PROGRESS TOWARD ABATEMENT OF MINE FIRES IN THE ANTHRACITE COAL FIELDS[1]

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Abstract.--Fires in abandoned underground mines pose a significant environmental hazard because of emission of toxic gases (typically carbon monoxide, hydrogen sulfide, and carbon dioxide), surface fracturing, subsidence, and ignition of surface fires. A minimum of 50 fires have occurred in the abandoned mines of the anthracite coalfields of Pennsylvania since 1945. Through the combined efforts of the Office of Surface Mining Reclamation and Enforcement, the U. S. Bureau of Mines, and Pennsylvania Department of Environmental Resources, 20 of these fires have been controlled or abated, most by excavating overburden and quenching heated materials. Another 13 have been controlled or abated by private colliers. Of the 33 "controlled or abated" fires, 13 have been "controlled" by constructing incombustible barriers around the fire, surface sealing, or allowing the local mine pool to inundate the area. Because these fires may still be burning, future problems could result if surface land uses are not planned. At least 17 mine fires are presently burning uncontrolled in the anthracite fields, but are not believed to pose a threat to life or property. Abatement (control or extinguishment) of three fires is underway or is scheduled in coming years. Possible abatement of another three fires is under study. Since 1980, a total of seven new underground mine fires have been discovered in the anthracite fields, and it is projected that a rate of one or two new fires per year is likely to continue into the future. The major proximate causes of new mine fires are spread of surface fires from coal refuse (culm) or igniting of exposed coal seams in strip mine pits. However, both typically result, in turn, from burning of illegal trash dumps.

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INTRODUCTION

Fires in abandoned underground mine workings have been a problem in the anthracite coalfields since the 1850's. Hazards typically associated with underground fires include smoke and toxic gas emissions (generally carbon monoxide, hydrogen sulfide, and carbon dioxide), surface cracking and subsidence, ignition of surface fires, and consequent property devaluation. While mining was underway, underground fires were fought by trained mining company personnel. However, the abandonment of the anthracite mines and dissolution of mining companies have meant that most underground anthracite mine fires must be fought by government. Since most of the underground workings are now inaccessible these fires cannot be attacked directly without the costly removal of overburden.

This paper discusses the present status of 50 underground mine fires which have been discovered in the anthracite fields since 1945. Although other fires are known to exist, insufficient information was available to include them in this report. Other fires may be burning, dormant, controlled, or abated, but have not been reported. Where abatement (i.e. control or extinguishment) activities have been undertaken, data summarizing the location, abatement method undertaken, and the year of completion as well as the organization fighting the fire are shown. For a group of completed projects the approximate costs of abatement, surface area affected, and other pertinent and available data are presented.

Some of the fires listed here are discussed in Chaiken et al. (1983). Other information was obtained from the Bureau of Abandoned Mine Lands of the Pennsylvania Department of Environmental Resources (DER), the Bureau of Mines (BOM) Wilkes-Barre Office files currently being maintained by the Office of Surface Mining Reclamation and Enforcement (OSMRE) in Wilkes-Barre, PA, or from consultants currently engaged in fire control work in the anthracite field.

BACKGROUND

Geological Setting

There are four anthracite coalfields underlying a surface area of 484 mi.^{2} situated in the north and central sections of eastern Pennsylvania. The geology is sedimentary and metamorphic with shales, slates, sandstones, and conglomerates predominating. Folding, faulting, and steeply pitched bedding planes are extensive. The coal measures occur in multiple beds, varying in thickness from 1 ft. to greater than 50 ft.

Mining has been extensive since 1850, but has declined since 1945. General mining practice was a modified type of room and pillar system directed against the drainage contour in areas with less than 10^{o} of pitch. In steeper areas, a chute and battery system was used. Extraction ratios varied from 50% to 90%. Multiple-bed mining was common throughout the coalfields, but pillar columnization was not practiced. Due to the multiple-bed mining, ventilation was provided by a complex system of inside slopes, tunnels, gangways, and airways which consequently provided a means of communication between the coalbeds. The result of the extensive and random mining in a complex geologic setting is frequent subsidence which defies pattern or prediction and which enhances natural ventilation, and disrupts the effect that manmade barriers, such as coal chain pillars, permanent ventilation stoppings, or other barriers, have on fire propagation. Coal outcrops were randomly strip mined to the excavation limits (10'-50') of available machinery. The strip pits were generally neither backfilled nor reclaimed, and exposed coal was left at the base of the pit.

All underground fire events have occurred in mined areas with less than 1,000 ft. of overburden. Presently a system of mine water pools (i.e. interconnected mine workings flooded by the local water table), separate in each field but persistent through the measures, limits the depth of the fires to a maximum of about 500 ft. and generally 200 to 300 ft.

Anthracite Coal Characteristics

Anthracite has the highest rank and grade of coals. Anthracite has a fixed carbon content that ranges from 92% to 98% and a volatile matter content of from 2% to 8%. It burns with a short, pale blue flame, emits little odor, and does not coke. (Stefanko, 1979) It also has an extremely low heat of conductivity and an ignition temperature ranging between 815^{o} F and 878^{o} F, indicating that the material may be both difficult to ignite and to extinguish. (Scott, 1944)

RESULTS

Since 1945 a minimum total of 50 mine fires have occurred in the anthracite coalfields of Pennsylvania (table 1). Of these, 33 have been controlled or abated, and 17 are presently burning. In the abated/controlled category, 20 fires have been successfully fought by government agencies (DER, BOM, or OSMRE) while another 13 fires have been successfully fought by private colliers. These 13 fires include three fires (Humbert, Pine Hill, Wadesville) considered dormant solely on the basis of no surface evidence of fire and three fires (Susquehanna #8, Lansford #4, and Primrose) which were extinguished by the "natural" rise of the mine pool which

Table 1.--Current status of 50 underground anthracite mine fires currently burning or abated by various groups since 1945.

Fire Name	Location	Year Completed	Lead Abatement Agency	Abatement Method	Present Status 1987
			GOVERNMENT EXTINGUISHED		
			Excavation (Including Trenching) 1980 - Present		
Larksville	Larksville	1985	BOM, OSMRE	Trench, excavate	Out
Maffett	Sugar Notch	1987	OSMRE	Excavate	Out
Archbald	Archbald	1986	OSMRE	Excavate	Out
Forestville	Forestville	1986	OSMRE	Excavate	Out
Hughestown	Hughestown	1984	OSMRE	Excavate	Out
Sugar Notch Outcrop	Sugar Notch	1984	OSMRE	Excavate	Out
			Excavation (Including Trenching) 1945 - 1980		
Kulpmont	Kulpmont	1950 1958 1960	BOM PADER & County BOM	Trench Strip Excavate to mine pool level	Out
Mt. Carmel	Mt. Carmel	1950 1952 1967	BOM State & County PADER	Surface seal Surface seal Excavate	Out
Tower City	Tower City	1954	BOM & Owner	Excavate	Out
Cedar Avenue	Scranton	1953 1965 1973	BOM BOM BOM	Excavate Flush and excavate Excavate	Out
Throop	Throop	1968	BOM	Excavate	Out
Kehley Run	Shenandoah	1969	PADER & BOM	Excavate	Out
Hazleton	Hazleton	1969	BOM	Excavate	Out
Swoyersville	Swoyersville	1958 1973	Collier BOM	Unknown Isolation trench	Burning Out
Peach Mountain	Peach Mountain	1949	Federal	Direct attack	Out
Coal Run	Coal Township	1963	BOM & State	Trench and flush an isolation barrier	Out
			Inundation		
Shenandoah	Shenandoah	1960'S	BOM	None	Controlled, isolated by mine pool and natural barriers
			Surface Sealing		
Shamokin	Shamokin	1951	BOM & County	Surface seal	Out
			Blind Flushing		
Eddy Creek	Dickson City	1974	BOM	Blind flush with crushed breaker refuse	Controlled
North Scranton	Scranton	1960	BOM & PADER	Blind flush with sand	Controlled
Eynon Street	Scranton	1965	BOM, PADER	Blind flush with sand	Controlled
			EXTINGUISHED BY MINING COMPANY		
			Direct Attack/Excavate/Trench		
Gilberton	Gilberton	1930'S	Collier	Inundate and backfill	
		1950'S	Collier	Strip and backfill a barrier	Controlled
Jersey	Avondale	1960'S	Collier	Direct attack	Out
Continental	Taylor	1950'S	Collier	Direct attack	Out
Loomis	Wilkes-Barre	1960'S	Collier	Direct attack	Out
Packer #5	Girardville	Pre-1964	Adjacent Colliers	Stripping	Controlled, strippings have isolated the fire area
			Inundate		
Lansford #4	Lansford	1964	Collier	Inundation by mine pool	Out
Primrose	Mahanoy City	1962	Collier	Inundation by mine pool	Out
Susquehanna #8	Wilkes-Barre	1950'S	Collier	Inundation by mine pool	Out

Table 1.--Current status of 50 underground anthracite mine fires currently burning or abated by various groups since 1945.

Fire Name	Location	Year Completed	Lead Abatement Agency	Abatement Method	Present Status 1987
			Surface Sealing		
Williamstown	Williamstown	1964	Collier	Surface seal (Plug in portal)	Controlled
			Blind Flushing		
Rahn #11	Tamaqua	Pre-1964 1969	Collier Collier	Place water to extinguish Blind flush with sand	Controlled
			NO SURFACE EVIDENCE		
Wadesville	St. Clair	Pre-1968	Collier		Out
Pine Hill	Minersville	Pre-1968	Collier (Presumed)		Out
Humbert	Archbald	Pre-1970	Collier		Presumed out, no surface evidence of active burn
			BURNING UNCONTROLLED		
Coaldale	Coaldale	1983			Burning
Bear Valley	Zerbe Township		PADER		Burning (Preliminary analysis, fire is isolated)
Top Ross Outcrop.	Sugar Notch				Burning
Forestville	Forestville	Active	PADER		Burning
Carbondale	Carbondale	1950 1974 1986	BOM & DER BOM & DER OSMRE	Flushing silt Excavation	Burning (Preliminary analysis fire is isolated)
Wanamie-Glen Lyon	Hanover	1960'S	Collier	Underground seals	Burning
Locust Gap	Locust Gap	1930	Collier	Direct attack	Burning
Centralia	Centralia	1966 1974 1978 1983	BOM OSMRE	Excavate Flush a flyash barrier and excavate Reinforce barrier Diagnostic drilling	Most citizens relocated, burning
Warrior Run	Warrior Run	1971	BOM	Combination-flushing and excavation	Burning
Summit Hill	Summit Hill	Pre-1950	Collier	Flush with silt, place water to extinguish	Burning
Laurel Run	Georgetown	1971	BOM	Trench and flush a sand barrier	Burning
Lansford #9	Lansford	Pre-1964	Collier	Place water to extinguish	Burning
Potts Colliery	Locustdale	1959	Collier	Place water at fire zone to extinguish	Burning
			ABATEMENT IN PROGRESS (DER)		
Maysville	Maysville	Active	PADER	Trench, excavate	Under contract for extinguishment
Truesdale	Hanover Township	1928	Collier	Underground seals	
		1950'S & 1960'S	Collier	Underground seals and backfilling	
		Active	PADER	Trench and excavate	Under contract for extinguishment
Glen Burn	Glen Burn	Active	PADER		Under study

occurred when pumps in the mines were shut off. One fire (Williamstown) was abated by surface sealing and another fire (Rahn #11) was controlled by blind flushing with sand. The other five successful efforts were by direct attack or underground sealing.

The 20 fires fought successfully by government agencies include 15 excavation operations, one combination inundation/natural barrier operation (Shenandoah), one surface sealing operation (Shamokin), and three flushing operations (Eynon Street, North Scranton, and Eddy Creek). Seven of the 33 fires (Eynon Street, North Scranton, Eddy Creek, Rahn #11, Bear Valley, Gilberton, and Packer #5) have been controlled by confining, isolating, or preventing fire spread to inhabited areas. Each of these fires is still burning or may reignite.

The 17 fires which have not been controlled include two currently being abated by excavation techniques (Truesdale and Maysville), one which is under study and was formerly considered isolated (Glen Burn), and 14 which are burning uncontrolled, typically in areas where effects on people are not expected. The burning uncontrolled fires are, however, on the DER Inventory of fires to be abated.

ABATEMENT TECHNIQUES

As noted by McElroy (1938) and Chaiken et al. (1983), the private colliers' preferred method of eliminating a mine fire was by direct attack, using an appropriate excavation technique (i.e. mechanical mucking or hand shoveling and loading) to remove and isolate the hot material, and using available water for quenching. An alternate choice was construction of seals to starve the fire of oxygen and reduce the intensity of the fire to a point where it could be excavated. Another alternative was to install barriers to retard fire spread, usually by blind flushing of non-combustible material through boreholes drilled into abandoned workings. At some fires multiple abatement activities (e.g. flushing, followed by excavation) were undertaken, often because the first method employed did not work. Some fires are still burning despite multiple abatement attempts (table 1).

The widespread abandonment of underground mines in the anthracite coalfields has severely restricted access to underground fire sites. Because of the limited access, certain abatement techniques and combinations of techniques have evolved. The most common abatement techniques are excavation, inundation, flushing, and surface sealing.

Excavation

As shown in table 1, excavation (with associated quenching of hot material) was the preferred method of government-funded abatement for underground anthracite fires between 1945 and the present. (For the purpose of this work, trenching has been considered a type of excavation.) Chaiken et al. (1983) showed that excavation was 80% successful in the elimination of underground anthracite fires versus a success rate of approximately 50% for blind flushing and/or barrier construction, and even less for inundation and surface sealing. However, the recent finding that a remnant of the Carbondale fire exists, coupled with the spread of the trenched and flushed fire at Coal Run, reduces the reported excavation success rate to 60%. From the data summarized here, the excavation technique has been successful in 15 of 19 mine fire abatement projects conducted between 1960 and the present. Of the four unsuccessful excavation projects (table 3), three were combination excavation/flushing projects (Warrior Run, 1971; Centralia, 1966 and 1974; and Coal Run, 1963). It should also be noted that although initial excavation phases at Cedar Avenue in 1953 and 1965, (Dierks et al. 1971) and Kulpmont in 1950 were initially unsuccessful, the excavation technique was later successfully applied at both sites. We believe that in two unsuccessful excavation/flushing project cases (Warrior Run and Centralia) the fire breached the flushed barriers which had been installed. At Coal Run, fire advance has been checked in the direction of an installed trench but has spread in another direction. The fourth excavation project which was unsuccessful is Carbondale. OSMRE is currently monitoring to delineate the location and extent of the fire underground. Results of the study indicate that the fire was not completely excavated. However, at present the fire is confined within barriers caused by natural and manmade underground conditions, and indications are that the fire will burn itself out without causing significant damage to people or the environment.

Table 3.--Costs of unsuccessful attempts to extinguish mine fires by excavation, by government agencies, 1945 to present.

Fire Name	Surface Area (Acres)	Cubic Yards Excavated (Thous.)	Cost (Thous.)
Carbondale	250		6,750
Warrior Run	18	58	732
Centralia	300		3,900
Coal Run	100		197

Since 1980, both OSMRE and the DER have exclusively relied on the excavation technique; six underground fires have been excavated by OSMRE and all have been successfully extinguished. The DER is currently eliminating two extensive underground fires (Maysville and Truesdale) by the isolation trench and excavation method. It also should be noted that all current OSMRE anthracite refuse bank fire abatement work is accomplished by excavation.

The most notable drawback to the excavation abatement method is cost. As shown in table 2, costs of excavation are substantial, typically into millions of dollars. The exceptions to these high costs are fires which are rapidly excavated when the fire is first discovered (e.g. Maffett and Archbald).

Table 2.--Costs of mine fires successfully excavated by government agencies, 1945 to present.

Fire Name	Surface Area (Acres)	Cubic Yards Excavated (Thous.)	Cost ($Thous.)
Larksville	10	2,000	8,300
Maffett	2	15	215
Archbald	8	166	425
Forestville	4	340	900
Hughestown	4	166	608
Kehley Run	30 Est.	5,400 Est.	11,700
Hazleton	8	845	1,445
Swoyersville	8	932	797
Throop	7	420	762
Kulpmont	30		180
Mt. Carmel	170		8268
Tower City	6		241
Cedar Avenue	34	2,500 EST.	5504
Sugar Notch Outcrop	1	4,000	28
Peach Mountain*			

*Griffith et al. (1960)--No details given

Sealing

Surface sealing was implemented on three fires (table 1). The seals applied at the Williamstown and Shamokin fires have been successful; however two efforts at sealing the Mt. Carmel fire were ineffective, and the fire was later excavated (table 1). The Williamstown and Shamokin fires involved relatively small surface areas (1-7 acres), whereas the Mt. Carmel fire involved 170 acres. The use of surface sealing as an abatement technique in the anthracite measures has been and is considered to be an ineffective method largely because of the effects of subsidence, which severely reduce seal effectiveness (McElroy 1938; Chaiken et al. 1983).

Inundation

The inundation abatement method has been effective in four of nine cases (table 1). Inundation by the "natural" rise of the mine pool (when pumping of water from the mines is stopped) has been the prime method of success, accounting for three of the four abated fires (Susquehanna #8, Lansford #4, and Primrose). Passing water over or concentrating water on fire-affected and burning materials has not proven to be an effective technique. The low conductivity of the coal and surrounding strata, the relatively short length of time the water is applied, and the naturally pitched mining horizons which limit the amount of workings which can be inundated, contribute to the ineffectiveness of the technique. It is also evident that fires burn at the top of the workings and may "burn" in the rock strata above the mine workings, perhaps in the gases volatilized from the coal.

A combination flushing/inundation technique has proven effective in only three cases out of nine attempts (table 1). It is our conclusion that the flush barriers do not provide a tight enough seals to contain water in the target area. Further fire tends to concentrate along the coal ribs, near the roof, and in higher elevations of the mine; those areas underground which are least likely to be inundated for the period of time required to extinguish the fire.

Flushing

Based on the available mine fire information, blind flushing is about 50% effective as an abatement or control technique; 12 cases of blind flushing were found (table 1), and five seem to be successful. McElroy (1938) reported a 50% success rate on abatement work prior to 1936. Chaiken et al. (1983) reported the same on abatement work prior to 1979. The inaccessibility of the workings and caved underground conditions are the main obstacles to success of the blind flushing technique (McElroy 1938). Further, it is likely that the flushing materials used do not provide a tight enough seal to preclude oxygenation of the fire area.

However, it must be noted that blind flushing with sand has proven successful in three of the five fires controlled by the blind flushing technique. The reasons for this success rate are speculative, but sand is heavier and differently shaped than other flush barrier media (coal refuse and flyash), and consequently packs tighter and consolidates less over time. It should also be noted that in two of the three successful blind flushing projects using sand (Eynon Street, 1965; North Scranton, 1960), relatively flat workings were present. We believe that flushing will not be successful in controlling a fire in steeply pitching areas because the material will flow to the low points and not form a barrier.

FUTURE OCCURRENCES

A minimum total of 12 fires were controlled or abated by government and industry in the period between 1945 and 1960 (table 1). In 1962 there were 23 fires burning out of control. By 1968, 25 fires were burning out of control, with nine carried over from the 1962 survey. In 1979, BOM files listed 12 underground fires actively burning in abandoned anthracite mine workings. The list included five carried over from the 1968 record. In the intervening nine years (1979 through 1987), two fires (Carbondale, 1974; Laurel Run, 1971) listed as abated or controlled in 1979 have reignited or are still burning, and seven new fires were abated or controlled. Based on these available data, it is estimated that one or two additional underground fires per year will occur in the anthracite fields.

Although the origin of each fire is difficult to pinpoint, a survey of project files indicates that approximately 70% of the fires whose origin is mentioned, were started in strip pits or bank areas where illegal dumping had occurred. The occurrence of illegal dumping in the anthracite fields is expected to increase because of the availability, location, and number of unreclaimed strip pits; the increasing cost of trash disposal; and the recent closings of numerous landfills in the area.

SUMMARY

Since 1945 a total of 50 underground mine fires in the anthracite coalfields of Pennsylvania have been discovered, and 33 of these have been abated or controlled. Government agencies (BOM, OSMRE, DER) have conducted work at 26 of the listed mine fire sites and have been successful at 20 sites. Private colliers have attempted to abate 22 of the listed sites and were successful in 13 attempts. A total of 17 underground mine fires are known to be burning at present, three of which are undergoing abatement work by DER.

The most successful abatement technique is excavation or a form of excavation. Excavation has been successful in over 70% (15 of 21) of its applications, and is likely to be unsuccessful only when excavation is not complete. However, because of the inaccessibility of the mine workings and the need to remove overburden, excavation is probably the most expensive abatement technique.

The high costs involved in the excavation or a modified excavation technique have led to the use of other abatement methods such as flushing, inundation, and surface sealing. Success rates for the other abatement methods are below 50%. The main obstacles to the success of the other abatement techniques are natural phenomena such as the occurrence and extent of subsidence and local geology. Consequently, to assure that the fire is extinguished the excavation technique is the method of choice in abating underground mine fires.

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