

Coal Dust Explosions in the Cement Industry

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ABSTRACT: The number of coal fired industrial systems and utility power plants is rapidly increasing because of the high cost and uncertain availability of fuel oil and natural gas. For many cement producers in the United States, the conversion from fuel oil and natural gas to pulverized coal has been difficult, frustrating, and in a few cases, very costly. This study deals mainly with coal safety requirements in the cement industry which accounts for a very small percentage of coal usage in pulverized coal firing systems. It also deals with the safety requirements associated with coal grinding, drying, blending, transporting, and storing. Case histories investigated by the Mine Safety and Health Administration (MSHA) will be discussed, and recommendations will be made for future fire and explosion prevention.

KEY WORDS: coal dust, fires and explosions, cement plants, coal fired systems, safety

To achieve the goal of safe, efficient, and economical coal firing system designs, both users and regulatory personnel must have an understanding of the hazards involved in coal fired systems and the nature of the problems involved in the use of pulverized coal.

The potential for fires and explosions connected with the use of coal is uniquely different from other fuels. Knowing and understanding the hazards involved are the first steps in developing safer systems.

History

In the 1960s a large number of cement and electric utility power plants converted from coal as their primary fuel to either fuel oil or natural gas. The use of fluid fuels was economical and provided a clean, relatively simple firing system. In addition, the use of fluid fuels met the Environmental Protection Agency (EPA) standards for clean air. Since the 1973 oil embargo the steep rise in the cost of oil has caused many plants to convert back to the use of pulverized coal as their primary fuel for the firing systems.

At the present time the majority of cement plants are using coal as the primary fuel. For startup of kilns, boilers, and furnaces the use of liquid fuels is still a common practice.

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Phenomena of a Coal Dust Explosion

To understand fully the hazards of using pulverized coal as a fuel in a cement plant, one must become familiar with the factors that typically enter into the development of an explosion. A typical pulverized coal fuel system must process bulk coal into a form that can be efficiently utilized as a fuel to heat the kiln for calcining the raw materials (clay, limestone, and so forth) into clinker (see Appendix). This is usually accomplished by grinding and drying the bulk feed in a pulverizer so that the coal emerging from the pulverizer will consist of 70 to 80% particulate that will pass through a 200-mesh U.S. screen sieve (that is, particles with a diameter of 74 μm or less). High temperature air from the clinker cooler is often used to dry the coal and convey it from the pulverizer to the burning pipe in the kiln. The coal pulverizer is one of the most hazardous pieces of equipment from a fire and explosion viewpoint because fuel and oxygen for combustion are always present.

A dust explosion is often described as a rapid burning of combustible particulate within a confined area, which results in the generation of intense heat and corresponding pressure rise. If not vented adequately, the rise in pressure caused by the rapid buildup of heat can cause damage to the confining vessel and the surroundings. The following factors must be present to cause a dust explosion:

- (1) the presence of dust in suspension in a concentration above its flammable limit,
- (2) sufficient oxygen to enable combustion of the fuel,
- (3) a source of energy to ignite the fuel, and
- (4) a certain degree of confinement of the suspended dust mixed with oxygen.

Factors Affecting Dust Fire/Explosion Probability

Factors that influence the dust fire/explosion probability include the following:

1. Fuel-Bituminous coal is the fuel typically used in a pulverized fuel system. All U.S. bituminous coals and coal dust passing through a 200-mesh sieve having a diameter of (74 μm or less) present a dust explosion hazard.

The minimum explosive concentration is the minimum quantity of dust in suspension that will propagate an explosion if exposed to an ignition source of sufficient magnitude. For high-volatile bituminous coals, the minimum explosive concentration lies between 50 and 100 g/m^3 (0.05 to 0.1 oz/ft^3) [1, 2]. A coal pulverizer under normal grinding conditions will, in most cases, be loaded with a concentration of coal dust above this minimum concentration. The upper explosive limit is not well-defined but is above 4000 g/m^3 (4.0 oz/ft^3) [3].

2. Oxygen-the drying and conveying air in the pulverizer contains sufficient oxygen to support combustion of a coal dust cloud above its lower flammable limits. If coal containing a high percentage of moisture is being dried, the drying air will be diluted with water vapor which will result in a reduction of the oxygen level in the air. This reduction may reduce the rate of pressure rise and maximum pressure generated if an explosion occurs but will not prevent an ignition unless the overall oxygen concentration is reduced to about 13% (for bituminous coals under a strong ignition source).

3. Ignition sources-Many possible ignition sources may be present in a pulverized fuel system. Frictional sparks can be generated within the pulverizer itself by tramp iron or other foreign objects which may find their way into the system. Also, hard inclusions in the coal, such as pyrites or rock, may be a source. The action of these materials against one another or moving parts in the mill may produce sufficient heat and sparks to initiate a fire or an explosion. Broken damper plates or fan blades from fans or ducting may also create frictional sparks which can ignite coal dust clouds or accumulations. The high temperature of the drying air often can provide enough heat to

ignite coal accumulations in the mill under certain conditions. Feeding hot coals from storage piles into the pulverizer may also provide an ignition source. Defective electrical equipment is yet another possible source.

The minimum ignition temperature of a coal dust cloud can range anywhere from 425°C for dried lignites to 800°C for certain anthracite coals [4]. Bituminous coals typically ignite somewhere between 500 to 625°C [2,4]. The minimum ignition temperature for the generation of a smouldering fire in a coal dust layer is much lower, however, and certain bituminous coals may be ignited at temperatures as low as 160°C [5]. The electrical energy required to ignite a bituminous coal dust cloud is on the order of 60 mJ and increases with increasing turbulence of the dust cloud [2].

4. *Self-heating of dusts* - Another important phenomenon which may lead to fire or explosion in a pulverized fuel system is that a spontaneous combustion, or self-heating. Spontaneous combustion occurs when a pile or accumulation of coal, over a period of time, begins to auto-oxidize and leads to a runaway exothermic reaction accompanied by the evolution of heat and/or flame. The principal factors that affect spontaneous combustion are as follows (this listing comes mainly from Ref 5):

(a) Rank-Tendency to self-heat increases with decreasing rank. Coals are classified by rank in accordance with the ASTM Classification of Coals by Rank (D 388). Lignites and subbituminous coals are most susceptible to spontaneous heating.

(b) *Air flow rate* - sufficient to maintain high oxygen concentrations on the coal surface, but not high enough to remove heat by convective cooling, will increase the tendency toward spontaneous heating.

(c) *Particle size*-The smaller the coal particle, the greater the exposed surface area and the tendency to undergo spontaneous heating.

(d) *Moisture content of the coal and the air* -At temperatures below 100°C, the rate of heat generation by moisture absorption exceeds the rate of heat generation by oxidation. Lower rank coals, if predried and subjected to moist air, are most susceptible to self-heating because of the above effect.

(e) *Temperatures*-The rate of oxidation is a direct function of temperature. The higher the temperature, the faster the rate at which coal reacts with oxygen.

(f) *Impurities in the Coal*-Presence of sulfur mineral pyrite and marcasite may accelerate spontaneous heating. Generally, the pyrite content must exceed 2% before it has a significant effect.

(g) *Pile geometry* - Size, depth, and shape of the stored coal pile is another factor that affects spontaneous combustion.

Coal rank, particle size, air permeability, geometric size of the pile, and moisture content of the coal and the air are the most important factors.

5. *Coal selection* - Use of coal as a fuel in cement or power plant operations can present special problems to a plant operator because of the wide range of coals and quality of coal available on the market. To ensure safe operation of a pulverized coal fuel system, operating parameters will change as the type of coal or blend of coals is varied. It may be difficult to predict the behavior of a particular coal in the system in regard to the fire and explosion hazard involved. Selection of safe and efficient inlet and outlet air temperatures in the pulverizer, to ensure safety in the event of a planned or unplanned shutdown, is often a result of trial and error. The experience of the operator in dealing with various types or blends of coal is often a key factor in the prevention of fires and explosions in pulverized coal fuel systems.

As previously mentioned, the tendency of coal to undergo self-heating is inversely related to the rank of the coal. Self-heating increases with decreasing rank. ASTM has developed a standard procedure for the ranking of coals (ASTM D 388). Coals having 69% or more fixed carbon on a dry mineral, matter-free basis are classified according to fixed carbon value. Coals having less

than 69% fixed carbon are classified according to their calorific values on a moist, mineral-matter-free basis.

It is sometimes difficult to predict the tendencies of blends of coals to undergo self-heating, and experimental testing may be necessary to accurately predict the behavior of these blends under plant conditions.

Laboratory Testing

Select laboratory testing is routinely carried out to investigate cement plant explosions involving pulverized coal dust. Samples of dust taken from the pulverizer are screened, and a particle size distribution profile is obtained. A proximate analysis test provides information on volatile matter and fixed carbon content of the particular coal sample. U.S. coals, having a volatile ratio (also known as moisture, ash free [maf] volatility) of 12% or more [5], present a dust explosion hazard.

$$\text{Volatile Ratio, \%} = \frac{\% \text{ Volatile Matter}}{(\% \text{ Volatile Matter} + \% \text{ Fixed Carbon})} \times 100$$

The minimum explosive concentration is also determined to indicate the lower flammability limit of the sample and provides an indication as to whether or not the sample is ignitable by an inductive spark ignition source. This test is carried out in a 1.2-L Hartmann tube apparatus [6]. If the particular sample is not ignitable by spark ignition source, tests are conducted in a 20-L vessel [1] using stronger ignition sources.

Results of these tests are incorporated into the investigative report and provide legal documentation of the explosibility properties of the coal being used at the particular facility where the explosion took place.

Coal Fired Systems

There are three types of coal fired systems used in cement plants

1. *Direct Fired System* (Fig. 1) is the simplest to operate, control, and maintain. It has the lowest equipment cost and is the safest system in terms of dust explosion probability. Coal is pulverized in the mill and is fed with the primary air or hot drying gases directly into the kiln. The main source of air or hot drying gases is from the clinker cooler, the kiln, or preheater exhaust.

The system has one major disadvantage in that all the air required to dry the coal is blown directly into the kiln. The primary air, which is usually high in moisture and low in temperature (about 79.4°C [175°F]), feeding directly into the kiln can adversely reduce the overall efficiency of the kiln and its ability to make good clinker. Another disadvantage is that the coal dust fines-air mixture flowing through the high-speed fan blades can cause impurities or foreign objects to be lodged in the fan and ductwork. This may cause a serious frictional ignition problem that can lead to an explosion. The foreign objects or impurities can also cause fan blade wear resulting in a serious maintenance problem.

2. *Semidirect fired system* (Fig. 2) was developed to overcome some of the disadvantages inherent with the direct fired system. In this system the pulverized coal and the transporting gases or air leaving the coal mill are separated by means of a cyclone. The cyclone collects the pulverized coal at its bottom but allows the air to pass freely out its top. The air is recirculated back to the coal mill as makeup air after it is separated from the pulverized coal. The coal remains in the cyclone hopper until it is discharged by the rotary feeders. Two advantages are that the mill system fan operates in a partially closed loop and that the coal feed is controlled by the rotary feeders and not by the primary air flowing through the coal pulverizer. The volume of air flowing through

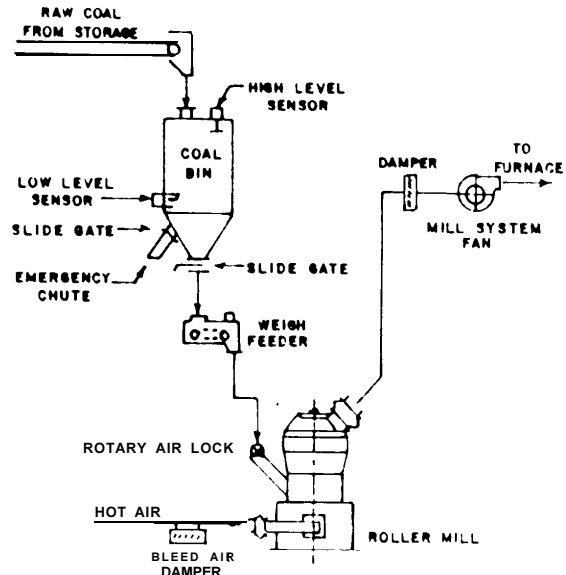


FIG. 1-Direct fired system.

the coal mill and directly to the kiln or burner can be reduced, increasing the thermodynamic efficiency of the system.

However, this system has a number of disadvantages. During the separation process in the cyclone, some of the coal fines are inevitably carried out of the cyclone top with the recirculating air. These coal fines are less damaging to the mill system fan blades than in the direct system but

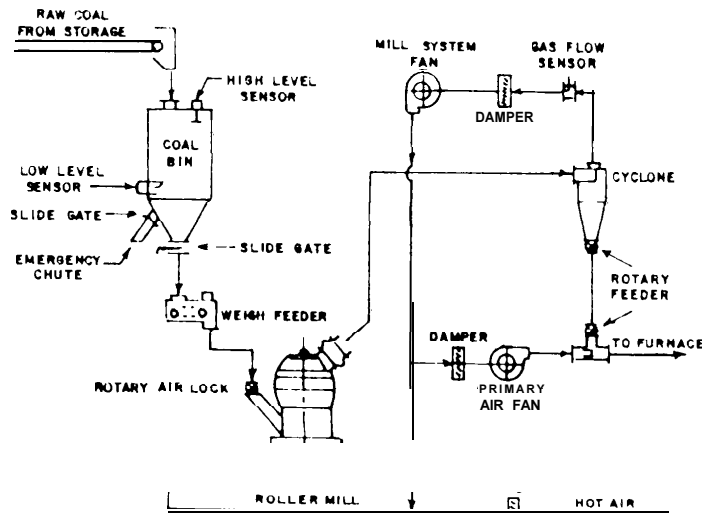


FIG. 2-Semidirect fired system

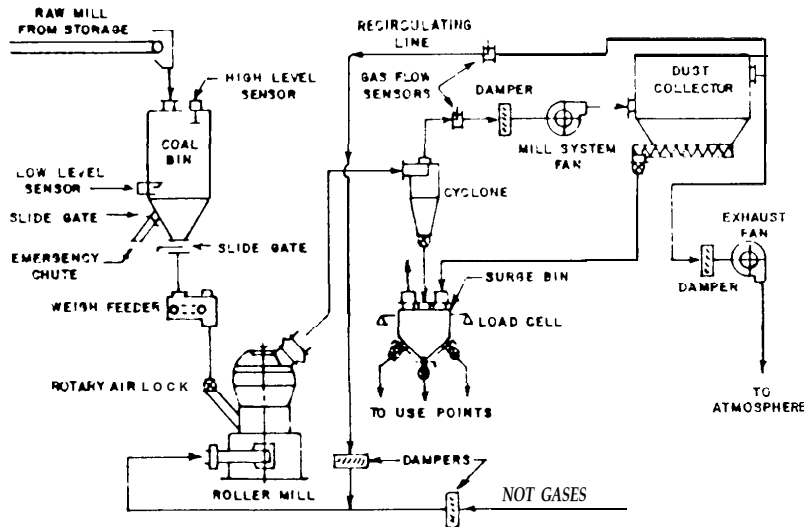


FIG. 3-Indirect fired system.

constitute a more serious fire and explosion hazard. Moisture from the coal in the recirculating loop can accumulate and settle in the circuit leading to coal agglomeration, plugging, and other problems. One other major disadvantage is that the cyclone storage capacity is rather small, so a mill shutdown will soon cause a coal feed shutdown and result in kiln cooling and system shutdown unless some other fuel source is available for firing the system.

3. *Indirect fired system* (Fig. 3)-In this system the hot air circulating loop, used for drying the coal and transporting it through the coal mill and into the cyclone, is completely separated from the system that transports the pulverized coal to its use points. The system provides for storage of large quantities of pulverized coal in a silo or bin (surge bin), usually with a three-day maximum capacity, so that the coal firing can be maintained even during a mill shutdown. One important feature of this system is that none of the drying and transporting air in the recirculating loop, from the pulverizer to the cyclone to the baghouse dust collector and back to the pulverizer, is used to transport the coal fines to the firing points. The drying and transporting air vents the coal moisture directly to the atmosphere via an exhaust fan. There is a filter baghouse dust collector in the recirculating loop downstream from the cyclone which prevents the coal fines from being recirculated back to the pulverizer or accumulating anywhere in the loop. The baghouse dust collector feeds its fines directly to the surge bin. Since the drying air circuit is completely separated from the coal-firing circuit, clean and dried exhaust gas may be used as inert gas in the recirculating loop instead of air. This allows the use of a much greater proportion of high-temperature secondary air to primary air in the kiln resulting in a more efficient combustion regime.

The disadvantages of an indirect system include higher capital costs and greater danger of coal dust explosions than with direct or semidirect fired systems as a result of the added handling and storage requirements of the pulverized fuel. The presence of the baghouse dust collector and surge bin would add to the coal dust explosion hazards.

Coal Storage Systems

There are two main types of coal storage systems used in the cement industry.

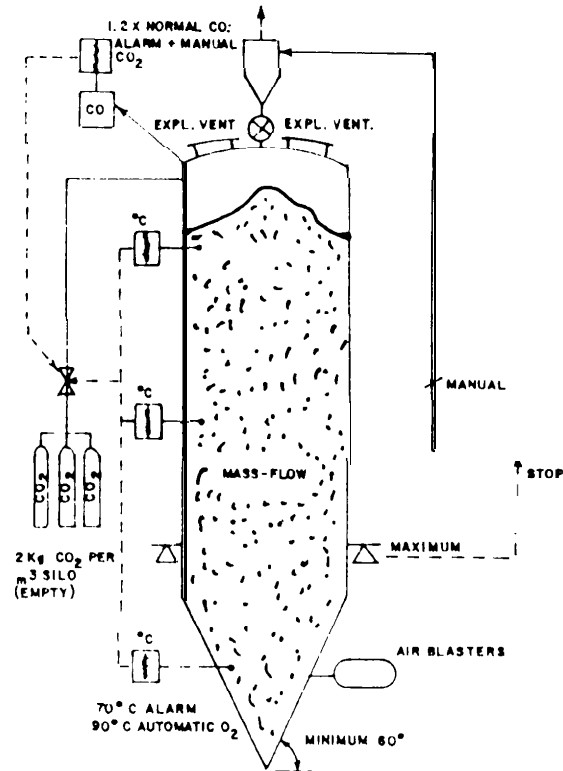


FIG. 4--Coal bin.

1. *Coal bin or silo* (Fig. 4)-Bins are usually constructed of steel, but concrete is also used. Bins are circular, square, or rectangular in cross section and generally designed for a three- or four-day capacity. The hoppers should be designed for mass flow to eliminate static coal deposits. The bin outlet should be large enough to prevent arching or plugging. All bins should be self-cleaning, and internal surfaces should be kept free of stiffeners, weld strips, or flange surfaces.

For explosion venting design, many factors must be considered. The National Fire Protection Association (NFPA) Guide for Explosion Venting (NFPA 68, see Appendix) should be used in evaluating each installation. Explosion venting provides relief for explosion force build-up inside the bin and limits the damage should an explosion ever occur.

2. *Coal stockpiles* can either be in the open or under a covered storage shed area. The storage site selected should be located away from any heat source, well drained, free from standing water, and preferably on a dry, high ground area. The storage area should be cleared of all foreign materials such as wood, rags, waste oil, or other materials having low ignition temperatures. Coal should be spread in horizontal layers and piled so as to ensure effective ventilation to dissipate heat or packed firmly to ensure the minimization of communicating voids containing air.

Problem Areas in the Coal-Firing System

The uniqueness of coal and the variability of coal properties from area to area make the present engineering technology and the latest state of the art for buildings and operating facilities for safe

fueling of cement kilns difficult. Almost every operator using a coal dust-fired kiln will acknowledge that the installation has certain physical features that make the operation inherently hazardous and that he or she operates the facility cautiously and, during certain critical situations, with a degree of uncertainty.

Most coals used in the firing of kilns have the tendency for spontaneous ignition in accumulated piles. The following factors also can create hazardous conditions:

1. *Storage of coal* - If the coal is stored improperly on stockpiles, it can self-ignite creating a serious fire hazard. However, in coal silos or bins, where coal heating is already in progress, the added confinement may cause a serious fire and explosion hazard.

2. *Handling of coal within the firing system* -Western coal is more friable than eastern coal. It fractures more easily in handling, conveying, and stockpiling and produces a higher percentage of fines which contribute to the dust accumulation. Dust accumulations increase the risk of fire and explosion. However, western coals have a higher moisture content, but they tend to dehydrate which causes fissures and subsequent degradation of lump size. Also, western coal has a higher tendency for spontaneous combustion. Volatile gases resulting from thermal decomposition when the coal is heated can cause a serious explosion in a confined area such as a silo or surge bin. Coal with high moisture content will need a higher coal mill inlet temperature for drying purposes.

3. *Accumulations of coal dust during system operation* -During operation of the coal pulverizer and the coal-dust-handling facilities, coal fines can collect at dead areas within the pulverizer and at bends in ducting. Given certain conditions coal fines could create a fire and explosion hazard.

4. *Unplanned shutdowns* - Unplanned shutdown of the coal firing system can be due to power failure, system fan failure, kiln shutdown, or coal feed shutdown causing mill shutdown. If the problem causing the unplanned shutdown persists and the coal in the mill cannot be moved, a fire may occur creating a critical situation which will result in an explosion during startup. Many of the fires and explosions in the coal processing installations have occurred following an unplanned shutdown. Most fires have occurred in the pulverizers, baghouses, or in bins during idle periods. Most explosions have occurred in the pulverizer or in the cyclone immediately after restart of the system.

5. *Debris in the pulverizer* -Debris or foreign material entering the system with the coal feed to the pulverizer can create a hazardous condition. Tramp iron in the pulverizer can cause high-temperature sparks capable of initiating a dust explosion. If foreign material becomes lodged within the system, it will alter the design air flow and can cause dead spots where coal dust may accumulate.

6. *Baghouse dust collector* -The baghouse is one critical area where the cement industry using indirect and semidirect systems has experienced many fires. Freshly ground, high-temperature coal fines that escape from the cyclone enter the baghouse for final separation from the drying air circuit. This coal is highly susceptible to autoxidation. The likelihood of a fire as a result of spontaneous combustion is increased during idle periods within the system where the coal can also degas volatile constituents which can contribute to fire or explosion. Static electricity in the baghouse can provide a source of ignition also, and proper grounding methods and use of semiconductor bags are essential to minimize the hazard.

7. *Pulverized coal surge bins* -The coal surge bin where freshly ground coal is stored prior to delivery to the burner is a critical area in the system. The primary hazard associated with the surge bin is fire from spontaneous combustion or a related phenomenon during shutdown periods. The risk is increased as a direct function of the amount of coal stored in the bin in any given period of time.

Case History of Accident Investigations

A total of 26 fire and explosion accidents were investigated by MSHA inspection personnel from 10 June 1977, through 4 Feb. 1985, in cement plants throughout the United States. In most

casts, the inspection personnel required technical assistance from the Safety and Health Technology Center in Denver, Colorado, or from the Safety Technology Center in Bruceton, Pennsylvania.

During a typical investigation technical information was collected on the system operating parameters which included the system flow sheet, quantity of air, coal dust samples, types of coal, and so forth. The coal samples were sent to the Safety Technology Center in Bruceton for laboratory testing for composition, particle sizes, and explosibility of the dust. The tests completed in the Bruceton Laboratory were all based on several ASTM standards (see Appendix).

All 26 incidents occurred in the coal fired systems. In most cases there was substantial damage to equipment, building, and operating facilities. In addition, some of the incidents caused severe personnel injuries which included second- and third-degree burns and one fatality.

The Ad Hoc Committee on Coal System Safety of the Portland Cement Association (PCA) had compiled 13 fires and explosions that occurred in the indirect fired systems at cement plants. About half of the incidents involved fires and/or explosions in the filter baghouse of the indirect-fired systems. The other half involved the cyclone dust collectors and pulverizer coal mills.

The Ad Hoc Committee concluded that there was a trade-off between operating efficiency, fuel costs, and safety. Lower rank coal requires high mill inlet temperatures, and the use of indirect systems has improved the firing efficiency and fuel consumption but has increased the fire and explosion hazards.

The following accidents in coal fired systems and coal storage facilities of cement plants have been investigated.

Explosion date: 4 April 1978-New York

A combustible gas and coal dust explosion occurred in the kiln. The dust buildup was attributed to incomplete combustion, excessive coal feed, temperature too low to sustain combustion, or a combination of all three. The successive startup and shutdown cycles during the early operating stages, while the coal feed was kept to a minimum, may also have contributed to the dust buildup.

There were no injuries to personnel but there was extensive damage to the dust and breech chamber at the kiln feed end and to the ductwork leading from the multicyclone to the electric precipitator.

Recommendations: To investigate the application of a total hydrocarbon analyzer, equipped with flame-out alarm and automatic fuel shut-off.

Explosion date: 16 Oct. 1979--Montana

A coal dust explosion occurred inside No. 1 mill exhaust fan housing. As a result of one or a combination of kiln puffs (minor explosions), the system fan damper failed, one piece fell into the inlet of the exhauster and could have hit or rested on the rim of the whizzer wheel or on the inlet ductwork. The other half could have lodged itself in a section of the ductwork or possibly even in the mill converter head, temporarily blocking off the mill air flow. This blockage would account for the pressure rise indicated by the control room charts. The piece lying at the inlet of the exhauster and hitting the whizzer wheel could also explain the rattling metallic noise reported.

Two persons received second- and third-degree burns. There was extensive damage to the mill exhaust fan (Figs. 5 and 6).

Conclusions: The following conditions were believed to have existed before the explosion:

1. Coal feed was 97% minus 200 mesh.
2. Air temperature at the fan outlet was 65.6°C (150°F) and was dropping.
3. Transport air velocity was low allowing the settling of coal fines to the bottom of the burner pipe.

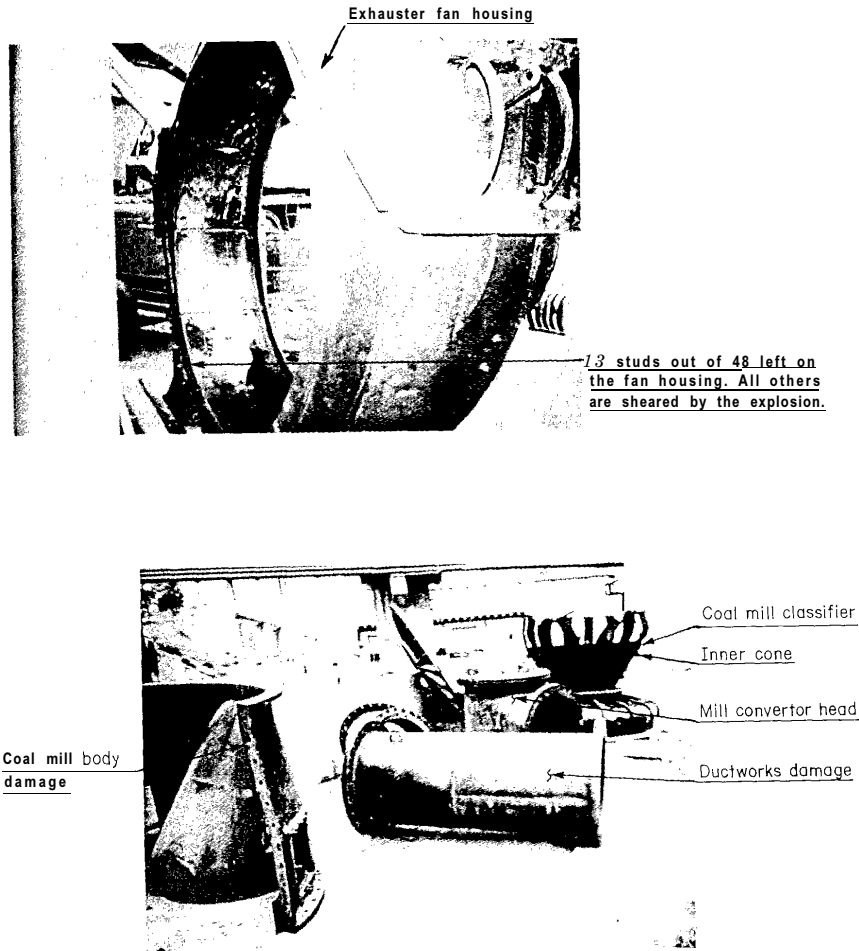


FIG. 5 -Explosion damage to coal mill component parts, ducting, and exhaust fan housing.

4. Operator reduced the coal feed rate to 50% of the original rate thus creating a fuel to air ratio that was at the lower explosive limit.

5. Damper section failure at the fan inlet resulted in metal contact with the fan blades. This failure provided a probable ignition source (friction causing sparking). The other section was found in the inside of the inner cone of the bowl mill.

Explosion date: 6 Feb. 1981~Pennsylvania

The explosion was the second (the first was on 2 May 1980) that occurred during the restart of the plant following an unintentional power failure.

Both explosions occurred immediately after the coal mill circulation fan was restarted.

There were no personnel injuries. The major damage was confined to the cyclone.

Recommendations: The principal hazard resulting from a power stoppage is the heat buildup in the base of the coal mill. It was recommended that the plant should provide cooling in this area

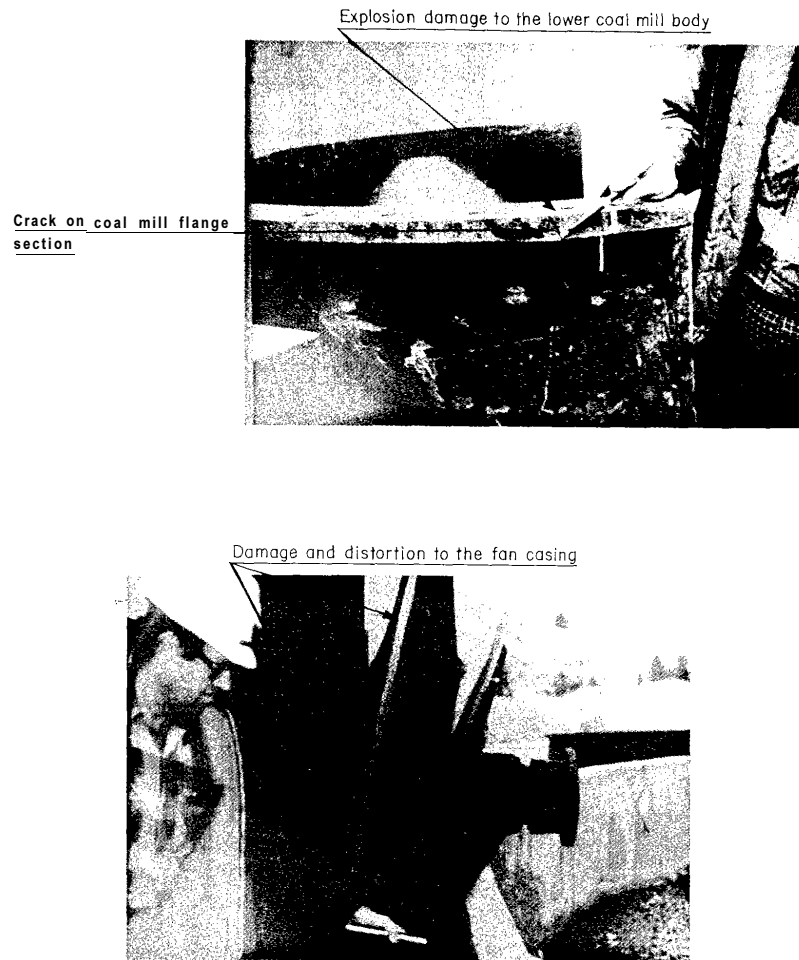


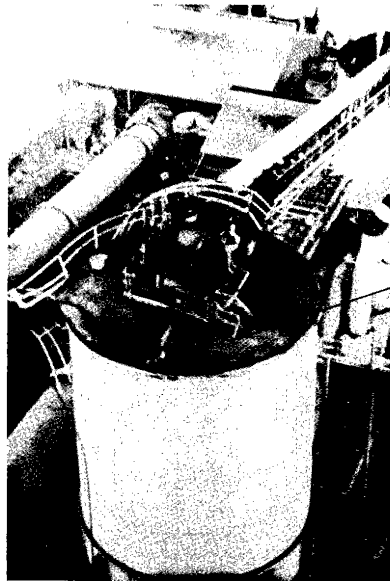
FIG. 6 -Explosion damage and distortion to fan casing and to the lower section of the mill.

after a power loss. An immediate automatic injection system consisting of high-pressure water through fog nozzles was installed. Another safety measure that was recommended was an explosion-suppression system to be installed in the cyclone. In this system pressure sensing devices are used to actuate pressurized cylinders of fire suppression agents.

Explosion date: 18 July 1984-California

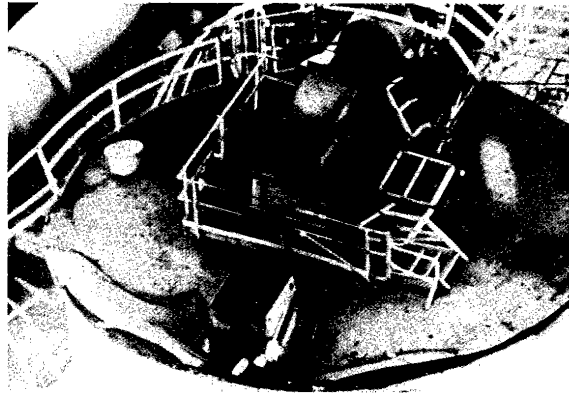
An explosion occurred in a coal bin. Fire was initiated by spontaneous combustion. Carbon dioxide application from the top was insufficient to prevent the development of an explosive atmosphere in the confined space above the coal. When a smoldering fire burns for a considerable time without being detected, the buildup of volatile gases can produce an explosive mixture resulting in an explosion.

There were no injuries to personnel, but there was extensive damage to the bin top and to the conveyor housing feeding the bin (Figs. 7-9).



Explosion damage shown on the top of the coal bin

Hand rail damage



Belt conveyor distortion due to the explosion force

Damage shown on the coal bin cover due to the explosion

FIG. 7 -Explosion damage to equipment and structures on top of coal bin

Recommendations: The bin must be tightly constructed to reduce air leakage to a minimum. The application of carbon dioxide (CO₂) should be applied near the bottom and at the top of the bin to produce a small positive pressure inside the bin preventing leakage of air into the bin. An effective carbon dioxide inerting system should be developed for handling similar conditions in the future. A weak wall construction system was suggested for covering a sizeable area on the top of the bin for future installations (see also Fig. 4 for other recommendations).

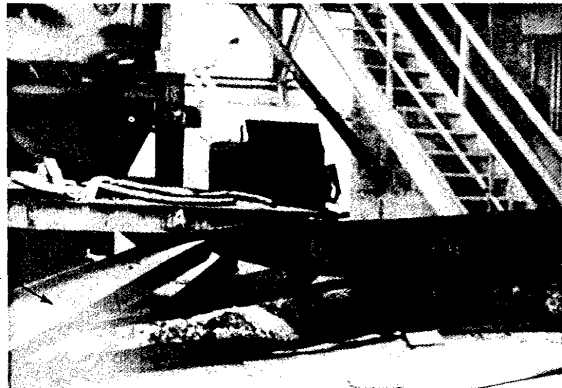
Explosion date: 23 Jan. 1985-New York

Three employees were injured, one fatally, when they were thrown off the platform as a result of an explosion in the Bowl Mill.



Closer view of the explosion damage and distortion of the belt conveyor section on the coal bin.

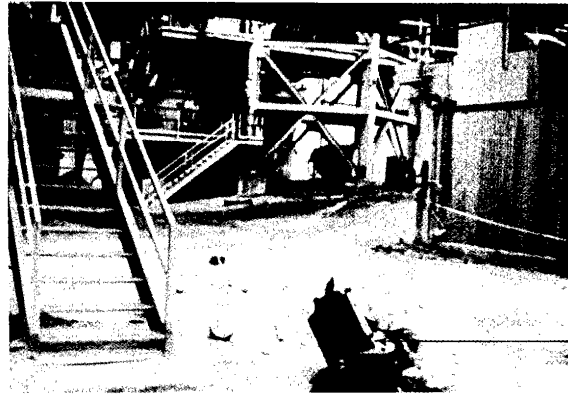
Hand rail damage



I-beam distortion supporting the bin's cover, belt conveyor chute and other equipment on the top of the coal bin.

FIG. X-Explosion damage to conveyor section on coal bin top and to the bin I-beam support.

The Bowl Mill was shut down as a result of abnormalities in the mill operation and an unusually large amount of rejects from the coal mill reject chute. A foreman and two repairmen climbed on a platform and proceeded to remove the stud nuts securing the mill (west) inspection door. One repairman removed seven of the eight stud nuts and tried to break the seal by forcing it with a screwdriver. An explosion forced the inspection door open throwing the three persons to the floor. The explosion forces caused extensive mechanical damage to the primary air fan in addition to fatally injuring one person (Fig. 10).



Belt conveyor motor and speed reducer's resting position.

FIG. 9 - Final resting position of conveyor motor and speed reducer after the explosion (about 45.72 m [150 ft] away from the bin).

Explosion date: 18 June 1985-New Mexico

An explosion occurred in the coal grinding mill circuit during a scheduled shutdown of a cement kiln.

There were no injuries to personnel, but property damage and disruption of production resulted. Physical damage was limited to the 914.4-mm (36 inch) diameter hot air supply pipe which had separated at the welded joint, bent and distorted coal screw feeder covers, the hot air inlet damper (badly bent), and minor distortion of the cold air inlet control damper.

Prevention and Recommendations

The following special precautions are necessary to ensure safe operation of coal fired systems:

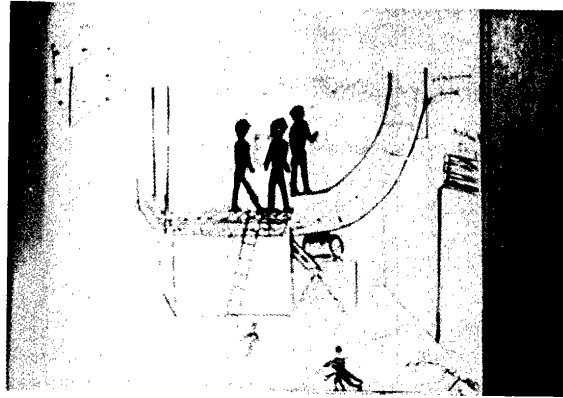
1. Elimination of one or more legs of the Fire Triangle or Explosion Pentagon

(a) *Inerting*

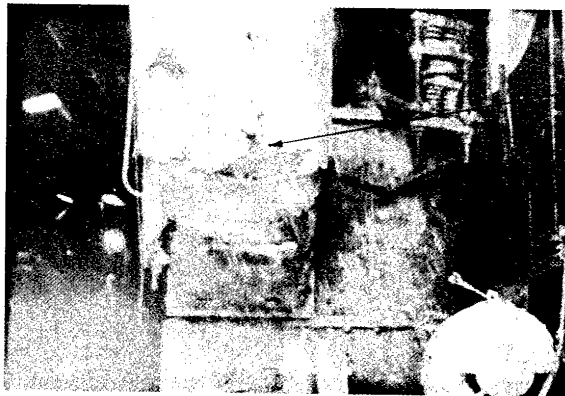
- (1) Use of oxygen-deficient air in the pulverizers (indirect system) under normal operating conditions.
- (2) Use of rock dust, carbon dioxide, or water systems in the pulverizers and dust collectors when shutdown occurs (taking into consideration that rock dust could contaminate the coal).
- (3) Inerting with water sprays and steam when overtemperature conditions are observed. Care must be taken to prevent the development of a dust cloud which may then explode.

(b) *Removal of ignition sources*

- (1) Use of magnets and metal detection to remove tramp iron from the system.
- (2) Cutting and welding operations should be carried out in accordance with recognized safety codes or guidelines (American Welding Society, American National Standards Institute [ANSI], NFPA).
- (3) Electrical components should meet the National Electrical Code and NFPA requirements and appropriate NFPA dust explosion codes (see Appendix).
- (4) Hot coal from storage areas should be discarded and not fed into the pulverizer. Particular care should be exercised during startup and shutdown.
- (5) Proper control measures should be instituted to prevent spontaneous combustion.
- (6) Grounding of dust collector bags or use of semiconductor bags to prevent static electricity discharge.



Sketch of a mill explosion showing the location of people before and after.



Explosion damage to the ductworks and insulation.

FIG. 10 -Explosion damage to mill ducting, insulation, and the inspection door.

- (7) Smoking and open heat sources should be prohibited in hazardous areas of the plant.
- 2. Good housekeeping
 - (a) Prevention of dust accumulations by control of spillage, leakage, and degradation of coals to fines during handling and resultant dust buildups.
 - (b) Cleaning and removal of extraneous combustible materials from the workplace.
 - (c) Design, implementation, and maintenance of dusttight equipment.
- 3. Equipment design
 - (a) Small compact design of pulverizers, cyclones, dust collectors, and storage bins with a minimum of dead space.
 - (b) Elimination of dead spots, ledges, corners, or other areas where dust can accumulate in equipment or ducting.
 - (c) Storage bins designed with proper discharge angles and smooth internal surfaces and vibrators to facilitate removal of the coal.

- (d) Auxiliary electric power systems available to operate key pieces of equipment in the event of a power failure.
 - (e) Use of overtemperature and overpressure controls to warn of a potentially dangerous situation.
 - (f) Fire and/or explosion suppression systems can be installed on pieces of equipment susceptible to fires and/or explosions.
 - (g) Detection equipment can be installed to monitor carbon monoxide (CO) buildup in the pulverizer, cyclone, storage bin, or dust collector. The design of the carbon monoxide monitoring system is based on the fact that CO buildup is related directly to the oxidation rate of the coal. An analysis system is needed to compare the CO content of the incoming and outgoing mill air and indicate the difference. The principal advantage of this system is that it can detect CO buildup and, therefore, may give the operator sufficient lead time to adjust operating conditions, apply fire extinguishing measures, and, if necessary, shut down the mill to prevent an explosion.
 - (h) The use of explosion venting design should be considered for controlling the explosion damage.
4. Education and training. Written procedures should
- (a) Be specific to prevent any variations in the interpretation and application by different operators.
 - (b) Be readily available to all operating personnel.
 - (c) Contain the necessary information for system checkout, warmup, and shutdown including short-term, long-term, and emergency operating conditions.
 - (d) Be modified immediately when operational changes are deemed necessary.
 - (e) Be reviewed regularly with all operators to prevent gradual changes in the actual operating practices. A safety meeting or group training session is helpful for this review and updating.
 - (f) Be established for fire fighting with periodic drills
5. Preventive maintenance
- (a) A routine maintenance program should be developed for pieces of equipment sensitive to breakdown, such as motors, dampers, and fan blades.
 - (b) Periodic inspections should be carried out to ensure that key pieces of equipment are in good operating condition.

APPENDIX A

Glossary

- ash** inorganic residue remaining after ignition of combustible substance, as determined by prescribed test methods
- calorific value (heat of combustion)** heat produced by combustion of a unit quantity of a solid or liquid fuel when burned at constant volume in an oxygen bomb calorimeter
- clinker** fused product of a kiln which is ground to make cement
- coal bin (coal silo or coal bunker)** container, circular in cross section, used to store run-of-mine coal. It is placed ahead of the coal pulverizing mill in the coal fired system
- coal surge bin** bin used for storing pulverized coal approximately 200-mesh (74 μm or less)
- explosion pentagon** the three elements present in the fire triangle plus two additional elements necessary for explosion-suspension of fuel within the flammable limits and confinement
- fire triangle** the three elements necessary for a fire-fuel, heat (ignition sources), and oxygen
- fixed carbon** solid residue, other than ash, obtained by destructive distillation, as determined

by prescribed methods. It is principally carbon but may contain appreciable amounts of sulfur, hydrogen, nitrogen, and oxygen

proximate analysis determination, by prescribed methods, of moisture, volatile matter, ash, and fixed carbon (by difference)

pulverized fuel solid fuel reduced to such a size that more than 50% will pass through a 200-mesh U.S. sieve (74 μm or less)

rank term used to classify coals according to their degree of metamorphism, or progressive alteration, in the natural series from lignite to anthracite

run-of-mine raw coal as it is delivered by mine cars, skips, or conveyors and prior to treatment of any sort. It is usually the average grade of coal or ore produced in a mine

ultimate analysis the determination, by prescribed methods, of carbon, hydrogen, sulfur, nitrogen, ash, and oxygen (by difference)

APPENDIX B

Standards

The following standards are applicable to this paper:

ASTM Standards

D 121-78	Standard Definitions of Terms Relating to Coal and Coke
D 197-82	Standard Method of Sampling and Fineness Test of Pulverized Coal
D 311-30	Standard Method of Sieve Analysis of Crushed Bituminous Coal
D 388-82	Standard Classification of Coals by Rank
D 3172-73	Standard Method for Proximate Analysis of Coal and Coke
D 3176-84	Standard Method for Ultimate Analysis of Coal and Coke

Other Standards

NFPA 68-1978	Guide for Explosion Venting
NFPA 69-1978	Standard for Explosion Prevention Systems
NFPA 70	National Electrical Code
NFPA 85E-1985	Prevention of Furnace Explosions in Pulverized Coal-Fired Multiple Burner Boiler-Furnaces
NFPA 85F-1982	Installation and Operation of Pulverized Fuel Systems

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