

EVALUATION OF A NOVEL FIRE BLOCKING GEL TO PREVENT AND SUPPRESS MINE FIRES

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Abstract

The National Institute for Occupational Safety and Health (NIOSH) and Northwest Barricade LLC (NWB) conducted a study to evaluate the effectiveness of a novel fire blocking gel for use in underground coal mines to extinguish or to retard the growth of a coal fire. The gel agent was subjected to controlled laboratory testing to assess its ability to delay coal ignition. It was then evaluated to determine if manual fire hose application could be used to apply the agent to mine roofs and ribs to provide a safe egress for mine rescue teams from a fire area. The gel agent was also evaluated in a water sprinkler system to determine its potential for use in conveyor belt fire suppression systems. The agent was then tested in live-fire exercises to examine its effectiveness in retarding and extinguishing a deep-seated coal fire and wood fire. Lastly, the ability of a Mine Rescue Team to quickly and safely apply the gel agent to a mine entry during a simulated mine fire exercise was determined.

Barricade II Fire Blocking Gel Description

Barricade II¹ is a fire prevention, retardant, and firefighting substance initially designed to protect residential and other structures from wildfires. The product is non-toxic and biodegradable, according to its Material Safety Data Sheet, using only a safe, superabsorbent polymer and food grade components in the formulation.

Since its initial development, Barricade II has been found to be equally effective in protecting structures and in extinguishing fires, including but not limited to magnesium, gasoline and diesel fuel, wood, tires and trees. Barricade II, when injected into water at very low percentages (2.0 to 3.0 pct), forms a gel coating that provides thermal protection to structures, vehicles, fuel tanks, or any other object when exposed to a fire. It is specially formulated to adhere to vertical, horizontal and inverted surfaces such as walls, glass, metal, fiberglass, and wood. Barricade II produces a virtually instantaneous gel when mixed with water through a shear device such as an eductor fire nozzle, eduction into a water stream, or batch mixing. The gel/water stream from a nozzle is applied directly to the surface to be protected. The viscosity of the gel/water mixture can be controlled by changing the mix ratio of the gel in water at the eduction or mix point. Different concentrations and viscosities can be produced depending upon the particular fire retardant, suppressant or extinguishing application needs. For example, for application and adherence to horizontal, sloping or vertical surfaces, or to the underside of horizontal surfaces, the concentration will range from 2.0 to 3.0 pct. A lower concentration of Barricade II in water results in a thinner coating that will flow around and under surfaces such as on trees, bushes and plants. This is particularly advantageous in enhancing the effectiveness of firebreaks and for aerial application during wildfire. For these applications, mix ratios range from 1.0 to 2.0 pct.

Barricade II is produced by dispersing a superabsorbent polymer in vegetable cooking oil with food grade stabilizer and thickener. The dispersion is composed of a dry, cross-linked polymer of at least one hydrophilic monomer dispersed in vegetable oil. The polymer is a copolymer of acrylamide and acrylic acid derivatives (e.g.,

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an acrylate salt). The polymer may also be a terpolymer of an acrylate salt, acrylamide, and 2-acrylamido-2-methylpropanesulfonic acid (AMPS) salt. The polymer particles resulting from the polymerization are generally ground to less than about 74 microns in size, usually with 70 pct of the particles being less than 37 microns in size. However, polymer particles having a size ranging from about 10 microns to about 200 microns may be used. A low hydrophile-lipophile balance (HLB) surfactant is used to aid in the dispersion of the dry polymer particles in the vegetable oil. A particularly suitable low HLB surfactant is sorbitan monooleate, used in chocolate production. A suspending agent, fumed silica, is used to provide stability and flowability to the dispersion. This allows the dispersion to be introduced to the water supply in a liquid form.

The gel is formed after the dispersion is added to the fire-fighting water. Gel formation generally occurs in about three seconds or less. The gel has a viscosity ranging from 100 cps to 50,000 cps. The polymer particles in Barricade II absorb significant quantities of water in relation to their size and weight. The protective gel consisting of water-laden polymer particles evaporates less quickly than plain water. After several hours or several days, the outermost layers of drying gel can be replenished by misting with water.

The information provided in this paper is from research conducted under Centers for Disease Control (CDC), National Institute for Occupational Safety and Health (NIOSH) Contract #HHSD200200824618C, Technical Solutions for Enhancements to Mine Safety Using Barricade II Fire Blocking Gel. Northwest Barricade LLC, in association with Barricade International, Inc., and Safety Solutions International, Inc., completed the work between April 2008 and October 2008. CONSOL Energy, Inc. provided assistance in the laboratory coal ignition testing and provided experienced mine rescue team members to participate in the testing at their Robinson Run Mine and the NIOSH Lake Lynn Fire Suppression Facility. The purpose of this contract was to conduct tests of this product only. There may be other fire-fighting products (gels, foams, etc.) available that might produce similar results using similar test methods.

Experimental Results

Laboratory Coal Ignition Testing

Laboratory tests were conducted at the CONSOL Energy, Inc. R&D test facility in South Park, PA to determine the effect of treating coal with the Barricade II gel on the time to evaporate water from the coal sample, delaying the eventual ignition of the coal. Also, the effect of water to gel ratio on this time value was evaluated. Minus 60-mesh Pittsburgh Seam coal was used in all of the laboratory ignition tests. The as-received moisture content

of the coal ranged from 12-15 percent. Tests were conducted on coal samples treated with Barricade II gel in percentages by volume of 0.5, 1.0, 1.5, 2.0, 2.5, and 3 pct in water. Tests were also conducted on untreated coal and coal mixed with water as control samples. To make the coal/Barricade II samples, 7.5 g of the coal and 7.5 g of Barricade II at the various water/concentrate ratios were weighed by electronic scale and then hand-mixed for several minutes until visually homogeneous. The coal/Barricade II test samples were mixed at the Barricade International laboratory in Hobe Sound, Florida and sent to the CONSOL Energy, Inc. laboratory in South Park, PA.

The ignition tests were conducted on 1-gram samples of the coal and coal/Barricade II mixtures in a LECO TGA 701 ThermoGravimetric Analyzer² (TGA). The TGA controls the temperature and rate of temperature increase of the furnace containing the coal sample by the rates programmed by the laboratory chemist. The temperature of the furnace was raised to 107 °C and allowed to remain at that constant temperature until the weights of the crucible contents reached stability from moisture loss. The furnace temperature was then increased at a rate of 40 °C/min until it reached 750 °C and then held at that temperature until the sample was completely ashed.

The untreated coal sample and the coal/water mixture reached a constant weight, indicating complete drying of the samples, at 107 °C in 33 minutes. The drying time for the Barricade II treated samples increased with increasing amount of Barricade II gel, ranging from 50 minutes for the 0.5 pct mixture to 78 minutes for the 3.0 percent mixture. The results show that the samples treated with Barricade II significantly slowed moisture loss compared to the coal-only and coal-water only control samples. The longer time required for moisture loss in turn delays coal ignition. This test demonstrates what is experienced in practice when the Barricade II concentrate-water mix is applied to combustible materials. The Barricade II protects the material from impinging fire by coating the material with enough water to delay or prevent combustion for periods of time directly proportional to the volumetric ratio of Barricade II to water. The furnace test also shows that Barricade II's effectiveness as a fire retardant increases as the amount of concentrate increases.

Manual Applications of Barricade II Gel on Coal

Barricade II is used in above ground applications as a fire retardant or fire stop to protect residential structures and other combustible materials. It is hypothesized that the

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application of the gel to the roof and ribs of a mine entry or conveyor belt could retard or stop a propagating coal or belt fire, providing valuable time for miners to fight the fire or escape, if necessary. However, since the product is specifically formulated for above ground applications, tests are needed to determine if the gel will adhere to coal mine surfaces, particularly rock-dusted surfaces, to determine the optimum application methods, and the durability and stability of the product when applied. Tests were conducted at CONSOL Energy's Robinson Run Mine and in the NIOSH Bruceton Safety Research Coal Mine. The objectives of the tests were to determine appropriate manual application techniques to apply the product to the ribs, roof, floor, and conveyor belt, and the product's adherence and stability when applied. Factors evaluated included the gel/water mixture ratio, ventilation, nozzle type, and application method.

CONSOL Energy's Robinson Run Mine test

The first test was conducted in a conveyor belt entry at the CONSOL Energy, Inc. Robinson Run Mine in West Virginia. The measured air volume in the belt entry was 25,725 cfm. The estimated air temperature was 55 °F. The first application of Barricade II occurred in the belt entry through 100 feet of standard 2 inch fire hose with a water pressure of 240 psi. The nozzle used was a Gel Pro-30³ manufactured by Cordova, Inc., specifically designed for education of Barricade II gel, shown in figure 1.

The nozzle is modified to educt and mix Aqueous Firefighting Gel, Class A and B foams or wetting agents. The variable ratio eductor allows three different mix settings (1 pct, 3 pct and 6 pct, depending upon the viscosity). The eductor is calibrated for 30 gal/min at 100 psi and can operate in the pressure range of 70 to 150 psi. Eduction nozzles such as the Gel-Pro 30 work on the venturi principle with an attached vacuum chamber. There are two orifices that the gel concentrate moves through. There is an orifice in the body of the nozzle at the venturi and one in the vacuum chamber that also includes a spring valve to prevent potential back pressure from forcing water back into the gel concentrate container. These two orifices must be sized appropriately to allow for the maximum flow rate and pressure.



Figure 1. Gel Pro-30 nozzle.

In the initial test, the Barricade II was educted from a 4 gal bucket through 5/8-in hose into the eduction nozzle. In general, the concentration of Barricade II desired for adherence to vertical and inverted surfaces is approximately 3 pct. In this case, due to the high pressure through the fire hose, 240 psi, water volumes flowing through the eductor nozzle were significantly higher than is normally seen with the standard application pressures of 100 psi or less. It was determined from video footage of the Barricade II application that the concentration of Barricade II was between 1 and 2 pct. The total Barricade II concentrate used was 3 gallons. Assuming a 30 gallons/minute flow rate through the Gel-Pro 30 nozzle, 165 gallons of water were mixed with 3 gallons of Barricade II. This is a concentration of 1.8 pct had the water pressure been 100 psi. Because of the high pressures, however, it is reasonable to assume a lower concentration was applied during the test. As a result of the lower than expected concentration, the Barricade II/water solution from the nozzle did not have optimum adherence to the mine surfaces.

After making some adjustments, the pressure was reduced to 170 psi. While still exceeding the desired maximum pressure for optimum Barricade II application, and using the same nozzle, Barricade II was applied to the roof, rib and belting. In the area of the test, rock dust had been applied and was approximately 0.5 cm thick. Excellent adherence to the rock-dusted rib and roof was observed. In a few small places, the rock dust with applied Barricade II "sloughed" from the rib due to the thickness of the applied gel. The belt entry ventilation had no effect on the application. Based on these observations it was the opinion of those present at the test site and, from the project team's experience in other high wind surface applications, that the ventilation velocity in the track entry would have no impact on the application of gel in entries with higher ventilation flows. Observations confirmed that, consistent with standard use and application methods, a wide spray pattern is better for effective and efficient application of the

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gel/water mix. The narrow spray pattern tended to strike the surface with too much force to allow the Barricade II to adhere effectively. The wide stream application allowed the miner applying the gel to better “lay” the gel onto the surfaces.

Based on the tests performed at CONSOL’s Robinson Run Mine the following can be concluded about the adherence and use of Barricade II in an underground coal mine application:

- Barricade II, when applied at high water pressures (> 150 psi) has an adherence capability that is less effective than it would be at lower water pressures (<150 psi).
- Barricade II adheres effectively to the roof, rib, belting, and to rock dusted surfaces that are present in underground coal mines.
- The application of Barricade II is best when applied with a wide nozzle spray pattern and is less effective when the spray pattern is narrow.
- After the application of gel, even at the higher water pressures, hydration occurs and the gel coating expands in thickness and becomes more visible and prominent on mine and mine equipment surfaces.

Bruceton Safety Research Coal Mine test

The next test was conducted in the NIOSH Safety Research Coal Mine at Bruceton, Pennsylvania. The objective of this test was to apply the gel to a larger area in the mine simulating the application by a mine rescue team to retard the propagation of a coal fire. Another objective of this test was to monitor the stability and duration of the gel. During a pre-test visit, the area of application, water system, and fire hose were inspected, temperature and humidity readings were taken, and a test application was performed with a 30 gal/min Gel-Pro education nozzle, and a 15 gal/min Quik Atak education nozzle. The pre-test application was conducted by Barricade personnel on a rib in an area adjacent to that selected for the actual test. It was determined that the 30 gpm nozzle provided the best method of application for this test.

The test application was conducted by a CONSOL Energy, Inc. mine rescue team. The team was given the option of using a 4 gallon container in a backpack, or using the 4 gallon container to be carried behind the nozzle man by a hose man. The team decided to have the hose man carry the bucket and be responsible for renewing buckets as needed during the application. The ambient air temperature during the application was 62°F and the relative humidity was 70 pct. Airflow was not measured but was perceptible. The water was delivered at 100 psi through a standard 1½-in fire hose attached to a 2-in water line. The entry height was six feet and the width varied from 13 to 18 feet. The gel was applied to the roof and ribs of a 60-ft-long section of the entry as the team advanced in the entry. During the advance, the hose man had to supply one additional 4-

gallon bucket of Barricade II concentrate. The advance application took 5.2 min. Total spray time as determined from the video was 4.3 min. Bucket change-over took 52 s. The team examined the roof, ribs and face for application consistency and decided that no additional application was necessary. The amount of Barricade II concentrate used for the application was 5.5 gallons. Total water used through the 30 gpm nozzle for the 4.33 minute application was 129 gallons, yielding an average Barricade II to water percentage of approximately 4 pct. The total square feet of application to the roof, ribs and face was 1580 ft². Figure 2 shows the roof and rib after the application test.



Figure 2. Roof and rib after gel application.

The rescue team was very satisfied with the ease and speed of application. They were also favorably impressed with the uniform ¼-inch thickness and adhesion of the application. The nozzle man stated that it only took a minute of application to understand the optimum spray pattern from the nozzle for maximum effectiveness of application. The rescue team members and Barricade personnel also observed the area of the entry that was treated during the pre-test, five days earlier. The gel was still hydrated and would be effective in retarding a fire.

The team viewed the application area 24 and 48 hours after the test application. Although some slight slippage due to gravity was observed in some areas of the application, no significant visual difference was noted, as shown in figure 3, at 48 hours. The mine foreman reported from an examination after 8 days that the gel was still wet and still had some depth. In a subsequent examination 16 days after application, it was noted that the gel was drying along the ribs but still had texture and depth on the roof.



Figure 3. Roof and rib 48 hours after gel application.

Sprinkler System Application of Barricade II Gel on Conveyor Belting

Tests were conducted at the Lake Lynn Fire Suppression Facility (FSF) to evaluate the application of Barricade II through a typical mine sprinkler system installed along a belt drive and belting material. The sprinkler system at the FSF uses fusible link sprinkler heads rated for 68°C. The water supply system delivers water to the sprinkler heads through 1½-inch branch lines tapped into a main 4-inch water line. Each sprinkler head delivers 60 gal/min at 175 psi. Each 1½-inch branch line services 2 sprinkler heads; a sprinkler head above the top belt and a sprinkler head between the top and bottom belt. The sprinkler system is designed and installed in accordance with Federal regulations for use in underground coal mines. To determine the adequacy of water/gel mixture flow through the system, the piping was configured to isolate one of the branch water lines and the two corresponding sprinkler heads located above the top belt and between the top and bottom belt. The fusible links were removed from the sprinkler heads to allow for immediate flow upon water introduction. The Barricade II gel concentrate was introduced into the water flow using an eductor, shown in figure 4, rated at 120 gal/min. Two tests were completed. In the first test, one gallon of Barricade II was allowed to enter the system when the water supply was turned on. The second test was timed and took 30 s to educt 1½ gal of Barricade II into the water flow. Figure 5 shows the Barricade II/water spray flowing from the top sprinkler head during the second test.



Figure 4. Eductor in 1-1/2 in water line.



Figure 5. Second water/Barricade II sprinkler flow test.

The results of the sprinkler system application of Barricade II gel on the conveyor belting, shown in figure 6 after the second flow test on the top belt surface, indicates that the introduction of Barricade II into a main water line and sprinkler system in a concentration that would both flow throughout the system and be in a concentration to be effective in firefighting is feasible. The gel coating on the belt surface showed uniform thickness and consistency, equivalent to a coating applied through the end of a fire hose. Based on the sprinkler system application results and previous unreported tests conducted in above-ground experiments on the application and extinguishment of rubber tire fires, it is evident that the introduction of Barricade II into the sprinkler system to extinguish a belt fire should yield the same effective results as was found by using gel through the end of a fire hose.



Figure 6. Barricade II coating on top conveyor belt after sprinkler application test

Coal Fire Extinguishment Tests

To determine the effectiveness of Barricade II in extinguishing a coal fire, two large-scale tests were conducted in the Lake Lynn FSF. In the first test, the coal fire was extinguished by NIOSH and Barricade personnel. In the second test, the extinguishment was by an experienced CONSOL mine rescue team.

Test 1

In the first test, a 12-inch-deep layer of minus 2-inch Pittsburgh seam coal was spread evenly in a steel mesh box, 3-ft-wide by 6-ft-long, shown in figure 7.



Figure 7. Test 1 coal fire configuration.

The coalbed was raised approximately 9 in from the floor to allow ventilation from all sides of the coalbed. Six thermocouples were placed through the side of the box extending to the center of the coal, 6 inches from the bottom of the coal. A thermocouple was placed 6 inches from the fire initiation point on the upstream side of the ventilating current and each subsequent thermocouple was spaced at 1-foot intervals. The fire was ignited by placing a methane burner at the upstream end of the coalbed. The

methane burner was turned off at 90 min when the coalbed was able to sustain the fire. Ventilation in the FSF was maintained at 300 ft/min. Fire temperature data from the thermocouples was recorded throughout the burn process.

The fire was allowed to burn for 23 hours. During that time, the fire propagated through the coalbed, so that the entire coalbed was on fire at time of extinguishment. Barricade II was educted into the fire hose at a 3.0 pct concentration at the hose nozzle. The gel concentrate was applied through the same eduction nozzle used in the in-mine application experiments. The person extinguishing the fire carried a 4 gallon supply of the Barricade II gel concentrate in a back-pack system. After 23 seconds of application, the coal fire was suppressed and cooled to a point that re-ignition did not occur. Water vapor was readily visible, but coal smoke was significantly suppressed. The team member extinguishing the fire noted that yellow fumes were emitted during the suppression process, but there was no re-ignition of the fire. It was also noted by the team that, except for nozzle overspray, there was virtually no gel or water directly below the fire box. This indicates that the mixture was adhering to the coal. It was observed that Barricade II application also had an “encapsulating effect” on the coalbed, shown in figure 8.



Figure 8. Coalbed after Barricade II/water mixture application.

Test 2

The second coal fire test was conducted to evaluate the use of the Barricade II gel concentrate applied by an actual mine rescue team. In this test, a 12-inch-deep layer of minus 2-inch Pittsburgh seam coal was spread evenly in a 6-ft-long by 3-ft wide solid steel trough. The fire was ignited with accelerant and wood pallets to obtain fast involvement. CONSOL Energy, Inc. provided experienced mine rescue team members to participate in the testing at Lake Lynn. Figure 9 shows the coal fire just prior to extinguishment.



Figure 9. Coal fire just prior to extinguishment by mine rescue team.

After a brief training exercise on the proper use of Barricade II application through end-of-hose education, the CONSOL team extinguished the fire. The CONSOL team used a standard 1½-in fire hose with the Gel-Pro 30 education nozzle. The water pressure was 125 psi and the Barricade II/water concentration used was 4 pct. The fire was extinguished in 70 seconds. A hand-held temperature probe was used immediately after the test and showed temperatures in the coalbed ranging from 75 - 100 °C. Figures 10 and 11 show the team approaching the coal fire and applying the gel/water mixture. Figure 12 shows the coal bed immediately after extinguishment.



Figure 10. Mine rescue team approaching coal fire.



Figure 11. Mine rescue team extinguishing the coal fire.



Figure 12. Coal bed just after extinguishment.

Coal Fire Retardant Test

A primary use of Barricade II in above-ground applications is as a coating to protect combustibles from fire. For example, it is often applied to residential structures in the path of forest or wild fires. Tests were conducted to determine the retardant capability of Barricade II in a coal fire. A test was designed and conducted to compare coal treated with Barricade II to untreated coal exposed to fire. A 15-in-deep by 3-ft-wide by 15-in-long layer of minus 2-inch Pittsburgh seam coal was placed in the upwind side of the 3-ft wide by 6-ft-long box wire-mesh box that was used in the first burn test. A 15-in-deep by 18-in-wide layer of coal was placed on one side of the remaining 4.75 ft box and a similar layer of coal coated with a 3 pct mixture of Barricade II was placed on the other side of the box. The gel was applied by spreading the coal on the floor and applying the agent to the coal prior to being loaded into the test box. Thermocouples were placed in the coalbed, 9 inches from the sides of the box in the middle of the coal layer at 1 ft intervals beginning at 6 inches from the upwind side of the box. Figure 13 shows the treated and untreated coal in the box prior to ignition.

Figure 14 shows a top view of the location of the thermocouples. The area shaded in blue is the coal treated with the 3 pct mixture of Barricade II.



Figure 13. Coalbed prior to ignition.

T7	T8	T9	T10	T11	T12
Thermocouple Locations					
T1	T2	T3	T4	T5	T6

Figure 14. Top view of thermocouple locations in coalbed.

A methane gas burner was placed at the upwind side of the box for 90 minutes to ignite the coal fire. Air velocity in the FSF throughout the test period averaged 450 ft/min. The coal was allowed to burn to completion (approximately 130 hours). Temperature readings were also taken with a handheld thermocouple probe near the in-place thermocouples at various times throughout the test. Figure 15 shows the temperatures in the coalbed 18 hours into test.

As can be seen in figure 15, the untreated side had higher temperatures than did the Barricade II treated side.

66	300	145	30	28	40
Treated Coal with Barricade II					
110	490	350	38	41	38
Untreated Coal					
52	415	160	97	40	40

Figure 15. Temperatures in the coalbed at 18 hours.

Figures 16 and 17 show the temperature-traces of the thermocouples in the treated and untreated coal. In figure 14, thermocouples T1 through T6 were in untreated coal. In figure 15, thermocouple T7, although on the “treated” side, was placed in the first 15 inches of untreated coal. Thermocouples T8 through T12 were in Barricade II-treated coal. The temperature-time plots show two effects of the gel treatment, an insulating effect and a time delay effect. The rate of temperature rise at the thermocouples in the treated side was actually greater. The untreated side shows a gradual increase in temperature, indicating that the fire front had a steady advance through the coalbed typical of coal fires. This indicates that there was an insulation effect that was gradually diminished due to encroaching fire cooking off the gel treatment at which time the temperature rapidly increased. This insulation effect resulted in a delay in the treated coalbed reaching its maximum temperature compared to the untreated coal. For example, T3 begins to increase at 14:42 compared to T9 at 17:32 and T4 at 29:39 compared to T10 at 30:42. What is also important to consider when analyzing the temperature/time data is that there was no confining membrane between the treated and untreated coalbeds. Therefore, the treated coal was being encroached by the fire both from the front and untreated coalbed side.

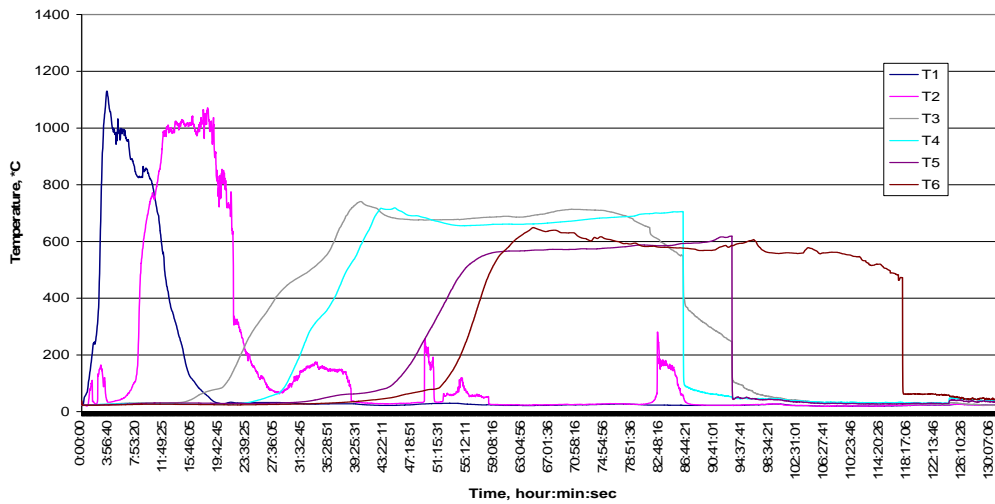


Figure 16. Temperature-time history of untreated coalbed

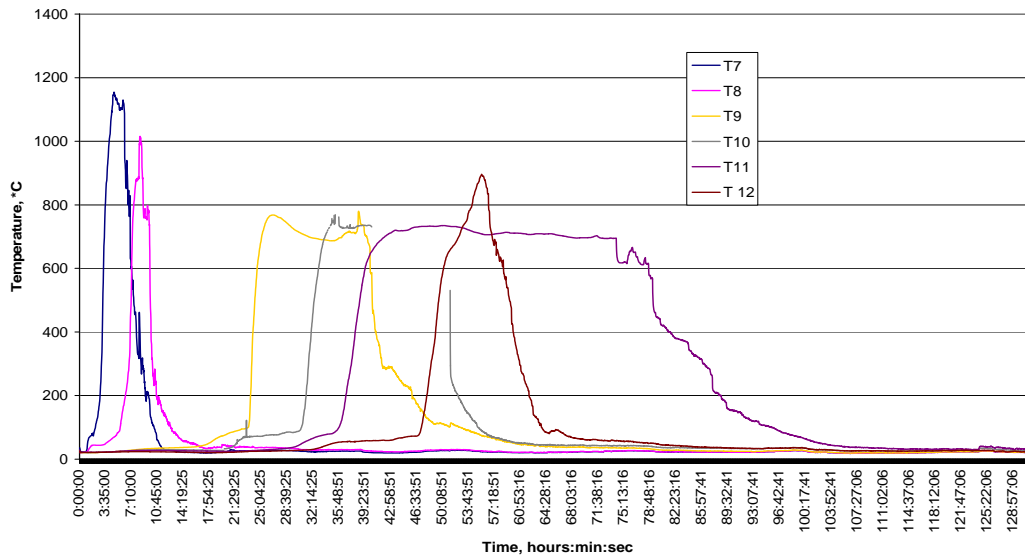


Figure 17. Temperature-time history of treated coalbed.

Wood Fire Retardant and Extinguishment Demonstration

Tests were also completed using a wood pallet fire to demonstrate both the retardant and extinguishment capabilities of Barricade II on a wood fire. Two stacks of six wood pallets each were placed over a pan that contained a 2 gallons of a fuel oil/gasoline accelerant. One stack was treated with Barricade II through a Gel-Pro 30 education nozzle at a 3 pct concentration prior to stacking. The accelerant was ignited and allowed to burn until the untreated stack was fully involved with fire. As shown in figure 18, the Barricade II treated stack was fully protected from ignition even though the accelerant flames penetrated throughout the stack.



Figure 18. Wood pallet fire test.

When the untreated pallets were fully involved in fire, the CONSOL mine rescue team members quickly extinguished the fire using a hose with a 3 pct concentration of Barricade II, shown in figure 19. From start of extinguishment to the fire being out took 28 seconds.



Figure 19. CONSOL personnel extinguishing wood pallet fire.

Conclusions

This paper describes tests conducted to evaluate the effectiveness of the Barricade II fire blocking gel under the Centers for Disease Control (CDC), National Institute for Occupational Safety and Health (NIOSH) Contract #HHSD200200824618C, Technical Solutions for Enhancements to Mine Safety Using Barricade II Fire Blocking Gel. The purpose of this contract was to conduct tests of this product only. There may be other fire-fighting products (gels, foams, etc.) available that might produce similar results using similar test methods.

Laboratory oven tests showed that the application of Barricade II to coal can delay its ignition by slowing moisture loss and subsequent temperature rise of the coal.

Barricade II can be applied quickly and effectively by a mine rescue team to large areas of ribs and roof in mine entries to potentially retard an advancing mine fire. The retarding action could provide an effective route of egress for firefighting personnel. Based on in-mine tests, the gel remained viable for several days.

Testing demonstrated that Barricade II can be used as a water replacement in a sprinkler suppression system similar to the type used in an underground coal mine belt drive installation.

Testing showed that the gel can retard a spreading coal fire when the coal is pre-treated with the gel. Barricade II can also quickly and effectively extinguish and cool a coal fire.

Barricade II can retard the spread of a highly engaged wood pallet fire to an adjacent Barricade II treated stack of wood pallets and quickly and effectively extinguish and cool a diesel fuel initiated wood fire.

Barricade II can be an effective addition to mine firefighting techniques through end-of-hose education as was demonstrated by mine rescue personnel. Application of Barricade II to the ribs and roof of an underground coal mine during a fire emergency can potentially protect fire fighting and rescue personnel's ingress and egress by retarding the spread of the fire.

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