

COAL DUST EXPLOSION HAZARDS

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ABSTRACT

There are a large number of facilities throughout the world which handle coal, such as preparation plants. Many other facilities use coal as a fuel, such as cement and lime factories. Although coal can be handled safely and can be an efficient fuel, there are explosion hazards which are accentuated as the particle size is reduced. Particle sizes of coal which can fuel a propagating explosion occur within thermal dryers, cyclones, baghouses, pulverized-fuel systems, grinding mills, and other process or conveyance equipment. This paper discusses how explosions can occur within these facilities.

FIRE TRIANGLE AND EXPLOSION PENTAGON

There are three necessary elements which must occur simultaneously to cause a fire: fuel, heat, and oxygen. These elements form the three legs of the fire triangle. By removing any one of these elements, a fire becomes impossible. For example, if there were very little or no oxygen present, a fire could not occur regardless of the quantities of fuel and heat that were present. Likewise, if insufficient heat were available, no concentrations of fuel and oxygen could result in a fire.

On the other hand, for an explosion to occur, there are five necessary elements which must occur simultaneously: fuel, heat, oxygen, suspension, and confinement. These form the five sides of the explosion pentagon. Like the fire triangle, removing any one of these requirements would prevent an explosion from propagating. For example, if fuel, heat, oxygen, and confinement occurred together in proper quantities, an explosion would still not be possible without the suspension of the fuel. However, in this case, a fire could occur. If the burning fuel were then placed in suspension by a sudden blast of air, all five sides of the explosion pentagon would be satisfied and an explosion would be imminent.

Remembering the three sides of the fire triangle (fuel, heat, oxygen) and the five sides of the explosion pentagon (fuel, heat, oxygen, suspension, confinement) is important in preventing fires and explosions at any facility. By eliminating the possibility of either suspension or confinement, an explosion cannot occur, but a fire may occur. By eliminating the fuel, the heat, or the oxygen requirements, neither a fire nor an explosion can occur.

Fuel

Coal, as a primary fuel, must meet several requirements in order to be explosive. These requirements are volatile ratio, particle size, and quantity. The volatile ratio is a value established by the former United States Bureau of Mines to evaluate the explosibility of coals based on large-scale tests in the Experimental Coal Mine. To calculate the volatile ratio, a proximate analysis must be performed in the laboratory on a sample of the coal. This analysis determines the volatile matter and fixed carbon quantities of the coal along with moisture and ash. The volatile ratio is defined as the volatile matter divided by the summation of volatile matter and fixed carbon of the coal.

This method for calculating the volatile ratio produces a value independent of the natural or added incombustible in the coal. It has been determined that coals with a volatile ratio exceeding 0.12 present a dust explosion hazard. All bituminous coals fall into this category. Since anthracite coals, by definition, have a volatile ratio of 0.12 or less, they do not present an explosion hazard. It is important to note that both bituminous and anthracite coals can be involved in fires, but only bituminous coals can be involved in explosions.

Another important requirement of the fuel is related to particle size. Experiments have shown that bituminous coal particles passing through a U.S. standard 20-mesh sieve can participate in a coal dust explosion. A 20-mesh sieve allows particles up to 841 microns or about 0.03 inch to pass and these are the largest particles that contribute to a coal dust explosion. As the particle size is reduced even further, a more severe explosion hazard is realized. Typically, in pulverized-fuel systems, the coal is reduced to a particle size where more than 85% will pass a U.S. standard 200-mesh sieve with openings of 74 microns or about 0.003 inch. These coal dust particles require less energy or temperature to ignite and, since heat transfers more quickly between smaller particles, the pressure and rate of pressure rise during an explosion are accentuated.

The third requirement for explosibility is related to the quantity of coal dust available, known as the minimum explosive concentration (MEC). This is the minimum quantity of dust in suspension that will propagate a coal dust explosion and generate sufficient pressure to cause damage. The MEC for bituminous coal is approximately 0.10 ounce per cubic foot or 100 grams per cubic meter. When pulverized coal dust at the MEC was dispersed in an entry, a cap lamp 10-feet within the cloud was not visible to observers standing in front of the dispersed dust. Also, a person cannot breathe in an atmosphere containing dust at the MEC. This amount of dust in the air is 25,000 times greater than the average concentration of respirable dust to which a coal miner may be exposed during an 8-hour shift. A layer of pulverized coal dust at the MEC deposited on the floor of the Experimental Coal Mine in Bruceton, Pennsylvania averaged 0.005-inch thick. This thickness is almost unobservable. In other words, if footprints are visible in coal dust on the floor or the coal dust is seen on the walls of a plant, then there is enough coal dust at that particular location to propagate an explosion.

The upper explosive limit is not well-defined and experiments have shown that a coal dust loading of 3.8 ounces per cubic foot would propagate a low-velocity explosion and that a 5.0 ounces per cubic foot loading would quench itself within 10 feet of ignition. The presence of other flammable dusts or gases can lower the MEC of the coal, which increases the hazard. On the other hand, the hazard can be lessened with the addition of ash, rock dust, inert gas, and any other inert material.

Heat

The heat requirements to complete the fire triangle or the explosion pentagon can be in the form of temperature or energy. The ignition temperature of a coal dust cloud decreases as the volatile content increases. At high volatile contents, the ignition temperature of a coal dust cloud approaches a limiting temperature as low as 440°C (824°F). The ignition temperature of a Pittsburgh Seam coal dust cloud is fairly constant as the particle size increases to about 180 microns. Further increases in size result in rapid rise in the ignition temperature requirements. As the particle size decreases, the coal dust becomes easier to ignite.

The ignition temperature of a coal dust layer also decreases as the volatile content increases. At high volatile contents, the ignition temperature of a coal dust layer approaches a limiting temperature as low as 160°C (320°F). With dust layers on hot surfaces, the minimum ignition temperature decreases sharply as the thickness of the deposit is increased. This is due to the

fact that thicker dust layers capture and hold heat more readily. To illustrate the variety of coals, the minimum ignition temperatures to ignite clouds of various ranks of coal are as follows:

Coal Rank or Type	Minimum Ignition Temperature (°C)
Pocahontas Seam bituminous	610
Pittsburgh Seam bituminous	525-560
Sub-bituminous blend (as received)	475
Sub-bituminous blend (dried)	455
Lignites (as received)	450-600
Lignites (dried)	425-555

Visually, a temperature of approximately 537°C (1000°F) is obtained when an object is heated to a dull red in a darkened room. Resistors in controllers or other electrical components may exceed this temperature. Also, temperatures at the top of a 200-watt incandescent bulb approach 250°C and, at the top of a 1500-watt incandescent bulb, can exceed 300°C.

There is also a variation in the minimum ignition temperature of coal dust layers as follows:

Coal Rank or Type	Minimum Ignition Temperature (°C)
Pittsburgh Seam bituminous	170
Rhode Island (Cranston) anthracite	520
Illinois No. 7 bituminous	160
Pocahontas Seam bituminous	220

Electrical or frictional sparks can also provide the heat source for initiating a fire or explosion. Experiments have shown that a coal dust cloud can be ignited directly by frictional sparks in the absence of methane. Dust clouds of lignite and sub-bituminous coals can ignite with as little as 30 millijoules of energy. Bituminous coal from Kentucky and from the Experimental Coal Mine (Pittsburgh Seam) in Bruceton, Pennsylvania required 30

and 60 millijoules, respectively, as the minimum ignition energy of a cloud. Below a moisture content of between 5%-8%, there is no effect on the explosibility parameters for minus 200-mesh Pittsburgh Seam coal dust. Beyond 8% moisture, the minimum amount of energy required for an explosion increases dramatically and, at 15% moisture, about ten times more energy is required.

Also, the minimum ignition energy of coal dust varies with oxygen content of the atmosphere, volatile content, and the amount of fine dust that will pass a U.S. standard No. 200-mesh sieve (74 microns). Coals are easier to ignite with increases in the oxygen content, or the volatile content, or in the amount of fine coal. However, there is a limiting value of minimum ignition energy which varies for each coal.

All coal dusts should be regarded as prone to ignition when exposed to the frictional sparks of badly maintained machinery or when they become contaminated with tramp metal. For mixtures of coal dust and flammable gas, the critical minimum ignition energy is that which affects the gas. When ignited, the gas releases sufficient energy to suspend and ignite a coal dust cloud.

Oxygen

As the volatile content of a coal increases, less oxygen is required to complete the fire triangle or the explosion pentagon. Less oxygen is also required as the rank of the coal decreases. Semi-anthracite has a very low volatile content and lignite is at least as volatile as high-volatile bituminous coals. However, at ambient temperatures, the oxygen content must be reduced to below 13% to prevent ignition of bituminous coal dusts with a strong ignition source.

Suspension

For fires to occur, suspension is not a necessary step but completion of the explosion pentagon does require that the fuel be placed in suspension. There is certainly danger present whenever coal dust is placed in suspension because, in most circumstances, it need only find a heat source to initiate an explosion. If a coal dust layer on the floor is smoldering, an explosion is imminent if the layer is somehow placed into suspension. In this case, heat to satisfy the fire triangle and the explosion pentagon is already present.

The speed and duration of the moving air in an explosion is capable of dispersing additional coal dust from the floor, walls, overhead beams, and equipment. A hurricane causes substantial damage when the wind speed is 150 to 200 miles per hour (230 to

290 feet per second). In most coal dust explosions, the air speed exceeds 200 miles per hour. In fact, a coal dust explosion will generally die out if the air speed is less than 100 miles per hour (150 feet per second).

The maximum explosion pressure developed is about 90 psig for Pittsburgh Seam coal. The maximum rate of pressure rise for Pittsburgh Seam coal is 2000 psi per second. These parameters are important in predicting the violence or destructive powers capable of being generated when a particular dust is suspended and ignited. Since the maximum pressure is 90 psi for Pittsburgh Seam coal and the rate of pressure rise is 2000 psi per second, it is easily seen that only about 0.045 seconds elapse before the maximum pressure is realized. In a pulverized-fuel system using Pittsburgh Seam coal and designed to withstand 50 psi, vents must rupture within 25 milliseconds, otherwise pressures become excessive and equipment in the system is destroyed.

Good housekeeping practices are extremely important inside a plant because process equipment is not always able to withstand the internal pressures generated by an explosion. Once the explosion flame and pressures burst from the confinement into the plant, a secondary explosion may be fueled by any additional dust suspended by the blast. When good housekeeping practices have eliminated coal dust in the plant, there would not be any fuel to allow a continuation of the explosion flame. This secondary explosion is responsible for the most damage to the plant itself. Also, the secondary explosion is usually responsible for the loss of lives or the serious injuries to personnel that occur.

Confinement

Confinement is not a leg of the fire triangle, but to complete the explosion pentagon, it is essential. Basically, confinement keeps the fine coal particles in close proximity after they are placed in suspension. Without the closeness, heat transfer could not occur rapidly enough to allow continued propagation. Without confinement, a propagating explosion is not possible, but rather, only a large fireball with no appreciable forces associated with it. If an explosion is vented to the atmosphere outside the plant, confinement is eliminated and only part of the coal forced out of the vent will be burned, with the remaining unburned coal falling to the ground. As with the suspension leg of the explosion pentagon, if confinement is lost, the air speed will drop, additional coal dust will not be placed in suspension, and the explosion will extinguish.

EQUIPMENT CONSIDERATIONS

There are many explosion hazards associated with facilities utilizing pulverized-fuel systems. However, with an understanding of the explosion phenomena, these types of accidents can be avoided. The same knowledge applies to preparation plants where large tonnages of coal are processed. Each area where coal is handled and each piece of equipment in the process poses individual hazards. Some of those areas and equipment are discussed in subsequent sections of this report.

Raw Coal Stockpile

The raw coal for a pulverized fuel system is usually received from a variety of sources and the size is generally limited to approximately 2 inches or smaller. This raw coal is typically stored on an outside stockpile where it is moved around by front-end loaders. The fire and explosion hazards associated with this stockpile are usually limited to spontaneous combustion. Hot material must never be loaded into the pulverized-fuel system. There is a definite possibility of an explosion occurring within the pulverizer because all sides of the explosion pentagon could occur simultaneously. It is recommended that these hot spots be removed from the coal stockpile and spread until cooled.

Raw Coal Storage Bin

If there are no hot spots in the coal, the front-end loader will load the coal onto a conveyor belt, which feeds a coal storage bin. These bins are usually equipped with mechanical sensors to detect high-level or low-level coal storage. There is also an emergency chute for unloading the bin in the event of a problem inside the bin. Coal in the bin may be susceptible to spontaneous combustion; however, some airflow is required to provide the oxygen necessary for heating. However, thermocouples are sometimes located inside the bin to give warning of a fire, but carbon monoxide sensors would be more reliable for detecting an incipient fire. The raw coal empties from this bin onto a weigh scale. The weigh scale is a short conveyor belt that monitors the weight and the feed rate of the raw coal to the pulverizer. When any problems are detected in the system, the coal feed to the pulverizer is stopped completely.

Coal Pulverizer

Under normal operating conditions, coal is dropped from the weigh scale into a rotary airlock before it enters the pulverizer. The rotary airlock allows the coal and its inherent moisture to enter the pulverizer, but prevents any outside air from entering the system. Generally, the outside air has a higher oxygen content than the air circulating in the system and this additional oxygen

could lead to completion of the explosion pentagon and potential disaster.

Coal that passes through the rotary airlock falls on the grinding table inside the pulverizer. The coal feed rate and the size of the grinding table are variable. For example, a C. E. Raymond 443 Roller Mill has a table diameter of 44 inches and 3 grinding rollers and, reportedly, can handle up to 25 tons per hour of raw coal. The coal is ground between the rollers and the rotating grinding table and is thrown outward by centrifugal force. It is typical for a mill to pulverize the coal to where 85-97% of the coal will pass a U.S. standard No. 200-mesh sieve. The finer the coal, the greater the explosion hazard.

As the coal is being ground, hot air enters the bottom of the pulverizer and passes up through the pulverizer. The air is used for its drying and conveyance abilities. This hot air can come either from the clinker cooler or can come from the kiln hood. However, hot air from the clinker cooler is generally around 400°F as opposed to hot air from the kiln hood which is between 900°F and 1200°F. These elevated temperatures can lead to heating in any coal that has deposited along internal surfaces.

The main explosion hazard associated with a pulverizer is related to start up and shutdown procedures. When a system goes down under load, all the coal falls out of suspension. The internal surfaces are at elevated temperatures and the process of spontaneous combustion begins immediately. If the system is then restarted without full knowledge of internal conditions, an explosion could occur when the hot particles are suspended.

Primary Fan

The drive motor at the base of the mill can provide power for both the mill and the primary air fan, if the fan does not have a separate motor. The one advantage to having a single-drive motor is economical. The major disadvantage is that, in the event of a pulverizer shutdown, there is no way to pneumatically clear the coal out of the mill because the primary fan would also be down. This could lead to spontaneous combustion problems inside the mill that would make restarting the system hazardous. Before restarting, it must be verified that no hazardous conditions exist within the system.

The primary fan does force the coal particles into the kiln. If this fan is downstream from the pulverizer, it exerts a negative pressure, or suction, on the pulverizer. With higher pressures outside the pulverizer, typically nothing leaks out while a little air may leak in. However, a disadvantage to this sequence

is the fact that pulverized coal will pass through the rotating blades of the primary air fan. This is not a problem unless an ignition source occurs within the fan. On the other hand, if the primary air fan is upstream of the pulverizer, then it exerts a positive pressure on the pulverizer. In this case, fine coal particles may find their way out of the mill through any small crack or fracture in the mill or through parts of the mill that are not well sealed. This leads to accumulations of coal dust in the plant and, if an explosion ruptures the pulverized-fuel system, it could use this coal dust as additional fuel for a serious secondary explosion.

Dust Cyclone

After the coal has been pulverized to a fine enough size, the circulating air lifts it out of the top of the pulverizer and through a classifier. When these fine coal particles pass out of the classifier, they may be transported through a duct leading to a dust cyclone. The coal-dust-laden airstream enters the cyclone where separation of the pulverized coal and circulating air is accomplished. The cyclone is designed such that the pulverized coal falls into the bottom of the cyclone, while the clean circulating air is allowed to pass out of the top of the cyclone. However, the cyclone is capable of removing approximately 95% of the coal fines from the circulating air. The other 5% of coal fines will pass out of the top of the cyclone and continue through the system fan.

A limited amount of coal is stored in the base of the cyclone for a short period of time. The rotary valve then feeds the coal into the airstream of the primary air fan. Immediately, the coal dust is blown into the kiln. It has been reported by an operator of a semi-direct system that only about 25 pounds of fine coal dust would be in the cyclone at any time. Without any bulk storage of pulverized coal in the system, a shutdown of the pulverizer will stop the continuing coal feed to the kiln.

System Fan

The clean air that flows out of the top of the cyclone passes into the system fan. Primarily, the system fan provides an airstream to transport fine coal from the pulverizer to the cyclone. Basically, the circulating air travels in a loop comprising the system fan, the pulverizer, the dust cyclone, and the connecting ducts. In this respect, the air provided by the system fan enters the pulverizer, but only that air passing through the primary fan enters the kiln.

As previously stated, the pulverized coal does not pass through the blades of any operating fan. The fact that the system fan is a clean fan is an advantage. However, when discussing the dust cyclone, it was mentioned that about 5% of the coal fines are not removed. This indicates that accumulation of coal fines can occur in the closed loop, including the system fan. With sufficient fuel and oxygen in an area, only an ignition source need be present for a fire or explosion to occur. Along these lines, start-up and shutdown are critical times. During shutdown, an accumulation of coal may begin to smolder in a state of spontaneous combustion. If this condition is not detected before start-up, the smoldering coal could be placed into suspension by the system fan and the five sides of the explosion pentagon would be satisfied.

Baghouse

The air that passes out of the top of the cyclone, with the 5% coal dust, is transported to a baghouse. This baghouse is designed with many filter-type bags hanging vertically, which are capable of removing the remaining coal dust from the circulating air. In the baghouse, all the coal dust is captured in filter-type bags and the air circulating from the system fan is vented to the atmosphere. The primary advantage is twofold: first, all coal dust can be used as fuel; secondly, the air vented to the atmosphere carries a high-moisture content and is not recirculated through the system. This allows hot, dry air from the kiln hood or clinker cooler to be mixed with air from the system fan before entering the pulverizer. The moisture content of this air is lower than that which is vented to the atmosphere from the baghouse because it is not involved in coal drying until it enters the pulverizer.

Kiln

After the coal-laden primary air passes through the primary air fan, it is blown through the burner pipe and directly into the kiln. The burner pipe is a long cantilever, which can extend 35 feet or more into the kiln, but is usually limited to 10-15 feet. The rotation and slope of the kiln cause the raw material to fall towards the lower end of the kiln where the burning zone is located. It is in this burning zone that the process of transforming the raw material to clinker takes place at around 2800°F. This temperature and the length of the flame are directly related to the volatile matter and the moisture in the coal.