PRB COAL DEGRADATION – CAUSES AND CURES

By

Roderick J. Hossfeld
Jenike & Johanson, Inc.
1 technology Park Drive
Westford, MA 01886-3189
978.392.0300 (voice) 978.392.9980 (fax)
rjhossfeld@jenike.com

Rod Hatt
Coal Combustion Inc.
114 South Main Street
Versailles, KY
(voice) 859.873.0188
rod_hatt@coalcombustion.com

Introduction

The coals produced in the Powder River Basin (PRB) are environmentally and economically attractive to power companies. This type of coal has made enormous inroads to power plants due to this regardless of any difficulties plant personnel might experience. The difficulties in handling and storing PRB coal are due to fines generation and spontaneous combustion issues. Many have worked on addressing these concerns and how we can improve our utilization of these fuels. (1-10)(Refer to Appendix A for some basic bulk solids handling considerations for PRB coal.)

PRB coal is extremely friable and will break down into smaller particles virtually independent of how the coal is transported or handled. PRB represents the extremes of handling problems: *dust* is an issue when the coal is fine and dry. Bunker and chute *plugging* is an issue when the same fine coal is wet. Once the coal is exposed by mining, the degradation process begins – the majority of the damage can occur in a very short time, even as short as a few days. The extent of the degradation that occurs depends in large part on the distance to the plant from the mine, i.e., how long the coal is exposed to the atmosphere during transportation. Additional factors such as crushed run of mine (CROM) size, and specific handling procedures also impact the degradation process. Additional decomposition occurs during handling and storage in a pile and bunker, bin or silo. We believe that the root cause of the degradation is loss of moisture that impacts the coal both mechanically and through the generation of additional surface reaction area, chemically. The combination of the two is what makes PRB coal so difficult to handle.

This paper focuses on the mechanisms, both inherent and external, that cause this rapid degradation of the coal particles, and poses some of the questions that could lead to preventing, or at least retarding the degradation of the particles, and thus avoid the results of the associated problems with handling and storage, such as dust, perceived loss of inventory, bunker hang-ups and especially spontaneous combustion.

What is PRB coal?

The Powder River Basin extends from Wyoming into Southeast Montana, with the bulk of the PRB coal being supplied from the Southern Powder River Basin (Wyoming). PRB is classified by the American Society for Testing and Materials (ASTM) as a sub-bituminous A or B (11)coal. Scientists report that these coals have been burning naturally for over 2 million years. Early Native Americans held these coal fired lands to be spiritual. Prehistoric inhabitants of the PRB used porcellanite as weapons and tools. Procellanite is formed from the intensively coal baked shale or siltstone near or in the coal as it burned. You would know this material as slag. The fires are in part caused by the spontaneous combustion of coal. These same properties show up at the plant as hot coal, fires and explosions. While low in sulfur (0.4 to 1.4 LB/MMBTU), PRB coal is also low in heating value (8,000 to 8,800 BTU/LB, on an as received basis for Southern PRB, with one or two mines in the north going as high as 9,400 BTU/LB). Additionally, its friability results in fines and, when dry, the dust (Fig. 1) increases the explosion hazard potential. On the other hand, this same fine coal can be high in moisture content (Fig. 2), which increases its handling difficulty in equipment. Most of the plants currently burning or converting to burn PRB coal have difficulty with these characteristics.

Fig. 1 PRB coal – “dry”

Fig. 2 PRB coal – “wet”

PRB coal is relatively low ranked. This means that the coal is relatively young. Specific ASTM ranking is just a laboratory method for drawing a line in the sand to differentiate different types of coals. It is basically describing the geological process of transforming plant material to anthracite. The first phase of coalification (fossilization) is to preserve the plant material from oxidation. This peat moss like material is still basically plant material. The first coal like material formed is lignite, or brown coal. The coalification process basically squeezes out oxygen and water. As the plant material becomes less like wood and more like oil, the pore structure constricts limiting the water retention capacity of a coal Chemically, as the oxygen content decreases the coal becomes more hydrophobic or water repelling (water and oil don’t mix). This water retention capacity is measured using the equilibrium moisture test. Sub-bituminous coals like the PRB coals are the next step in the coal ranking system. Then comes the low ranked Bituminous C type coal. This is the ranking of many Illinois Basin coals. The higher ranked Bituminous B and C coals are generally found in the Appalachian coalfields. Most of the coal tests that ASTM has standardized were written around higher ranked bituminous and anthracite coals. The tight pore structures of these coals limited the amount of inherent moisture they could hold. Typically these high ranked coals have equilibrium moistures of 1-10. The first step of determining coal quality in the lab is to air-dry the sample to near equilibrium with the laboratory humidity levels. This is done to minimize any impact on lab results of additional drying or absorption of water from the air. In high rank coals, the moisture lost in the air-drying step is near equivalent to the surface moisture.

The residual moisture is that moisture that is still locked up in the coal after air-drying. The higher ranked coals that ASTM standards were based on possess this well-defined split between the air-dried or surface moisture and the residual or near equilibrium moisture. This is not the case for low rank coals like PRB coal. The sponge-like or wood like nature of PRB coals make the split between surface moisture and inherent moisture a rather fuzzy line.

Most of the quality differences between PRB coal and the higher ranked coal can be explained by understanding that the PRB coal has this looser pore structure and additional moisture retention capacity. PRB coal also has more oxygen chemically bonded to the coal and this make the coal hydrophilic (water liking). This helps explain why the PRB coal is likely to reabsorb water after it has dried and degraded.

Self-heating characteristics

Spontaneous combustion of coal is a well-known phenomenon, especially with PRB coal. This high-moisture, highly volatile sub-bituminous coal will not only smolder and catch fire while in storage piles at power plants and coal terminals, but has been known to be delivered to a power plant with the rail car or barge partially on fire. An “explosive” case study [1] was presented at the PRBCUG (Powder River Basin Coal Users Group) Annual Meeting in Houston, March 2003 that is a case in point. The dust in a tripper room ignited, causing a major explosion at Wisconsin Public Service J.P. Pulliam Generating Station in Green Bay Wisconsin in June 1991. At the time, the plant was burning a 50/50 blend of PRB coal and bituminous coal, and a fire existed in one of the coal bunkers. Dust within the atmosphere of the tripper room was ignited by a minor explosion, or *puff*, within the bunker, which triggered a massive explosion in the tripper room, blowing out the outer building walls and roof. While fires prior to this were not uncommon with bituminous coal in the bunker, this was the first serious dust explosion.

Figure 3. Tripper room after explosion at WPS J. P. Pulliam Generating Station

The coal properties that affect spontaneous combustion risk include:

- Moisture content of the coal or how much drying and rewetting it has been exposed to.
- Friability or how much size degradation occurs.
- Particle size or exposed surface reaction area.
- Rank, PRB coal contains a high percentage of reactive components that tent to decompose as a coal's rank increases to Bituminous and Anthracite.
- Pyrite concentrations greater than two percent (PRB coal is low in pyrite so at least it is not impacted by this

(portions of this section from (12)(Kim 1977)

These properties primarily influence the rate of heat generation during the self-heating of coal. Since most of the combustible matter in coal is carbon, when coal stored in an atmospheric environment, the carbon slowly oxidizes to form carbon dioxide and carbon monoxide. PRB coal is also one of the highest hydrogen content coals. The oxidation reaction of hydrogen forms water. The production of both water and carbon gases in the coal will not help the situation. These reactions produce heat; since coal is a relatively good insulator, much of this heat is trapped, increasing both the temperature and the rate of oxidation. Depending on how the coal is stored, heat production may substantially exceed heat loss to the environment, and the coal can self-ignite.

Self-heating occurs when the rate of heat generation exceeds the rate of heat dissipation. Two mechanisms contribute to the rate of heat generation, coal oxidation and the adsorption of moisture. The reactivity of coal is a measure of its potential to oxidize when exposed to air. The mechanism of coal oxidation is not completely understood. The coal's minimum Self Heating Temperature (SHT) is sometimes used as a relative indication of its reactivity. There are various methods used to determine a coal's minimum SHT, but they all require running a test in real time and monitoring the temperature of the coal as any reaction occurs. These tests are typically a relative measure of a coal's propensity to self-ignite. In general, a coal's reactivity increases with decreasing rank.

The moisture content of a coal is also an important parameter in the rate of heat generation of the coal. Drying coal is an endothermic process, in which heat is absorbed, and the temperature of the coal is lowered. The adsorption of moisture on a dry coal surface is an exothermic process, with a heat producing reaction. If it is partially dried during its mining, storage, or processing, coal has the potential to readsorb moisture, thus producing heat. Therefore, the higher the moisture content of the coal, the greater the potential for this to occur. The most dangerous scenario for spontaneous combustion is when wet and dry coal are combined; the interface between wet and dry coal becomes a heat exchanger (13) (Smith and other 1991). If coal is either completely wet or completely dry, the risk is substantially reduced. In general, the moisture content of coal increases with decreasing rank. For example, PRB coal has a higher inherent moisture content than bituminous B type coal.

The oxidation of pyretic sulfur is also a heat producing reaction. The heat generated can cause the temperature of the surrounding coal to increase, thus increasing the rate of oxidation. Also, as it oxidizes, the pyretic sulfur expands, causing coal degradation to occur. Reactions involving reactive components of the PRB coal, can also be a source of heat generation.

Friability and previous oxidation of the coal are also important factors in the self-heating process. The friability of the coal is a measure of the coal's ability to break apart into smaller pieces. This exposes fresh coal surfaces to air and moisture, where oxidation and moisture adsorption can occur. Previous oxidation makes coal more friable. Although the oxidized matter is less reactive, the porous nature of the oxidized coal makes the coal more susceptible to air and water leakage when exposed to higher pressure differentials, such as in a pile or bunker.

Causes of degradation

From the time it leaves the mine, PRB coal starts to degrade. The most dramatic result of this can be found by observing the top surface of an open railcar delivering PRB coal to the plant from the mine. The large particles have distinct cracks and will shatter into smaller pieces when dropped from a height of only 6 feet. Particles contained deeper in the bed of coal within the railcar do not appear to be similarly affected.

The root cause of this degradation of PRB is the drying and resultant cracking and particle size degradation and oxidation. There are many variables that are potential contributors to attrition of PRB coal once it is exposed to air: ambient temperature (heat), moisture (addition and loss), compaction, impact (drop height), interparticle motion (due to general handling), and time. It is felt that all of these impact the total degradation process, however the loss of moisture appears to dominate the process.

The moisture that contributes to the problem of spontaneous combustion comes from humidity and from other PRB. New PRB added over old PRB seems to create more heat at that interface. The fine particles typically have a higher total moisture content compared to the coarse particles, due to their larger surface area per unit volume. See Figure 4 below for size verse surface area relationship.

Test program

The test program investigated the influence of one variable on the degradation process – *time*. In a relatively dry environment as time proceeded the coal dried out. As the coal dried out it cracked and broke down into smaller particles The role that particle size plays in this effect can be investigated by exposing large and small particles to a controlled environment (temperature and moisture) and monitoring the weight loss (moisture or volatiles loss) over time.

Two different types of tests were run.

Test Program 1. The first test simply allowed large PRB coal particles to sit at ambient conditions (inside a building) for 6 days while photos were taken.

Test Program 2. The second test placed both fines (-1/4 in. particles) and coarse (3 inch particles) in an environmental chamber at controlled conditions (72°F and approximately 45% Relative Humidity, with some excursions) for 16 days.

Results of test program 1

The first test simply allowed large PRB coal particles to sit at ambient conditions (inside a building) for 6 days while photos were taken. To see the results of this test, refer to the series of photos of one such particle in Figures 4a – 4f.

Figure 4a. PRB coal at start of test.

Figure 4b. PRB coal after 5 hours.

Figure 4c. PRB coal after 2 days.

Figure 4d. PRB coal after 4 days.

Figure 4e. PRB coal after 6 days.

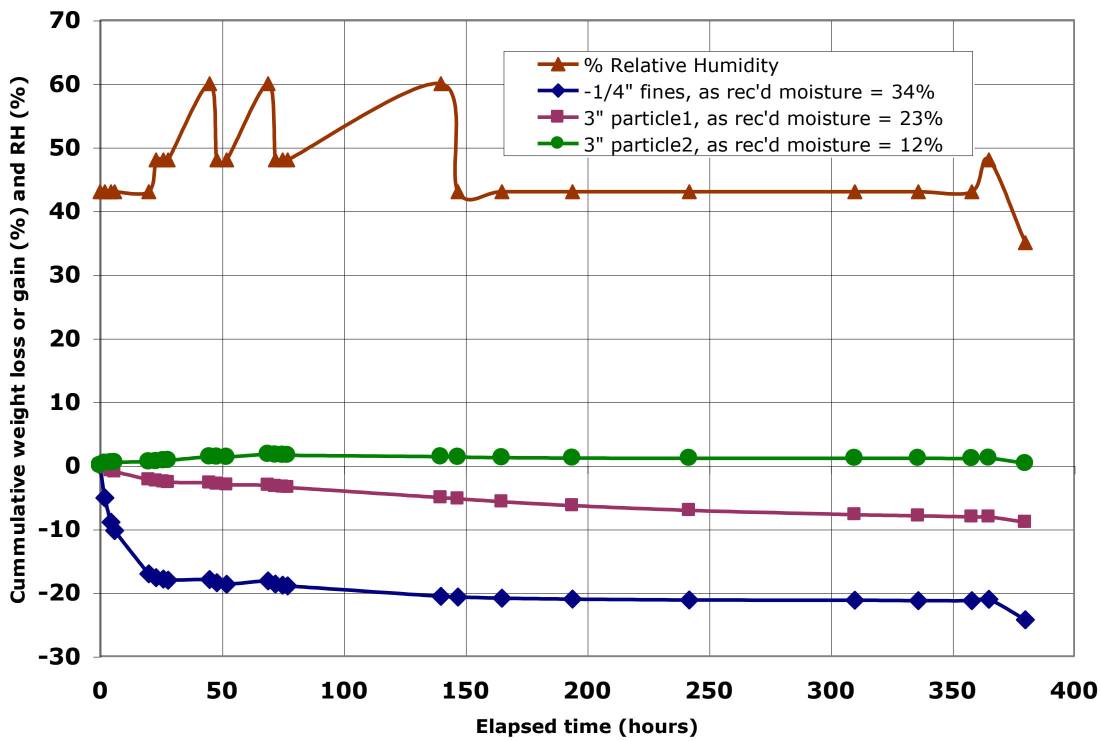
Figure 4f. PRB coal after 6 days.

As is evident from the photos, degradation of the coal starts immediately upon exposure to the environment. In fact, cracks started to appear within one hour after the start of the test.

Results of test program 2

Three samples of fines (-1/4 in. particles) and three samples of coarse (3 inch) particles were placed on individual trays and placed in an environmental chamber. The temperature was kept constant at 72°F and the Relative humidity at approximately 45% RH (with some excursions) for 16 days. The weight of the samples was monitored and recorded over that time period. The temperature of the coal was monitored also, using a thermocouple, but no change in temperature of the samples was noted. It was not anticipated that any heat would be generated because drying of coal (loss of moisture) is an endothermic reaction. It is likely that even if any small amount of heat were generated due to the slight gain in moisture (exothermic reaction) on one of the large particles, the heat would quickly dissipate because the coal surface area was relatively small compared to the environmental room. The effect of moisture addition on heat generation is a good candidate for further study. The results of this test are shown in Figure 4.

Figure 5. Cummulative % Moisture/Volatiles Loss/Gain for PRB Coal exposed to atmosphere



The moisture values were determined by drying small samples at 107°C in a forced convection oven and recording the weight change, until no additional weight loss was recorded. The loss in weight of each sample, divided by its original weight before drying, is denoted as the *moisture*. The fines, with an *as received* (starting) moisture of 34%, lost the largest percentage of weight (18%) during the first 24 hours compared to the coarse particles. One coarse particle (particle2) with a starting moisture of 23%, lost only 3% of its weight during the first 24 hours and 9% over 16 days; another coarse particle (particle 1) with a starting moisture of only 12%, actually *gained* weight (0.75% in 24 hours, with a net gain of 0.3% over 16 days). The moisture content of the samples at the end of the test is essentially the *equilibrium* moisture. This was determined to be approximately 10% for the fines and 13% for the coarse particles. As shown in Figure 4, the *rate* of moisture loss (or gain) decreased well before the test ended. For example, both the fines and coarse Particle2 approached their *equilibrium* moisture content after 7 days. However, Particle1 still had not reached its *equilibrium* moisture by the end of the test (16 days).

Test conclusions

One of the six samples, large particle2, showed an indication of the potential for coal to adsorb more moisture. If more moisture, i.e., humidity, were available, it is likely that particle2 had the potential for adsorbing more moisture, setting up the conditions for self-heating. As discussed previously, the adsorption of moisture on a dry coal surface is an exothermic process, with a heat producing reaction. A Wyoming University/Wyoming State Geological Survey (xxx) study found that larger, partially dried particles produce heat as they adsorb moisture. However, as was the case with our tests, the Wyoming study dealt mostly with dry coal, so data on this effect is limited.

Preventing and/or retarding degradation

Some of the same procedures that are followed to minimize the potential for spontaneous combustion can be followed to prevent particle attrition:

Coal Handling

- Any process that can keep the coal from additional drying
- Larger slower moving belts
- Shorter free falls, especially in open air in windy conditions

Coal pile

- Sealing the pile minimizes air ingress and air movement in the pile. This also helps prevent moisture loss and size degradation.
- Protecting the pile from the wind. A steeper slope creates greater wind resistance, forcing air into the pile. Protecting the pile from the wind (e.g., wind screens) minimizes air movement through the pile.
- Minimizing drop heights to control drying and attrition due to impact.

Coal bunker

- Minimizing drop heights to control drying and attrition due to impact.
- Design for a mass flow pattern (see Appendix A).
- Provide an inerting agent or atmosphere (not recommended on a normal basis)

Considerations for further study

The effect of moisture addition on heat generation is a good candidate for further study. Particles that are partially dried could be subjected to varying levels of increased relative

Humidity, while monitoring the internal temperature of the large coal particle or bed of coal fines. References

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