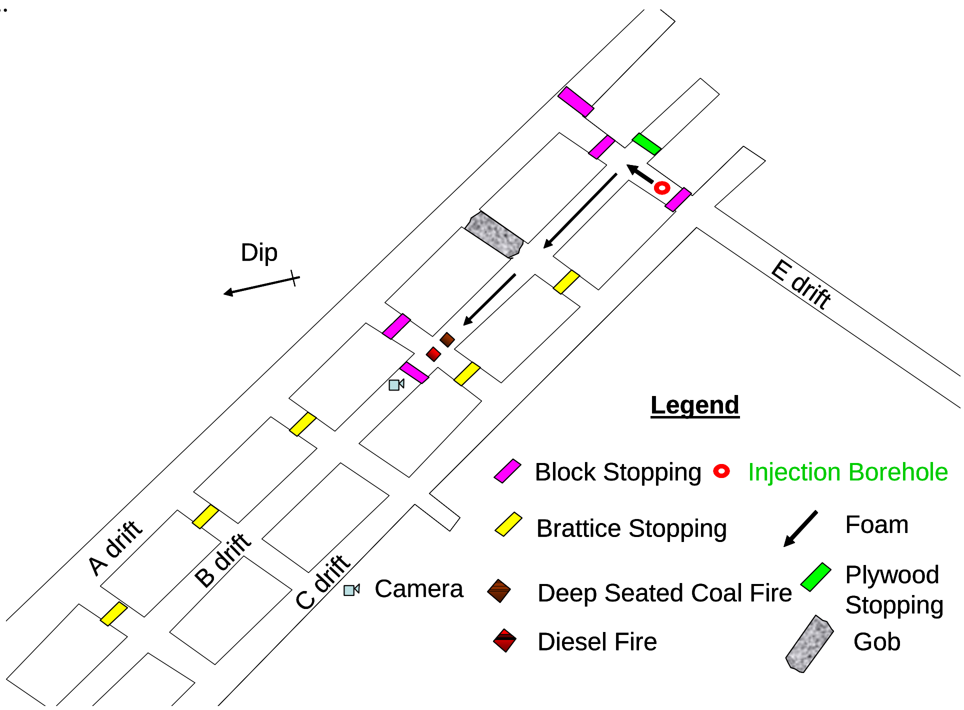

Figure 14. Schematic of Lake Lynn Mine experimental setup for second foam experiment.

The diesel fuel fire was monitored by two thermocouples located 4 inches above the fuel layer. The coal fire was monitored by seven thermocouples located throughout the coal pile. Both fuel and coal trays were also monitored by a thermal imaging infrared camera that enabled researchers to remotely view the fire through the foam.

Figure 15 shows the temperature-time trace for the thermocouples located above the diesel fuel tray fire. The fire was ignited and allowed to burn for 10 minutes before the foam reached the fire. Temperatures of about 800 ºC were recorded 4 inches above the fuel layer. The foam reached the fire at 10:51 a.m. and easily enveloped the fuel tray and extinguished the fire.

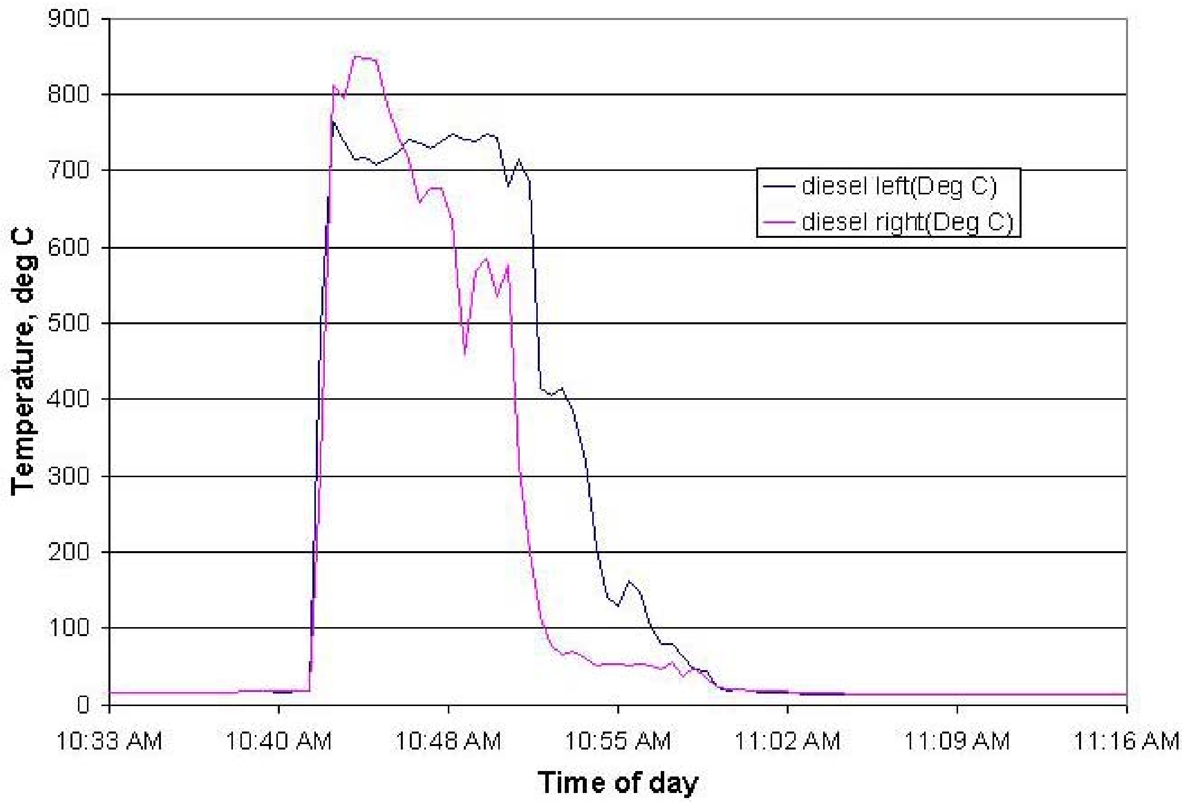

Figure 15. Temperature-time traces for thermocouples located above the diesel fuel fire.

Figure 16 shows the temperature-time plot for the thermocouples located in the coal fire tray. This fire was ignited one hour before the foam injection. Temperatures near the top of the coal pile reached about 850º and 625 º C. Other areas of the coal pile were between 100º and 250º C, with the exception of two on the outer edge of the coal pile which only reached about 50º C. The foam reached and enveloped the coal fire tray at 10:51 am, quickly cooling the hot spots. Temperatures deeper inside the coal pile slowly decreased over the next hour.

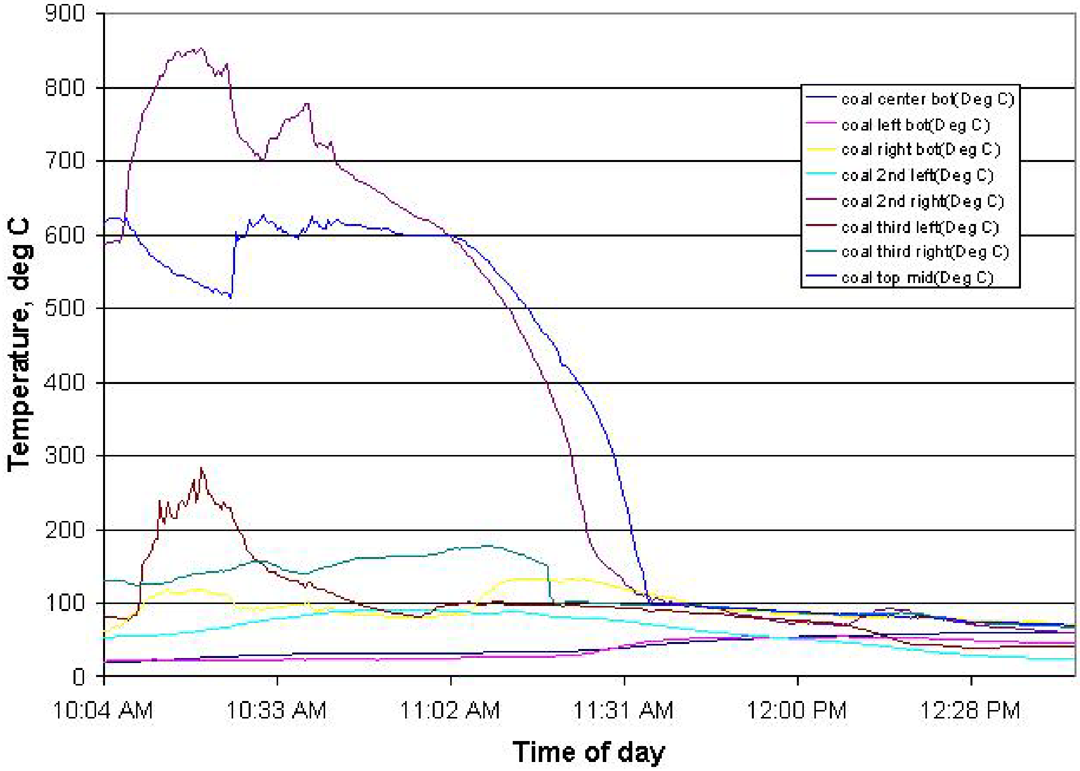

Figure 16. Temperature-time trace for thermocouples located in the coal pile fire.

In addition to direct temperature measurements, an infrared camera was used to thermally image the fuel and the space above the coal tray. Figure 17 shows a photograph of the thermal imaging of the coal fire shortly after the foam reached the fire. The space above the fire tray was reduced to about 15º C. The foam temperature downstream from the fuel tray is above the ambient temperature of the foam, as indicated by the thermal imaging camera, showing that the foam is carrying heat away from the fire. At the same time, the maximum temperature in the coal pile, as measured by the thermocouples, was about 90º C. This indicates that the foam can quickly be used to cool the airspace near a deep-seated fire, reducing the chance for spreading the fire. In addition, the use of nitrogen as the carrier gas reduces the oxygen concentration in the airspace, reducing the chance of a methane ignition.

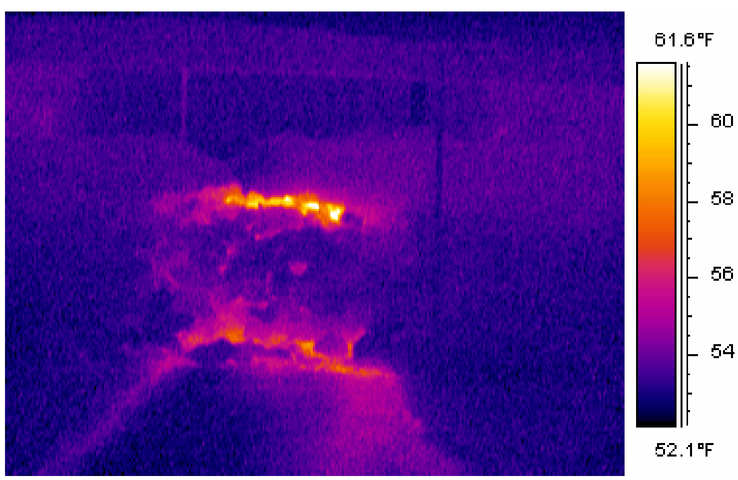

Figure 17. Thermal imaging camera view of foam moving over the coal fire.

In this experiment, the foam reached the roof in B drift because of the configuration, which essentially closed off B drift. In this confined experiment, foam was observed coming through the top of the rock pile in the second crosscut between A and B drifts.

EXPERIMENT 3

The third experiment was designed to evaluate the ability of the foam to fill a single mine entry. The 500 ft long E drift in the LLEM was used for this experiment. A schematic of the LLEM setup is shown in figure 18. In this experiment, concrete stoppings were constructed in the crosscut between B and C drift and in C drift to isolate E drift, creating a single entry. Several blocks were removed from the first course of blocks in these stoppings to allow water to flow away since any water from the degradation of the foam would flow and pool in the area, possibly causing the block structure to fail. The foam exited the borehole at the roof and filled the entry towards D drift. The slope of E drift is much more severe than in the multiple entry section of the mine, 6.2 percent up dip. A longwall shearer machine is located near the upper end of E drift and was utilized to evaluate the foam's ability to move around the obstruction.

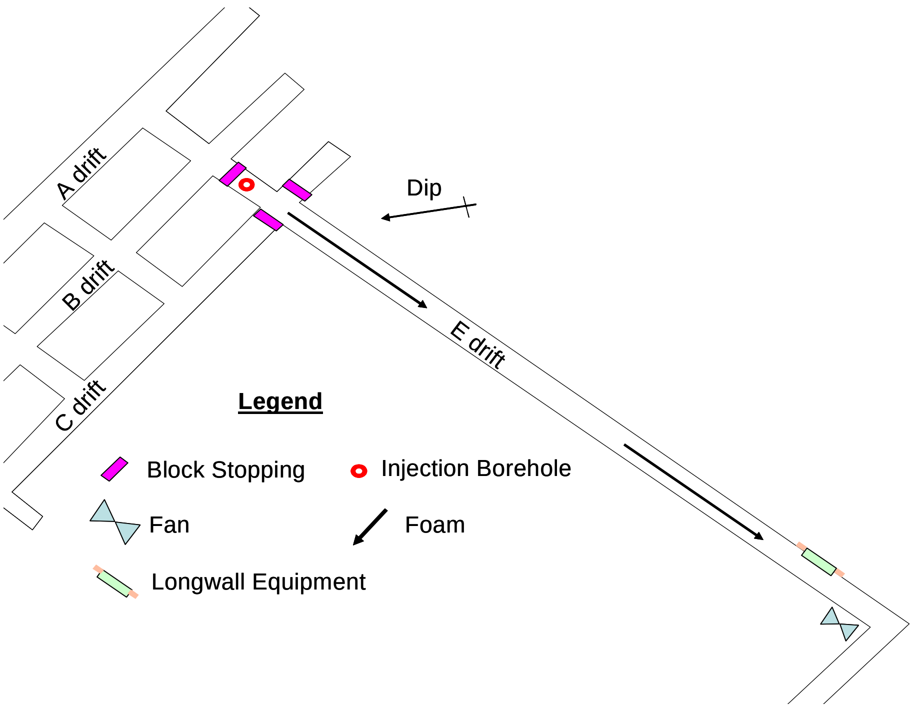

Figure 18. Schematic of Lake Lynn Experimental Mine setup for third experiment.

The foam was delivered through the borehole and began moving up the entry. The foam roofed quickly because of the slope of the entry and the rate of up dip movement. The rate of advance of the foam plug, as measured by the toe of the foam, was constant at 1.5 ft/min once the foam roofed and began moving up the entry. Over the first 50 minutes, the foam had not yet reached the roof since it was filling the first crosscut at the intersection of C and E drift. The pressure exerted on the concrete stoppings was approximately equal to the foam density. This is an important engineering design parameter that needs to be considered when using foam and how it will react to obstructions in the mine entry. Figure 19 shows the length of the foam plug versus time.

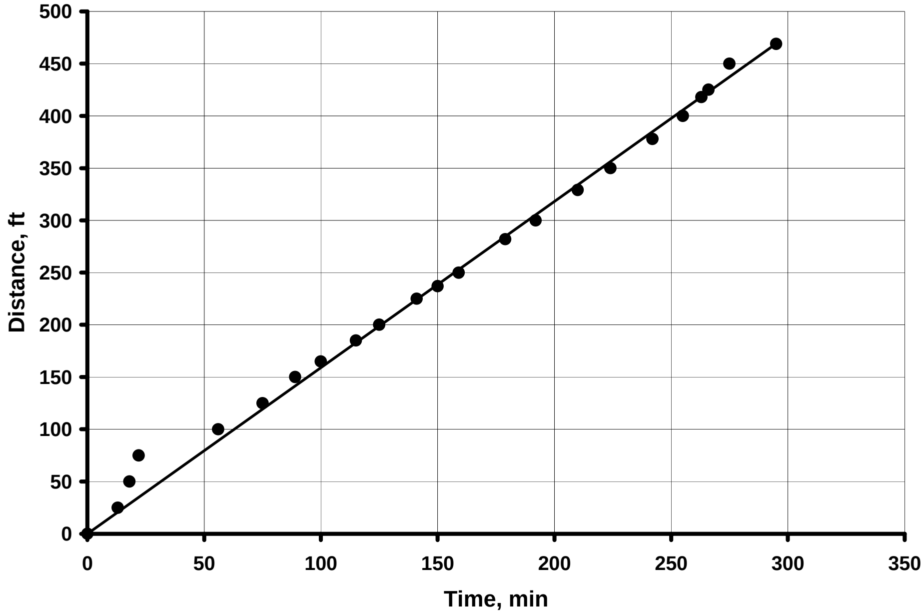

Figure 19. Foam advancement versus time in E drift.

Figure 20 shows a photograph of the foam plug when it was approximately 50 feet from the borehole. Notice that the plug had roofed quickly, unlike the behavior of the foam in B drift where the foam was flowing down dip.

Figure 20. Researcher measuring the height of the foam plug in E drift.

The foam filled the entire length of E drift in five hours. The experiment was stopped when the foam reached the fan shaft at the end of E drift to prevent disruption of the ventilation system. The rate of foam dissipation was measured over the next seven days, and is shown in figure 21. At the time the foam injection was stopped, the foam length was 469 ft. The plug decayed over the next seven days. Initially, the foam was quite stable, decaying at a rate of only about 5 ft/day (650 ft^3/day) after the first day. The rate eventually increased to about 45 ft/day (5,850 ft^3/day) at seven days. The rate of decay over the first three days is comparable to the results from the stability test conducted earlier in the A drift stub. The rapid increase in decay rate after three days is possible attributed air pathways developing over the top of the foam plug as the foam degraded allowing airflow to pass over the foam. This likely increased the rate of dehydration of the foam.

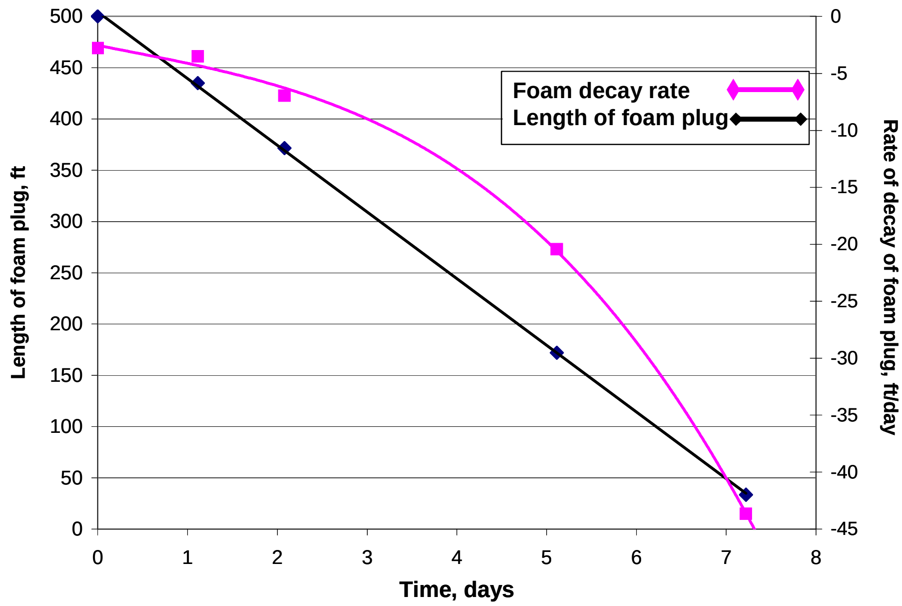

Figure 21. Length of foam plug and rate of decay over time.

SUMMARY

The foam experiments were very successful in evaluating many of the parameters that can affect the use of foam for remotely fighting mine fires. However, these experiments were also limited in their scope with respect to the type of foam used, the geometry and slope of the mine entries, and the size and types of fires. Therefore, these results should be used as guidelines for the use of foam, and not as design specifications for its use.

The foam used in the stability test during experiment 1 showed good stability over time. Foam stability is a function of the concentration of foam concentrate in the water flow, the water flow volume, and the gas flow volume, so stability parameters can be varied based on the particular application. In addition, the life of the foam can be dependent on the mine temperature and wetness or dryness of the environment, water hardness, and pH. These parameters were not varied in this experiment. This experiment also showed that the foam stability can be managed from the surface with a good degree of accuracy. However, periodic monitoring of the foam consistency on the surface is recommended to ensure stable foam is entering the mine.

The foam flow movement, speed, and ability to reach the roof and fill the entire cross-section of the mine entry was shown to be highly dependent on the slope of the mine floor. In the first two experiments, the foam flowed quickly and did not reach the roof of the mine until it was obstructed by the crib blocks. In the third experiment, the foam roofed very quickly because of the upslope of the mine floor and the obstructions that did not permit down dip flow, but the rate of advancement of the foam front was much slower than in the two early experiments. In confined applications where the objective is to flow the foam from the bottom of the borehole to a fire location some distance from the borehole, this parameter is extremely important. In a situation where the location elevation of the fire is below the foam entry point into the mine, the foam will flow quickly, but an obstruction such as a remote seal, will be critical to allow the foam to completely fill the mine entry void from floor to roof. In situations where the foam will need to be pushed up an entry, it will be critical to get the location of the foam injection as close to the fire as possible, and an obstruction or obstructions down dip from the foam injection point will be critical to get the foam to flow up the entry. Again, the use of remotely installed seals could be necessary. In situations where the mine entry is level, the foam should flow in both directions away from the injection borehole, but the flow will be highly dependent on obstructions. Unfortunately, this scenario was not able to be demonstrated at the Lake Lynn Experimental Mine.

The nonlinear configuration used in the first two experiments demonstrated that the foam will flow around corners, but again the major influence on its effectiveness was elevation and obstructions. In the first two experiments, the foam flowed past the rock rubble pile in the second crosscut between A and B drift, essentially treating it as a stopping. The stopping in B drift acted to turn the foam into the crosscut between A and B drift. However, when the foam reached A drift, which was open in both directions, the foam only flowed in the sloping direction.

The ability of the foam to suppress a liquid pool fire was shown in the second experiment. However, the foam's ability to reach and cool a hot, deep-seated fire was not able to be adequately addressed in these experiments. The foam was able to infiltrate the rock pile and quickly cool the heating elements in the second experiment, but the temperatures were not high enough to truly test the foam's cooling ability. The foam did cool the high temperatures in the coal fire, but this was a relatively small fire. The foam's inability to penetrate through the rock pile in the first experiment was noted. In the second experiment, the foam moved through the rock pile near the roof when confined to the B drift. This indicates that the compaction of a gob and other possible pathways will determine the foam's ability to infiltrate and penetrate gob material.

ACKNOWLEDGMENTS

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REFERENCES

Banerjee, S. C. and A. K. Acharya. High Expansion Foam – Its Use In Mine Fire. J. Mines, Metals, & Fuels. Oct. 1986, pp. 448 – 451.

Brack, M, D. Bublitz, S. Crosley, K. Farmer, L. Wallace, and T. Wiggins. The Pros and Cons of Class A Foam. Fire Engineering, Jul. 1992, pp. 59 – 66.

Colletti, D. J. Class A Foam For Structure Firefighting. Fire Engineering, Jul. 1992, pp. 47 – 57.

Conti, R. S. Inflatable Partitions For High-Expansion Foam Generators. J. Mining Eng. June, 1995, pp. 561 – 566.
Conti, R. S. and E. S. Weiss. Inflatable Devices For Combating Underground Mine Fires. Proc. Minesafe International 1998, Sept. 28, 1998, pp. 388 – 393.

Grady, C. Compressed Air Foam – An Idea Whose Time Has Come. American Fire Journal, Jan. 1994, 4 pp.

Hartmann, I, J. Nagy, R. W. Barnes, and E. M. Murphy. Studies With High-Expansion Foams For Controlling Experimental Coal Mine Fires. Bureau of Mines Progress Report, Aug. 1958, 17 pp.

Komai, T., T. Isei, N. Shikada, M. Kinoshita, T. Suzuki, L. Zong-cheng, H. Guang-yang, F. Yun-guang, and X. De-chang. Underground Fire Extinguishing by the Combined System of Inert Gas Generator and Foam Generator. Shigen, National Research Institute for Pollution and Resources, 1989, pg. 32.

Nagy, J., E. M. Murphy, and D. W. Mitchell. Controlling Mine Fires With High-Expansion Foam. Bureau of Mines Report of Investigations 5632. 1960, 28 pp.

Omans, L. P. Fighting Flammable Liquid Fires, A Primer, Part 1: The Family of Foams. Fire Engineering, Jan. 1993, pp. 50 – 61.

Omans, L. P. Fighting Flammable Liquid Fires, A Primer, Part 2. Fire Engineering, Feb. 1993, pp. 50 – 58.

Omans, L. P. Fighting Flammable Liquid Fires, A Primer, Part : Fire Engineering, Mar. 1993, pp. 93 - 104.

Scott, F. E. and J. Nagy. Fighting Fires With High-Expansion Foam. Coal Mining and Processing, June, 1968, pp. 42 – 45.

Voracek, V. Necessary Data on High-Pressure Foam Generator of a Nitrogen Foam For Its Utilization In the Field of Both Prevention and Suppression of Spontaneous Combustion of Coal In Caved Areas of Longwall Faces. Research Mining Institute, Inc. CZ-716 07, Ostrava – Radvanice, Czech Republic. 13 pp.