THE USE OF CONTAINMENT BARRIERS AND FIRE FIGHTING FOAMS FOR THE EXTINGUISHMENT OF COAL WASTE BANK FIRES: A LABORATORY STUDY[1]

J. R. Jones[2], A. G. Kim[2], and A. M. Kociban[2]

Abstract: The U.S. Bureau of Mines studied the integrated use of grout barriers as a potential method to isolate and fire fighting foams to extinguish coal waste bank fires. Small scale tests were conducted in a 2.5 m^3 gravel pile utilizing a series of electric heating elements within the pile to simulate a burning coal waste bank. Testing focused initially on a polyurethane grout mixture that is relatively inexpensive, could be readily pumped through coal waste, and would reduce the permeability and porosity of the waste material effectively to contain the subsequently injected fire fighting foam mixture. The grout mixture that best satisfied these conditions was a mixture of one-third water and two-thirds polyurethane, which had an expansion ratio of about 15:1, reduced the permeability of coal waste from 50 darcys to less than 1 darcy, and the porosity from 20% to less than 1%. In small-scale heating tests, injection of a medium-density, medium-expansion foam reduced temperatures 0.5° C/min without the grout containment barrier and 0.75° C/min with the containment barrier about two hours after the respective foam injection tests.

Introduction

Burning coal waste banks can cause a variety of environmental problems in both active mine areas and abandoned mine lands. These can include the emission of noxious or toxic fumes, the potential of the fire spreading to adjacent and nonaffected areas of the waste bank or in some cases to areas outside the confines of the waste bank, and other safety hazards associated with surface fires. For subsurface mine fires, many methods have been used as a means of extinguishment, including water injection, the use of cryogenic gases and liquids, and excavation. In many cases, these extinguishment projects have been used in conjunction with some type of constructed internal barrier within the mine in order to isolate the fire as well as contain the extinguishment material within the fire zone. An effective barrier should also prevent the transfer of heat from the burning zone to the nonburning areas of the mine. The materials used to form these underground barriers have generally been cement-type grouts.

Previous research has demonstrated that induced gas flow patterns through coal waste or materials with size characteristics similar to those of wastes can be reasonably predicted (Jones and Chaiken 1990, Jones et al. 1992). Prediction of flow patterns within waste materials is essential in order to maximize the potential for successful extinguishment of fires in burning waste banks. Because these flow patterns represent the paths the heated gases will travel from the burning areas toward unburnt areas, as well as the likely route the extinguishment materials will follow during the extinguishment phase, the permeability and porosity of the waste bank material should be understood. The physical behavior of the extinguishment materials during the extinguishment process will also influence the effectiveness of heat reduction, and how well, and for how long the material can be contained at or near the burning zone.

To test a possible alternative method for the extinguishment of waste bank fires, the U.S. Bureau of Mines undertook a series of integrated bench-scale experiments using coal waste material, limestone gravel, polyurethane grout, and medium-density fire-fighting foams as testing materials to determine (1) the reduction of permeability and porosity after polyurethane grout injections, (2) the durability of the injected grout material

---

[1]Paper presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994.

[2]J. Richard Jones, Geologist, Ann G. Kim, Supervisory Research Chemist, Andrew M. Kociban, Physical Science Technician, U.S. Bureau of Mines, Pittsburgh Research Center, Pittsburgh, PA, 15236.

Proceedings America Society of Mining and Reclamation, 1994 pp 121-128

DOI: 10.21000/JASMR94040121

https://doi.org/10.21000/JASMR94040121

with respect to atmospheric weathering conditions, (3) the flow characteristics of a variety of polyurethane mixtures through the waste materials, (4) the effectiveness and flow characteristics of the medium-density, medium-expansion fire-fighting foam as an injected material in transferring heat and cooling a heated zone during an extinguishment process, and (5) estimated material costs associated with the combined use of polyurethane grout as a containment barrier and medium-density foam as the extinguishment material for field-scale testing. The results summarized in this report indicate that based on bench-scale testing, the integrated approach has potential application as a means of extinguishing burning waste bank fires.

Methods, Materials and Testing

Waste Materials

The coal waste material for this test was collected from an active coal preparation plant in western Pennsylvania. It was partially weathered. The size of the waste material was determined in the laboratory by standard methods (fig. 1). Other characteristics of the waste are presented in table 1. Permeability of the material was measured at 50 darcys within a six-sampling port 0.3 m^3 permeameter under constant- head conditions. The porosity of the material was found to average 20%. The limestone gravel used for the heated series of tests was roadbed material averaging about 5 cm across its longest (a-axis) dimension. The permeability of the gravel was about 500 darcys with a porosity of about 28%.

Table 1. Refuse characteristics

	As-received	Dry	Dry ash-free
Proximate Analysis, %:			
Moisture	2.78	--	--
Ash	67.37	69.29	--
Volatile matter	12.49	12.85	41.85
Fixed carbon	17.36	17.86	58.15
Ultimate Analysis, %:			
Hydrogen	1.84	1.57	5.11
Carbon	19.23	19.78	64.42
Nitrogen	0.27	0.28	0.91
Sulfur	5.29	5.44	17.72
Oxygen	6.00	3.64	11.84
Ash	67.37	69.29	--
Heating value (Btu/lb)	3,344	3,440	11,203

Polyurethane Grout Injection

To test the effectiveness of polyurethane grout as a potential containment barrier for burning waste banks, a series of injection tests were conducted with a variety of polyurethane grout and water mixtures. The test series included the injection of 100% polyurethane grout, 80% polyurethane grout - 20% water; 67% polyurethane grout - 33% water, 50% polyurethane grout - 50% water, and 10% polyurethane grout - 90%

water into 1 m long by 7.6 cm diameter polyvinyl chloride pipes filled with the coal waste. The various mixtures were injected at 0.6 m depths from the top of the pipes through a 0.6 cm rod. Injection pressures were 345 kN/m^2 for each test. A volume of 0.2 L of each grout mixture was used for the injection tests.

The particular mixture that appeared to best satisfy the goals of this part of the experiment outlined in the introduction contained about 2 parts polyurethane grout - 1 part water. The coal waste - polyurethane grouted mixture cured within 5 min, has an expansion ratio of about 15:1, and maintained its integrity after being exposed to atmospheric conditions for over a 1-yr period. The permeability of the grouted coal waste using this mixture was reduced from 50 darcys to less than 0.01 darcys, and porosity was reduced from 20% to less than 1% within the confinement of the polyvinyl chloride pipe.

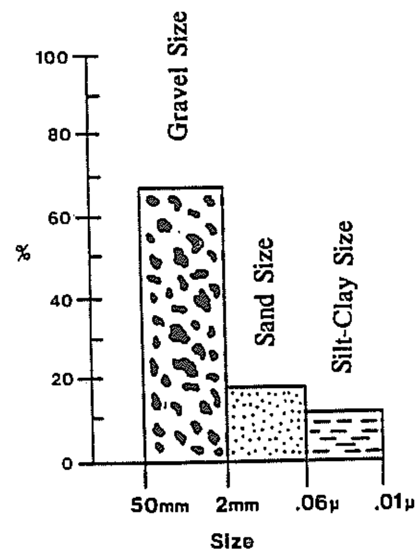

Figure 1. Histogram of sediment size distribution of coal waste material.

Additional testing of this grout mixture under less confined conditions also showed satisfactory results. For this test, another 0.2 L of the grout mixture was injected at 345 kN/m^2 through 0.6 cm rods at eight injection points into a 3 by 1.5 by 1.2 m box containing similar coal waste. The curing time was about 8 to 10 mins. Porosity was reduced from 20% to about 3%. Air flows induced by a suction fan through the waste measured with magnahelic gauges at nine monitoring ports within the box showed an average flow reduction of about 50% from 1 cm-H_2O to 0.52 cm-H_2O. The expansion ratio of the 2 parts polyurethane - 1 part water grout mixture in the unconfined box was about 8:1.

Foam Injection

Removal of heat from burning coal requires the passage of some heat- absorbing agent through a burning zone (Chaiken et al. 1984). Attempts in the past to use water have demonstrated that although water is capable of removing heat, its distribution through the waste pile cannot be readily controlled. To test alternative methods, a medium-density, medium-expansion fire fighting foam was evaluated as a heat transfer agent.

Foam is a dispersion of gas bubbles in a liquid. It is produced when a mixture of a surfactant and water encapsulates a small volume of air. Contiguous bubbles create a foam. A high-density (0.15 g/cm^3), low-expansion (10:1) foam is a wet foam with a lower ratio of gas to water. A low-density (0.002 g/cm^3), high-expansion (100:1) foam is a dry foam with a high ratio of gas to water. A medium-expansion, medium-density (about 0.05 g/cm^3) foam falls between these two extremes, and is considered most applicable to mine fire control type problems (Kim et al. 1992). A medium-expansion foam combines desirable qualities of high- and low-expansion foams and has an apparent density of about 0.05 g/cm^3. A typical foam in this range would contain 95% gas and 5% liquid. The liquid ratio of water to surfactant is about 99:1.

Foam used as an extinguishment material will be sensitive to the permeability and porosity of the burning waste bank. According to the Hershel-Bulkey model, the effective viscosity of the foam is more sensitive to changes in the width of flow channels than to the height of the material into which it is being injected (Kim and Chaiken 1993). This indicates that in a nonhomogeneous porous bed in which there is a distribution of channel widths and heights (i.e., the permeability "network" of the material), the effective viscosity and the

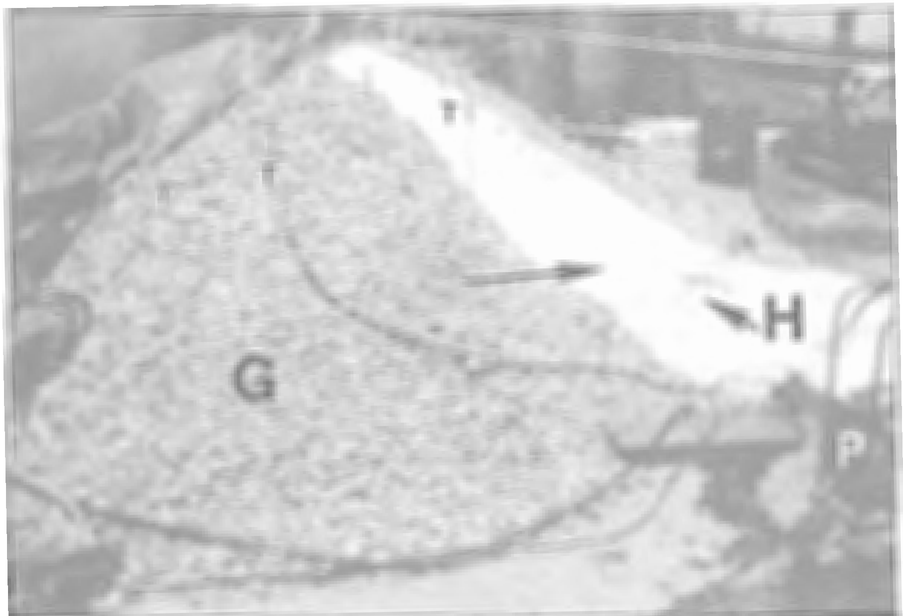

Figure 2. Simulated coal waste pile. G, gravel material, P, foam pump, H, heated zone, T, thermocuple. Arrow denotes foam.

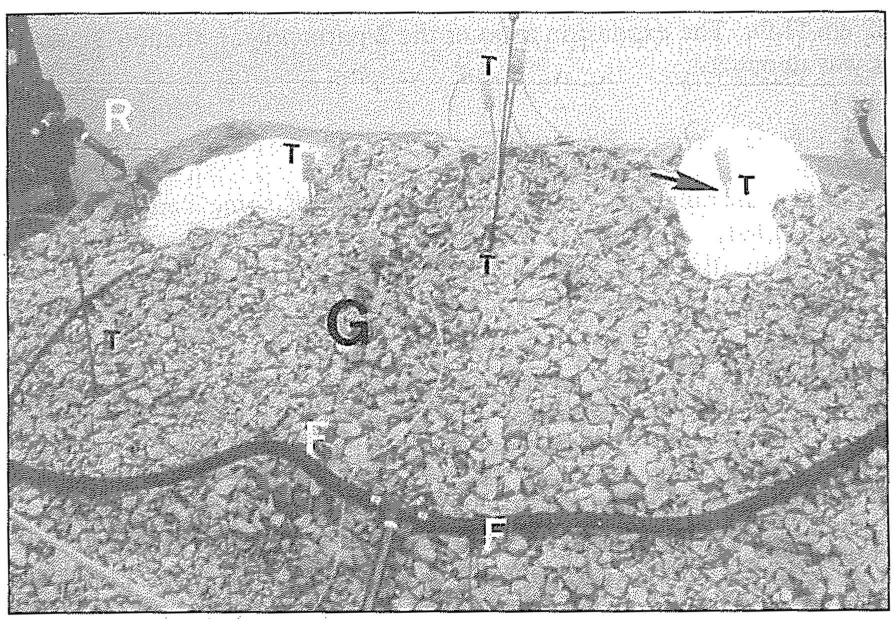

Figure 3. Simulated coal waste pile illustrating foam moving upward from gravel pile. G, gravel material, R, foam injection rod, F, foam injection tubes, t, thermocouples. Arrow denotes foam.

buoyant force will favor the upward flow of foam through a wide channel preferentially to lateral flow through a narrow channel. On the basis of this reasoning, foam injection rods should be placed below the level of the burning waste bank zone to ensure maximum contact of the upwardly moving foam through the burning zone. The amount of foam that is needed to effectively cool and transfer heat within a burning waste bank depends on the area affected by the fire, and the temperature of the heated zone.

To test the potential of foam as an extinguishment and cooling material, a 3 by 1.2 by 0.6 m limestone gravel pile was used to simulate a bench-scale waste bank fire (fig. 2). Two 1 m, 240 V heating elements were placed within the center of the gravel pile. A series of 14 thermocouples were placed at points within the pile to monitor temperatures during the heating process before and after foam injection into the pile was completed. Two 2.5 cm pipes inserted into the pile below the heating elements were connected to a foam pump. These served as the foam injection points (fig. 3).

Temperatures varied from about 180° C at the center to about 40° C at the edges of the heated zone after about 6 h of heating. A mixture of 18.9 L. of medium-expansion foam (99% water - 1% surfactant) was injected into the pile at 30 s intervals for about 30 min until the entire 18.9 L mixture had been pumped through the two injection rods. Injection pressures were about 35 kN/M^2. Visual observations during the injection process showed an initial conversion of the foam into steam, which escaped from the top and sides of the gravel pile. As injection continued, hot water and steam were observed flowing from the base of the pile. About 5 min after injection, intact foam was observed moving upward and flowing out the top and sides of the gravel pile (fig. 3). Temperature changes about 2 hr after foam injection showed an average rate of decrease of about 0.5° C/min (fig. 4a).

To test the effect of foam injection on reducing temperatures within a confinement barrier, the 2 part polyurethane - 1 part water grout mixture was injected into the pile at 345 kN/m^2 through a series of 0.6 cm rods. Six rods were placed in two rows about 0.7 m away from the center encircling the heated zone. A volume of 0.2 L of the polyurethane grout mixture was injected through each rod and allowed to cure for about 12 hr. This essentially constructed a barrier within the test pile.

The heating and foam injection procedure for this test followed those described above. Steam-water-foam flows were similar to those observed during the foam injection into the ungrouted heated pile were produced (fig. 3). Temperature reduction 2 hrs after foam injection within the containing grout barrier averaged 0.75° C/min (fig. 4b).

Material Costs

The material costs of extinguishing a burning waste bank would be dependent on the extent of the fire within the waste bank. The material costs incurred during our experiment can be used to provide cost estimates for the integrated polyurethane grout barrier and foam injection method. Assuming a 20% porosity and a 10:1 grout expansion ratio, it would cost about $\$10/m^3$ to form an effective barrier within coal waste material. A medium-density foam surfactant costs about $6/L. It took about 0.2 L of surfactant to cool 0.5 m^3 of material from a temperature of 180° C to about 100°C. So the surfactant cost to cool a 1 m^3 of hot or burning coal waste would be less than $4. By way of comparison, it has been estimated that it would take about 30,000 L of medium-density foam surfactant and 3,000,000 L of water to cool an underground mine fire and proximal heated zone with a heat content of 1.5 trillion calories (Kim et al. 1992).

A potential field application of the process is illustrated in figure 5. After the fire is located within the waste pile, grout is injected to form a containment barrier around the fire zone. Foam would then be pumped at points below the fire zone. The amount of grout and foam necessary to successfully extinguish a waste bank fire would be dependent upon the area of burning zone as well as the heat content of the burning coal waste.

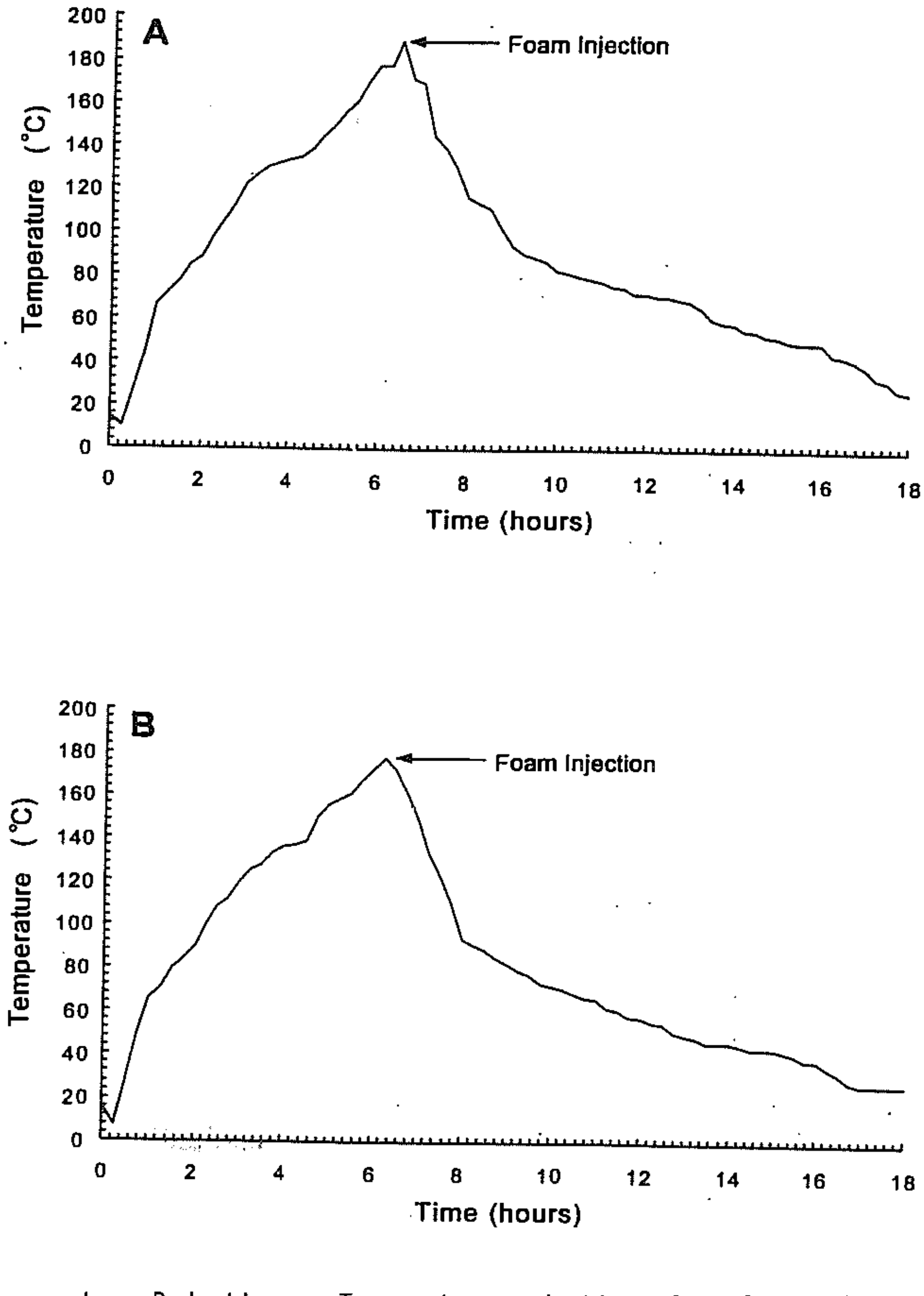

Figure 4. Temperature Reductions. Temperature reduction after foam injection near heated zone in simulated waste bank fire (A). Temperature reduction after foam injection within containment barrier near heated zone in simulated waste bank fire (B).

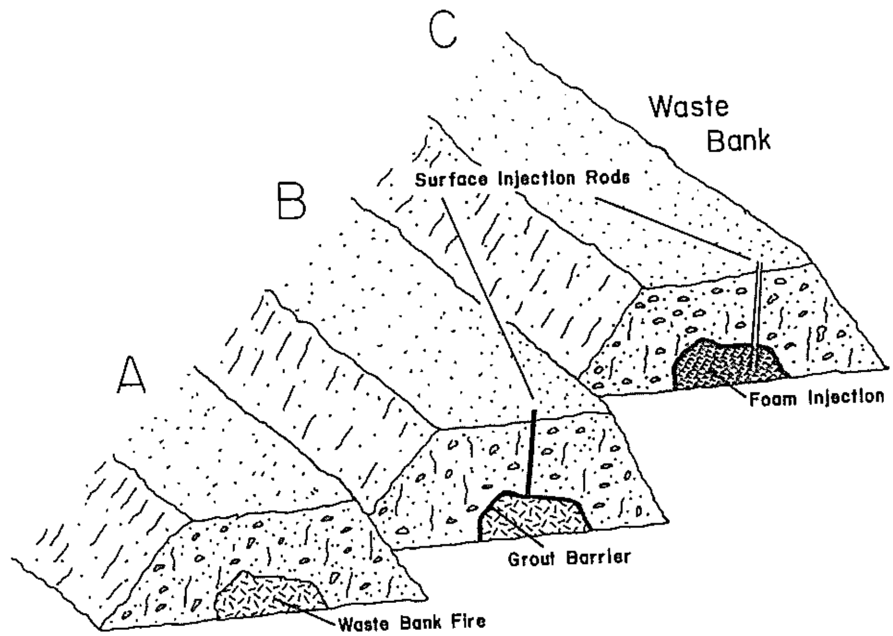

Figure 5. Idealized model of extinguishment process. Fire zone within waste bank (A). Grout containment barrier encircling the burning waste (B). Foam injection below fire zone (C).

Conclusions

Bench-scale testing indicates that a medium-density, medium-expansion fire fighting foam combined with a polyurethane grout containment barrier appears to be an efficient and cost-effective means of extinguishing a waste bank fire. A containment barrier composed of 2-part polyurethane - 1-part water grout effectively reduces the permeability and porosity of coal waste material. This mixture's flow characteristics, ease of injection, and cost make it superior to cement-type grouts that have been used to form containment barriers in underground mines. The use of the foam is also cost effective in transferring heat from within a burning waste pile. The use of the grout barrier to contain the foam increases the heat transfer rate from 0.5° C/min to 0.75° C/min.

Literature Cited

Chaiken, R. F., E. F. Divers, A. G. Kim, and K. E. Sorok. 1984. Calamity Hollow Mine Fire Project (in five parts) 4. Quenching the fire zone. BuMines RI 8863. 18 pp.

Jones, J. R. and R. F. Chaiken. 1990. Fire diagnostics simulation for burning coal wastebanks. p. 521-525. J. Skousen, J. J. Sencindiver and V. Samuels, (eds.). In Proceedings of the 1990 Mining and Reclamation Conference, American Society for Surface Mining and Reclamation, WV Publications Services, Morgantown, WV.

http://dx.doi.org/10.21000/JASMR90020521

Jones, J. R., A. G. Kim, J. P. Slivon, and A. M. Kociban. 1992. A laboratory study of containment barriers for coal waste bank fire extinguishment. Northeast Sectional Meeting of the Geological Society of America, Abstracts With Program. p. 43.

Kim, A. G., L. E. Dalverny, and J. R. Jones. 1992. Large mine fire: extended diagnostics and foam injection plan. BuMines, Final Report 14-09-0050-3320, 108 p.

Kim, A. G. and R. F. Chaiken. 1993. Fires in abandoned coal mines and waste banks. BuMines IC 9352. 58 p.