Spontaneous Combustion of Coal

By
K. P. Shah
Email: kpshah123[at]gmail.com (Please replace [at] with @)
Committed to improve the Quality of Life

For more articles on mechanical maintenance, visit www.practicalmaintenance.net

The information contained in this article represents a significant collection of technical information about spontaneous combustion of coal and care to be taken for their use in a power plant. This information will be also useful for coal storage and coal transportation. This information will help to minimize accidents and achieve increased reliability at a decreased cost. Assemblage of this information will provide a single point of reference that might otherwise be time consuming to obtain. Most of information given in this article is mainly derived from literature on the subject from sources as per the reference list given at the end of this article. For more information, please refer them. All information contained in this article has been assembled with great care. However, the information is given for guidance purposes only. The ultimate responsibility for its use and any subsequent liability rests with the end user. Please view the disclaimer uploaded on http://www.practicalmaintenance.net.

(Edition: November 2017)

Spontaneous Combustion of Coal

To reduce sulfur emissions or non-availability of traditional coal, there has been a shift in recent years from use of more traditional bituminous coal to subbituminous coal, such as Powder River Basin (PRB) coal and Indonesian coal like ENVIROCOAL by PT Adaro, Indonesia. These coals tend to react with oxygen in the air and have tendency for spontaneous combustion. This has resulted in fires at facilities that previously had excellent safety records.

Operators familiar with the unique requirements of burning PRB coal will tell you that it's not a case of "if" you will have a PRB coal fire, it's "when."

Spontaneous combustion of coal is the process of self heating resulting eventually in its ignition without the application of external heat. It is caused by the oxidation of coal. If the rate of dissipation of heat is slow with respect to the evolution of heat by oxidation there will be a gradual buildup of heat and temperature will reach the ignition point of coal thereby causing fire or explosion.

Normally, if the supply of oxygen is stopped or used up, as in the middle of a stockpile, the temperature will then decrease, stabilize and self heating will not proceed further.

In view of above, important information on spontaneous combustion of coal and care to be taken for their use in a power plant is given in this article. The information will be useful for coal storage and coal transportation also.

Coal Rank

The degree of change undergone by a coal as it matures from peat to anthracite - a process known as coalification - has an important bearing on its physical and chemical properties and is referred to as the rank of the coal. Coal is classified into four general ranks/categories. They are lignite, subbituminous, bituminous and anthracite.

Low-rank coals, such as lignite and subbituminous coals are typically softer, friable materials with a dull, earthy appearance. They are characterized by high moisture levels and low carbon content and, therefore, low energy content. High-rank coals are generally harder and stronger and often have a black vitreous luster. They contain more carbon, have lower moisture content, and produce more energy.

Anthracite coal with the highest carbon content, between 86% and 98% is having a heat value of nearly 15,000 Btu/lb (34.9 MJ/kg). Bituminous coal has a carbon content ranging from 45% to 86% and is having a heat value of 10,500 to 15,500 Btu/lb (24.4 to 36 MJ/kg). Subbituminous coal with 35 to 45% carbon content is having a heat value between 8,300 and 13,000 Btu/lb (19.3 and 30.2 MJ/kg). Lignite having the lowest carbon content, between 25 and 35% is having a heat value ranging between 4000 and 8300 Btu/lb (9.3 and 19.3 MJ/kg).

American Society for Testing and Materials (ASTM) standard D 388 - 98 classifies coals by rank, that is, according to their progressive alteration, in the natural series from lignite to anthracite.

The higher rank coals are classified according to fixed carbon on the dry basis; the lower rank coals are classified according to gross calorific value on the moist basis. Various classes as per the standard, in order of rank are: anthracitic (highest rank), bituminous, subbituminous and lignitic (lowest rank). Each class contains number of groups as under.

Class	Group
Anthracitic	Meta-anthracite
	Anthracite
	Semianthracite
Bituminous	Low volatile bituminous coal
	Medium volatile bituminous coal
	High volatile *A* bituminous coal
	High volatile *B* bituminous coal
	High volatile *C* bituminous coal
Subbituminous	Subbituminous *A* coal
	Subbituminous *B* coal
	Subbituminous *C* coal
Lignitic	Lignite *A*
	Lignite *B*

Rank is assessed by a series of tests, collectively called the proximate analysis, that determine the moisture content, volatile matter content, ash content, fixed carbon content, and calorific value of a coal.

Moisture Content

Moisture content is determined by heating an air dried coal sample at 105-110°C (221-230°F) under specified conditions until a constant weight is obtained. In general, the moisture content increases with decreasing rank and ranges from 1 to 40 percent for the various ranks of coal. The presence of moisture is an important factor in both the storage and the utilization of coals, as it adds unnecessary weight during transportation, reduces the calorific value, and poses some handling problems.

Volatile Matter Content

Volatile matter is material that is driven off when coal is heated to 950°C (1742°F) in the absence of air under specified conditions. It is measured practically by determining the loss of weight. Consisting of a mixture of gases, low-boiling-point organic compounds that condense into oils upon cooling, and tars, volatile matter increases with decreasing rank. In general, coals with high volatile-matter content ignite easily and are highly reactive in combustion applications.

Mineral (Ash) Content

Coal contains a variety of minerals in varying proportions that, when the coal is burned, are transformed into ash. The amount and nature of the ash and its behaviour at high temperatures affect the design and type of ash-handling system employed in coal-utilization plants. At high temperatures, coal ash becomes sticky (i.e., sinters) and eventually forms molten slag. The slag then becomes a hard, crystalline material upon cooling and resolidification. Specific ash-fusion temperatures are determined in the laboratory by observing the temperatures at which successive characteristic stages of fusion occur in a specimen of ash when heated in a furnace under specified conditions. These temperatures are often used as indicators of the clinkering potential of coals during high-temperature processing.

Fixed Carbon Content

Fixed carbon is the solid combustible residue that remains after a coal particle is heated and the volatile matter is expelled. The fixed carbon content of a coal is determined by

subtracting the percentages of moisture, volatile matter and ash from a sample. Since gas to solid combustion reactions are slower than gas to gas reactions, high fixed carbon content indicates that the coal will require a long combustion time.

Calorific Value

Calorific value, measured in British thermal units (Btu) per pound or Mega joules (Mj) per kilogram, is the amount of chemical energy stored in a coal that is released as thermal energy upon combustion. The calorific value determines in part the value of a coal as a fuel for combustion applications.

A Btu is the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit.

Oxidation and Weathering of Coal

At atmospheric temperature, freshly exposed coal has affinity for oxygen of the air in contact with it. The oxygen is absorbed by coal on its surface by a purely physical process which, however, rapidly gives place to a chemical chain reaction resulting in oxidation of certain constituents of coal. As oxidation of coal is an exothermic reaction, heat is generated with decrease in calorific content (quality of coal).

If the heat produced due to oxidation is dissipated, the rate of oxidation of freshly exposed surface of coal decreases continuously during the progress of oxidation, that is, with time.

Weathered coal is the coal in which the exposed surface of the coal has reached the stage of saturation and no further interaction with oxygen at ambient temperature occurs.

If the heat produced due to oxidation is not dissipated by a flow of air or by the conductive properties of the coal, its temperature increases. As the temperature increases, the oxidation reaction rate increases (typically doubling for each 10°C). Eventually the temperature can rise above the ignition point of the coal and combustion can result, commonly called spontaneous combustion.

In view of above, any condition (for example, oxidation of pyrites, rewetting of dry coal, high ambient temperature, etc.) that results in increasing temperature of coal will accelerate process of spontaneous combustion.

Mechanisms of Spontaneous Combustion

At atmospheric temperature, freshly exposed coal has affinity for oxygen of the air in contact with it. The oxygen is absorbed by coal on its surface by a purely physical process which, however, rapidly gives place to a chemical chain reaction resulting in oxidation of certain constituents of coal. Like all other oxidation reactions, the interaction of oxygen with coal is an exothermic with production of a small quantity of heat.

The oxygen absorption reaction is considered to take place as follows:

Coal + O_2 → Coal-O_2 complex → Oxidized coal + CO, CO_2, H_2O + Heat

The mechanisms involved in the oxidation of coal leading to spontaneous combustion form a complicated process, consisting of the following four overlapping stages.

The first stage is the adsorption and chemisorption of oxygen. During this stage, the coal increases in weight as the oxygen is adsorbed and heat is generated. This process occurs markedly up to 70°C and continues up to 350°C. However, the oxygen-enriched adsorption complex is unstable, and it may decompose and react further.

At the second stage, i.e. above 80°C, the adsorption complex decomposes, and the weight of the coal decreases. This process is common in relatively low temperature ranges, i.e. between 80 and 150°C. The decomposition of this complex yields mainly carbon monoxide. Inherent moisture is driven off between 100 and 150°C.

During the third stage, which takes place between 150 and 230°C, further chemical reaction leads from the unstable adsorption-chemisorption complex to the formation of the stable oxygen-carbon compound oxycoal, with an excessive evolution of heat. This process also leads to the evolution of carbon monoxide.

At even higher temperatures, the formation of oxycoal stops and combustion begins. With the sharp rise in temperature, there is a rapid decrease in weight, with the excessive formation of soot, and the coal substance begins to incinerate/burn.

The process leading to spontaneous combustion can be summarized as follows:

- Oxidation occurs when oxygen reacts with coal.
- The oxidation process produces heat.
- If the heat is dissipated, the temperature of the coal will not increase.
- If the heat is not dissipated, then the temperature of the coal will increase.
- At higher temperatures the oxidation reaction proceeds at a higher rate.
- Eventually a temperature is reached at which ignition of the coal occurs.

The following table summarizes various stages in the process of self heating and spontaneous combustion as per Das and Hucka - "Control of Spontaneous Combustion of Coal Through an Analysis of its Mechanism and the Affecting Factors," Society of Mining Engineers of AIME, Preprint # 86-62, Presented at the SME Annual Meeting, New Orleans, LA, March, 1986.

Stage	Reaction	Weight	Temperature (°C)	Heat generated (cal/g)	Remarks
Adsorption	Water Adsorption	Gain	Any temp.	2-25	• Physical process • Large amount of heat produced
Chemisorption	Oxygen absorbed to form peroxides	Gain	70	2-16	• Traces of water required • CO is typical product
Peroxygen decomposition	• Disintegration of peroxygen • Release of water from coal	Loss	70-150	4-18	• Wet spots in the stockpile can be visible • Steam can be seen coming from
Oxycoal formation	Formation of stable oxygen complexes	Gain	150-230	6-27	Much heat
Onset of combustion	• Devolatilization • Combustion	Loss	230	10-58	Much heat
Active burning	Combustion	Loss	>230	3,500-7,800	Much heat

Factors Affecting Spontaneous Combustion of Coal

Spontaneous combustion depends on number of internal (intrinsic) and external (extrinsic) factors.

Internal Factors (Nature of Coal) are:

- Rank of coal
- Presence of iron pyrites
- Content of volatile matter
- Moisture content
- Friability/breakability, particle size and surface area of coal
- Ash content

Extrinsic Factors are:

- Atmospheric conditions (Ventilation / air flow rates, ambient temperature, rain, etc.)
- Storing methods and conditions

Rank of Coal

Coals of different ranks have different capacities to absorb oxygen.

The rate of oxidation decreases with increase in rank of coal.

Lower rank coals containing higher moisture, oxygen and volatile content are more easily oxidized and hence, the risk of spontaneous combustion is higher in lower rank coals.

Presence of Iron Pyrites

Iron pyrite (FeS_2) easily oxidizes by its own in presence of oxygen of the air and moisture at ordinary atmospheric temperature according to the following equation.

$2FeS_2 + 7O_2 + 16H_2O = 2H_2SO_4 + 2FeSO_4 . 7H_2O + Heat$

The reaction also yields reaction product having greater volume than the actual pyrite, with the result that it would break open any coal in which they are engrafted and thus exposing a greater surface of coal to the air.

Hence, presence of pyrite increases the potential of coal for spontaneous combustion, particularly when the pyrite concentration exceeds 2% and when it is in very finely divided state.

Volatile Matter (VM) Content

Volatile matter in the coal is generally easier to oxidize than nonvolatile content. Hence, increase in volatile content of coal increases the rate of oxidation.

Schmidt-Elder found that coal with 38% VM oxidizes 3 times as fast as coal with 18% VM.

The research institute of Ostrava-Radvanice (Czechoslovakia) considers coals having a volatile content of 28% and more, liable to spontaneous combustion.

Moisture Content

The high moisture coals have higher tendency of spontaneous heating.

Moisture inherent in coal, present in the surrounding oxidizing atmosphere, or produced from oxidation of coal in the early stages of oxidation influences the oxidation process. It acts as a catalytic agent.

Particle Size and Surface Area of Coal

The smaller the coal particle, the greater the exposed surface area in contact with the air and the greater will be the rate of oxidation and tendency towards spontaneous combustion.

Friable coals tend to produce coal fines which due to larger surface area have a greater tendency for spontaneous combustion.

Ash Content

Ash present in coal generally decreases the oxidation rate. Certain constituents of the ash, such as lime, soda and iron compounds, may have an accelerating effect, while others, such as alumina and silica, produce a retarding effect.

Ventilation / Air Flow Rates

In case of a strong ventilating current or at very high airflow rates, almost unlimited oxygen is available for the oxidation of coal, but the dissipation of the heat generated by oxidation is very efficient. The strong ventilating current conducts away the heat produced from oxidation without materially rising the temperature of coal. However, it may degrade coal quality (calorific value).

On the other hand, a week ventilating current or a low flow rate might supply air just sufficient for oxidation but not sufficient to keep down the temperature.

If there is no airflow through a pile, there is no oxygen from the air to stimulate oxidation. Hence, a good rule to be observed would be "No ventilation at all".

Storing Methods and Conditions

Segregation of Different Sizes of Coal

Small particles having higher surface area oxidizes faster but flow of air is restricted in them.

Large particles allow free circulation of air and oxidizes but heat can get dissipate.

However, in case of mixture of sizes, it gets enough oxygen but the heat generated cannot be dissipated fast enough and results in heating of stockpile.

Hence, as shown in above figure, if storing method results in segregation of different sizes of coal, it will lead to heating and spontaneous combustion.

Spontaneous combustion in a stockpile can be prevented by stacking the coal layer by layer with compaction of each layer because coal stacked in this manner will prevent air movement through the stockpile and also limit moisture percolation.

Moisture Content Changes and Size Degradation

In its natural state within a seam (in mine), coal is always more or less completely saturated with water. Hence, mined coal when exposed to air will tend to lose moisture until equilibrium between it and the ambient atmosphere has been established. Evaporation of external or surface moisture will initially inhibit self heating of coal as the process is endothermic. If the relative atmospheric humidity then increases, the coal will reabsorb moisture; and this cycle of desorption and reabsorption of moisture can be repeated many times.

During drying, desorption of moisture from the external surfaces of a coal lump will always be faster than desorption from its interior; and, since desorption is accompanied by some volume shrinkage, it will create internal stresses that cause the lump to disintegrate. Similar stresses are set up during reabsorption of moisture, which will also be faster at the surface than in the interior, and so lead to differential expansion. The disintegration is usually termed "slacking" and will, among other matters, substantially increase the total surface area which the coal presents to air.
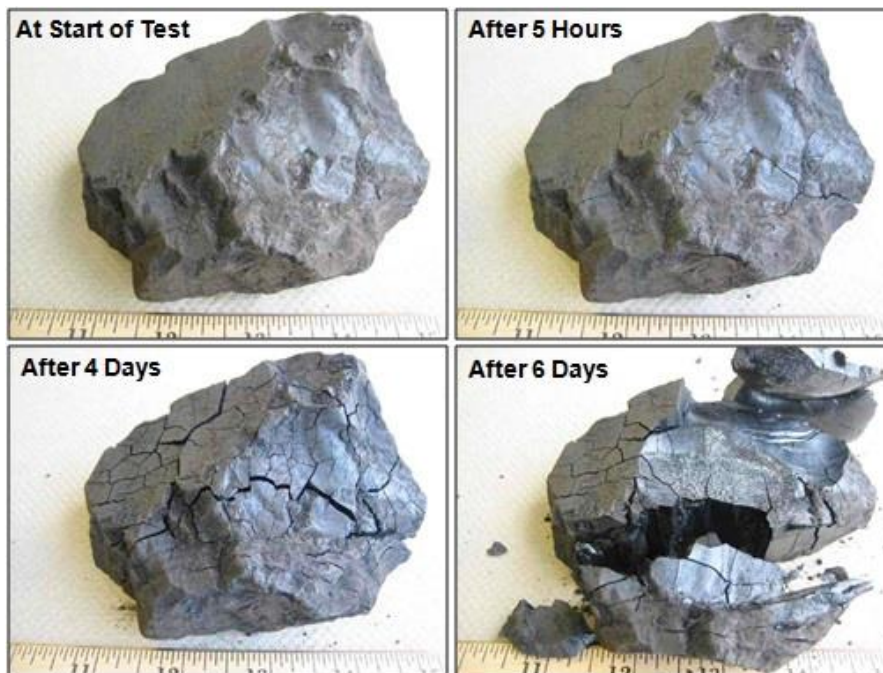
Photos of PRB Coal Particle Exposed to Ambient Conditions

Above figure shows series of photographs taken over time in a test to study degradation of PRB coal due to loss of moisture when it is exposed to ambient conditions (inside a building)

for 6 days. As is evident from the photographs, degradation of the coal starts immediately upon exposure to the environment. In fact, cracks had started to appear within one hour after the start of the test!

As well as causing slacking, absorption of moisture by coal will generate considerable heat - the **heat of wetting**. The heat of wetting can raise the oxidation temperature of the coal by 25 to 30°C and increase oxidation rates six- to eight-times. Unless this heat is quickly dissipated, it will accelerate the process of spontaneous combustion.

Following table shows the heat of wetting for various types of coal (as per Das and Hucka).

Coal Rank	Vol. Mat. (%, daf)	Carbon (%, daf)	Heat of Wetting (cal/g)
Subbituminous	45	77.5	25
HV Bituminous	35	82.5	10-15
MV Bituminous	30	85	3-4
LV Bituminous	20	89	2
Anthracite	5	93.3	6-9

It can be seen that for subbituminous coals, the heat of wetting is almost two times of bituminous coals. This might be due to the higher surface area of subbituminous coals, which is typically about two times that of bituminous coals. The higher surface area is due to the greater number of micro fractures present in subbituminous coal particles.

Wetting of coal takes place when stock piled coal is exposed to rain after a period of dry, sunny weather, or when wet coal is placed on a dry pile.

The three areas/places in a power plant which are at risk of fire caused by spontaneous combustion of coal are: coal stockpiles, coal conveyors and coal bunkers.

Information about prevention, monitoring/detection and controlling/coping of spontaneous combustion or fire of coal in these areas is given in the following sections.

Coal Stockpiles

In a power plant, coal is generally stored as stockpiles in the coal yard.

Prevention of Spontaneous Combustion

Spontaneous Combustion in a Stockpile

Recommendations for mitigating the effects of factors responsible for spontaneous combustion of subbituminous coal are as under.
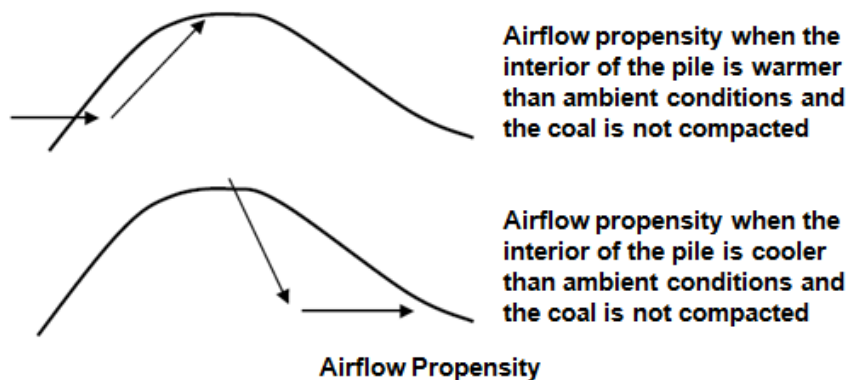
Avoid segregation of coal. Improper stacking might result in segregation of coal particles and hence increased propensity to oxidation.

Differences in air temperature between the pile and the outside air can encourage air movement through the pile, thereby increasing oxidation. Hence, just dumping the coal in a big pile might lead to problems. A pile which has been compacted can help to prevent free air movement throughout the pile, thereby reducing oxidation. It is a standard practice to compact the stockpile. The most effective compacting technique involves laying down the coal in 2 - 3m thick levels/layers and using a bulldozer to travel back and forth on the coal to lightly compact it.

It is not necessary to compact the coal to the point of being rock hard, one or two passes with a bulldozer is sufficient to compact the coal. Too much travel on the coal with heavy equipment such as bulldozers may result in excessive generation of fines with associated dust problems during subsequent reclaim operations.

Stockpiles built by the use of end dump tip trucks, are usually well compacted due to the travel of the trucks across the stockpile to dump their loads.

It is also recommended to lightly compact the "toe" of the pile (that is, the outer bottom edge of the coal pile), which is susceptible to air flow. The compacting of this portion of the pile prevents air from flowing into or out of the bottom of the pile when the coal pile is either warmer than or cooler than ambient conditions as shown in the following figure.

Airflow propensity when the interior of the pile is warmer than ambient conditions and the coal is not compacted

Airflow propensity when the interior of the pile is cooler than ambient conditions and the coal is not compacted

Airflow Propensity

Slopes should be kept as shallow as possible, 20 - 25°, however the size constraints of the coal yard may not allow slopes to be built this flat. It may be necessary therefore, to use a backhoe or loader to dress and compact the slope sides to minimize heating on these slopes.

Any stockpile should, if practical, be rectangular in shape presenting a minimum face (width) to prevailing wind direction and the ingress (entrance) or egress (exit) ramp constructed on the windward face. It is recommended that height of a high grade uncompact coal pile should be limited to about 15 feet while height of layered and compacted coal pile should be limited to about 26 feet.

The top of the coal pile should be contoured so that few, if any, peaks and valleys are present. Wind will promote heating in the peaks, and water can accumulate in the valleys.

The base of the coal yard should not allow pooling of water underneath the coal pile, and promote drainage of water away from the coal.

If fires occur, they will normally be on the edges of the pile where coal is difficult to compact but readily accessible for its removal. In view of this, accessibility to all sides/edges of a stockpile should be maintained.

Moisture contributes to the spontaneous combustion as it aids in the oxidation process. As rewetting of coal is exothermic process, it liberates heat. Hence, measures must be taken to keep stored coal from being exposed to moisture.

In view of above, it is recommended that dry and wet coal should be stored separately; wet coal should not be piled on dry coal and dry coal should not be rewetted.

Covering of a Pile by LDPE Sheets

As shown in the above figure, inert covering material such as LDPE / PVC / tarpaulin sheets with sufficient heat resistivity can be used to cover the openly kept stockpile. Coal filled bags may be kept above the covering sheet to keep the covering sheet in position against wind. It will prevent rewetting of the coal due to changes in atmospheric humidity and rain. It will also help in cutting off oxygen to come in contact with coal.

There are crusting agents in use that seal the stockpile surface, however they are expensive to apply.

Blending of coals to achieve the correct level of sulfur content is being practiced as a means to use high sulfur coal (high in pyrites) by blending it with low sulfur coal (high in moisture). However, blended coal can greatly increase the rate of spontaneous heating. Hence, it is recommended to storage them in separate piles and blend them just before feeding them to coal bunkers.

In reasonable weather conditions and with good stockpile management the coal will remain in a stable condition for years. However, heating may occur if coal is stockpiled without any stockpile management for periods in excess of 30 - 40 days and/or unfavourable weather condition, in particular conditions with strong winds. In view of this, coal must not be stored

in stockpiles for long periods. The "first in - first out" (FIFO) principle should be implemented to reduce to a minimum the amount of time the coal is kept in stock.

<u>Dust Control</u>

Dust is fine coal, less than 0.5 mm in size. Majority of the dust is formed by attrition, that is, coal particles falling and tumbling on each other, which occurs during mining, shipping, storage and reclaim. Additional dust is formed as equipment such as bulldozers and loaders travel over the coal. Some dust is caused by the breakage of large coal particles as it ages, i.e., dries and cracks. All these processes occur more rapidly with subbituminous coals, than with bituminous coals. As dust can lead to explosions, it is very important to prevent its generation. Following is recommended to prevent generation of dust in subbituminous coals.

To minimize dust generation due to loss of moisture from large coal particles, their surface moisture level should be maintained. For this, water should be sprayed to keep the piles damp. It will prevent dust generation and will also suppress it. As stockpiles are normally only dried out for a few centimeters below the surface and beyond this depth the coal will have close to its original moisture levels, it is not necessary to soak the piles.

Water can be sprayed on the entire pile to prevent its generation and control fugitive dust arising from wind around the pile. However, water should not be used as thick jet. Sprinklers are recommended instead of water jets. Many coal yards have large agricultural sprays to wet the entire pile. Some customers wet the pile daily, and others only add water as needed.

The recommended practice is to fog spray or mist the stockpile surface as frequently as necessary to maintain the surface coal in a moist (but not wet) condition. That is, watering should be done frequently but sparingly.

The least favourable weather conditions for dust control are periods of low humidity with strong winds. The frequency of spraying should be increased to maintain dust suppression during these periods and minimize surface coal breakdown and then, minimize further dust particle generation.

Surfactants should be helpful to increase the efficiency of the water added to 'wet' the fine coal.

Monitoring / Detection

Detection of spontaneous combustion in its early stage is very much essential for its prevention. Hence, stockpiles should be checked at least once per day for signs of heating.

Spontaneous combustion can be detected fairly early in their development, i.e. before any obvious smoke and/or flame. Any of the following may assist in early detection, depending upon the particular circumstances.

Usually the first indication of a heating that can be detected by the human senses is the distinctive smell in the air coming from the suspected area. A strong smell indicates that the heating has made sufficient headway. However, it may be noted that physical symptoms like smell cannot detect heating at a very early stage, at least not up to 120°C or so.

Generally hot spots will also issue steam for several days before any active burning takes place.
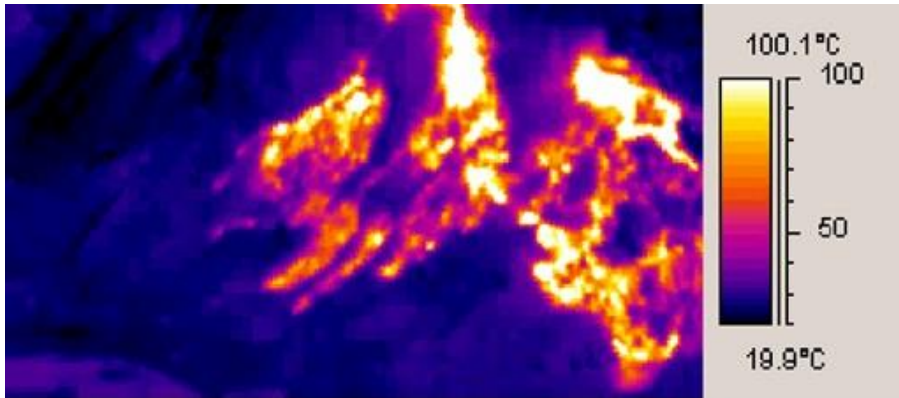
Typical Thermal Image of a Spoiled Stockpile

Hot spots may be detected by thermal imaging. Above figure shows typical thermal image of a spoiled stockpile. Thermal imaging acts as an early warning system by spotting any abnormal rise in temperature. They are useful to detect near surface heating. A fixed mounted camera can be used to constantly survey an area.

Use of Handheld Camera for Monitoring of Coal Stockpile

As shown in above figure, routine surveying of stockpiles using thermal imaging camera is an excellent precaution in situations where spontaneous combustion may be likely to occur.

Manufacturing economies have resulted in the dramatic fall in the cost of thermal imaging cameras. This in turn has made the technology easily affordable by anyone.

Controlling/Coping of Spontaneous Combustion or Fire

Well-formed subbituminous coal stockpiles with smooth compacted surfaces will exhibit a steady increase in overall temperature with day by day variations depending on ambient weather conditions until a (relatively) stable temperature condition is reached around 40°C. A well-managed stockpile will be fairly stable at these temperatures for long periods.

However, heating may occur if subbituminous coal is stockpiled without any stockpile management for periods in excess of 30 - 40 days and/or unfavourable weather condition, in particular conditions with strong winds.

Under extreme weather conditions, particularly high winds isolated "hot spots" may occur on the exposed coal surfaces. These "hot spots" may stabilize if weather conditions improve. Intermittent heavy rains can also initiate heating behavior in stockpiles after a few days.

Hot spots in coal stockpiles are a local effect only and are confined to small areas that are easily handled.

Hot spots in coal stockpiles are normally confined to coal at or near the stockpile surface, usually within 1 - 2 meters of the stockpile surface. It is generally thought that the first 0.5 - 1 meter of coal in the stockpile is able to dissipate heat to the ambient air. Coal that is within 1 - 2 meters of the coal surface can still receive some oxygen from the ambient air but cannot effectively dissipate the heat generated and therefore the heat tends to build up. Coal more than 2 meters from the stockpile surface will use up the entrained oxygen, which will in turn stop the heating/oxidation reactions from progressing any further. Additional oxygen cannot reach this deeper coal and therefore the oxidation reaction is effectively stopped.

It is recommended that if the coal temperature in a hot spot increases above 50°C, remedial action should be undertaken. This action entails removing the hot coal from the pile, spreading it in a thin layer and allowing it to cool (approximately for 1 hour). The coal can then be replaced to the pile and the affected area compacted back. Compacting normally prevents a further hot spot from occurring in that location.

The coal yard operators should monitor the temperatures in the coal pile every day. Coal above 65°C (and certainly above 70°C) should be cut out, cooled down and after cooling compacted back into the pile.

The use of water for temperature control is considered to be poor practice and may actually promote heating. Hence, except in extraordinary situations the use of water for temperature control is not recommended and should be discouraged.

Coal Conveyors

All conveyor systems are at risk of fire caused by the ignition of transported materials or equipment failure. But the propensity of subbituminous coals like Powder River Basin (PRB) coal to self ignite introduces exceptional hazard requiring special fire prevention and automatic detection and suppression efforts.

Prevention of Fire

Poor Housekeeping

Good housekeeping is most important to prevent fire at coal conveyors. Above figure shows an example of poor housekeeping. Housekeeping means controlling dust and preventing spillage. Floating dust must be contained within transfer points, and spillage from belts must be minimized. The accumulation of PRB coal below a conveyor or on conveyor parts can contribute to spontaneous combustion. Floating dust either in the air or settled on beams, pipes, conduits, equipment and fixtures provides fuel for explosions. In view of this, good housekeeping constitutes effective and regular cleanups.

A manual, daily wash down with a hose is beneficial, but it's generally not totally effective at removing PRB coal dust and debris. Fixed, automatic wash down systems designed for broad coverage are widely available. Compared to manual wash down systems, such systems reduce labor costs and significantly improve the level of housekeeping.

For optimum results, a custom-designed combined fire suppression and wash down system may be considered. Plants that have installed and regularly operate this kind of integrated hydraulic water spray system have report being satisfied with its performance.

It is recommended not to allow stopped conveyors to stand with coal on them for an extended period.

Monitoring / Detection and Control

Despite the best prevention efforts, even the best PRB coal handling systems are likely to experience fires. Hence the faster these fires are detected and extinguished; the lower will be the cost due to plant damage and down time.

A fire condition within a conveyor system may be considered to be static or moving as explained below.

Static Fire: Fire on a stationary conveyor belt, or within the conveyor mechanism/housing.
Moving Hazard: Hot or burning product imported onto a traveling conveyor belt.

Each of the above condition requires a different form of fire detection system to provide a reliable fast responding and trouble free system.

Static Conveyor Fire

In addition to the accumulation of PRB coal resulting to spontaneous combustion, a mechanical fault in the bearing of a roller, or the friction between a seized roller and the belt, may result in a buildup of heat which can be sufficient to ignite the belt, when the belt stops.

Many different types of fire detector as listed below have been tried for conveyors.

- Collective reflectors (thermocouple hoods)
- Ionization and optical point smoke detectors
- Point heat detectors
- Point flame detectors
- Obscuration detectors employing infra-red beams
- Pneumatic detectors with fusible bulbs

Experience has shown that above devices are either unsuited to the environment producing unwanted alarms due to dust or fog, or are so insensitive that a fire can propagate and cover many metres of a length of the static conveyor before they are operated.

Linear heat detection has proven to be a more sensitive solution for static fire protection and IR Heat Detectors for moving fire protection.

Patol (Patol Limited, website address: www.Patol.co.uk) supplies two types of linear heat detection (LHD) cables.

- Electrical - Analogue
- Electrical - Digital

Typical Arrangement for Electrical - Digital LHD Cable
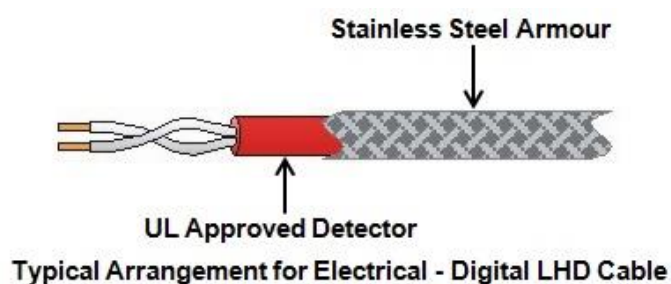
Above figure shows typical arrangement for electrical digital LHD cable.

In both cases the LHD cable comprises of a robust cable that will annunciate an alarm if any portion of the LHD cable experiences an abnormal temperature. Patol recommends using digital LHD cable.

Typical Digital LHD Cable Routing
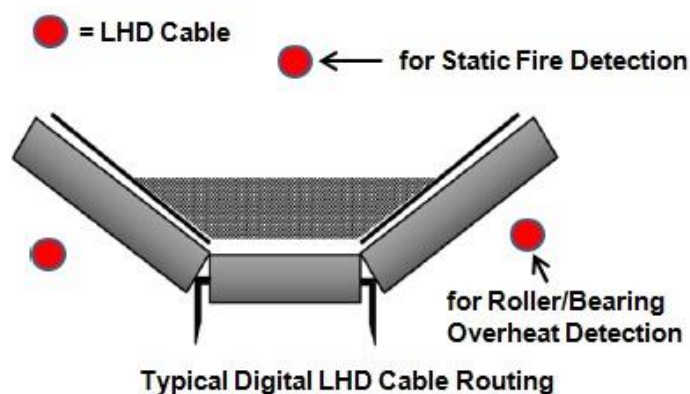
As shown in above figure, to protect the upper side of the conveyor, typically a detector run should be installed above the centre of the belt at a height of 1 to 1.5 m. Normally this is achieved by the use of a steel catenary support wire to which the LHD cable is affixed. To protect the underside of the conveyor, typically LHD cable runs should be installed at the conveyor sides to detect heat generated around the belt edges from events occurring on the underside. The LHD cable is mounted above the return roller (belt) on each side.

However, each specific conveyor arrangement must be considered in order to determine the optimum mounting method.

The LHD cable must always be mounted by clips or thermal spacers, such as to be in the air flow. It must not be mounted directly to steel work which would act as a heat sink and retard response.

Enclosed conveyors should have extra detection cable at ceiling height to detect dust ignition on cable trays, pipes etc. located above the conveyors.

Patol's DDL controller with distance locator display activates on fire condition and displays the distance into the zone the alarm has occurred.

Fires on Moving Conveyor

One of the most reliable ways to detect fires on a moving conveyor is to monitor for infra-red "black body" emissions.

Patol's IR Black Body Emission Detector employs IR filters that select longer wavelengths and are "blind" to the visible spectrum. They can detect both high energy emissions from very hot/glowing embers, and those from abnormal but relatively low temperature product transiting the monitored belt area.

Whist some detectors may be able to respond to burning product (550°C to 1000°C) the correct type of IR Black Body Emission detector will also respond to an abnormal but non-ignited conveyor load (100°C to 200°C).

Patol's IR Heat Detectors have a target range of 80-1000°C.

The detector when mounted above the conveyor at a height of between 1.0 and 1.5 metres should be able to cover the full width of the belt with its optical system. The system must also detect glowing product of up to 30 mm diameter and less.
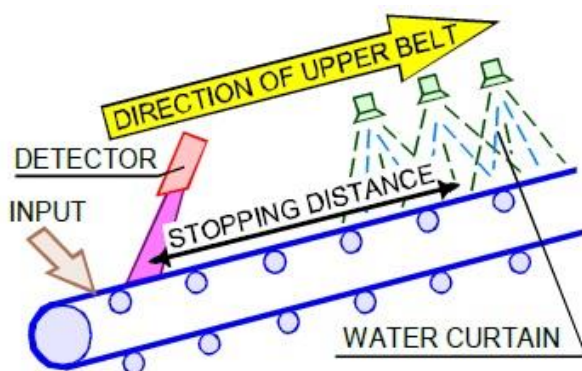
Typical Mounting Detail for IR Heat Detector

As shown in above figure, the infra-red detector should be mounted at the start of each conveyor such that on detecting a fire the belt could be stopped such that the fire would be within a water spray deluge curtain and before it can discharge the fire to another belt or silo, etc.

The Infra-Red Detector is configured to automatically stop the conveyor and raise an alarm.

At this stage the water spray can be initiated:

- Automatically by the IR Detector.
- Manually, after an operator has observed the belt.
- Automatically after a time delay, if not overridden by the operator.
- Automatically by LHD cable detection.

As these "stop zones" will be remote from the plant control room, they could be monitored by CCTV cameras.

In addition to the arrangements described above for belt "loading" points, an IR Detector should be installed just prior to the conveyor system discharge to silos and hoppers.

The detector must be located sufficient distance back from conveyor end in order to be able to stop the detected "hazard" within a water spray zone and before discharge of the belt.

In the case of very long conveyors due consideration should be taken of the fact that abnormal heat can be aided to develop into ignition by the movement of the product in air and therefore it may be prudent to install additional intermediate IR detection units.

Patol's IR Detectors are supplied with either Compressed Air Inlet or separate Blower for 'Air Cleansing'.

For more information on LHD cables and IR Black Body Emission Detectors, please contact Patol Limited (website address: www.Patol.co.uk).

Note:
Infra-red thermal imaging camera is a very useful tool for monitoring static objects like stockpiles, bunkers and silos. However, IR camera is not usually practical for detecting fires on moving conveyors because the imaging period is longer than the fire's dwell time. Hence IR black body emission detector is employed to detect fire on a moving conveyor.

Coal Bunkers / Silos

The expectation is that once the coal is transported into the feed bunkers of the power plant, it is no longer in idle storage but in a continuous flow pattern through the bunker, the coal feeders, the pulverizers, and then burned. If this continuous flow pattern is maintained for all of the coal put into the bunker, and the coal is not already at or near the spontaneous combustion point when delivered to the bunker, and no low temperature combustibles (such as paper, wood, or rags) have been introduced into the bunker along with the coal, then no fires will develop in the coal bunkers. Typically, a power plant bunker would have from 24 to 36 hours storage when full, so the retention time of the coal in the bunker should be considerably less than the oxidation process time to spontaneous combustion. Unfortunately, this expectation is not always realized, and coal fires in bunkers are a too frequent problem.

Prevention

Coal feeding should be carried out in such a way that there is minimum size segregation. When coal is filled into a bunker, size segregation begins to take place. Large chunks of coal tend to roll out to the periphery of the bunker, while smaller chunks and fines stay in the center. This size segregation facilitates air migration up along the sides of the bunker. It also presents a practical firefighting challenge when applying water from above. Water tends to "rathole" through voids and can bypass the seat of the fire.

The hazardous situation that sets the stage for a majority of fires is coal stagnation in various parts of the bunker. Coal trapped in dead flow areas of a bunker for uncertain time periods sets up the breeding conditions for spontaneous combustion. Coal stagnation is caused by obstructions in the coal flow path / rough surface, moisture and most critical, poor design of the bunker itself.

Rectangular bunkers with fairly flat (about 55°) slopes as they neck down to the delivery chutes would result in "ratholing" coal flow and dead storage in valley angles and throughout

the lower bunker volume. The problem can be eliminated by designing a cylindrical bunker with steep angled conical hopper.

Replacing the internal bunker bracing beams (if provided) with pipe sections will cause less obstruction to coal flow past it than with the beams.

The most common flow problem experienced when handling subbituminous coals like PRB coal is flow stoppage, that is, a no flow condition. This condition can result either from bridging/arching or ratholing.

Illustration of Bridging and Ratholing
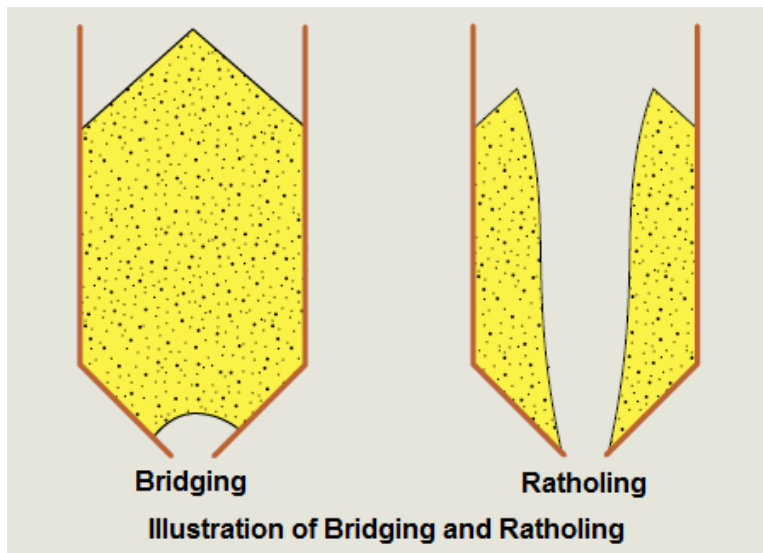
As shown in above figure, bridging/arching occurs when an obstruction in the shape of a bridge or an arch form over the silo, bunker or hopper outlet as a result of material's cohesive strength. When coal forms a stable bridge/arch above the outlet, discharge is prevented and no flow condition results.

Ratholing can also occur due to the material's cohesive strength and coal flow takes place in a channel located above the silo, bunker or hopper outlet. Once the flow channel has emptied, no further material discharge will occur from the outlet resulting in a no flow condition.

Funnel Flow and Mass Flow Patterns
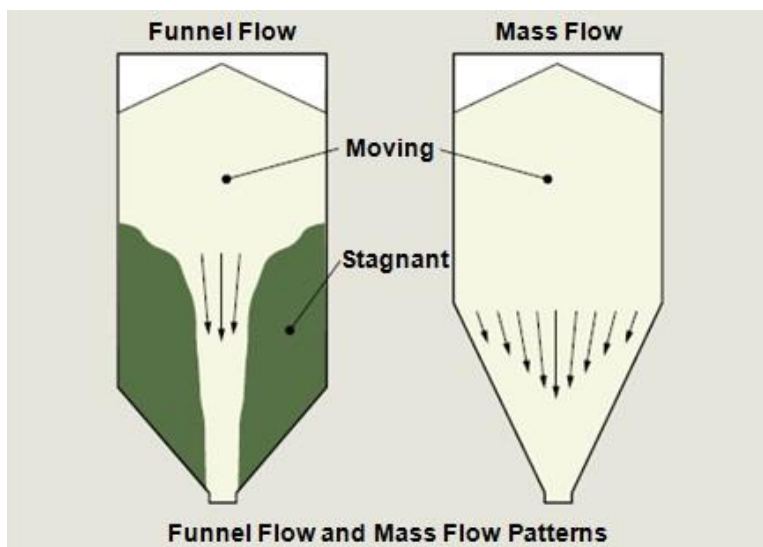
As shown in above figure, there are two primary flow patterns that can develop during material discharge - funnel flow (or "ratholing" as it is commonly called) and mass flow.

In funnel flow, an active flow channel forms above the hopper outlet with stagnant material at the periphery. As the level of material in the silo decreases, material from stagnant regions may or may not slide into the flowing channel. When the material has sufficient cohesive strength, the stagnant portion does not slide into the active flow channel, which results in the formation of a stable rathole. In addition to flow stoppages that occur as a consequence of ratholing, funnel flow can result in a first-in-last-out flow sequence and increases propensity for spontaneous combustion. Funnel flow, also reduces the usable capacity of the silo.

In mass flow, all of the material is in motion whenever any is withdrawn from the hopper. Material from the center as well as the periphery moves toward the outlet. A mass flow hopper provides a first-in-first-out flow sequence and eliminates material stagnation. Requirements for achieving mass flow include sizing the outlet large enough to prevent arching, as well as ensuring the hopper walls have sufficiently low wall (material/surface boundary) friction and are steep enough (> 60° from horizontal) to achieve flow along them. If air blast cannons are used, assure that they are not operated on low coal levels where they could create a large cloud of coal dust in the silo or bunker.

If you are having a funnel flow pattern in your bunker, you should draw down the bunkers periodically to remove stagnant coal (periodically run the bunkers very nearly empty, lowering workers in safety harnesses and breathing gear into the bunkers to lance out any idle coal pockets to insure starting again with a clean bunker). The optimum periodicity can be determined by a plant's experience with each type of coal, and the design of the bunkers. Typically Powder River Basin (PRB) coals should not be left in a ratholing bunker for more than 14 days, depending on whether the PRB coal is fresh off a train or reclaimed from a stockpile.

In case there is a flow problem in spite of having adequate slope, interior surface of the bunker may be lined with Ultra High Molecular Weight (UHMW) polyethylene or SS liners.

Since availability of oxygen is required in creating spontaneous combustion, it is important to provide sufficient downspout length between the bunker outlet and the feeder inlet so that an effective air seal will be maintained when pressurized pulverizers are used.

If a natural seal due to long downspout is not available, it is recommended to provide some form of inert gas sealing in the downspout. It is suggested that, especially with units fitted with flue gas clean up systems, the cooled clean gas could be utilized as a seal gas.

Continuous insertion of CO_2 into the lower bunker outlets could be beneficial in reducing fire potential. However, the installation and operational costs of such a system on the scale needed for a large central station generating unit would be prohibitive.

Obviously, external sources of heat such as steam lines should not be in close vicinity of the bunker walls.

Other measures that can be taken to prevent bunker fires include eliminating hot coal from the stockpile. Hot coal from the stockpile, loaded into a bunker, can mix with stagnant coal and quickly cause a fire.

Access to the interior of bunkers and silos for firefighting is one of the most important aspects of successful fire suppression. However, ease of access is often severely limited. The PRB Coal Users' Group recommends planning for access to hard-to-reach spaces and

install access ports around the bunker or silo at various levels as per requirement to accommodate the injection of firefighting agents.

An active bunker or silo typically doesn't experience a fire under normal operating conditions. If a fire occurs while the bunker is actively moving coal, the bunker may have design irregularities that are contributing to some kind of coal accumulation/stoppage. Coal should not be stored in bunkers and silos for long periods. For planned outages, operators should take every precaution to ensure that all idle bunkers and silos are completely empty and verify it by visual checks. Bunkers and silos should be thoroughly cleaned by washing down their interior walls and any interior structural members.

One of the Most Frequently Asked Question

One of the most frequently asked question concerning bunkers is: "What do we do with the coal in a bunker if the mill trips and will not be back in service for an extended period of time?"

The appropriate answer depends on several factors:

- How long will the mill be down?
- How long has it been since the silo was emptied?
- How old is the coal in the silo?
- Was the coal loaded straight from a train or from the stockpile?

If the mill is going to be down for less than about 10 days, the silo has been emptied in the past two weeks, the coal is directly from a train, and the CO levels are low, then you may establish a CO_2 blanket or purge on the silo. The CO_2 will help keep the silo somewhat inert and slow down the oxidation process. An air-filled rubber plug should be placed in the feed pipe above the feeder to prevent any CO_2 from bleeding off into the mill. During a CO_2 purge, the silo should be monitored daily for CO buildup. For this practice to be effective, the enclosure must be completely sealed - especially the bottom cone, because CO_2 is about 1.5 times heavier than air.

While CO_2 blanketing is a useful tool for short term measure, it should not be used if there is a possibility that a fire already exists.

If the mill is going to be out of service for more than 10 days, the coal is from the stockpile, or the silo has not been emptied in the past two weeks, then you should not perform a CO_2 purge, but instead should empty the silo immediately.

The other option is to inhibit the oxidation reaction by excluding air supply to the coal.

Application of DusTreat DC9136
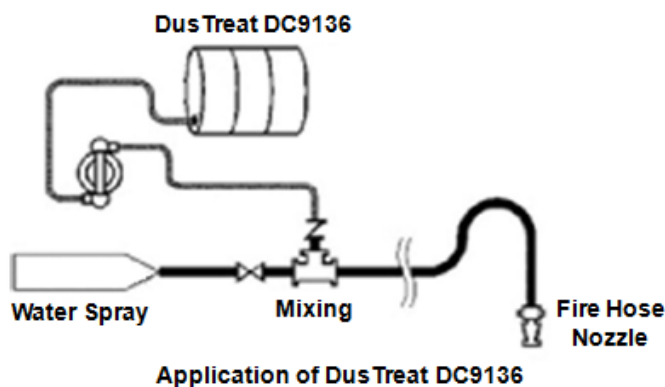
General Electric Company (GE) has developed a crusting product for bunker-fire inhibition - DusTreat DC9136. As soon as a mill / boiler is taken offline, a simple portable spray system comprising 30-50 metres of standard fire hose, mixing tee and air driven diaphragm chemical pump is used to deliver a 15% solution of DusTreat DC9136 directly onto the coal in the respective feed bunker as shown in above figure.

The DusTreat DC9136 solution dries to form a thin, organic sealing cap on the coal that can exclude air and thereby inhibit coal oxidation. Coal treated this way has been found to remain stable for several months.

The whole spray operation takes two men just 15-30 minutes for its application. On resumption of production, the seal merely crumbles and is combined with the coal, so there is no need for its removal.

For more information on DusTreat DC9136, please contact General Electric Company / Suez. Address of their website: www.gewater.com / www.suezwatertechnologies.com.

Many other companies are also supplying crusting products like DusTreat DC9136.

Alternate path for getting the coal out of a bunker should also be provided. It would include the use of diversion chutes or under bunker conveyor system. A diversion chute will enable to dump burning coal out of the bunkers without damaging the coal feeders. However, a limitation of the diversion chute would be that the burning coal from the bunker is usually dumped out on the floor under the bunker and, if the fire is serious, it must be extinguished there and the resulting mess has to be man-handled out of the plant.

If coal is not burning, it may be transferred to the coal yard using a vacuum system and trucks. However, the vacuum system must be rated for hazardous environment.

Monitoring / Detection

Typically, a fire is detected in a bunker when the paint on the bunker starts blistering and smoking. By this time, the fire is well advanced. Good power plant operators say that they can smell when a fire has started if they are in the upper bunker area.

With no foolproof way of eliminating fires in some bunkers, early detection of the start of a spontaneous combustion is desirable.

Bunkers and silos that contain PRB coal should be monitored frequently for signs of spontaneous combustion by using carbon monoxide (CO) monitors and infra-red scanning or temperature scanning.

Monitoring for the presence of carbon monoxide is the way to find out soonest whether there is a fire in the making. CO is an odorless, toxic gas that is liberated at the very early stages of spontaneous combustion. CO is flammable at 12% to 75% volume in air [OSHA's permissible exposure limit for CO is 50 parts per million (ppm) during an 8-hour time period]. Though it may be normal to experience a rise and fall of background CO levels in bunkers and silos during normal operation, monitoring will provide notification if the gas begins to continually trend upward from background levels. Desired alarm set points can be determined after the normal background level of CO is determined for your particular plant. The best way to make use of CO monitoring is to watch for a continuing upward trend of CO rather than to wait for the level of CO to reach a specific set point.

Normal background CO levels may be found out by installing CO data-loggers and observing the CO generation trends under normal operating conditions of the plant. Typically, CO level of 50 ppm is normally present as background level when coal is being handled, moved or transported. Based on the normal background CO levels, the selection of the CO system (range, etc.) and alarm set points may be decided.

About 50 ppm of carbon monoxide above the residual carbon monoxide level indicates that internal temperature is in excess of 70°C.

Although monitoring of either oxide of carbon (CO or CO_2) is adversely affected by dilution, their ratio is not. In view of this, many times people monitor the $CO:CO_2$ ratio.

Intelligent Gas Alarm India Pvt. Ltd. (website address: www.gasalarm.co.in) is one of the company supplying CO and CO_2 monitoring systems.
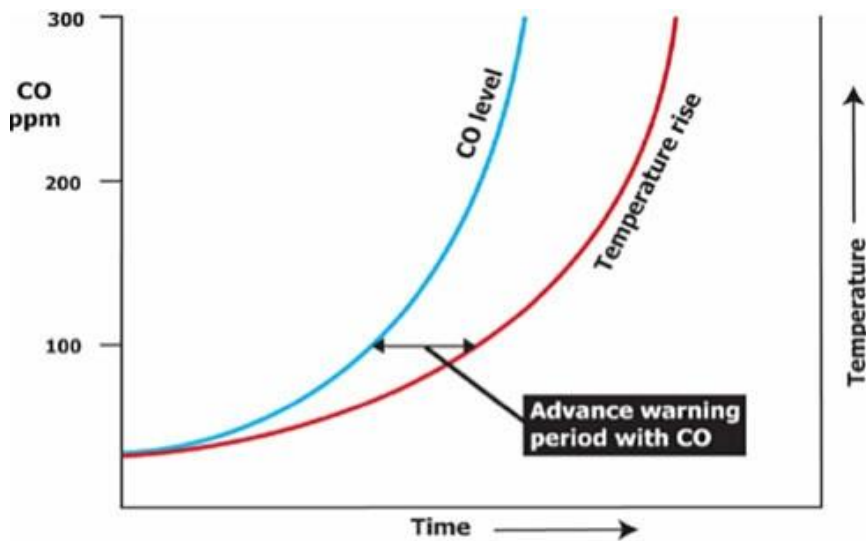
Fire Advanced Warning - CO vs Temperature

Thermal detection using thermocouples can provide an indication of a fire inside a bunker or silo. However, thermal detection will not provide the early warning that CO monitoring does.

Infra-Red Image of PRB Coal Silo Fire

Periodic monitoring of the bunker or silo using an infra-red camera to scan the outside and/or inside of the enclosure is a common practice.

Such a scan as shown in above figure provides a visual picture of the coal's thermal condition and is especially helpful at pinpointing the exact location of a hot spot deep inside a silo or bunker.

However thermal measurements have their limitations. A fire starting well away from the side walls and downspout could be well advanced and in a violent combustion stage before temperature rise is noted on the outer walls of the bunker.

Controlling/Coping of Spontaneous Combustion or Fire

Smoke means fire. Immediate response is required when an odor of coal roasting or burning is detected as coming from a silo, bunker, or hopper. Delays in taking action only allow the rate of burning to increase.

Once a fire starts in the bunker, what can be done about it?

Even the most universal firefighting substance, water, cannot be used indiscriminately. Trying to douse it with water or steam is not the solution. Water or steam in contact with hot coal will produce water gas with possible explosive conditions developing at the top of the bunker.

Water gas is a mixture of carbon monoxide and hydrogen. Both these gases are highly flammable and are produced in the reaction between hot carbon and water. The chemical reaction for it is:

$$C + H_2O = CO + H_2$$
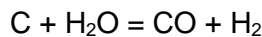
Because of the wide explosive limits of water gas (4% to 74%), the highly toxic nature of carbon monoxide and the presence of a source of ignition, production of water gas should be avoided as much as possible.

If water is applied, it is advisable that it be applied carefully and from a safe distance. Carbon monoxide and hydrogen levels should be monitored during its application.

Even in surface operations where the risk of explosion is lower, it is advised that crews fighting spontaneous combustion using water should monitor carbon monoxide and hydrogen levels.

Use of CO_2 is not recommended as it is not considered to be an effective means of putting out the fire and the action could produce high CO levels or even explosions.

Explosion in a bunker (called primary explosion) usually leads to secondary explosion in the area above the bunkers. Don't be fooled by the terminology! The secondary explosion is far more powerful than the primary explosion, and will cause damage to the building structure above the silos or bunkers. The secondary explosion will continue to propagate until it consumes the fuel in front of it or it is no longer confined.

One advanced tool in coal fire suppression is the chemical agent known as F-500 Encapsulator Agent (F-500) is supplied by Hazard Control Technologies Inc, Fayetteville, GA 30214 (website address: www.hct-world.com).

Most power plants are equipped with water deluge systems in their dust collectors, bunkers, tripper rooms, as well as over their conveyors. Wetting and chemical agents can be added to

these deluge systems to increase their effectiveness, but there are significant differences between wetting agents, foams, and the relatively new product, F-500.

Wetting agents rely solely on reduction of the surface tension of water. Coal and other fuels can float on top of these agents, and keep burning.

Foam products rely on two mechanisms - they reduce the surface tension of water, and they establish a blanket that deprives the fire of oxygen.

F-500 works by three mechanisms described below.

F-500 reduces the surface tension of the water. This makes the water droplets smaller creating more surface area to absorb heat and better penetrate into the pores of solid fuels.

Hydrophyilic Polar Head

Hydrophobic Non-polar Tail

Large, Amphipathic F-500 Molecule
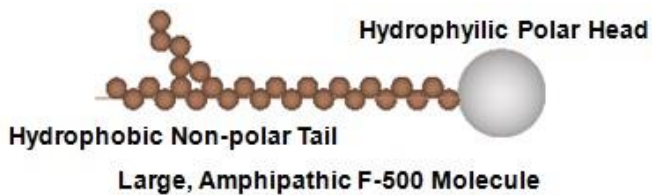
F-500 is a large molecule and is amphipathic, meaning it has a hydrophilic polar head and a hydrophobic non-polar tail.

As the tails of the large F-500 molecules try to get away from the water, they protrude from the surface of the water droplets with the F-500 molecules forming a protective shell around the water droplets.

Water droplet surrounded by F-500 molecules with extruding non-polar tails

Water Droplet with Protective Shell
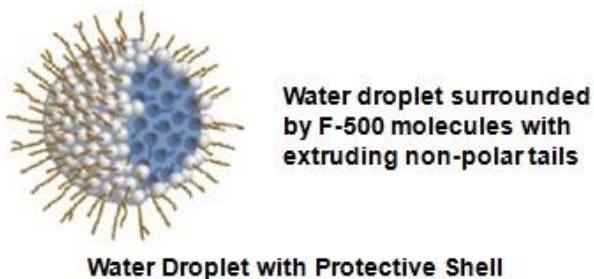
The heat is absorbed through the non-polar tails into the water drops. Unprotected, these droplets would convert to steam. However, as they are surrounded by F-500 molecules, they absorb the heat. Tests have shown that these molecules absorb 6-10 times more heat than plain water droplets. The cooling of the fuel is also rapid. As it reduces the temperature, burning is prevented.

F-500 tails have an affinity for hydrocarbons and attach themselves to the fuel, whether it is liquid or vapor. These protected droplets form a micelle or chemical cocoon around the hydrocarbon molecules rendering the fuel nonflammable and nonignitable.

The final mechanism is the interruption of the free radical chain reaction. This reduces smoke and soot, reducing toxins and improving visibility for firefighters.

F-500 is not foam. Hence it has no requirements to form and maintain a foam blanket to affect fire extinguishment.

F-500 is typically diluted to a 1-3% solution and applied using common firefighting nozzles and eductors and requires no special equipment. F-500 can be premixed and stored in the apparatus tank as well as proportioned and applied with apparatus-mounted eductors and proportioners.

Due to the lack of an appropriate Encapsulator Agent test protocol, F-500 is a cULus Classified Wetting Agent for use on Class A and Class B fires. Additionally, F-500 has been used in the field and found to be effective on Class D fires.

In addition to its effectiveness in fire suppression, F-500 is environmentally safe, nontoxic, non-corrosive and 100% biodegradable. There are no special permits required for the purchase, transportation, or handling of F-500. Typically, after a fire incident, the standing water and F-500 are allowed to simply evaporate.

F-500 has a 15-year shelf life. For more information on F-500 please contact Hazard Control Technologies Inc. (website: www.hct-world.com).

<u>Firefighting Procedure</u>

Top most reason for major fires and dust explosions in the power industry is lack of procedures or training for abnormal operations.

A deep-seated hot spot in bulk storage can be very difficult to extinguish. However; with the proper training and equipment these fires can safely and effectively be extinguished without incident.

Immediate response is required when the odor of burning coal or other evidence of a coal fire inside a bunker is detected. Delay in taking action allows the rate of burning to increase and requires additional effort to control or suppress the fire later on. Upon detection, an action plan must be developed and implemented. However, following actions should be avoided:

- DO NOT attempt smothering the fire with a layer of fresh coal.

- DO NOT run burning PRB coal through the feeders and mills. Doing so places the plant, equipment and employees in jeopardy due to the very high possibility of creating an explosion within the bunker, feeder or mill.

- DO NOT attempt to extinguish the hot spot with plain water, Class A or Class B foam. Plain water will not penetrate the coal or the burning hot spot. Foams also will not penetrate the coal and the blanket they create will retain the heat and combustible vapors creating an environment for a hybrid vapor/dust explosion.

- DO NOT attempt using inerting or dry ice. Neither method has proven to be successful in extinguishing deep-seated hot spots. Inerting can be used as a method to slow the development of a hot spot while emergency response teams are organized.

An action plan / procedure to deal with a hot spot / fire in a silo or bunker should include the following steps.

Once a hot spot is detected or suspected, the first step is to do nothing until a complete assessment is performed.

Map the coal silo or bunker with laser thermometer or thermal imaging camera and record temperatures to determine the location and intensity of the smoldering coal and to track the progress in extinguishing the fire. Continue regular temperature monitoring until the fire is extinguished.

Once a fire is confirmed, stop all coal moving activities. Dust collectors, belts, and other equipment that service the affected location or equipment that may create dust in the area must be shut down. This is to minimize the chance of a fire or explosion occurring during fire suppression.

Do not use the bunker dust collector. Use of the bunker dust collector during the fire may cause a fire or explosion in the dust collector. The dust collector can also act as a draft inducer, pulling air up through the bottom of the silo or bunker, thus accelerating the fire.

Close and verify that the coal feeder inlet gate is 100 percent closed.

Perform a wash down to remove combustible dust deposits on elevated surfaces above the silo or bunker.

Fire-suppression System
(A system to spray a combination of water and F-500)

Smoke inside the silo or bunker can be reduced by fogging the headspace by activating the silo or bunker deluge fire-suppression system, using F-500 at a 3% concentration. (Note: As shown in above figure, such systems are not fire-suppression systems per se. They are hybrids that can be used for dust control and housekeeping or activated to deliver an extinguishing agent in the event of fire.) This will remove coal dust from the walls and roof beams, and will wet the top of the coal. In lieu of a permanent deluge system, a hand watering line with a fog pattern can be used, although access to the coal dust on the beams may be limited. The agent will act as a scrubber and increase visibility and encapsulate CO gas.

Open any overhead hatches or doors leading to the exterior of the plant. Do not open fire doors to the plant interior. Once the fire is attacked, smoke and steam will escape from the bunker and will need to be ventilated to the exterior.

Experience indicates that the very best method of attack is to get the extinguishing agent directly to the seat of the fire. In view of this, once the hazards of a secondary combustible dust explosion have been eliminated the responders can begin attacking the hot spot with a specially designed piercing rod and the F-500.

The piercing rod is assembled in 5-ft sections. But the longer the rod, the harder it is to maneuver it inside the silo or bunker. Rods are generally made of stainless steel and come in several diameters (0.75 inches, 1.25 inches and 1.5 inches). The tip of the rod is perforated and cone-shaped, which allows it to be easily inserted deep into the coal and used at any angle. The rod can be inserted through the top or the sides of the silo or bunker if access ports have been preinstalled.

Application of Piercing Rod

Above figure shows an emergency response team getting trained on use of a piercing rod on a coal pile fire.

After the area has been thoroughly wetted and as much coal dust as possible has been removed, insert a firefighting piercing rod (FFPR) through an opening in the top of the silo or bunker, directly onto the top of the fire. The FFPR may have to be angled toward the fire depending on the location of access holes in the top of the silo or bunker. Using the FFPR helps minimize the amount of water and F-500 required to safely extinguishing the fire.

Never assume that the fire has been extinguished until it has been confirmed with thermal imaging and CO monitors.

Open drain pipe or pipes located just above the mill feeder gate to decant any water prior to opening the feeder gate.

After extinguishment, the final step is to monitor the hot spot until all the material has been removed from the silo or bunker.

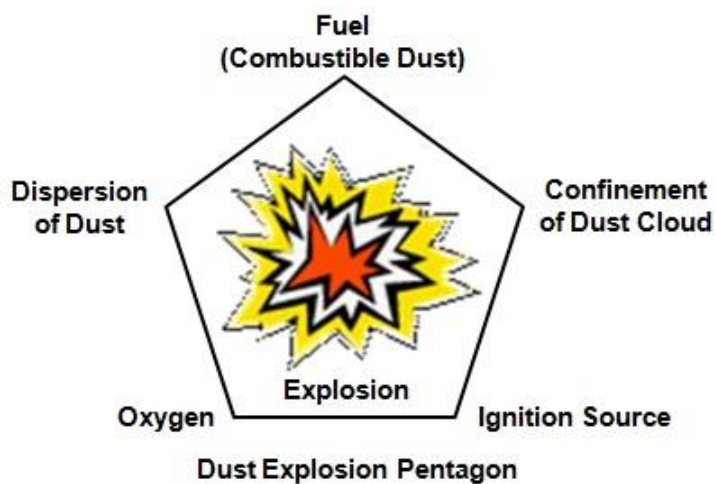## Combustible Dust Explosion and Dust Collectors

Every plant operator generally knows the three-sided fire triangle showing the ingredients necessary for a fire. To review, the ingredients necessary for a fire are: fuel, an ignition source (heat or a spark) and an oxidizer, typically the oxygen in air. Mixed in the right proportions, these three components will cause a fire.

Any solid material that burns can be explosible when finely divided into a dust. For example, a piece of wood can become explosible when reduced to sawdust. Even materials that do not burn in larger pieces (such as aluminum or iron) can be explosible in dust form. A dust fire requires dust (fuel), oxygen and a heat source. For a dust fire to escalate to an explosion there must also be a significant amount of dust dispersion through the air (like a dust cloud) and the space must be confined (any walled room is considered a confined space when it comes to combustible dust).

Combustible Dust Explosion

The working of an explosion is usually explained in terms of the "Dust Explosion Pentagon," which consists of five factors that are essential for a dust explosion to occur:

- Oxidant (usually oxygen in the air)
- Ignition source (heat, open flame, electric spark, mechanical spark from friction or impact, static electricity)
- Fuel (combustible dust)
- Dispersion of the dust (suspended dust burns more rapidly)
- Confinement of the dust (creates pressure buildup, leading to explosion)

Dust Explosion Pentagon

A dust explosion will occur when all five of these factors are present. When combustible dust in a container, room or piece of equipment becomes suspended in the air, even a small spark can create a dust explosion. This is known as the primary explosion. The primary explosion is often relatively small and weak. The primary explosion is often followed by a secondary explosion. Dust that has accumulated on floors, in ductwork, on equipment, etc. at the facility becomes disturbed by the pressure wave generated by the initial explosion, and this newly-suspended dust ignites and a secondary explosion occurs. The effect can continue, as the blast wave from the secondary explosion can cause more dust to become suspended in the air, creating further dust explosions.

Footprints to Disaster

It has been determined that a 1/32 inch buildup over a surface area equal to 5% of the floor area of a room, greatly increases the likelihood of a secondary explosion. All surfaces within the room, including equipment, piping, and rafters, are included in this determination. OSHA regulations require that dust accumulation cannot exceed 1/32 inch on any surfaces equaling 5% of the floor area in the room. As a rule of thumb - if your footprints are visible in the coal dust on the floor of your plant, you have an explosion hazard.

An explosion cannot occur if any one of the five factors of the explosion pentagon is eliminated - something that's hard to achieve consistently at a power plant. But hard doesn't mean impossible.

Dust Collectors

Ignition of combustible dust can occur as a result of spontaneous combustion. Since a dust collector provides confinement for the dust cloud, danger lurks in a dust collector for its explosion. In view of this, please note the following points about use of dust collectors.

PRB coal dust cannot be stored in a dust collector hopper for any period of time. The dust collector must be pulsed and purged every day. If PRB coal dust is left in the dust collector and it is shutdown, the dust could begin to smolder. When the dust-collector fan is started with smoldering coal dust in the hopper, it will explode.

It's important to know if the vent area on the dust collector is sufficiently sized to vent the pressure wave that would be created in a coal dust explosion. Without adequate vent area, an explosion in the collector could fragment the collector, or propagate back into the system since most dust collectors do not have back draft dampers.

Another common problem with dust collectors is that their explosion vents discharge to the inside of a building. With this arrangement, power plant designers inadvertently designed a bomb! If a primary explosion is vented inside a building, and if there is coal dust on the beams and floors, there will be a serious, secondary explosion inside the building - where employees tend to be found.

Never open a door or any access to the inside of a dust collector that is on fire or may be on fire. There have been numerous incidents where plant personnel opened a door of a dust collector that was on fire, and thereby created a draft that dispersed coal dust and caused a devastating explosion.

In case fire protection systems are using water, extra care must be taken to avoid opening the dust collector while the floating dust is still burning. Water followed by fire can pour out and endanger personnel.

References:

A Guide to Stockpiling and Storage by Pt. Adaro Indonesia.

Spontaneous combustion of the organic matter in discards from the Witbank coalfield by R.M. Falcon, Journal of The South African Institute of Mining and Metallurgy, July 1986.

Spontaneous Combustion by Dr. D. P. Mishra, Department of Mining Engineering, Indian School of Mines University, Dhanbad, India.

Hazard Awareness: Combustible Dust, Presenter: Justin Clift, for Hazard Control Technologies Inc., Fayetteville, GA 30214 USA (website: www.hct-world.com).

Fire Protection in Coal Handling Facilities, New and Retrofit, Technology Report 81-10, by Society of Fire Protection Engineers, 60 Batterymarch Street, Boston, Massachusetts 02110, USA.

Fire Safety for Conveyor Systems by Patol Limited (website: www.Patol.co.uk).

Managing silo, bunker, and dust-collector fires, by Diana Merritt, Western Kentucky Energy Corp, and Randy Rahm, Western Resources Inc. published in POWER, November/December 2000.

PRB Coal - Material Handling Challenges and Solutions by Jayant Khambekar and Roger A. Barnum, Jenike & Johanson, published in Power Engineering (http://www.power-eng.com), Volume 117, Issue 3 (March 2013).

Fire Protection Guidelines for Handling and Storing PRB Coal by Edward B. Douberly published in Power (http://www.powermag.com) | 06/03/2013.