SPONTANEOUS COMBUSTION – COAL CHARACTERIZATION AND ENVIRONMENTAL FACTORS

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In the West, during the last few years, the issue of spontaneous combustion, particularly coal characterization and environmental factors that affect spontaneous combustion, has been getting much attention in the mining industry. Spontaneous combustion is the self-ignition of a substance to rapid oxidation of its constituents without an external source of heat. In other words, coal produces heat just through oxidation.

Over a 10 to 15-year time period, about 15% of reportable underground mine fires are due to spontaneous combustion. This is an average of about two fires per year defined as reportable mine fires by MSHA. But that really doesn't do justice to the problem or to the western mining industry because if you mine coal in the West, you deal with spontaneous combustion every day and it's a fight to keep it from getting to the point where it becomes a reportable mine fire.

Spontaneous combustion occurs when heat is produced, and there are two ways to produce heat with coal. You can oxidize the coal, or you can produce what is called the heat of wetting by driving moisture from the coal and then reabsorbing it. This can happen through environmental conditions, and if the heat produced is greater than the heat dissipated (which can occur through conduction, convection, and vaporization), then there is a heat rise in the coal mass. When the temperature gets too high and the coal gets too close to the fire, the coal can eventually burst into flame.

So with that in mind, there are three stages that this oxidation process and moisture absorption go through. At temperatures below 100° C, moisture and oxygen are absorbed onto the coal surface producing CO and CO_2. This is a typical situation in every coal mine. Every coal mine has some background CO in its ventilation system because there is always some self-heating occurring on the coal surfaces. However, the dissipation of that heat, much like rust, produces heat and, therefore, some CO and CO_2 will be evident.

During the next stage, when temperatures are between 100 and 250° C, there will still be the same by-products CO/CO_2, but the rate at which the oxygen is absorbed will increase dramatically. At this time CH_4 is not being produced, but it is driven off the coal. This may produce rises in the methane concentration. When temperatures reach a very high level, greater than 250° C, a critical stage has been reached. Now coal can be pyrolized or decomposed without oxygen. At this stage oxygen in the actual coal molecule can provide the source of oxygen to oxidize other parts of the coal and produce heat. This usually doesn't occur until well above 250°, but at this time you may start to see some hydrogen, and the CO and CO_2 will be going up exponentially.

So what factors can influence when this heating takes place, how fast it takes place, and what stage it's in? There are a number of factors: geologic conditions, mining conditions and mining practices. This explains why one coal that looks and has the same chemical composition as another might self-heat.

Can you characterize a self-heating tendency of a coal based on its properties? Well, there are two things that can produce heat. The first is reactivity of the coal. The second is how much moisture it has in it. If that moisture gets desorbed, the coal can reabsorb moisture and produce heat. Things such as pyrite in the coal can also oxidize to produce heat. There are also properties that can affect the ability of air and water to reach the coal surfaces where the oxidation takes place. This can be due to friability of the coal which generates more fresh surfaces and prior oxidation of the coal through things such as old fire zones.

At NIOSH, a lot of research on reactivity was done a few years ago under the Bureau of Mines. We had an adiabatic oven which used a 100-gram sample; we had an isothermal heating oven which used a 50-gram sample; and we had a moderate-scale, near adiabatic oven, which used about a 6-pound sample. We conducted several large-scale tests where we used about 3 tons of coal and got self-heating to occur, and we also used another research apparatus called an oxygen absorption apparatus.

Most of the research was focused on the adiabatic oven to characterize the reactivity of the coal. We did a lot of tests to evaluate different conditions that the coal might be in-dried versus undried oxygen concentration of the air, effect of the particle size of the coal and moisture content of the air, and the effect of slowing any of these reactions through chemical additives to inhibit chemical reaction. We used an adiabatic calorimeter where air is passed down through the oven to preheat it, up through the coal sample, and out the outlet. The adiabatic condition meant no heat loss. This restriction was monitored by thermocouples just inside the boundary of the coal and out in the oven. As the coal produced heat, the temperature rose relative to the oven temperature.

Four tests were run in each series starting at 90°. The test at 90° was done to obtain a very quick exothermic reaction within 4 hours. At 90°, the coal would have eventually caught on fire. A test done at about 70° has about an 8° temperature rise before it stops rising. A test done at 75° achieved thermal runaway, and at 80°, a little faster thermal runaway occurred. So what we've done is to determine what the minimum self-heating temperature of this coal was. For a sample of Ohio Coal from the Clarion seam, self-heating occurred at 75°.

We came up with a method of characterizing the reactivity of the coal which we called the self-heating temperature of the coal—the minimum initial temperature at which a coal undergoes sustained exothermic reaction in the adiabatic oven.

We analyzed about 40 different coal samples. The highest tested was the Marylee seam coal from Alabama which was the low-vol bituminous coal. It had a minimum SHT of 135° C. The most reactive coal that we looked at was a number 80 seam coal from Wyoming which is high-vol C bituminous. It had a self-heating temperature of 35°. The rest fell in between.

So what does this tell us? This tells us that the number 80 seam coal is more reactive than all of the others. The B seam coal is less reactive than the ones above it, but more reactive than the ones below it. Do these temperatures ever get reached in underground mines? No. What happens in underground mines is that the coal self-heats from whatever the ambient temperature of the seam is, but it is more adiabatic than can be produced in the laboratory, so there will be an increase in temperature. The SHT measures the relative reactivity of the coal.

We did know a number of coal operators who had "sponcom" problems, and through field studies we concluded that any coal that we did in our calorimeter that had a self-heating temperature of less than 70° usually had a self-heating problem at the mine. We defined that as high self-heating potential.

Coals that had a self-heating temperature greater than 100° did not usually have self-heating problems in the field. However, those in the middle sometimes did and sometimes didn't. So we identified them as medium propensity. Depending on other factors, samples in this range may or may not exhibit self-heating under field conditions. Thus, we have a ranking scheme for characterizing the self-heating potential of coal.

Each test takes a couple of weeks to do. We came up with a statistical correlation that showed that we could predict the self-heating temperature by knowing the dry ash free oxygen content of the coal which can be obtained from an ultimate analysis. The relationship was found to be: 140 minus 6.6 times the oxygen content in a dry ash free state. This would be the self-heating temperature. This was good to about a 10% error, and this shows the correlation of the predicted versus the experimental temperatures for 20 coals in this study.

We did experimental self-heating temperature predictions for the E and F seam coals for Colorado, and the predicted temperature for the E coal was 38°. We got 40° in our apparatus. For the F seam, the predicted temperature was 30° and we got 35°. In other words, the higher the self-heating potential, the better the correlation.

How do we use this data? Mining was proposed in Northwest Colorado—longwall mine—where the seam above had undergone spontaneous combustion. The developers wanted to know if they should expect the same kind of self-heating potential in the proposed workings. They applied the formula to all of their drill hole samples and contoured the results on an isothermal map. The highest value was 70°. So the coal is expected to be very reactive. There were some spots that were in the 30° and 35° range. These results justified proposing a bleederless ventilation system to control spontaneous combustion and the design was approved. That is one of the control measures for spontaneous combustion in the regulations now. If you can prove a spontaneous combustion problem, you can at least apply for a bleederless system as a control measure.

So let me get into some of the environmental factors that can affect spontaneous combustion propensity. The first are geologic factors. There are several conditions that can affect the transfer of air and moisture to the coal bed. It has nothing to do with reactivity but whether you can get air and moisture to coal that is very reactive. If a lot of communication exists with the surface, then potential to have air and water paths to gob is high.

The potential for gob heating increases when mining faults. This slows down the mining rate and allows and permits longer contact between ventilating air and the gob, so you're passing air over the same place in the gob for longer than normal which can produce heating. In rare cases, active faults can be a source of heat which also raises the temperature.

Joints similar to faults act as conduits for air and water into the coal bed providing communication with the gob. So, even in sealed areas, air may be reaching the gob.

Clay veins can also slow down mining. Dikes can cause mining delays. Also, the coal around dikes is usually more friable because of the heat attending the event that produced the dike. It can change the coal resulting in more reactive or higher porosity coal.

Cleats may also influence sponcom especially if seals are being installed between pillars. The permeability of the seal may be much less than in the adjacent pillars. In this situation, air may be drawn through the pillar because of the ventilation pressure differential resulting in heating in the pillar next to seals.

We have determined that butt cleat density of four per square foot or more, or one face cleat per square foot, may indicate a problem. This is made worse when the ventilation pressure is high. Features such as channel deposits also slow down the mining and may provide a means for air to get to the coal.

The depth of cover is also important. Shallow coal seams are closer to the surface, and therefore, have a higher chance for air and water conduits to mined out areas. If the cover is greater than 1,000 feet, the ventilation pressures may increase the likelihood of pressure differentials across seals. Simple conditions such as this could be overlooked in examining the potential for sponcom. Rib sloughage and floor heave that commonly occur at greater depth also add coal to the airways. This material is often fine and when exposed to air increases the likely spontaneous combustion.

Geothermal sources may increase the seam temperature. A mine in central Utah a few years ago had a geothermal source and the temperature of the coal increased with every panel. When it got to about 104° F, mining was curtailed because the CO rate was going up so fast a fire was likely and mining was suspended.

Rider seams above the main seam are also reasons to be concerned. This coal will eventually end up in the gob and it will ultimately be ventilated. Therefore, there is potential for this coal to react. How far away riders are from the main seam is important.

Self-heating potential is also subject to ambient temperatures. The rate of reaction doubles for every 20° F increase in ambient temperature. So if ambient temperature is 75° typical of Western coal it would be about four-times more reactive than it would be at a typical Eastern temperature of 55°.

Coal bed thickness is very important. Western coals are thick compared to average eastern conditions roof coal is frequently left for support. This coal ultimately ends up in the gob It's a source of coal particles, and depending on the friability, the ventilation scheme, how much the gob compacts, and the reactivity, it can be a significant cause of sponcom.

Seam gradient can affect migration of air in the gob. This can be a significant factor, if the gradient is 5% or more.

Floor heave may expose broken seams in the floor. It may also contribute to leakage in the sealed areas.

The question has been asked, what's better—longwall or room and pillar? Well, neither is inherently more risky than the other. It depends on the mining conditions and practices, but longwall mining enhances many of these factors due to the formation of the gob and the subsequent ventilation of that gob while mining. So it does increase the risk in that it brings a lot of these factors into play.

The recovery ratio affects how much coal is left in the gob. Recovery depends on the coal thickness, the roof and floor stability, and the coal quality. The decision on how much coal to mine is not likely to be made on the basis of sponcom potential. However, being aware of the situation can assure that more preventive measures are taken along with more monitoring for detection of combustion products. Many site factors can't be controlled. It is, however, important to be aware that some of them may increase the risk of sponcom.

Design of a longwall operation can influence the sponcom potential. If yielding pillars are employed, they will eventually end up as a coal source in the ventilated gob. If stiff pillars are used, they will not contributed directly to the source of coal in the gob but may exacerbate floor heave and rib sloughage which may have the same result.

How large the panel is makes a difference, but width is more critical than length. In wide panels, the air comes across ventilating behind the shields. The velocity is fairly high so that heat generated by the oxidizing coal is dissipated. In the high velocity zone, there generally isn't a problem. On the fringes of the compacted gob, the velocity is so low that not enough oxygen is supplied to sustain the reaction. Somewhere in between is an area called the critical velocity zone. The ventilation velocity is enough to deliver the oxygen but not fast enough to carry away the heat that is being produced. If the longwall ceases to advance, air keeps passing through the critical velocity zone, and the temperature begins to increase. CO monitors may indicate an increase in combustion products. Wider panels move forward at lower rates, and the critical velocity zone stays in the same place longer. If no increase is noted by the monitors, then the face is advancing at an appropriate pace. If CO is increasing it means that the critical velocity zone is too long or extends into the gob too far. That's why face ventilation velocity is a critical environmental factor and this factor depends on width of the face as well as the advance rate.

So what can be done to minimize the adverse factors. A computer program called SPONCOM has been developed which considers geological factors, mining conditions, and mining practices as well as the coal characteristics. The program takes the user through a Windows-based computer program that asks things such as the width and thickness of the seam and the ambient temperature. It takes that information, combined with the reactivity of the coal, provides the rank and predicts self-heating temperature of the coal, and determines whether or not conditions or practices increase the risk of spontaneous combustion. If they do, it identifies them and provides a measure of the degree of risk.

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