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A Review of the Mechanisms of Gas Outbursts in Coal

By David M. Hyman

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	m	meter
cm^3/g	cubic centimeter per gram	m^3	cubic meter
$cm^3/(kg \cdot min^2)$	cubic centimeter per kilogram square minute	min	minute
g	gram	mm	millimeter
h	hour	m^3/mt	cubic meter per metric ton
kPa	kilopascal	MPa	megapascal
L	liter	pct	percent
L/min	liter per minute	s	second

A REVIEW OF THE MECHANISMS OF GAS OUTBURSTS IN COAL

By David M. Hyman[1]

ABSTRACT

Outbursts are sudden and violent releases of gas and coal that result from a complex function of geology, stress regime, and gas pressure and content. The Bureau of Mines has reviewed methods for prediction and mitigation of such outbursts in use worldwide, as an aid in selecting the proper techniques for use in specific mine environments. Outburst-prone coal may be distinguished from normal coal by its sorption-desorption velocity. Three types of methods used to characterize the kinetics of sorption-desorption are described; all are based on the ability of outburst-prone coal to release, through desorption, methane or carbon dioxide much more rapidly than normal coals. Other prediction methods, based on borehole samples, are also described.

Various mitigation methods described and evaluated include (1) working the least stressed, less disturbed, lowest gas content seam in multiple-seam areas; (2) mine opening geometry; (3) inducer shot firing; (4) water infusion; (5) localized stress relief, using boreholes or by cutting a reliever slot in the longwall face; and (6) other gas drainage methods.

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INTRODUCTION

An outburst is defined as a violent, simultaneous release of gas(es) and comminuted rock material into a working face or the interior of a borehole. In general, an outburst event has the following phases (1):[2]

1. A stressed volume of rock containing gas(es) is exposed to a rapid change of confining stress. This rock volume has been highly fractured as a result either of some preexisting geologic disturbance (such as a fault) or of mining-induced stress concentration.
2. Gas(es) adsorbed in or contained in sandstone or evaporite rocks are rapidly released into the fractures, which already contain free gas. When more gas enters the fracture space than can be transported away through the less permeable rock body, a state of stress due to gas pressure may be reached where the rock body cannot contain the increasingly stressed fractured rock volume.
3. When the rock body can no longer contain the stressed and fractured rock volume, containment ceases and the fractured rock mass and gas(es) undergo movement as they are driven by the gas into a pressure sink, e.g., a mine opening or borehole.
4. After the movement of the fractured rock and gas(es), there may be continued gas flow from the fractured but in-place rock that forms the outburst cavity. This gas flow generally decreases over time.

Two major theories--the "pocket" and the "dynamic" theories--can describe the basis of the coal outburst mechanism. The pocket theory holds that there exist certain volumes of "soft" or crushed coal enclosed by "harder" or less fractured coal that form reservoirs of gas contained in the fracture void space. These crushed coal volumes are associated with faulted or sheared zones and with intensely folded strata. This comminuted coal has little unconfined compressive strength and is separated from the mine opening by an intact zone of coal under sufficient stress to become a "permeability dam." When mine development approaches a "soft coal" region, an outburst can result if the region is not sufficiently drained of free gas and/or the stresses in the region are not dissipated (2).

The dynamic theory holds that a volume of relatively gassy coal, which is highly stressed and penetrated by mining-induced fractures, is outburst prone. When a mine opening and induced stresses approach such a coal volume, the coal fractures, releasing high-pressure desorbed gas, and the coal face fails, resulting in an outburst (2).

Common to both theories is high-gas-content fractured coal that is able to desorb gas rapidly upon release of confining pressure. This rapid desorption feature of outburst-prone coal is the basis for a rather extensive set of predictive methods, which are detailed later in this report.

Other aspects of outburst-prone coal include low in situ strength due to fissuring, high free-gas pressure, and association with geologic structures such as fracture zones and igneous dikes. These aspects are also the basis of a variety of predictive methods (2).

Outbursts in coal mines represent considerable hazards. The most immediate hazard is the unexpected inundation of the ventilation systems with asphyxiating volumes of gas. When methane is the released gas, an explosive hazard can be created, possibly exacerbated by ejected coal dust. The force of the released gas and displaced material can be sufficient not only to disrupt mine ventilation but to debilitate stoppings and ground control structures such as arches and posts, and to injure or kill mine personnel. Additionally, an outburst zone presents a ground control problem due to the fissile nature of the rock that forms the remaining outburst cavity. Furthermore, gas may continue to be emitted, and without

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[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

appropriate ventilation can accumulate in the outburst cavity.

While the scientist and researcher would prefer to describe the mechanics of coal-gas outburst in very exact quantitative terms, the mining geologist and engineer need to reliably foresee the preconditions and precursors. The body of literature concerning coal-gas outbursts has abundant works (1-8) that represent overviews of the outburst phenomena at both national and international levels. Case studies of outbursts are extensive, and the bibliographies of the aforementioned references contain numerous examples. An overview of some of the more commonly practiced coal-gas outburst prediction and prevention methods used was compiled as a result of Bureau of Mines research.

COAL-GAS SORPTION-DESORPTION METHODS

A fundamental component of a coal-gas outburst is the ability of coal, whether in a fractured or relatively solid state, to release sorbed gas fast enough and in a large enough volume to overcome confining stresses and drive the outburst process. Whether one subscribes to the "pocket" theory of outburst mechanism or the "dynamic" theory and its mathematical description (9), the desorption kinetics are at the heart of the outburst mechanism. Studies in West Germany (10) and Wales (11) suggest that outburst-prone coal has essentially the same gas content and capacity as normal coal. Figure 1 shows this as well. What distinguishes the coals in terms of outburst potential is their sorption-desorption velocities. A popular theory holds that outburst-prone coal is much more extensively microfissured than normal (non-outburst-prone) coal. This permits a shorter diffusion path and a higher surface-to-volume ratio.

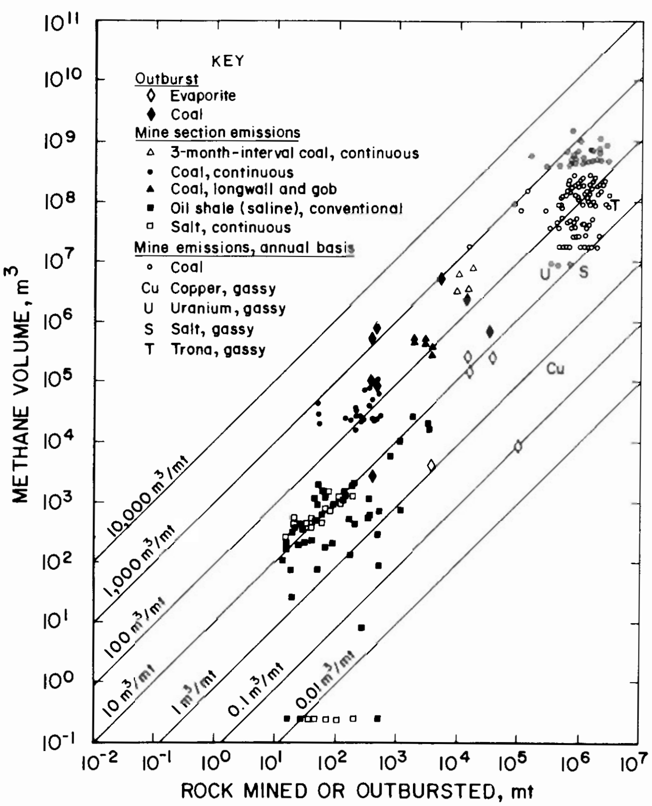

FIGURE 1.—Methane emissions from mining events.

To compare the desorption rates between outburst-prone and normal coal, a gas emission equation and some of its constants from the literature (2, 11) were used in the following analysis. The emission equation used is Airey's empirical relationship for gas emission from coal lumps (12):

$$V(t) = A(1-e^{(t/t_o)^n})$$

$$= A(1-\exp^{(-t/t_o)^n})$$

and

$$A = V_L \frac{(k_L P)}{1+k_L P}$$

where

$V(t)$ = volume of methane desorbed after time t, min,

A = equilibrium sorption capacity of coal at gas pressure, P, kPa,

t_o = time constant min related to coal chip size, min,

n = constant related to coal type or rank,

V_L = maximum Langmuir sorptive capacity of coal sample, cm^3/g,

k_L = Langmuir strength of attraction for gas to sorb, kPa^{-1}.

The value of t_o is defined as the time required for the subject coal sample of a given effective chip size to desorb 63 pct of its gas content. A calculated t_o range of about 5 to 15 min (11) is consistent with microfissure densities with corresponding t_o values for outburst-prone coals (2, 12). The coal constant, n, had been found empirically to be about 0.5 for anthracite, 0.33 for bituminous coals, and 0.25 or less for outburst-prone coal. As studies have indicated that some outburst-prone coals do not have a markedly different gas content than that of normal coal in the same coalbed, the same in situ equilibrium gas content, A, will be used in the analysis. Assuming that coal chips have been obtained from both a normal coal volume and an outburst-prone zone, the relative (with respect to a constant) desorption curves for normal bituminous (n = 0.33, t_o = 60 min), anthracite (n = 0.5, t_o = 60 min), and outburst-prone (n = 0.25, t_o = 15 min) coal chip samples are calculated and presented as figure 2. As shown in figure 2, the outburst-prone coals initially desorb at a faster rate than normal coals. The highest contrast in desorption rates occurs within approximately the first 10 min of desorption time. It is apparent from this

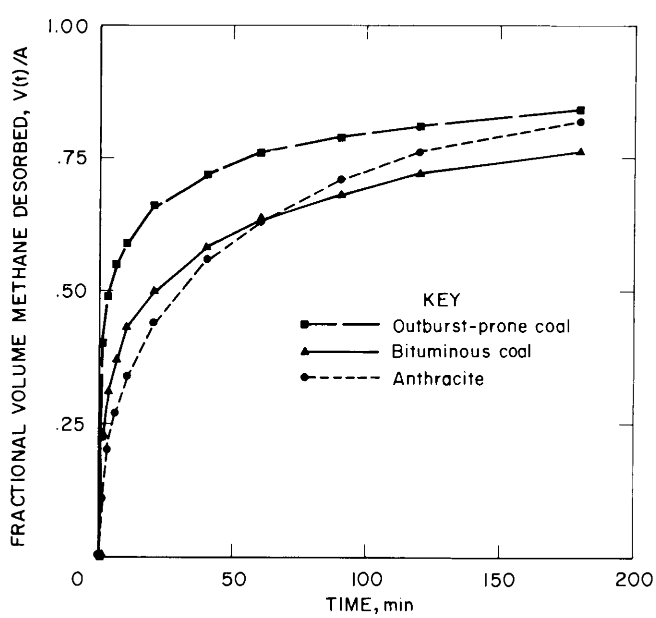

FIGURE 2.—Comparison of theoretical coal chip desorption.

simplistic illustration that in order for desorption indices to differentiate between normal and outburst-prone coals, they must be determined within this short span of time. It also follows that extraordinary care must be exercised in quickly obtaining and preserving (if necessary) coal chip samples for these predictive index determinations. One should also recognize that preserving coal chip samples in a pressurized chamber does not prevent the chips from undergoing structural degradation over time (5).

Three basic classes of tests characterize sorption-desorption kinetics (5). The first class comprises volume-desorbed methods, or so-called ΔV methods. One such method practiced on a working-mine-section scale is the V_{30} index (1, 13). The volume of methane emitted within the first 30 min after shot firing is measured and normalized to the mass of coal broken by the shot. This value is divided by the desorbable gas content (q_d), which is determined by a coal chip desorption test described later in this section. Normal coals have a V_{30} value ranging between 0.10 and 0.17, compared with about 0.40 for outburst-prone coals and >0.60 for outburst coals. This index is used in the Federal Republic of Germany as part of a hierarchy of tests to assess the risk of encountering an outburst.

Another volume-type index is used primarily in Australia to predict the risk of outbursts in advance of mining. This test is mainly used for carbon dioxide-coal outbursts (4). The Hargraves ΔV index uses a 4-g sample of drill cuttings sized from 0.6 to 1.2 mm. The cuttings are obtained from a drill hole and sealed in a desorption meter within 1 min of being cut by the drill bit. The desorbed gas volume is measured from 1 to 6 min after drilling. When this value exceeds 1.2 cm^3/g, the subject coal is considered outburst prone. This threshold value is gas specific and colliery specific. The use of a slightly modified ΔV index with a shorter observation period was attempted in Belgium with some success. If the volume of gas (V_1) desorbed between 35 and 70 s after drilling is greater than 0.1 cm^3/g, there may be an outburst risk; a V_1 value greater than 0.2 cm^3/g indicates a serious outburst risk (7).

A rather large class of outburst prediction indices are the popularly known ΔP indices. These indices are based on pressure changes during either desorption or sorption tests performed on coal chip samples generally within the 0.25- to 0.50-mm size range. The basic ΔP index is the ΔP_{0-60} of Soviet origin (1, 7). This is a desorption type of test. Originally, different coal chip sizes were used for different ranks of coal, but the 0.25- to 0.50-mm chip size range has become standard through practice. A 3.5-g coal chip sample is placed into a 6.5-cm^3 chamber that has a free gas space of 4 cm^3. Other workers have used 3- to 10-g samples in a chamber with 4 to 10 cm^3 of free gas space. The chamber is then evacuated to a negative pressure of about 100 kPa for 90 min to degas the sample. The chamber is then pressurized to about 100 kPa with helium and evacuated; then the pressure change is monitored. A resultant pressure rise represents the baseline condition for the test procedure, as the helium is not sorbed by the coal. The sample chamber is then evacuated before being pressurized with methane at about 100 kPa for 90 min so as to saturate the coal sample. After saturation, the sample chamber is connected to an evacuated chamber to reduce the pressure in the sample chamber to a negative 100-kPa pressure very rapidly. The pressure rise is then measured 10 to 60 s after this chamber pressure reduction. The ΔP_{0-60} index is equal to the pressure rise at 60 s minus the baseline pressure rise for the assumed inert (with respect to sorption by coal) helium. The ΔP_{10-60} index is the difference between pressure rises measured at the 10- and 60-s time periods and indicates outburst-prone conditions when it is greater than about 1.3 kPa. When ΔP_{0-60} is greater than 2 kPa, the sample is considered to represent outburst-prone conditions. The primary disadvantages of the ΔP_{0-60} test are that it is a laboratory-based determination and requires 6 to 8 h to perform (1).

A variation on the ΔP_{0-60} method, developed by Lama (5), uses shorter observation times to evaluate the sorption kinetics of coal samples. This method is known as the $\Delta P_{express}$ method and correlates rather well with the ΔP_{0-60} method (5). For the $\Delta P_{express}$ method, a 50-g sample of coal chips within the 0.25- to 0.50-mm size range is sealed in a 250-cm^3 chamber. This chamber is evacuated for 5 min at a negative pressure of 100 kPa. After degassing, the sample chamber is pressurized with methane at about 200 kPa. The pressure drop due to adsorption is then measured for a 10-min period. While the $\Delta P_{express}$ index has a good correlation with the ΔP_{0-60} index, its usefulness as an outburst prediction has not been demonstrated. If the pressure drop curve due to adsorption for the $\Delta P_{express}$ method is examined for the 5- to 10-min time interval, and this pressure drop value (expressed in kPa) is divided by 300 s, the L_1 index results. This L_1 index is a measure of sorption rate and has had some success in detecting shear zones of coal.

A third class of indices for predicting outburst-prone coal measures the rate of change of desorption rates or desorption deceleration. In the Federal Republic of Germany a series of calculations is used that is based upon the desorption deceleration of borehole cuttings collected and sealed in a desorption meter within 1 min of cutting (1, 14). About 10 g of coal cuttings in the 0.4- to 0.63-mm size range are collected, and the desorption rates are measured over a 5- to 10-min period. For this time period, a power law relationship for desorption rate over time is assumed:

$$\frac{dV(1)}{dt} = \frac{dV(t)}{dt} \quad (t^k)$$

where time (t) is in minutes.

If this power law relationship is obeyed, a plot of logarithmic desorption rate versus logarithmic time will yield a straight line of slope k. The intercept at time = 1 min is the desorption rate at 1 min. When this intercept value is multiplied by a time constant, which is a function of coal chip size, the desorbable gas content, qd, is obtained. A value of qd greater than 9 m^3/mt indicates a suspected outburst condition. This qd, or desorbable gas content value, is the scale for the V_{30} index described earlier. Note that the 9-m^3/mt threshold for outburst-prone coal is very close to the smallest specific emission or outburst gas content for coal outburst presented in figure 3. A value of k greater than 0.75 $cm^3/(kg \cdot min^2)$ indicates that the coal sample is from an outburst-prone area. Normal coals have a k value of about 0.65 $cm^3/(kg \cdot min^2)$. The time constant, A, used to calculate qd is 29.4 min for the 0.4- to 0.63-mm coal chip size range and about 25 min for the more conventional 0.25- to-0.5-mm coal chip size range.

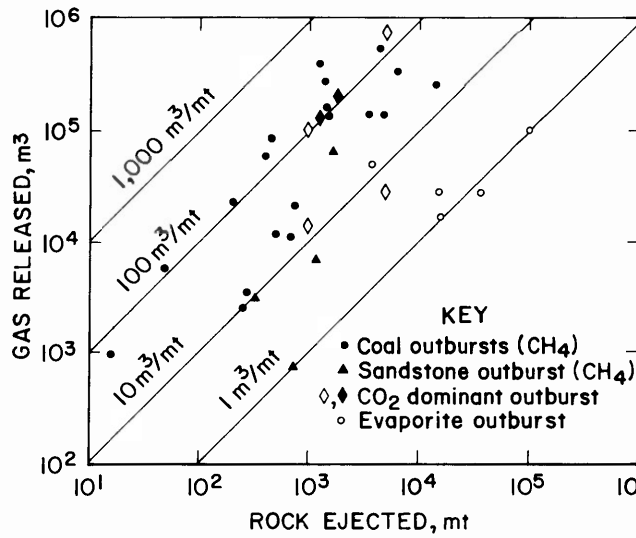

FIGURE 3.—Volumes of gas released by outburst events.

What these methods, and the others described in the literature have in common is a means to differentiate outburst-prone coals from normal coals. This is based upon the ability of the former to release, through desorption, methane and/or carbon dioxide much more rapidly than normal coals. Such is the basis of the British desorption ratio, where a sample's desorbable gas content for a certain time period is divided into a mine-specific representative desorption volume. When this ratio exceeds 4, then the sample in question is considered to represent an outburst-prone zone (1). This property of very rapid desorption is a fundamental precondition to the development of gas and coal outbursts. Given coal chips of a particular size range (e.g., 0.25 to 0.50 mm) from outburst-prone coal and normal coal, one would expect the outburst-prone coal chips to have a smaller effective size due to some partitioning feature (such as microfissuring) in their structure that would help explain their faster desorption kinetics. One might also expect this smaller effective size to contribute to increased friability and lower strength in comparison to normal coal in the same coalbed (10-11). Other types of outburst-prediction methods also take advantage of these aspects.

BOREHOLE PREDICTION METHOD

During the drilling of boreholes into outburst-prone zones, drillers often note gas "kicks," increased gas flows, and disproportionately large volumes of drill cuttings (10). In the Federal Republic of Germany, a drill-cuttings-to-hole volume ratio greater than about 3:1 to 7:1 is indicative of outburst conditions in the coal penetrated by the drill hole. The borehole diameters ranged from 50 to 140 mm in the work reported (10). A French study did not establish an outburst risk threshold for drill cutting volumes from 43-mm-diameter drill holes even though 2 to about 130 times more cuttings were encountered than could be accounted for by hole volume (1). Since volume measurements of drill cuttings are not accurately reproducible owing to differences in bulking between samples, a gravimetric method would be more useful.

A more direct and hopefully more useful prediction method based on the sheared and/or low-strength qualities of outburst-prone coal is presented by Kidybinski (15-16), whose two papers describe the use of a borehole penetrometer with a conical tip to determine faulted areas and adjacent zones of relatively soft coal, as an outburst prediction tool. This use of this tool yields a coal and/or rock strength index, Z, that is equal to the applied thrust on the cone divided by the penetration distance. In tests at three mines, the coal strength was found to be related to in situ gas pressures. Some preliminary empirical relationships were developed, but more research is required to develop a more definitive relationship.

MITIGATION OF OUTBURST EVENTS

The ultimate method for preventing an outburst event during mining is to predict potential zones of outbursts and avoid them or at least reduce their outburst potential. As the outburst mechanism is a complex relationship between geologic structure, mining-induced stresses, and gas content and pressure, the removal or mitigation of one or more of these elements can possibly reduce outburst potential. Geologic structures such as faults or sheared zones can be avoided to a certain extent. Stresses can be reduced by changes in mining rates, methods, and geometry. Gas contents and pressures can be reduced by drainage. Most of the methods practiced throughout the world involve relieving stress concentrations and/or in situ gas pressure.

A whole-seam stress reduction method applicable in areas where several minable coal seams occur in close proximity is known as "working the protective seam" (1). The idea behind this method is to mine the least stressed, and/or lowest gas content, and/or least disturbed coalbed of those in a multiple-seam configuration. It is preferred to mine as a protective seam an overlying one, instead of an underlying one, unless the outburst problems are more severe than the ground control problems due to subsidence from undermining. If conditions permit, the pillars could be superimposed for the protective and outburst-prone seams so as not to defeat the stress-relief aspect of this protective method. Mining the protective seam can also induce some fissuring and thus potentially drain some portion of the gas in the outburst-prone seam. Not only does the gas drainage effect tend to help lower the overall gas content of the outburst-prone seam, it also can help lessen the magnitude of the desorption rate by allowing the desorption process to begin prior to mining. The overall effect of mining a protective seam is to reduce the stress and gas dynamic potential fields of the outburst-prone seam (17). Thus, it is no surprise that this method is one of the most effective methods of reducing outbursting probability. Unfortunately, this method is applicable only in multiseam configurations. In single-seam configurations, other methods must be employed to reach the same end of reducing the stress and gas dynamic potential fields of an outburst-prone coalbed.

Given an outburst-prone coalbed, a variety of methods have been practiced to relieve stress concentrations. Mine opening geometry control is a relatively effective method. Stress concentrations are greater at the face of a single heading or roadway than along a longwall face. Retreat longwalls are less prone to outbursts than advancing longwalls. Pillar extraction is less prone to outbursting than retreating longwalls, but this may be due to degassing more than to stress relief. The most outburst-prone mining operation is when a heading or tunnel moves from one coal seam through a rock interburden to an adjacent coal seam (4). In general, longwall mining methods with gate roads not developed more than 2 m ahead of an advancing longwall face are less liable to trigger outbursts than are room-and-pillar mining methods (1).

Besides mine opening geometry, several stress-relief measures are practiced at the mine face level. Inducer shot firing is employed in several countries to relieve stress accumulations and to trigger outbursts in a relatively controlled fashion. One form that inducer shot firing takes is destressing at the ends or gate road faces of a longwall panel. This precautionary shot firing involves drilling holes outby the gate road faces, usually to a depth of about 3.7 to 4.6 m, although in Turkey holes up to 8.3 m deep are used (8). These holes are charged with explosives. When an outburst-prone zone is predicted within the longwall face area, shot firing is performed by detonating explosives in boreholes across the longwall face on both sides of the suspected zone (1). The explosive charges can be detonated either simultaneously (camouflet) for maximum shock loading, or with short delays to facilitate mucking operations. A variation on this shot-firing theme is termed pulsed infusion shot firing. For this method boreholes 4 to 9 m deep are drilled, charged with submarine explosives, filled and pressurized with water, and detonated. Although shot firing has been used with some success in controlling the occurrence of outbursts and in mitigating to some extent the severity of further outbursts in the treated area, it is an inherently hazardous practice; also the deleterious effects of expelled coal and gas due to outbursting still occur and must be considered when using these techniques. To a limited extent, the erection of a barricade 8 to 15 m from the face can mitigate these deleterious effects. Unfortunately, such barricades introduce problems for postshot face ventilation gas checks (4).

A less energetic method of destressing and fracturing an outburst-prone zone in a coalbed is through water infusion. Water infusion for destressing is a modified form of water infusion for dust and gas emission control. It is performed where prediction methods such as proximity to a fault, high P_{0-60} values, or discharge of a large relative volume of drill cuttings indicate an outburst-prone zone. The infusion method has been implemented in the Federal Republic of Germany (19) by drilling 50-mm-diameter boreholes at a spacing of three to four gate road widths in the suspect zone. The boreholes are drilled into the suspect zone and generally are less than 10 m from the face; depending on the nature and extent of the suspected outburst-prone zone, they can be up to 60 m from the face. Water is pumped into the holes at about 70 to 100 L/min, at pressures up to 40 MPa but averaging 11 to 23 MPa. Each hole pattern is infused sequentially until either cracking or separation of the coalbed occurs. The infused water both redistributes stress and forces free gas in the fractures away from the face. Water infusion becomes hydraulic fracturing when a series of pressure pulses are applied to the water in the hole. A major drawback to water infusion is that its degassing or gas-displacing effects are relatively short-lived; consequently, it must be performed frequently, potentially interfering with production.

Localized stress relief can be accomplished through the use of boreholes in terms of relieving both local stress and gas pressure. These stress-relief boreholes have diameters of about 82 to 300 mm. An effective borehole diameter is found by drilling holes of progressively larger diameters until an excessive volume of cuttings is discharged, indicating a miniature outburst event in the hole. The relief hole spacing is found by reducing borehole spacing until no audible stress readjustments are heard (4) as the holes are bored. The length of these boreholes is 10 to 25 m in advance of the face. Additionally, cavities can be excavated at some depth in the borehole to trigger an outburst in the borehole to further relieve stress and gas pressure. This practice is known as "perforation" in Hungary and has also been used in the U.S.S.R. and Australia. A considerable drawback to perforation is controlling the coal dust and gas ejected from the hole.

A stress-relief technique practiced in the U.S.S.R. is the cutting of a reliever slot in the longwall face. A cutting cable saw is used to cut an 80-mm slot about 3 to 5 m deep, effectively undercutting the face. Different slot orientations and cutting depths are used, depending on local conditions (17).

Relief of excess stress removes, through redistribution, a portion of the triggering energy for an outburst. The reduction of gas pressure as well as gas content also removes potential energy from an outburst-prone zone. An outburst-mitigation method therefore reduces gas pressure in a gas drainage borehole, as well as reducing stress concentrations to a limited extent.

In general, gas drainage boreholes have smaller diameters (40 to 100 mm) than stress-relief boreholes. The strategy in gas drainage is to degas volumes of rock in advance of mining with lateral and vertical holes in gate roads and faces (4). It has been found that open hole or free-flow drainage is not as effective or efficient as applying a negative pressure of 7 to 40 kPa. Studies (1, 17, 19) have shown that application of a slight negative pressure to increase the borehole pressure sink increased gas output from the drainage holes by factors of 2 to 4 times compared with free-flow drainage. What determines the spacing of boreholes in a gas drainage plan is a complex function of coalbed permeability, gas pressure, pressure gradient, degree of water saturation, gas dynamics of the coal, and duration of drainage. A Chinese experiment (1) involved the drilling of 22 gas drainage holes of 75-mm diam into an outburst-prone coalbed. These holes were monitored for 19 months. When mining operations penetrated the drained zone, no outburst events occurred. A 6- to 7-m radius of influence was calculated, indicating that a 10- to 15-m gas drainage hole spacing would be effective for this mine. The Japanese (20) performed a gas drainage study in which 65- to 90-mm boreholes were drilled at 10- to 20-m spacings. The gas drainage was aided by suction. During drainage, test holes were bored and gas pressure and flow measurements were made. Mining was started when the test boreholes showed that gas pressures and flows had been lowered. This gas reduction occurred after 1 to 2 months.

A gas drainage experiment was conducted in an Australian coalbed containing shear zones that were outburst prone (21). The experiment consisted of drilling three 100-mm-diameter holes parallel to each other and separated by about 10 m. The holes were drilled to 23-, 45-, and about 60-m depths. The longest hole penetrated a shear zone. Gas pressure and flows were monitored for about 140 days. The shortest hole produced 0.35 L/min per meter of length, the 45-m hole produced about 2 L/min per meter, and the hole that penetrated the shear zone produced 63 L/min per meter. The gas pressure in the shear zone dropped from an initial 410 kPa to about 200 kPa after 30 days and to about 100 kPa after 80 days. The depth of the coalbed was about 500 m, and the holes were drained without the application of suction. When mining intercepted this drained shear zone, no outbursts occurred. In another experiment in the same mine, 40-kPa suction was applied to boreholes, yielding 200- to 400-pct increases in flow rates. The range of influence for drainage holes in this mine was estimated to be about 30 m.

While not all gas drainage exercises reported in the literature have prevented outbursts, they have been somewhat effective in draining gas and reducing gas pressure in advance of mining. Gas drainage works best in outburst zones where the coal is crushed or comminuted, as in a fault or shear zone. Outburst-prone zones where the coal is relatively intact are not very amenable to gas drainage without the application of borehole stimulation techniques.

SUMMARY AND CONCLUSIONS

The body of scientific literature that describes outburst mechanics, preconditions, prediction techniques, and prevention or defensive measures is extensive. Effective management of outburst zones requires that they be predicted in advances of mining by geological investigations to delineate fault or shear zones and igneous intrusions. A variety of physical testing methods is available to predict outbursts, centering on relatively rapid (on the order of minutes) desorption tests. Borehole prediction methods rely on the instability and fissile nature of outburst-prone coal or gas and comminuted coal expulsions from boreholes. As outbursts are a complex function of geology, stress regimes, and gas contents, available defenses attempt to relieve stress and gas pressures once an outburst-prone zone has been defined and geologically mapped.

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