EXPLOSION HAZARDS
FROM THE USE OF PULVERIZED COAL
AT INDUSTRIAL PLANTS

BY
L. D. TRACY
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EXPLOSION HAZARDS FROM THE USE OF PULVERIZED COAL AT INDUSTRIAL PLANTS

By L. D. Tracy

INTRODUCTION

When pulverized-coal fuel in the industrial plants of the United States caused fires and explosions that killed workers and damaged property, the Bureau of Mines availed itself of the opportunity to study the conditions under which such disasters occurred, and thereby collect information that would complement investigations of dust explosions in coal mines.

Studies at industrial plants have failed to show any factors that have not been determined before in tests with coal dust in the laboratory and in the bureau's experimental mine. However, enough data have been obtained upon circumstances under which coal-dust explosions have occurred and are liable to occur to justify a review of conditions and practices in a number of plants or mills that have suffered from disastrous explosions. This bulletin, therefore, presents both the bad and the good features of pulverized-coal plants and gives recommendations for safe installation and operation. Consequently, in the preparation of this bulletin much of the material on explosions in plants is based on the results of tests at the experimental mine and in the laboratory dust gallery.

ACKNOWLEDGMENTS

The Bureau of Mines acknowledges the hearty cooperation of officials at the various industrial plants in which investigations have been made and their permission to publish the facts as determined.

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data in connection with the discussion of electrical hazards. Reinhardt Thiessen contributed the discussion on the microscopic analysis of partly consumed coal dust. Vernon C. Allison, assistant physical chemist, and Alan Leighton, former physical chemist of the bureau, conducted the tests in the dust-explosion gallery. A. C. Fieldner, supervising chemist, and Joseph D. Davis, assistant supervising chemist, gave many valuable suggestions upon spontaneous combustion. To all of these the author wishes to express his appreciation for the assistance afforded him.

EXPLOSIBILITY OF PULVERIZED COAL

USE OF PULVERIZED COAL IN INDUSTRIAL PLANTS

In this bulletin pulverized coal is defined as any coal which has been reduced so finely by crushing, pulverizing, or other means that it can be conveyed by compressed air, screw conveyer, or by an air current induced by a fan, from the place of preparation to the place of consumption where, being mixed with the proper amount of air, it may be burned in suspension.

Since natural-gas production has declined near a number of the large industrial centers, especially those where the plants require a steadily intense heat in the manufacture of their product, pulverized coal has been largely adopted as a substitute. As an adequate supply of natural gas becomes more and more difficult to obtain, it is reasonable to expect that the use of pulverized coal will increase.

Pulverized coal is being introduced in the steel industry as a fuel for sheet furnaces, billet furnaces, and small forge furnaces; in cement mills (where it was probably first used) for burning clinker; in large power plants for generating steam in the boilers; and in the large smelters (mostly reverberatory plants) in the West for the reduction of copper ore.

PHYSICAL CHARACTERISTICS

The principal constituents of coal that have a direct bearing on the explosibility of coal dust are moisture, volatile matter, fixed carbon, and ash. Fineness is the physical characteristic that governs the explosibility of pulverized coal.

Generally speaking, any crushed or pulverized coal which is retained on a 20-mesh screen does not enter into the propagation of an explosion when a quantity of finer dust is present; however, as the average pulverized coal used for industrial purposes is ground to such a size that 93 per cent will pass through a 100-mesh screen and 71 per cent through a 200-mesh screen, this question need hardly be considered here.
Pulverized coal in bulk is not explosive. It becomes dangerous only when stirred up into a cloud with the proper proportion of air and brought in contact with an open flame or a body having a temperature high enough to ignite it.

**MEASUREMENT OF EXPLOSIBILITY**

The degree of explosibility may be expressed by the percentage of incombustible matter that the dust must contain to render it non-explosive.

The Bureau of Mines has established a standard, derived from a long series of tests at its experimental mine, by which the explosibility of any coal dust may be measured. To determine the explosibility of dust that may accumulate in pulverized-coal installations in industrial plants the curve shown in Figure 1 may be used, which is based on various bituminous coal dusts, 85 per cent of which will pass through a 200-mesh screen,¹ and represents the border line between explosive and nonexplosive dust.

The distinction between an explosive and a nonexplosive bituminous coal dust is the content of inert matter. The amount of incombustible dust that must be present in a mixture of coal dust and inert dust to render this mixture nonexplosive is directly proportional to the ratio of the volatile matter in the coal to the total amount of combustible matter and is expressed by the formula

\[
\frac{V}{V+F.C.}
\]

where, by chemical analysis, \( V = \) percentage of volatile matter in the pulverized coal and \( F. C. = \) percentage of fixed carbon.

In Figure 1, the abscissas of the curve represent the ratio of volatile matter to total combustible in the pulverized coal, and the ordinates the amount of incombustible matter which the coal should contain to render it nonexplosive. The curve is applied as follows: Assuming that the analysis of the pulverized coal shows the chemical constituents to be:

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<td>Volatile matter</td>
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<td>Ash</td>
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<td><strong>Total</strong></td>
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The ratio of volatile matter to total combustible, expressed as \( \frac{V}{V+F.C.} \), is approximately 0.27.


² This formula will not apply to a coal dust in which the ash of composition plus the inert matter equals 90 per cent.
The ordinate of the curve (fig. 1) corresponding to the abscissa 0.27 is approximately 66, which represents the amount of incombustible matter which a dust that has a ratio of 0.27 between volatile matter and total combustible must contain to render it nonexplosive.

By analysis this dust already contains 20 per cent of incombustible matter, the sum of the ash and moisture content, and determination of the percentage of additional incombustible dust to be added to make the required 66 per cent is simple.

The use of this method of determining the explosibility of dust in an industrial plant is explained on pages 20 and 21.

![Figure 1](image)

**Figure 1.**—Curves showing relative explosibility of various pulverized-coal dusts

**TYPICAL PULVERIZED-FUEL SYSTEMS**

In order to understand properly the characteristic features of explosions and fires, in industrial plants, that result from the use of pulverized coal as fuel, it is essential to know the general working principles of the different types of fuel systems used commercially. For the most part these types may be divided into three classifications, the circulating system, the indirect system, and the unit system.

**DESCRIPTION OF THREE SYSTEMS**

The first two systems are largely employed in steel plants and other industrial works where more than one source of fuel consumption is in operation, for example, at a number of annealing furnaces, sheet furnaces, and ingot furnaces.

**CHARACTERISTICS OF UNIT SYSTEM**

The unit system (fig. 10) is generally used to operate one unit, such as a boiler, a single heating furnace, or a single cement kiln; the
pulverizer and the furnace that burns the coal are in the same building and usually in the same room. The circulating and indirect systems require transportation of the pulverized fuel from a main central pulverizing station to the place at which it is used, whereas in the unit system the fuel is fed directly from the pulverizer to the furnace and both are in the same building. Moreover, driers are ordinarily used in the circulating and indirect systems, but in the unit system a drier is rarely used. Although there are several different types of this system, they are similar in fundamental principles.

CHARACTERISTICS OF CIRCULATING AND INDIRECT SYSTEMS

The chief distinction between the circulating and indirect systems is the mode of transporting the pulverized fuel from the central plant to the furnaces, although the preparation of the fuel is practically identical up to that point. This preparation usually consists of crushing, drying, pulverizing, and storing, in the order named.

The coal comes from the mines to the plant as slack or run of mine, is shipped in hopper-bottom cars, and is ordinarily discharged into a chute between the rails that leads to an ordinary crusher, by which it is reduced to one-half or three-quarters inch size; then it is transported to a storage bin to be fed to the drier as needed. In nearly every installation, however, just before reaching the storage bin, the coal passes a magnetic separator which removes from the coal any "tramp" iron that may be present.

COAL DRIERS

One of the most essential pieces of apparatus in both indirect and circulating systems, and most important with respect to safety, is the drier. By present methods of transporting pulverized coal, it seems necessary that the coal be free from all moisture that it may have absorbed between its mining and its delivery to the pulverizing plant; otherwise it is liable to cake and block up the transport lines. Two types of driers are in general use, which may be termed "direct fired" and "indirect fired."

DIRECT-FIRED DRIERS

A direct-fired drier has an inclined cylindrical steel shell, averaging about 4 feet in diameter and 30 or 35 feet in length. The upper end fits into a hollow pillar through which the combustion gases pass away. The lower end is built into the furnace and a baffle wall interposes between the end of the shell and the fire box.

Raw coal enters at the chimney end and is delivered at the furnace end. As the shell rotates, the coal is turned over and the moisture is
driven off by the gases which pass over the furnace baffle wall and through the center of the shell to the stack. At the discharge end the dried coal falls from the drier shell into a screw conveyor, by which it is carried to the dried-coal bin.

Figure 2 shows the general construction of this type of drier. The important feature is the direct contact which the combustion gases maintain with the raw coal, in contradistinction to the “indirect-fired” type of drier, in which the gases come in contact with the coal only after they have been cooled to some extent by passing on the outside of the drier drum.

INDIRECT-FIRED DRIERS

There are three distinct types of indirect-fired driers, which may be conveniently grouped as class A, class B, and class C.

CLASS A DRIERS

Most class A driers range from 3 to about 6 feet in diameter and from 20 to 30 feet in length, exclusive of the combustion chamber. The drier shell is built in two parts, an outer and an inner shell, which are coaxial; the former is slightly larger than the latter and the delivery end is slightly lower than the intake end. The two shells are rigidly connected by heavy bracing midway between the ends.

One end of the inner shell terminates in the combustion chamber; at the discharge end an annular space is formed between the ends of two shells. The heated gases pass directly from the combustion chamber through the inner shell, giving up a large part of their heat to the inside of the inner shell, through which it is transmitted to the raw coal contained in the space between the two shells. Emerging at the lower end of the inside shell these gases, now somewhat cooled, are drawn through the space that contains the coal by means of an exhaust fan and pass out the stack.

The entire shell is slowly revolved by a driving mechanism. Plates are fastened at intervals around the inside of the outer shell and the outside of the inner shell, and parallel to their axes. As the shells revolve, these plates pick up the coal and shower it down through the hot gases, thus subjecting each individual particle of coal to the drying action of the heat. Figure 3 illustrates the class A drier.

CLASS B DRIERS

A class B drier consists of a single cylindrical steel shell ranging from 3 to 6½ feet in diameter and from 20 to 42 feet in length. The shell is fitted with rollers and mechanism which permit it to
rotate on its longitudinal axis. It is slightly inclined, and the higher or intake end is built into a brick housing which also supports the stack required to carry off the exhaust gases. The lower or discharge end terminates in a steel hood. Midway between the ends of the shell is the drier furnace, which has a large combustion chamber. The drier shell passes completely through the upper part of this chamber, from the top of which is a flue leading to the steel hood at the discharge end of the drier.

The heated gases from the furnace are brought in direct contact with the outside of the shell, pass through the flue to the steel hood, then through the interior of the shell and exhaust by way of the stack. Circulating about the combustion chamber, they have their temperature materially reduced before they come in direct contact with the coal as it passes down the center of the drier. Figure 4 illustrates the class B drier.

**CLASS C DRIERS**

Class C driers follow the multiple-tube principle, and consist of a number of parallel short steel tubes rotating inside of a furnace. The nest of tubes is slightly inclined to the discharge end and the coal, which is fed to the inside of the tubes, gradually works its way through the length of the tubes to the point of discharge.

Hot gases from the combustion chamber of the heating chamber circulate around the outside of the tubes and then, after appreciable cooling, are drawn through the interior of the tubes by an exhaust fan. The entire nest of tubes is so arranged that it rotates about a common axis. Shelves made of steel angles are riveted to the inside of each tube and pick up and drop coal at each revolution. In this manner the green coal is dried by the gases as they pass through the tubes. Figure 5 illustrates the class C drier.
After it is dried, the coal must be so finely ground that about 70 per cent will pass through a 200-mesh screen. At some plants dried coal is stored in a bin before it is pulverized and is fed to the pulverizer from the bin by a system of conveyors.

The fine dust may be separated from the coarser particles in the pulverizer by screens or by a current of air that passes through the pulverizer, carrying with it into a separator the finely ground coal, which is separated from the coarse and heavier particles. The latter fall back into the mill to be reground.

From the pulverizer, the finely powdered coal is transported to the pulverized-coal bins either by screw conveyers or by an exhaust fan that discharges into a dust separator from which much of the air is returned to the pulverizer, while the fine coal gravitates into the pulverized-coal storage-bin.

With this step, actual preparation of the coal for "pulverized-coal combustion" is completed. From this point on the fuel must be transported to its final point of consumption.
DISTRIBUTION OF FUEL TO PLANT

The circulating and indirect systems differ fundamentally in this respect. The former circulates a mixture of coal dust and air in large mains around the plant, the latter conveys the pulverized coal by compressed air or mechanical means to the point of consumption.

Figure 6.—Pulverized-coal burner for circulating system

CIRCULATING SYSTEM

In the circulating system the coal gravitates from the pulverized-coal bin to a screw conveyer, by which it is fed into a rapidly revolving blowing fan. Leading from the fan is the principal circulating main through which the cloud of coal dust and air is blown. This
circulating line varies in size, the diameter decreasing as the coal is
drawn off into the feed lines to the various furnaces. The maximum
diameter of a circulating line may range from 12 to 40 inches and the
minimum from 6 to 8 inches, and the powdered coal attains a
velocity of at least 80 feet per second. The air pressure at the out-
let of the fan will average 8 or 9 ounces per square inch and at the
return about 5 ounces.

The main circulating line may terminate in a dust separator that
returns the unused coal to the pulverized-coal bin or the coal may
be returned directly to the line again through the suction side of the
primary fan.

The circulating system of distributing pulverized coal is some-
what analogous to the piping of natural gas around a steel plant.
Each has its principal circulating main from which, at intervals,
feeders draw the fuel required for the units dependent on the main
line. Just before the feeder line reaches the burner a connection is
made with an air line, often known as the "secondary air line,"
through which the additional air required for complete combustion
is supplied. Figure 6 shows a burner, with a coal feeder line and
secondary air line. Figure 7 illustrates a typical pulverized-coal
circulating-system installation.

Secondary air is obtained from a fan which is operated independ-
ently of the fan that blows the pulverized coal through the circulat-
ing line. The average air pressure maintained in this line is about
5 ounces per square inch.

The plant being served by this system sometimes covers a great
deal of ground, necessitating a distributing main 1,500 feet or more
long. Under such circumstances it is a common practice to install
a booster fan in the line. The pulverized coal in the line is fed into
the suction side of the fan and forced through the remainder by the
increased pressure given by the booster fan.

**INDIRECT SYSTEM**

As stated on page 10, in the indirect system the pulverized fuel is
transported by compressed air or other mechanical means to the
place at which it is to be burned. One of three different methods is
generally used: Screw conveyers, air pressure, or the Fuller-Kinyon
pumping system. Figure 8 illustrates the general principle of
indirect systems.

**SCREW CONVEYERS**

Screw conveyers are in such common use for conveying other
materials that little explanation is needed in addition to the fact
FIGURE 7.—General arrangement of a pulverized-coal system with substation. 1, Track hopper; 2, reciprocating feeder to feed coal from the track hopper to coal crusher; 3, coal crusher to receive coal from the reciprocating feeder; 4, belt conveyer to deliver coal from the coal crusher to the bucket elevator; 5, stationary magnetic separator over the belt; 6, centrifugal discharge bucket elevator; 7, distributing screw conveyer with casing and flights, to receive coal from the elevator and distribute it in the coal bunker; 8, 3-ton coal bunker divided into two parts, so as to store two kinds of coal; 9, belt conveyer to deliver coal to the automatic scale; 10, automatic scale; 11, screw conveyers, to receive coal from automatic scale and deliver to coal drier; 12, rotary drier; 13, centrifugal discharge bucket elevator to deliver coal from drier to dried-coal storage bin; 14, 5-ton dried-coal storage bin; 15, coal pulverizers, complete with vacuum separator; 16, mill exhauster to exhaust pulverized coal from the separator and deliver it to the collector; 17, pulverized-coal collector above 25-ton bin; 18, auxiliary pulverized-coal collectors; 19, pulverized-coal storage bin; 20, special outlet castings with valves to let pulverized coal into ejector tanks; 21, compressed-air line; 22, vent line; 23, ejector, which delivers pulverized coal to the various substations through a 3-inch pipe line by means of compressed air; 24, pulverized-coal collector at substation, which receives pulverized coal from the ejector; 25, auxiliary collector; 26, 25-ton capacity pulverizer-coal storage bin; 27, special outlet casting to support feed screw; 28, special feed screw for feeding coal to the distributing system; 29, automatic regulator, which automatically controls the speed of the variable-speed motor that drives the feed screw, in order to feed the pulverized coal in proportion to the amount of air flowing through the distributing system; 30, vent pipe with top bent down to prevent its acting as a flue and thus producing suction on the system which might draw flame into the pulverized-coal main if blower should be stopped for any reason; 31, high-pressure distributing blower, to furnish the necessary air for distributing the pulverized coal to the furnaces; 32, pulverized-coal main to furnaces with branch lines to burners; 33, valve for regulating the flow of pulverized coal to the burner; 34, special burner for open-hearth furnaces; 35, cast-iron water-cooled burner; 36, air-blast line to deliver secondary air to form the proper mixture for burning pulverized coal; 37, return main to take surplus pulverized-coal and air mixture to pulverized-coal collector, which deposits the unused coal into 25-ton pulverized-coal storage bin. At this plant there are five substations, which are substantially the same as shown, one for annealing furnaces at foundry and one for open-hearth furnaces at foundry, one for forge plant, spring, and rivet shops, one for the miscellaneous order department, and one for plate-heating furnaces in the pressing department. The mixture of air and pulverized coal in the coal-distributing main is 1 pound of pulverized coal to 63 cubic feet of air. The mixture of air and pulverized coal when burning in furnaces is 1 pound of pulverized coal to about 200 cubic feet of air.
that such a conveyor discharges into a fuel bin that is large enough to hold a few hours' fuel supply. This bin is placed in operation near the furnace which is using the fuel.

**AIR PRESSURE**

Apparatus for conveying fuel by air pressure consists essentially of a blowing tank into which a given amount of pulverized fuel is admitted through an inlet, which is then closed while air under pressure is admitted. When the pressure in the tank reaches 50 or 60 pounds per square inch, the valve in the coal-transport line is opened and the air and coal are carried along through the transport line to their destination. In nearly all systems that use this mode of transportation some method of separating the air and the coal dust or of taking care of the dusty air displaced in the bin by the coal dust itself must be adopted. Perhaps the most common is the cyclone separator, although the bag collector is also used. By means of branch lines and switching devices, the coal can be deflected from the main transport line to any desired line. The transport line consists of iron pipe 2½ to 4 inches in diameter.

Various means are employed for signaling from the furnace to the central pulverizing station when the operator desires to have his fuel bin refilled.

The powdered coal gravitates from the pulverized-fuel bin into a screw conveyor, by which it is fed into an air blast that carries it into the burner. There are numerous types of burners and devices for controlling the proportion of air and fuel in order to obtain the highest efficiency.

**FULLER-KINYON SYSTEM**

The last of the three methods, the Fuller-Kinyon pumping system, is not unlike the air-pressure method, the main difference being the substitution of a screw pump for the blowing tank. This pump re-
ceives the pulverized coal from the storage bin, and just at the end of a revolving worm compressed air at very light pressure enters, thoroughly aerates the pulverized coal, and transforms it to a semi-fluid state, so that it is easily moved through an ordinary pipe line to the receiving bins. A screw feed and an air blast feed it from the bins to the furnaces.

Sometimes the air-pressure system is used in conjunction with the circulating system, especially at industrial plants where the furnaces are in several scattered buildings. In such plants, the coal is crushed, dried, and pulverized at one main central station; and in each building there is a large bin from which the pulverized coal is fed to the blower used to drive the fuel through the circulating lines. These pulverized-coal storage bins are generally filled from the central pulverizing station by the air-pressure system of transport. Figure 9 illustrates a typical air-pressure system.

UNIT SYSTEM

The unit system, as has been stated, is that system in which the pulverizer and the furnace consuming the coal are in the same building and generally in the same room. Although there are several different types of this system, they are all similar in fundamental principles.

In a typical installation of this kind, a pulverizer is placed near the furnace and the raw coal is fed directly into it. As fast as it is pulverized, the powdered coal is blown directly into the furnace by an air blast. However, some installations have a bin holding one or two hours' supply into which the pulverizer discharges, in order to provide a reserve supply of fuel if the pulverizer should be temporarily stopped. The fuel gravitates from the bin to an air blast by which it is blown into the burners. (See fig. 10.)

SUMMARY

In the foregoing descriptions of pulverized-coal systems no attempt has been made to cover in detail the different pieces of mechanism connected therewith, the main purpose being to explain their fundamental principles of operation for better understanding of the causes of the different accidents that have happened.

FIRE HAZARD OF PARTLY CONSUMED COAL DUST

In the buildings of an industrial plant a rather unsuspected danger lurks in the dust from some types of heating furnaces, which settles on and around girders, beams, electric cables, switchboards, and any other place upon which it can lodge. This condition is
especially true in works where a number of nut, bolt, rivet, and small forge furnaces use pulverized coal as fuel. Many of these furnaces were designed to burn natural gas, but because of the decreasing supply of this fuel they have been altered to burn pulverized coal without change in the shape or size of the combustion chamber. In some furnaces the gas connection still remains, and the coal lines are simply added as an auxiliary fuel system.

Combustion chambers designed solely for the economical consumption of natural gas are generally not large enough for the complete combustion of pulverized coal. Representatives of the Bureau of Mines found that this statement was borne out by the conditions found in some of the mill buildings in which these furnaces were used. Consequently, due perhaps to the velocity of the air blast and the small combustion space, minute unburned particles are apparently blown through the combustion chamber into the outer air.

PLANTS WHERE PULVERIZED COAL HAS REPLACED NATURAL GAS

Several plants of this nature have been inspected and samples of the dust taken and subjected to chemical and microscopic analysis. One of these plants manufactures bolts, screws, washers, spikes, and wagon hardware. For many years it had burned only natural gas in the small furnaces used in the manufacture of these articles. When the natural-gas supply decreased, a pulverized-coal system was installed. Soon after operation of the system started dust began to accumulate rapidly on the runways above the furnaces and on the
roof trusses, pipes, and roofs of adjoining buildings in alarming quantities.

The circulating system of pulverized coal was used to supply fuel to the furnaces, which were usually situated in a line along each side of the buildings. About 6 feet over the tops of these furnaces were long platforms or runways and in places the dust on these platforms had collected to a depth of ½ to 1½ inches. Eleven samples of this dust and other dust which had collected on the outside covering of the pipe lines leading to the various furnaces were taken and analyzed.

ANALYSES OF DUST

The chemical analyses showed that the volatile matter in the dust ranged from 6.3 to 23.5 per cent, the fixed carbon from 50.88 per cent to 67.08 per cent, and the ash from 22.29 per cent to 32.16 per cent.

PURE COAL DUST

Five samples of the pure coal dust taken from the fuel supply of the same furnaces were analyzed in order to compare the partly consumed coal dust, called "mill dust" for convenience, with pure coal dust. These analyses showed that the volatile matter ranged from 30.5 to 36.81 per cent, the fixed carbon from 46.86 to 52.48 per cent, and the ash from 9.26 to 21.84 per cent.

MILL DUST

Under the microscope a sample of "mill dust" which showed 23.5 per cent of volatile matter by chemical analysis was seen to contain a large proportion of very fine partly coked coal dust, a small proportion of fine or medium fine partly coked coal dust, and some dust thoroughly coked. In addition, the microscope revealed a large amount of yellow resinous-appearing matter, some particles of carbon which might be termed soot, and some small particles of ash.

A sample of similar dust, which by chemical analysis was found to contain but 11.25 per cent of volatile matter, showed under the microscope only a relatively small proportion of medium-sized partly coked coal dust and many thoroughly coked particles.

From these analyses and microscopic examinations it would seem that, for some reason, the pulverized coal was being blown out of the combustion chambers of the furnace before it had been thoroughly consumed.

TESTS UNDER MILL CONDITIONS

Notwithstanding the fact that these chemical and microscopic analyses indicated the explosibility of the mill dust that contained the higher percentages of volatile matter, it was believed that some tests should
be made which would more nearly approach conditions at steel mills. Although it is almost an axiom that pulverized-coal dust is inflammable, the pulverized-coal samples were subjected to the same tests as the samples of "mill dust" to establish a standard of the degree of inflammability for comparison with the results of similar tests of mill dusts.

**PULVERIZED COAL**

**WHITE-HOT DISH TEST**

The first of these tests consisted in heating a clay roasting dish 6 inches in diameter in a muffle furnace to 2,000° F. When the dish had reached this temperature, about 5 grams (0.176 ounce) of pulverized-coal dust was quickly dropped in a cloud upon it. The pulverized coal flashed the instant it touched the plate and propagated a flame of great intensity through the dust cloud.

This method of testing was particularly valuable, as it almost duplicated conditions in and around a steel mill where the red-hot iron and steel are often close to clouds of coal dust.

**MEKER FLAME TEST**

The second test of pulverized-coal samples was the Meker flame test, which was not dissimilar to that with the white-hot dish, but probably not as sensitive.

About 5 grams (0.176 ounce) of pulverized coal was blown in a cloud around the flame of a Meker burner by means of a bellows. The results were the same as those obtained in the test with the white-hot dish. The purpose of this test was to show what might happen if a cloud of coal dust in a mill should be blown across a naked flame.

**EXPLOSIBILITY TESTS WITH CLEMENT-FRAZER APPARATUS**

The coal samples were also tested for exposibility to establish a basis of comparison for similar tests of mill-dust samples.

The first tests were made with the Clement-Frazer apparatus described in Technical Paper 141. Briefly, this apparatus consists of a glass globe, possibly 6 inches in diameter, containing a small electrically heated platinum coil. A sample of coal dust is blown against the heated coil and the pressure of the resulting explosion is recorded by an indicator. In these tests about 100 mg. (about 0.0035 ounce) of pulverized coal was blown by 135 c. c. (8 cubic inches) of oxygen under a pressure of 15 cm. (about 5½ inches) of mercury against the platinum coil heated to about 2,000° F. The resulting explosions developed a pressure of 13.2 pounds per square inch in one test and of 14.5 pounds per square inch in a second test.

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In this test, complete combustion of all the dust probably did not take place. If a dust explosion occurs under conditions that favor the building up of pressure, some very high pressures may be obtained. This would be true of conveyer tunnels used in coal storage yards, as large amounts of coal dust may accumulate in such tunnels. In tests at the bureau’s experimental mine, pressures as high as 119 pounds per square inch were built up in 750 feet within 2.2 seconds.  

EXPLOSIBILITY TEST IN GALLERY

The second explosibility test was made in a dust-explosion gallery (fig. 11), practically a horizontal wooden box, 6 inches deep by 6 inches wide by 14 feet long, made of 2-inch planks held together with wooden clamps and iron rods. The top was constructed to be removable for observation of the results of the test.

A metal flap valve covered the rear end of the gallery; the front end was open. At uniform distances along the entire length of the gallery floor were 14 holes, into which were fitted three-fourths-inch pipe jets projecting vertically from a 2-inch horizontal pipe extending longitudinally beneath the center of the floor. The rear end of the pipe was closed by a cannon having a capacity of 5 grams (0.176 ounce) of powder; the other end was open. A loose metal disk covered the end of each pipe jet that led to the corresponding hole in the floor of the gallery, thus forming a pocket to contain 3 grams (0.105 ounce) of pulverized coal with which each hole was loaded.

To diffuse the dust into a cloud of more uniform density each hole was covered by a small square of coarse heavy screen held in place by large washers bolted to the floor.

To load the gallery, 3 grams (0.105 ounce) of pulverized-coal dust was poured into each of the 14 holes in the floor of the gallery. The squares of screen were then placed in position over each hole. The cannon in the end of the horizontal pipe beneath the gallery was loaded with 5 grams (0.176 ounce) of powder. Ten grams (0.353 ounce) of loose powder was placed between the first two holes in the floor. When the loading was completed, the top of the gallery was bolted on and the electric firing wires connected. The explosion of the powder in the cannon raised a dust cloud in the gallery and the loose powder was used to start the initial explosion of the coal-dust cloud. The cannon and loose powder were fired by means of electric spitters; the cannon was fired two seconds before the loose powder.

Small pieces of gun-cotton hanging 1 foot apart throughout the length of the gallery indicated, by their burned or unburned condition, the distance the explosion flame had traveled through the gallery.

After a standard of comparison had been obtained by testing pulverized-coal dust, similar tests were made of the mill-dust samples.

RESULTS OF TESTS

The results of the tests of pulverized coal and of mill dust have been tabulated in five groups in Table 1. Group 1 includes the pulverized-coal samples determined to be highly inflammable and highly explosive. Group 2 includes "mill-dust" samples that border very closely on pure coal dust in inflammability and explosibility. Group 3 contains "mill-dust" samples that are not quite as inflammable or as explosive as those in group 2. Group 4 comprises dust samples that are only slightly inflammable or explosive.
The dusts in group 5 are noninflammable and nonexplosive. In this grouping there is no rigid line of demarcation, but the samples have been classified according to their general behavior when tested.

Table 1.—Tests of pulverized coal and mill dust under plant conditions

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Material</th>
<th>Volatile matter</th>
<th>Fixed carbon</th>
<th>Ash</th>
<th>Pressure in Clement-Frazer apparatus</th>
<th>Inflammability grouping</th>
<th>Explosibility grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>31398</td>
<td>Pulverized coal</td>
<td>36.81</td>
<td>52.84</td>
<td>9.26</td>
<td>14.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>31371</td>
<td>do.</td>
<td>30.50</td>
<td>46.86</td>
<td>21.84</td>
<td>13.2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>31380</td>
<td>do.</td>
<td>36.08</td>
<td>52.43</td>
<td>9.26</td>
<td>14.5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>31413</td>
<td>Mill dust.</td>
<td>23.54</td>
<td>51.24</td>
<td>24.35</td>
<td>10.2</td>
<td>2</td>
<td>2</td>
</tr>
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<td>31372</td>
<td>do.</td>
<td>20.61</td>
<td>50.88</td>
<td>27.45</td>
<td>8.7</td>
<td>2</td>
<td>2</td>
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<tr>
<td>31376</td>
<td>do.</td>
<td>13.91</td>
<td>53.26</td>
<td>29.76</td>
<td>4.6</td>
<td>3</td>
<td>3</td>
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<td>31379</td>
<td>do.</td>
<td>13.45</td>
<td>58.19</td>
<td>26.32</td>
<td>0</td>
<td>3</td>
<td>3</td>
</tr>
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<td>31382</td>
<td>do.</td>
<td>12.40</td>
<td>63.40</td>
<td>22.29</td>
<td>0</td>
<td>3</td>
<td>3</td>
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<tr>
<td>31374</td>
<td>do.</td>
<td>11.53</td>
<td>55.30</td>
<td>32.16</td>
<td>0</td>
<td>4</td>
<td>4</td>
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<td>31377</td>
<td>do.</td>
<td>11.25</td>
<td>57.43</td>
<td>26.92</td>
<td>0</td>
<td>4</td>
<td>4</td>
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<td>31375</td>
<td>do.</td>
<td>10.99</td>
<td>56.29</td>
<td>31.83</td>
<td>0</td>
<td>4</td>
<td>4</td>
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<td>31381</td>
<td>do.</td>
<td>8.81</td>
<td>63.37</td>
<td>25.35</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>31378</td>
<td>do.</td>
<td>7.17</td>
<td>63.68</td>
<td>27.78</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>31383</td>
<td>do.</td>
<td>6.30</td>
<td>67.08</td>
<td>24.40</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

In Table 2 the samples are arranged in the order of their explosibility, determined by the amount of combustible matter required to render the mill dust nonexplosive, as explained on page 4. It indicates how closely the results of actual physical tests in the gallery and of the flame tests follow the order of explosibility, as shown by the amount of inert material required (column 5).

Table 2.—Dusts arranged in order of explosibility

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Material</th>
<th>Inert material required</th>
<th>Inert material (ash) in sample</th>
<th>Inert material to be added per pound of sample to render mixture inert</th>
</tr>
</thead>
<tbody>
<tr>
<td>31398</td>
<td>Pulverized coal</td>
<td>76</td>
<td>2.78</td>
<td>2.78</td>
</tr>
<tr>
<td>31380</td>
<td>do.</td>
<td>76</td>
<td>2.78</td>
<td>2.78</td>
</tr>
<tr>
<td>31413</td>
<td>do.</td>
<td>76</td>
<td>2.78</td>
<td>2.78</td>
</tr>
<tr>
<td>31371</td>
<td>do.</td>
<td>76</td>
<td>2.78</td>
<td>2.78</td>
</tr>
<tr>
<td>31373</td>
<td>Mill dust.</td>
<td>68</td>
<td>1.30</td>
<td>1.30</td>
</tr>
<tr>
<td>31372</td>
<td>do.</td>
<td>67</td>
<td>1.20</td>
<td>1.20</td>
</tr>
<tr>
<td>31376</td>
<td>do.</td>
<td>58</td>
<td>.67</td>
<td>.67</td>
</tr>
<tr>
<td>31379</td>
<td>do.</td>
<td>50</td>
<td>.47</td>
<td>.47</td>
</tr>
<tr>
<td>31382</td>
<td>do.</td>
<td>42</td>
<td>.34</td>
<td>.34</td>
</tr>
<tr>
<td>31374</td>
<td>do.</td>
<td>42</td>
<td>.26</td>
<td>.26</td>
</tr>
<tr>
<td>31377</td>
<td>do.</td>
<td>42</td>
<td>.23</td>
<td>.23</td>
</tr>
<tr>
<td>31375</td>
<td>do.</td>
<td>42</td>
<td>.17</td>
<td>.17</td>
</tr>
<tr>
<td>31381</td>
<td>do.</td>
<td>28</td>
<td>.0</td>
<td>.0</td>
</tr>
<tr>
<td>31378</td>
<td>do.</td>
<td>12</td>
<td>.0</td>
<td>.0</td>
</tr>
<tr>
<td>31383</td>
<td>do.</td>
<td>10</td>
<td>.0</td>
<td>.0</td>
</tr>
</tbody>
</table>
Column 3 shows the percentage of incombustible material which the total mixture of mill dust and incombustible material must contain to render it nonexplosive. Column 4 shows the amount of incombustible matter, such as ash, which the material already contains, and column 5 gives the amount in pounds of additional incombustible material which must be added to 1 pound of the sample to make the entire mixture nonexplosive.

The first four samples are pure coal dust, which will require from 2.12 to 2.78 pounds of incombustible material added to every pound of the sample to render the mixed dust nonexplosive. Samples 31373 and 31372 were taken from the accumulations of dust which came from the furnaces and settled all over the mill. This dust is exceedingly high in volatile matter and fixed carbon and low in ash for a fuel supposedly consumed. That it also is highly explosive is indicated by the fact that the two samples require, respectively, 1.36 and 1.20 pounds of incombustible material per pound of dust to render them nonexplosive. If such dust should be spread thickly over the runways, trusses, and pipes of any industrial plant, the hazard of fire or explosion would be very great.

The next group comprises samples 31376, 31379, and 31382, which were taken under conditions similar to those under which the preceding samples were taken. Comparison with samples 31373 and 31372 shows that there is a decided decrease in the amount of inert material required to make the mixture nonexplosive; in fact, a decrease of almost 50 per cent in sample 31376 and about 70 per cent in sample 31382.

Whether dust of this nature would ignite easily when raised in a cloud under the conditions existing in the average steel mill is problematical. However, the hazard which does exist is the impetus it would give to a fire started in some other manner.

The remaining samples are either near the border line between inflammability and noninflammability or are so absolutely nonflammable as to be harmless.

FIRE AT BURDEN IRON WORKS

A concrete example of the danger of similar dust was the fire at the Burden Iron Works, Troy, N. Y. ³

At this plant about 80 puddling furnaces were in service, approximately 20 of which were using pulverized coal as fuel. Each puddling furnace where this type of fuel was used had a 1-ton steel bin into which the coal was delivered by screw conveyer from the pul-

verizing plant and from which the fuel was directly conveyed to the
burner of the furnace.

The Burden Iron Works experienced one trouble common to many
plants that use this type of fuel—caking of powdered coal on the sides
of the bins. When this condition exists the coal ceases to run freely
from the bin to the conveyor and the furnace operator invariably
begins to hammer the bins to jar the caked coal loose. Consequently
the bins become badly battered and in time the coal is liable to leak
from them. This state of affairs existed at the plant on the night of
the fire, although the management had given orders forbidding the
hammering of the bins.

At the puddling furnace where the fire originated coal dust was
leaking in small quantities from the bin to the floor. The doors in
the sides of the building were open and a strong breeze blowing
through caught up the dust and whirled it in a cloud in front of a
furnace door just as the operator was pulling a heat.

As the dust came in contact with the red-hot metal and slag it
immediately ignited and flashed, the flames reaching to the wooden,
dust-laden roof trusses. The entire roof soon caught fire and burned
so rapidly that the men had to drop their tools and run for their
lives.

PROBABLE CAUSE OF INCOMPLETE COMBUSTION OF COAL DUST

Although the bureau investigated the dust conditions mentioned
in the foregoing section purely with respect to safety rather than
to efficiency, it seemed obvious that a furnace which more nearly
approached perfect combustion of the fuel would be the type that
would reduce the explosion hazard from accumulations of partly
consumed coal dust.

Nearly all the furnaces in the plants where samples of such dust
were taken were comparatively small, as shown in Figures 12, 13, and
14. Practically all were using the same combustion chamber which
had previously been connected with the natural-gas lines and discon-
nected when pulverized coal was substituted. A few, however, had
been slightly changed after the coal lines were put in operation.

TYPE OF FURNACE PRODUCING LEAST DANGEROUS DUST

To determine in some degree the type of furnace which was giving
out the least dangerous dust, iron shelves were so placed over the
arch and under the hoods of the furnace that the dust from one fur-
nace alone would fall upon the plate. The plates were placed in the
only part of a furnace where it was possible to be sure that the dust
collected was from that furnace. Table 3 gives an analysis of these
samples.
TABLE 3.—Samples of dust from furnaces

<table>
<thead>
<tr>
<th>Laboratory No.</th>
<th>Name of furnace</th>
<th>Moisture</th>
<th>Volatile matter</th>
<th>Fixed carbon</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>31470</td>
<td>No. 1-2-5 Pawtucket machinery</td>
<td>.022</td>
<td>4.58</td>
<td>61.62</td>
<td>33.38</td>
</tr>
<tr>
<td>31471</td>
<td>Little furnace No. 22</td>
<td>.22</td>
<td>4.53</td>
<td>54.45</td>
<td>39.80</td>
</tr>
<tr>
<td>31472</td>
<td>Pad-eye furnace</td>
<td>.27</td>
<td>4.55</td>
<td>56.18</td>
<td>39.00</td>
</tr>
<tr>
<td>31473</td>
<td>Furnace No. 37</td>
<td>.26</td>
<td>4.91</td>
<td>51.49</td>
<td>43.34</td>
</tr>
<tr>
<td>31474</td>
<td>Furnace No. 36</td>
<td>.46</td>
<td>2.94</td>
<td>58.93</td>
<td>37.67</td>
</tr>
<tr>
<td>31475</td>
<td>Hook-eye furnace</td>
<td>.40</td>
<td>4.82</td>
<td>53.45</td>
<td>41.33</td>
</tr>
</tbody>
</table>

The dust from which these samples were taken was the accumulation through a 24-hour period in a rather hot place. By comparison with the analyses of mill dust collected from more open parts of the building the amount of volatile matter is very low.

![Diagram of small furnace for heating rods used in bolt and rivet making machines](image-url)
Figure 13.—Furnace for heating small forgings

Figure 14.—Small furnace for heating rods used in bolt and rivet making machines
The percentage of volatile matter is much below that of the mill dust, the analysis of which has been given on page 2. This may possibly be due to partial distillation during the period in which the dust was accumulating, as the temperature was fairly high. The main point, however, is the comparatively high percentage of fixed carbon and low percentage of ash.

When the general shape of the combustion chambers of the different furnaces is compared with the analysis sheet of the so-called flue dust, it appears that those chambers having the greatest length—length being that dimension parallel to the axis of the flame—are the ones giving the highest percentage of ash. It would therefore seem reasonable to assume that they were giving off the least dangerous dust.

**FURNACE CONSTRUCTION**

The fact that the microscope shows the mill dust to be partly coked leads to the presumption that the coal dust probably passed too rapidly through the combustion chamber, was thrown against the end wall of the chamber before it was totally consumed, and then was deflected through the hood to the mill, where it was circulated by the various air currents and finally deposited on the roof trusses, pipes, runways, and platforms.

In an industrial plant where large quantities of this burned dust are being deposited on the trusses and platforms not only is a dangerous condition produced but uneconomical operation or faulty design of the furnace is indicated.

**OPINIONS OF WRITERS**

H. R. Collins, in a paper before the American Institute of Mining Engineers,⁴ makes the following statement: "Coal in pulverized form can be injected into a furnace on a column of air at a very low velocity, thus allowing the expanding gases to liberate their heat without erosion of the refractories."

Prof. W. Trinks⁵ states that as a rough average:

With oil or gas fire 3 B. t. u. per second can be liberated in each cubic foot of furnace space. If powdered coal is used, a difference arises between those furnaces in which the coal is burned over and near the material to be heated, and those furnaces in which a separate combustion chamber is used for the purpose of depositing the ash before it reaches the heating chamber proper. (In the former case 3 B. t. u. per second can be developed per cubic foot of furnace.) Under these circumstances only 1½ B. t. u. per second are developed for each cubic foot of furnace and combustion space. These figures give total

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volume of the empty furnace. If a separate combustion chamber is used the figures may be doubled, and if the adjustment of the combustion is perfect they may be trebled, or even quadrupled.

Charles Longenecker, of the Bonnot Engineering Co., in an article on the use of powdered coal as a forge-shop fuel, points out the necessity in designing drop-forgel furnaces of coordinating “the different variables, such as design of furnace, location of burners, and size of opening” if the best efficiency is to be obtained. He also recommends the installation of an exhaust-fan system for removing the flue gases from these furnaces.

Unless powdered-coal furnaces are designed with a combustion space that is amply large and correctly shaped the burning coal will soon wear away the brickwork. Modern furnaces are designed to reduce this wear, which is also reduced by introducing the coal into the furnace at a low velocity, and causing the flame to spread over a large area.

Blizard\footnote{Blizard, John, The preparation, transportation, and combustion of powdered coal: Department of Mines, Canada, 1921, p. 131; also Bull. 217, U. S. Bureau of Mines, 1923.} states:

With the present knowledge of the art of burning powdered coal the best results are obtained when the coal is burned at the rate of 1 to 1½ pounds per cubic foot of combustion space per hour. Good results can be obtained when the coal is burned at rates varying from ½ to 2 pounds per cubic foot of combustion space per hour, which gives a considerable working range.

* * * If it is desired to operate the boiler at high rates of working, a large furnace must be installed and the combustion space so arranged that the flames are given the longest possible path through the furnace.

SIZE OF COMBUSTION CHAMBER

Although Blizard was writing primarily about steam-generating plants, the above statement seems to agree with the contention held in preceding pages that shortness of the combustion chamber in the heating furnace was the main cause of partly consumed mill dust, though a contributing cause may have been that the supply and mixing of the air were insufficient to burn the coal completely.

As has been stated, most of these furnaces were originally designed to consume natural gas, and evidently pulverized coal can not be burned economically in such furnaces. Unless the combustion chambers are remodeled in accordance with the best modern practice in the art of burning pulverized coal, partly consumed coal will be blown out into the mill, settle on trusses and window ledges and in other places, and create a dangerous fire hazard. Conversely, quantities of such dust about a plant show that the furnace is uneconomical and fuel is being wasted.
AMOUNT OF ASH

Another factor may be included in the incomplete combustion of pulverized coal. The analyses of pure coal dust in Table 1 show that the amount of ash varied widely. Sample 31371 contained 21.84 per cent; sample 31398, 9.28 per cent; sample 31413, 13.39 per cent. This variation may be responsible to some degree for the particles of unconsumed or partly consumed coal.

The men who operate furnaces hold a general opinion that some times a furnace "heats properly" while at other times it is difficult to keep the right "heat." When a furnace is not heating properly it is natural for the operator to open the valve and let in more coal, especially if the circulating system is used, or to speed up the motor driving the feed-screw conveyer if the indirect system is in use. The reason for this "poor heat" may possibly be the high ash content of the coal or it may be that too much or too little air is admitted to consume the coal properly; consequently part of the powdered coal goes off unburned.

Whenever a plant has great trouble from incomplete combustion of the pulverized coal in the heating furnaces, especially when a number of furnaces are fed from the same circulating line, it might be well to procure at short intervals samples of the coal going to the furnaces until a representative sample of an entire day's run has been obtained. Analyses should be made of the entire sample and of the small samples, which would give definite data on the fluctuation in the quality of the coal being delivered to the furnaces. The flue gases should also be analyzed and the air supply adjusted to suit.

Technical Paper 133* and Bulletin 116* of the Bureau of Mines give in detail the proper methods to follow in order to obtain a knowledge of the quality of coal being used.

HAZARDS FROM ACCUMULATIONS OF PURE COAL DUST

In the preceding section the danger from the accumulation of partly consumed coal dust from rod, nut, and rivet heating furnaces has been discussed in detail. There is, however, a hazard from accumulations of pure coal dust which is not confined to pulverizing plants, but is present wherever ordinary run-of-mine or screened coal is handled by elevators and conveyers.

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THROWING POWDERED COAL ON OPEN LIGHTS

One of the earliest accidents occurred at the Brancepeth "C" mine in the county of Durham, England, on April 24, 1892.\(^\text{10}\)

The coal was hoisted from the mine and passed from the cleaning screens to a crusher, by which it was powdered. Elevators lifted the powdered coal to a storage bin about 24 by 31 by 31\(\frac{1}{2}\) feet in size, where it was held as a reserve supply for the coke ovens. Ladders were placed outside of the bin to afford ready access to the top and also inside, so that a person could climb to the top of the bin and go down inside whenever required. Four small landings or platforms were erected inside about equal distances apart. A few iron tie-rods passed through the bin.

At the bottom of the bin were movable slides through which coal was taken out for the coke ovens. The bin was roofed and windows were cut near the top to admit light to parts of the elevator machinery which required oiling. Just before the day of the explosion the employees went on a strike; consequently the bins were practically emptied of coal, except that in the bottom corners and the fine dust on the rafters and platforms.

Five men entered the bin through the bottom slides to shovel out the remaining coal, while the foreman entered by means of the ladders. Four open lights had been hung from one of the tie-rods, about 7 feet from the bottom of the box. The foreman directed two of the men to clean the accumulation of fine dust from the upper platforms. They commenced throwing the dust to the bottom of the bin, and in so doing raised an exceedingly dense cloud of coal dust. Very soon an explosion occurred which severely burned the six men inside the bin, broke the glass in the windows, and partly wrecked the top of the bin.

The two laborers at the top of the bin were thrown to the bottom by the explosion and were taken out through the slides; the foreman climbed out on the ladders. These three men were so badly burned that they died. The three men on the bottom were severely burned, but recovered eventually.

One survivor stated that he noticed the dust being ignited at the lamps; then came a second and larger flame, and the whole bin seemed filled with fire at once. Undoubtedly the dust cloud caused by throwing down the fine coal from the platforms at the top of the bin came in contact with the open lights hanging from the tie-rods and ignited.

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\(^{10}\) Oakley, Samuel, Explosion in a coal box; Colliery Engineer, vol. 12, April, 1892, p. 212.
LIGHTING TORCH IN DUSTY ATMOSPHERE

The accident described above was practically duplicated by a fairly recent explosion at a plant near Pittsburgh, Pa., where the boilers were equipped with automatic stokers. The coal was crushed by a gravity-fed crusher before it was delivered to the stokers from a hopper into which the coal had been dumped from the cars. Because the coal was friable, a cloud of dust surrounded the plant during the crushing operation. An elevator lifted the crushed coal to a bin, whence it gravitated to railroad cars on a track depressed about 20 feet below the upper tracks; in these cars the crushed coal was delivered to the stokers. The elevator was partly closed on three sides but at the foot it was open toward the depressed tracks.

Early one morning the chutes at the foot of the crusher became clogged, hence the machinery had to be stopped. One-half hour later five men went to the foot of the elevator to clear the chutes.

Although two incandescent lamps had been hung in the elevator shaft below the platform to guide the men, to provide more light one man carried a lighted torch, which was extinguished by a strong current of air as the men descended the shaft.

So far as could be learned, the last man had barely reached the bottom of the elevator when a burst of flame killed three of the men and burnt a fourth so badly that he died later. The fifth was painfully burned but recovered.

The cause of this accident was supposed to have been the lighting of a match to relight the torch. This act ignited the dust cloud at the foot of the elevator.

SHORT CIRCUIT OF ELECTRIC WIRES BY MOIST COAL DUST

An accident in a Pittsburgh steel plant shows a potent danger from coal dust accumulating around electric equipment. Dust collected across the terminals of a back-connected electric switch and, becoming moist, caused a short-circuit. In consequence, the main fuses in the power plant were blown with such violence that the fuse cartridges were shattered and the main panel partly wrecked.

Fortunately, this accident happened on Saturday, when the mill was practically shut down and there were no particles of coal dust suspended in the air.

OPEN STOVE IN BUILDING COVERED WITH COAL DUST

At one very large steel plant coal was delivered in coal barges to the plant by water, raised by a hoist, and conveyed to a crushing plant where it was prepared for by-product coke ovens. Some buildings were inflammable and covered with fine dust. In one building
that housed a 200-horsepower motor, power lines were carried on the steel framework and dust covered the floor and walls. The switch starting some of the motors operating the crusher was placed in a very dusty frame building, and whenever the switch was thrown in much arcing occurred. On the floor of one of the buildings was a salamander for heating the shed near the chute extending to the crusher and dust had settled all around it.

After Bureau of Mines representatives had inspected the plant a number of the foremen were invited to the bureau's experimental mine and a test was made of the inflammability of this dust.

A large funnel was connected to a compressed-air line and a short distance away a piece of burning waste was tied to a small iron rod driven into the ground. The air was turned on, raising the coal dust into a cloud and blowing it across the burning waste. The result is shown very well in Figures 15 and 16.

![Figure 15.—Ignition of pulverized-coal dust clouds](image)

**FIRES AT TWO WESTERN MINES**

The bureau has a record of two serious accidents which were somewhat similar to the above described tests at the bureau's experimental mine. In the first of these, six men were burned—three of them fatally; in the second, eleven men were burned—three of whom died as a result of their injuries.

These accidents happened near the tipple tracks at two western coal mines, and the circumstances under which each occurred were almost identical: As the miners are paid for lump coal only, forks are used by the miners for loading the coal into the mine cars. Consequently, a considerable amount of fine dust is left on the floor
of the mine for a time, but it is eventually shoveled into cars together with the roof rock which has been shot down to make the necessary head room in the haulage ways, and then it is hauled to the rock dumps on the surface. The roof rock is a black oily shale which, when mixed with fine coal, becomes so combustible that it often takes fire spontaneously and continues to burn as long as fresh material is dumped upon it. When burned, this rock makes good road material and track ballast.

The railroads serving both these mines were loading out the burned material from the side of the rock pile with steam shovels. The loose material from the side of the pile nearest the loading track had been cleaned up, leaving the side approximately vertical. This side was then shot down to provide additional material for the shovels. Before the shots were fired, some of the fine coal on the top of the pile still remained unburned, although the edges of the pile were in flames. As the shots were fired, the side of the pile
began to slide and crumple; the concussion of the shots combined with the movement of the material threw some of the fine coal into the air. This cloud of fine dust came in contact with the burning material and at once flashed into a cloud of flame which was carried, by the force of the slide and the rapid burning of the dust, several hundred feet from the rock pile and across the tracks. Every one in the path of the cloud who could not find shelter was badly burned.

The important point to be considered in connection with these two accidents is the condition under which they happened. That coal dust is dangerous when confined and mixed with the proper amount of air is universally conceded. It is, however, not so generally believed that a cloud of coal dust will ignite and flash in the open air. These two fatal accidents prove conclusively the danger, even in the open air, from a coal-dust cloud coming in contact with an open flame.

**TIPPLE FIRE IN COLORADO**

The burning of a tipple of the Colorado Fuel & Iron Co.\(^{11}\) may be cited as an example of the real danger that exists in the presence of a salamander containing burning coals when a coal-dust cloud may come in contact with it. A trip of mine cars loaded with coal broke away at the head of a steep incline leading to the tipple and ran down the incline and through the tipple shed at very high speed. As the runaway trip passed through, a dense cloud of coal dust was raised which exploded almost immediately. The flame and smoke extended 35 feet above the building, which caught fire in several places. Two men who were dumping coal saw the runaway cars coming and tried to escape, but both were severely burned, and the building was badly damaged.

The accepted cause of the explosion was that a spark from a stove in the weigh house ignited the dust cloud that had been raised by the runaway trip.

**DUSTY CONVEYER AND CHARGING PLATFORM AT GAS-PRODUCER PLANT**

At a gas-producer plant a conveyer carried coal to the charging platform. The floor around the conveyer and the platform was covered with dust. Samples of this dust were taken and analyzed. Table 4 gives the analyses of these samples.

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\(^{11}\) McNell, John, Prevention of accidents in coal mines: Coal Age, vol. 4, No. 2, July 12, 1913, pp. 42–43.
Table 4.—Analyses of dust samples from gas-producer plant

<table>
<thead>
<tr>
<th></th>
<th>Sample 79813 a</th>
<th>Sample 79814 b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatile matter</td>
<td>28.43</td>
<td>12.54</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>56.36</td>
<td>33.24</td>
</tr>
<tr>
<td>Ash</td>
<td>13.68</td>
<td>53.30</td>
</tr>
<tr>
<td>V + F. C</td>
<td>.335</td>
<td>.274</td>
</tr>
</tbody>
</table>

Inert material to be added per pound of sample to render mixture incombustible.

| Sample 79813 a  | 1.97 | .41 |
| Sample 79814 b  |      |     |

a Sample 79813 was taken on the platform around the producer and near the various poke holes. The analysis shows that this is almost pure coal dust. The potential danger is that much dust had accumulated so close to the poke holes that a dust cloud formed when one of these holes was opened would be ignited by the flame coming therefrom.
b Sample 79814 was brushed from around the conveyor floor, and although it borders on the dividing line between explosibility and nonexplosibility would add great impetus to a fire once started.

CARELESS PRACTICE

At many steel mills and other metal-working plants where pulverized-coal fuel is used it is customary to open the doors in the side walls for ventilation during warm weather. An air current swirling in through these doors or even through an open window might raise a cloud of this dust and blow it against red-hot metal or cinder, with serious results.

It will be noted that in the account of the Burden fire the originating cause was the very thing mentioned above—a dust cloud sweeping across red-hot slag. Some furnace men may assume that enough dirt may become mixed with the coal dust on the floor around the furnaces to counteract the dangerous characteristics of a coal-dust cloud.

Table 5 gives analyses of dust samples brushed from the floor around three types of furnaces in different operations.

Table 5.—Analyses of dust samples from floor around furnaces

<table>
<thead>
<tr>
<th></th>
<th>Sample 76723 a</th>
<th>Sample 78175 b</th>
<th>Sample 34284 c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatile matter</td>
<td>25.66</td>
<td>37.18</td>
<td>33.98</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>33.07</td>
<td>40.43</td>
<td>36.59</td>
</tr>
<tr>
<td>Ash</td>
<td>40.48</td>
<td>21.24</td>
<td>28.25</td>
</tr>
<tr>
<td>V + F. C</td>
<td>.44</td>
<td>.48</td>
<td>.48</td>
</tr>
</tbody>
</table>

Inert material to be added per pound of sample to render mixture incombustible.

| Sample 76723 a  | 1.38 | 2.28 | 1.14 |
| Sample 78175 b  |      |      |     |
| Sample 34284 c  |      |      |     |

a This sample was obtained by brushing the floor around pair furnaces, sheet furnaces, or continuous heating furnaces.
b This sample was taken from the floor of the kiln room of a cement mill.

table 5 shows that 100 per cent or more of the weight of the original sample must always be added as incombustible material to render the entire mixture incombustible.
A certain hazard exists at some power plants where the coal is dumped from the railroad cars near the front of the boiler furnaces. This hazard is illustrated by Figures 17 and 18, which picture a power plant where a concrete bin about 12 feet wide and 10 or 12 feet high had been built along the side of the boiler room. Cars of coal were switched in over the bin, the hoppers opened, and the coal dumped.

The inner side of the bin, which was only about 10 or 12 feet from the front end of the boilers, and therefore comparatively close to the fire-box doors, formed the outer side of the boiler room, and was constructed of planking nailed to 4 by 6 inch posts which extended from the floor to the roof of the boiler house. These posts were spaced 7 or 8 feet apart and the space between the posts of the third and sixth panels was not boarded up for 5 or 6 feet from the floor. This space was left to allow the coal to run out on the boiler-room floor and be easily reached by the men firing the boiler.

When coal was being dumped from the cars into the bins a tremendous cloud of fine coal dust came through the panel openings in the wooden partition. This cloud was dense enough to obscure the electric lights suspended from the roof, making it almost impossible for men to stay in the boiler room.
If this dust cloud should come in contact with the flames in the fire box of the boiler, with proper conditions of air and coal dust, the result would inevitably be a flash of flame extending through the greater part of the boiler room and at the very least painfully burning anyone near by.

A somewhat parallel case happened at a steel mill when a cloud of coal dust was blown by compressed air from a tank directly across the room toward an open door in a furnace. Instantly there was a flash and the entire room was filled with flames.

![Image](image.png)

**Figure 18.**—Interior view of bins shown in Figure 17. Coal running out on the floor in front of the boiler furnace

Whenever coal is being dumped near the fire box in a boiler or any kind of a furnace, the resulting dust cloud should be kept from coming in contact with the fire.

**Operating Hazards**

There can be little doubt that many of the accidents charged to pulverized-fuel plants are due largely to the fact that the characteristics of pulverized coal have not been understood. When plants are properly designed and operated, such fuel is probably no more liable to flash or explode than is natural gas.

Natural gas, however, has been recognized for years as a deadly menace when uncontrolled near an open flame; consequently the odor of gas escaping from a leaky joint or faulty connections is a danger signal and steps are taken at once to stop the leak. On the contrary,
if a coal-transport line or conveyer is leaking pulverized coal, but little attention is given to it. A cloud of coal dust floating in the air does not make a workman fear explosion or fire as does the odor of escaping gas, yet a leaking line of coal dust has the same potential danger as a leaking gas line.

**DANGER FROM LEAKY LINES OR COAL BINS**

The fire at the Burden Iron Works, mentioned on page 22, is a typical example of the danger from a leaky line or coal bin and illustrates fairly what may happen if a transport line or storage bin is neglected.

In one eastern plant the fuel bin at the furnaces was equipped with a bag that acted as a safety valve to relieve excess pressure when coal was blown into the bin. For some reason the bag burst while filled with air and dust, permitting the pulverized coal to come in contact with a spark from the furnace. The dust cloud immediately ignited and caused a fire. As a result, all the bags were removed and metal dust collectors substituted.

**IGNITION OF ESCAPING CLOUD OF PULVERIZED COAL**

An incident in an Ohio steel plant, though not an actual leak, exemplifies very well the danger of a stream of pulverized coal near an open flame. At this plant the indirect system of transporting coal was in use. The blowing tank and drier furnace occupied the same room, which was separated from the main manufacturing department of the plant by a brick partition wall. A shut-off valve was placed in the transport line just outside of the blowing tank to close the line while the compressed air was being admitted into the tank. Pulverized coal had lodged between the valve seat and the valve, causing some difficulty in operating the line; to remedy this the valve was taken apart and cleaned.

The air in the blowing tank was at approximately atmospheric pressure, as the air-pressure gauge registered zero; however, when the valve was taken apart some coal dust which had been lying dormant in the line was blown in a dense cloud directly toward the drier furnace, where it came in contact with some live coals. It immediately flashed and the entire room was filled with a mass of flame which rolled back and forth over a space about 60 feet long. Fortunately no one was burned and no damage was done.

**LEAK FROM TRANSPORT LINE**

A smaller fire occurred at a furnace in another mill of the same company, due to the fact that the plant was put in operation before
complete equipment for the furnace supply bin was installed. Figure 7 shows that on top of the bin is a separator which separates the powdered coal from the air used in forcing the coal from the pulverizing house to the furnace bin. At the time of the fire this separator had not been placed in position and the opening in the top of the bin through which the coal is discharged from the separator had not been covered, so that the transport line fed directly into the bin; therefore, when the bin was being filled dust came through the opening and the dust cloud came in contact with the fire in the furnace. It flashed and caused a small fire, but fortunately no damage was done.

![Figure 19.—Pulverized-fuel bins above heating furnaces](image)

**DUST BLOWN FROM OPEN BIN TO FURNACE**

In another plant of like character two somewhat similar flashes caused two deaths. The bins were directly above the furnaces, as shown in Figure 19, and were filled with pulverized coal through compressed-air lines directly into the bin. The top of each bin was covered with a one-quarter-inch iron plate provided with a door, which the furnace men were instructed to keep shut.

One accident occurred as follows: While pulverized coal was being delivered to one of these bins a man climbed to the top of the bin; he may have opened the door to see whether or not the bin was completely filled. A dense cloud of dust drifted out, probably through the open door, and came in contact with the furnace fire. Immediately it ignited and flashed up, enveloping the man in flames and burning him to death.

A second similar flash occurred at another furnace some time later, and also resulted fatally.
As a result of these two fatalities, this steel company has abandoned the use of the bins immediately over the furnaces and has constructed new ones entirely outside the main building, as shown in Figure 20.

The layout of the mills and the arrangement of the furnaces were admirably suited for this plan. The rear of the furnaces is parallel to and 15 or 20 feet from the sides of the building. The fuel lines are directly behind the furnaces they supply. The bin feeds into a screw conveyer which travels at a given rate of speed.

![Figure 20.—Pulverized-fuel bins outside of building in the open](image)

Outside of the building and parallel thereto under the bins is a galvanized-iron pipe which starts at 24 inches diameter and is reduced to 14 inches. At the larger end of the line is a blower which supplies the additional air required for proper combustion of the coal. The other end is tightly sealed.

The blower is designed to deliver no more air than is needed at the various burners. At each bin a 4-inch line connected to the air line runs under the screw feed and thence to the furnace. A Y connection beneath the screw feed receives the coal as it comes from the screw feed.

The air passing through the 4-inch line creates suction in the branch line and draws powdered coal into the air current to the burner. Close to the point at which the 4-inch line leaves the main air-supply line an 8-inch line is connected, leading to the burner in the furnace which carries the additional air required for complete combustion of the pulverized coal. Both lines are laid under the
brick-paved floor of the building to within a short distance from the furnace, where a vertical connection is made to the burner.

The general arrangement of the bins, air lines, and coal-feed lines as described above is ideal as to safety, because any dust cloud which might form around the pulverized-coal bins or any trouble in the air-supply line would not occur in the vicinity of the furnaces but outside of the building.

The question might arise whether stormy or cold weather would hinder operation of the coal-feeding apparatus. In order to protect the bins as much as possible, covers were built over them and no trouble has ever been experienced.

**Figure 21.**—Furnace-fuel bins above roof of main building with fuel-transport lines in the open

**Bins on Roof of Main Building**

Another steel plant accomplished the same purpose but in a slightly different way. Figure 21 shows furnace fuel-bins at this plant above the roof of the main building and the fuel transport-line also in the open. The hopper bottom of the bin extends below the roof, where it discharges into a screw feed by which coal is fed to a line that leads to the burner at the furnace. Behind the connection with the coal feed is a connection to the primary air line by which the pulverized coal is blown through the feed line to the furnace. A connection is also made to a secondary air line to provide the proper amount of air for efficient combustion.

Between the bottom of the bin and the furnace is the corrugated-iron partition shown in Figure 22, which prevents an unconfined dust cloud from coming in contact with the fire in the furnace. Should the bin overflow, the resulting dust cloud is carried away in the open air.
DANGER FROM FIRE IN DRIER

In connection with leaks of powdered coal coming in contact with open lights and furnace flames it is an extremely wise precaution so to arrange the entire main plant that the pulverizing unit shall be in a separate building as far from the manufacturing equipment as possible. Moreover, as a further safety measure the drier should be isolated from the other units of the pulverizing plant, either by being in a building alone or by having a fireproof wall with only the openings necessary for pipes, shafting, and conveyers between the furnace end of the drier and the remaining machinery. By doing this, the danger of a cloud or stream of pulverized coal coming in contact with open flame or red-hot cinders will be averted. The wisdom of this precaution is shown by the incident, mentioned on preceding pages, of the cloud dust blown from a control valve of a blowing tank and ignited by the fire in the drier.

That this accident is not unique is illustrated by an explosion in the drier room of an eastern plant.

LEAKY PIPE NEAR DRIER FURNACE

A drier of somewhat similar type to that shown in Figure 3 (p. 7) was in use, the only difference being that the fan which drew the hot gases through the drier drum was placed over the center of the
drum. This fan not only drew the hot gases from the furnace through the drier but also the fine dust which entered the drier with the crushed coal. The dust was separated from the gases by a cyclone separator and fell into a dust-collecting tank directly under the separator.

If this dust was entirely dry it was then blown into the powdered-fuel bin and eventually burned, but if it had collected moisture from the atmosphere while in the dust-collecting tank, it was drawn to the outside of the building through a 4-inch pipe leading from the bottom of the “dust tank.” This 4-inch line passed diagonally across the face of the furnace of the drier and about 8 feet distant.

Owing to a break in this pipe, a cloud of coal dust formed directly in front of the drier furnace and was drawn through the open fire-box doors; it was ignited and exploded; a second explosion followed immediately. This second explosion was due no doubt to the raising and igniting of a cloud of dust from the accumulations in and around the drier by the first explosion. Fortunately no fatalities resulted, although two men were painfully burned.

Whenever the pulverized coal becomes caked in bins, transport lines, or conveyers, it should not be jarred loose by hammering, which is liable to open joints and cause leakage of the pulverized coal.

Bins should be so constructed that the interior shall be free from projecting or rough surfaces which may retain any part of the coal. Means should be provided for easy cleaning of the bins from outside.

**OVERHEATED COAL**

There can hardly be any doubt but that the keystone of the arch of safety in a pulverized-coal plant is the proper operation of the drier.

The majority of explosions and fires in pulverized-coal plants can probably be traced directly or indirectly to overheated coal. Overheated coal and consequent fires in the drier drum come primarily from two causes—too hot a fire in the drier furnace and continuance of the drier-furnace fire after the drier drum has stopped operating but still contains a charge of coal. In direct-fired driers especially it is better to have a large body of moderately warm air pass through the drier drum than to have a smaller volume at much higher temperature.

Complaints are sometimes made that when there is a hot fire in the drier furnace the dried coal reaching the dried-coal bins is often somewhat moist. Paradoxical as it may seem, coal dried at an abnormally high temperature will cause more moisture than when dried at 100° to 150° F.
The higher the temperature of the atmosphere surrounding the coal, the greater the ratio of steam to dry air; also the hotter the coal, the hotter the surrounding atmosphere and the higher the steam content of the atmosphere around the coal. Most of this steam comes from the coal, though some of it probably comes in with the air as steam. On coming in contact with the colder sides of the bin, this saturated mixture of air and steam condenses.

When the coal is dried at a lower temperature less moisture is given off from the coal and hence there is less condensation. A good illustration of this principle can be found in the paper read by Mr. John Anderson, chief engineer of power plants of the Milwaukee Electric Railway & Light Co.\(^\text{12}\)

Concerning a test of pulverized fuel being run at the Oneida Street plant of that company, Mr. Anderson says:

During the first 24 hours of the test it appeared that moisture, with its attendant difficulties, was collecting in the storage bins. Cold-air drafts through windows along the sides of the bins caused this condition by rapidly condensing the vapor in the entrained air. When the windows were tightly closed it was eliminated.

**EXPLOSION AT CEMENT PLANT CAUSED BY OVERHEATED COAL**

A cement-plant explosion that killed two men and painfully burned three others typifies accidents caused by overheated coal. The drier was of the indirect-fired type described under class B on page 8. From the drier the coal was discharged into a pit, whence it was raised by a bucket elevator to screw conveyers which delivered it to the storage bins supplying the pulverizing mills.

The latter were operated electrically, and the controller that regulated the starting and stopping of the driving motor had three positions—the zero position, which completely shut off the current from the motor, the “starting position,” into which the controller was thrown while the motor was gathering speed, and the “full-speed position,” to which the controller was advanced to bring the motor to full operating speed. When in the “starting position” the controller would spring back to zero if the operator removed his hand, but when at “full speed” the controller would stay there until changed. The fan that exhausted the dust from the mill and delivered it to the collector was driven by the motor that operated the mill.

There were two such mills at the plant; one had been idle for several hours before the accident, but the other had been running for some time.

More or less trouble had been experienced before from fires in the driers and in the dried-coal bin, the latter often becoming almost red hot. When a Bureau of Mines representative made his investigation he noticed a very hot fire in the drier furnace and flames and sparks issuing from between the sides of the shell and the wall of the combustion chamber at the point where the shell passed through the wall.

The accident happened just as the idle pulverizing mill was being started; in fact, the controller was found at the zero position, indicating that the operator had brought it only to the starting position and there released his hold.

CAUSE OF ACCIDENT

It was established almost conclusively that the accident was caused by the feeding of hot coal into the pulverizer. The coal had evidently been heated to a very high temperature, which, if it had not increased, had at least not decreased between the time the coal left the drier and the time it was fed into the hopper of the pulverizer. Then one of two things happened. Either some hot coal remained in the pulverizer when shut down and grew hotter until it only needed the additional oxygen that would be supplied by the simultaneous starting of the fan and mill to blow it into a flame, or the coal was practically red hot when it left the feed hopper and passed into the mill.

In either case, when the fan was set in motion it raised a dust cloud that was ignited by the hot coal and, being confined, naturally exploded. The explosion in the mill raised the accumulated dust in and around the building, ignited it, and thus originated the explosion that extended through the building. Such was the force of this explosion that the flames swept through the pulverizing room and out the door, burning one man who was unloading a freight car 25 or 30 feet away.

ANALYSIS OF MILL DUST

The dust lying on the foundations of the mills, the floor, and window ledges had the following composition:

<table>
<thead>
<tr>
<th>Component</th>
<th>Moisture</th>
<th>Volatile matter</th>
<th>Fixed carbon</th>
<th>Ash</th>
<th>Dust</th>
<th>Pittsburgh coal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>per cent</td>
<td>do</td>
<td>do</td>
<td>do</td>
<td>1.70</td>
<td>2.63</td>
</tr>
<tr>
<td></td>
<td></td>
<td>37.45</td>
<td>46.46</td>
<td>14.39</td>
<td>34.32</td>
<td>57.60</td>
</tr>
<tr>
<td>V</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.4463</td>
<td>.3732</td>
</tr>
<tr>
<td>V+F.C.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In a parallel column is given an analysis of a typical sample of Pittsburgh coal. By comparison the table shows that the mill dust is almost as explosive as the pure coal dust.

CONDITIONS IN PULVERIZING ROOM

The dust in suspension in the plant's pulverizing room was so thick that the electric lights appeared as if seen through smoked glass and it was very difficult to see one's way around the machinery. Dust an inch thick covered the floor, machinery, and every other place upon which it could find lodgment. Here was a splendid example of how a coal-pulverizing plant should not be operated.

EXPLOSION AT STEEL PLANT CAUSED BY OVERHEATED COAL

An explosion that destroyed much property was caused in a manner somewhat similar to that described above.

The plant at which the accident occurred consisted of several buildings that contained annealing furnaces, open-hearth furnaces, plate mills, and warehouses: at the time of the explosion about 17 furnaces in the hot mill and 17 annealing furnaces were operating with pulverized coal as fuel.

The pulverizing plant, which crushed and pulverized about 100 tons of coal a day, was situated in a separate two-story building about two or three hundred feet from the buildings that contained the hot mills and annealing furnaces. This building was built of brick and steel with a flat fireproof roof. Along the center of the roof extended longitudinally a monitor of steel and reinforced concrete, well supplied with windows.

The direct-fired type of drier was used. Figure 2 shows that an arch extends transversely across the fire box from the rear wall to within about 1\(\frac{1}{2}\) feet of the front. On the arch is built a baffle wall about 2 feet thick at the base. The front is carried up flush with the front of the arch nearly 5 feet, whereas the back of the wall is only a little over 1 foot high. In conjunction with the rear wall of the furnace the consequent sloping back of the baffle wall forms a hopperlike pocket which holds the coal as it comes from the drier drum. At the bottom of this pocket is the screw conveyor to the pulverizer. The pulverizer was but a few feet from the drier and an air current of fixed velocity separated the finely pulverized material.

A pyrometer in the stack at the rear of the drier measured the temperature and recorded it on a chart in the office of the mechanical engineer some distance away. The normal drying temperature was about 150° F. On the evening of a cold winter day there was
a violent explosion in the pulverizing house, which badly damaged the building, killed two men, and burned two others.

Two men were on the second floor, probably near the belt conveyer which carried the coal from the bin to the drier; another was on top of the pulverizer and another on the ground floor near the bottom of the pulverizer. Suddenly a sheet of flame shot into the air from the vicinity of the pulverizer and rolled to the end of the building, then back through the entire building.

One of the men on the second floor was killed, as was the man standing on the pulverizer. The second man near the storage bin and the man on the ground floor were severely burned.

That it was more than a flash is shown by the appearance of the building after the accident. Practically all the doors and windows were blown out and the 2-inch reinforced concrete in the sides of the monitor roof was completely shattered. Figures 23 and 24 show the effects of the explosion on the building, Figure 25 the condition of the monitor roof, and Figure 26 the damage to the pulverizer and connections.

**PYROMETER CHART**

Just before the explosion the pyrometer chart in the mechanical engineer's office indicated the normal drying temperature of 150° F., while at the time of the explosion a temperature of 350° was recorded. This pyrometer chart was a very important factor in determining the probable cause of the explosion. Another important point is the fact that the pyrometer was placed in the stack end of the drier; consequently the temperature which it recorded would be much lower than that at the discharge end of the drier next to
the furnace. The pulverizer, the only apparatus in the building that showed injury, appeared to have been damaged by an internal expanding force.

**CAUSE OF EXPLOSION**

Figure 2 (p. 6) shows that in a direct-fired drier the hot gases from the drier furnace pass over the baffle wall and the screw conveyer and then directly through the center of the shell of the drier. Furthermore, the screw conveyer is so located that it forms a natural pocket in which may be caught small hot particles of coal from the drier furnace, carried by the draft over the baffle wall.

After thorough investigation it was concluded that just before the explosion either the fire in the drier furnace had so increased in intensity that the coal in the drier drum was ignited by the intense heat, or incandescent particles of coal from the drier furnace were mixed with the dried coal passing to the pulverizer through the screw conveyer. These hot coals, coming in contact with an explosive mixture of dust and air in the upper part of the pulverizer,
ignited it, causing a primary explosion which raised a dust cloud from the accumulated dust on the floor and machinery in the building. This cloud in turn was ignited by the flames from the pulverizer and thus propagated the explosion in the building.

**TWO SMELTER EXPLOSIONS CAUSED BY OVERHEATED COAL**

A similar explosion occurred in 1921 at a western smelter where the coal is dried in a direct-fired drier and carried by a screw con-

![Figure 25.—Damage done to concrete monitor roof by explosion of pulverized coal](image)

veyor directly to the feed for the pulverizer. About 7 a. m. one day the operator, after a general inspection of the plant, started the drier, and then pushed in the switch to start the pulverizer. Immediately there was an explosion that blew off most of the roof of the building and burned the operator severely. Apparently the coal that had remained in the screw conveyer between the drier and the pulverizer had become ignited through overheating of the drier during the preceding day's run and, when the drier was started, was
carried into the pulverizer. When the latter was started, the air current which separated the dust from the coarser particles raised the dust into a cloud, at the same time providing the amount of air necessary for combustion. The mixture was then ignited by the hot particles of coal and the explosion occurred.

Figure 26.—Damage done to pulverizer by explosion of coal dust

A southwestern smelter had a similar explosion which killed one man. The pulverizer had been idle for several days; the exhauster fan was started first, and then the pulverizer, and the explosion occurred a few seconds afterwards. This explosion was followed at once by a second one, due to the dust in the air. This dust had
probably accumulated around the outside of the pulverizer and was raised in a cloud and ignited by the first explosion in the pulverizer. Neither explosion caused serious damage to property.

Overheated coal from a direct-fired drier had apparently been smoldering in the pulverizer while it was idle. Possibly some gas had been driven off, but there was not enough oxygen for perfect combustion. This oxygen was supplied with the starting of the fan, which also raised the quiescent dust into a cloud. The hot dust was fanned into a flame which ignited either the gas that might have been generated or the dust cloud itself.

The foregoing accidents illustrate the danger caused by overheated coal in the driers and also the absolute necessity of keeping the pulverizers free from hot material.

**CORRECT TEMPERATURE OF DRIED COAL**

In this connection the question arises whether or not there is a tendency to force the capacity of the driers by using too hot a fire. The ideal operation of a drier, especially one of the direct-fired type, would be to pass a large volume of moderately heated air over the coal rather than a smaller volume at a comparatively higher temperature. Even though the dried coal may not be hot enough to cause partial combustion, there is a chance that spontaneous combustion may take place at plants where dried coal is stored in bins before pulverization. In that event hot coal may be delivered to the pulverizer, with results similar to those mentioned in the preceding pages.

Officials who are in charge of pulverizing-plant operations differ as to the proper temperatures at which coal should come from the drier. If the flow of coal from the drier to the pulverizing mills and thence to the point of consumption is continuous, the coal may have a higher temperature as it comes from the driers than would be permissible if either the dried coal or pulverized coal were to be stored for any length of time.

**DANGER OF STORING DRIED OR PULVERIZED COAL**

Because bituminous coal tends to absorb oxygen rapidly, and thereby reach a stage of combustion quickly, the storage of dried or pulverized coal should be limited to as small an amount as possible and yet permit the plant to operate continuously. A small reserve of pulverized coal may be maintained for emergency use. A commendable practice in some plants where pulverized coal is used as fuel is to regulate the coal supply so that no dried unground coal is in the plant when the heating furnaces are shut down for more than four hours.

The following table of maximum amounts of pulverized coal that may be stored for a given period has been recommended for adoption
by the National Fire Protection Association in its tentative "Regulations for the installation of pulverized-fuel systems."

**Maximum amounts of pulverized coal to be stored**

<table>
<thead>
<tr>
<th>Temperature of coal entering mills, ° F.</th>
<th>250</th>
<th>225</th>
<th>200</th>
<th>175</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum quantity of pulverized coal which may be stored, hours' supply for plant</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>16</td>
<td>18</td>
</tr>
</tbody>
</table>

The critical point at which oxidation of coal begins to increase rapidly seems to be about 150° F.; from that point the temperature increases very rapidly until the point of ignition is reached.

**GASES OF COMBUSTION**

In direct-fired driers the gases of combustion should not come in direct contact with the fuel being dried until the danger of ignition from the flames of the fire in the drier furnace is eliminated. The National Fire Protection Association regulations mentioned above contain this paragraph:

Driers shall be of such a type that the products of combustion of the heating unit shall not come in contact with the fuel being dried except at a distance of at least one-half the length of the drier, and in no case within 12 feet of the fuel bed.

To stop the operation of a drier without either by-passing the gases of combustion directly to the stack or pulling the fire is exceedingly dangerous. If the coal remains in the drier drum and intense heat from the drier furnace passes directly over the coal, there is a chance that a certain amount of gas may be distilled which may cause trouble later; or hot spots may develop which may be carried into the pulverizer and ignite the dust cloud raised by the air separator.

Driers should be equipped with by-passes for use when they are not in operation, so that the gases of combustion can not pass through the drier drum.

**RESPONSIBILITY OF OPERATOR OF DRIER**

The man who runs the drier—the one who actually shovels the coal into the furnace, not the person in general charge—has a responsibility similar to that of the man in charge of a battery of high-powered boilers. Sometimes the average factory or power-plant superintendent may little realize this fact. If a man tending a boiler forgets to keep the water in the boiler at the proper level, trouble is liable to result. If the man tending the drier furnace performs his duties improperly and allows it to be overheated, an explosion with possibly fatal results is almost sure to follow.
Modern boiler plants are equipped with automatic safety devices, such as safety valves, water glasses, try cocks, and fusible plugs. It is almost as important to equip a drier with safety appliances as it is a boiler.

A pyrometer with a recording chart, in the superintendent’s office, would be an effective check on the operation of the drier. The thermocouples should be placed at the most accessible point nearest the discharge end of the drier, so that they will give as nearly as possible the temperature of the coal as it comes from the drier.

In connection with this, a time punch might be installed so that a record may be had of the exact hour at which each heat inspection was made. If the recording chart is placed in the same building as the drier, it should be protected from damage by explosion or fire. Such a chart is a valuable aid in determining the cause of a disaster in the pulverizing plant from such explosion or fire, as was well demonstrated in the account of the explosion in a steel-mill pulverizing plant in which the record showed the drier temperature had risen 200° in a comparatively short time.

**IMPORTANCE OF HEAT CONTROL**

Since one primary cause of explosions of pulverized coal appears to be the overheating of coal in the driers, some effective means of heat control should prove advantageous; therefore it would seem feasible to install a thermostat at a convenient point in the drier and so regulate it that when the temperature at the point of installation exceeded a predetermined height a mechanism would automatically open a check damper and thus cool the fire in the drier furnace; or it might operate a by-pass that would allow the hot gases to pass directly out of the stack without going through the shell of the drier.

The temperature at which the thermostat would operate the regulating mechanism would be determined by the temperature at the point of the installation of the thermocouples. This temperature in turn would be governed by the maximum temperature at which the coal is to be dried.

As an illustration: If the thermocouples are placed in the stack end of the drier and register 430° F. when the dried coal shows a temperature of 150° F. the mechanism would be adjusted to operate at 430° F. When the stack temperature drops below 430° F., the mechanism would close the damper, and it would remain closed until the temperature was above maximum. The maximum temperature should be considerably above that required to dry the coal efficiently in order to avoid continual fluctuation, and yet at the same time not so high that the coal would become overheated.
Such an arrangement might be likened to the safety valve on a boiler, which blows off at 250 pounds pressure when the ordinary working pressure of the boiler would be 200 pounds of steam.

SEPARATION OF DRIER FURNACE FROM OTHER EQUIPMENT

To avoid possible ignition of dust clouds by the fire in the drier furnace a fireproof partition should separate the drier, or at least the furnace end of it, from the pulverizing and conveying machinery and coal-storage bins.

The necessity of this precaution has been recognized by the National Fire Protection Association in the regulations mentioned in the preceding pages. Rule 10 (a) states that:

The drier and drier furnace shall be separated from other equipment in the pulverizer house by means of incombustible partitions constructed of material having a fire resistance of not less than one hour based upon standard specifications for fire tests and materials of construction.

DANGER FROM MAIN FUEL LINE

Next to the drier, one of the most prolific sources of trouble is the large main through which in circulating systems the mixture of coal dust and air is blown around the plant, the unused coal being returned through air separators to the pulverized-coal storage bin. As has been stated, the pulverized coal is driven through this line by an air current induced by a fan. The pressure ranges from 7 to 10 ounces per square inch.

From this main line a feeder runs to the furnace, where just before it reaches the burner a connection is made with the secondary line which furnishes the air for combustion and which operates under a pressure of about 5 ounces per square inch.

SHORT CIRCUIT OF AIR CURRENTS

One of the principal sources of danger is the possibility of a short circuit in the air currents. Figure 8 (p. 13) shows that if the pressure in the circulating line is suddenly stopped a negative pressure may momentarily develop between it and the "secondary" air, with the possible result that the "secondary" air will be deflected into the circulating line. This deflection will create a tendency to draw hot particles of coal from the furnace into the circulating line. When this happens, if there is the right mixture of coal dust and air in the line, either an explosion or slow combustion (which may later cause an explosion) will take place, depending on the quality of the mixture.
ACCIDENT AT HARDWARE FACTORY

The Bureau of Mines investigated an accident in the forge shop of a hardware factory. By this accident one man was killed and two were seriously burned. In the building in which the explosion occurred were a number of furnaces used in heating the rods from which the finished product was made. These furnaces had burners for pulverized coal or natural gas.

The supply of gas or of coal was controlled independently at each furnace by valves in the feed lines. Moreover, the entire supply of gas could be cut off from all the furnaces by two main valves near the extreme end of the building. When the furnaces were using pulverized-coal fuel, these two main valves on the gas line were kept closed.

On the day of the accident the furnaces were being operated with pulverized coal and the gas had been shut off by the valves on the main gas line. During the day the fan on the coal-distribution line broke down and stopped running and as soon as possible a man went from furnace to furnace closing the valves in the coal-feed lines to the furnace. However, 10 or 15 minutes must have elapsed before every valve could be closed. About half an hour later the furnaces were again in operation with natural gas as a fuel. When the plant finally closed down the valves in the main supply line were shut and the gas cut off from the entire mill.

Late at night repairs on the fan were completed and it was started in order to blow out the coal, which had settled at the bottom of the circulating line, owing to the sudden stopping of the carrying air current. In order to clean the line more easily a section near the air separator on the roof had been removed. Two men went out of the building to watch the dust as it came out of the line, and a third man stood at the fan controller just back of the fan. The fan had been running but a few minutes when an explosion occurred which tore away the cast-iron fan casing and ignited the clothing of the man at the controller, who later died.

It was learned authoritatively that on several occasions smoldering coal dust had been found in the coal-circulating lines in other mills of the company.

CAUSE OF EXPLOSION

Engineers of the Bureau of Mines after careful investigation reached the conclusion that the sudden stopping of the fan and the consequent lowering of the air pressure allowed the secondary air to deflect from the burner into the circulating line, carrying with it incandescent particles of coal dust, which, owing to lack of air, did not cause the coal dust in the line to explode. The dust, however,
continued to smolder in the line until the fan was started again in
the attempt to blow out the line.

The starting of the fan did two things: It furnished enough air
to fan the smoldering coal into flames and at the same time raised the
dust lying at the bottom of the line into a cloud of a comparatively
lean mixture of dust and air, which was immediately ignited by the
newly fanned smoldering coal dust.

The resulting explosion, being confined by the spiral riveted steel
pipe, traveled back toward the fan, fed, no doubt, by the additional
dust blown toward the explosion wave. When the explosion wave
reached the fan casing, the pressure was too great for the thin casting
and consequently burst it.

OTHER THEORIES AS TO CAUSE OF EXPLOSION

The theory was rather strongly advanced that gas was leaking
from one of the gas-supply lines into the coal line. This is possible,
but in any event the source of ignition of gas or coal dust must have
been either hot-coal particles or flames backfiring from one of the
heating furnaces. In view of this possibility it would be a wise pre-
cautions to disconnect all gas lines when pulverized coal is being used
for fuel so that the gas line could be connected to the burner in the
furnace with little delay if the pulverized-coal apparatus was tempo-
rary shut down. This practice has been successfully followed by
some of the mills that use both gas and pulverized coal as fuel.

PROTECTION OF FAN

In such installations it would seem to be a wise provision to pro-
tect the fan from the force of any explosion in the circulating line.
At the Bureau of Mines experimental mine, where a great many coal-
dust explosion tests are held, it has been necessary to protect the fan
by placing it at an angle to the airway. An explosion wave travel-
ing along the airway passes by the branch leading to the fan and
continues to the relief doors at the end of the straight entry, and
only a comparatively small pressure wave reaches the fan.

Based on the experience of the bureau in its method of protecting
ventilating apparatus, the two following methods of protecting pul-
verized-fuel blowers are suggested. Construct a Y connection at the
bottom of the circulating line just in front of the fan, the main axis
of the Y to be a straight continuation of the axis of the circulating
line and the branch of the Y to lead directly to the fan connection.
Over the open end of the circulating line a light cap should be fitted
which would be blown off easily in event of an explosion. This end
should terminate in a concrete pit or some other suitable place so that
the explosion wave coming out of the end of the line could do no
harm. Figure 27 illustrates this method of protecting apparatus.
PRESENT ARRANGEMENTS

PROPOSED ARRANGEMENTS

FIGURE 27.—Methods for protecting fans from explosions in pulverized-fuel circulating line
OPERATING HAZARDS

ACCIDENT TO BLOWER

A peculiar accident in the pulverizing plant of a steel mill that cost the life of one man was reported to the Bureau of Mines, and is the only one of its kind brought to the attention of the bureau. The fan used to blow the pulverized coal through the circulating lines suddenly burst, the shaft and the impeller blades being smashed to pieces.

The blades of the fan were carried on a cast-steel spider keyed to a 1½-inch cold-rolled steel shaft which overhung its bearings. The blades were of soft steel faced with manganese steel to withstand the abrasive action of the coal. An investigation at the time of accident showed that the initial failure did not occur in the shaft. The evidence, however, indicated that the stress in the arms at the time of the failure was above the theoretical ultimate strength of the material, and that the blades and wearing parts were too heavy. In consequence the arms of the spider failed, throwing the impeller out of balance and causing the bending and failure of the shaft.

The steel company redesigned the blower and substituted a 4-inch shaft, notwithstanding the fact that the redesigned impeller, which was much heavier, did not overhang the bearings.

SLOW COMBUSTION OF COAL IN CIRCULATING LINE

An interesting question may be raised as to why slow combustion of coal occurs in the circulating line on one occasion and on another, under apparently the same conditions, a violent explosion takes place.

PLUGGING OF LINE BY COAL

Engineers of the bureau who investigated a fire learned that the main circulating line of the system had plugged up just before the fire was discovered. The blower fan was immediately shut down and this action probably prevented an explosion; otherwise some of the burning particles would have been carried along until they came in contact with a lean enough mixture of coal dust to cause an explosion. Past experience indicates that this explosion would probably have occurred at or near the air separator at the end of the return line.

As soon as possible the line was cut near the furnace that it was supplying with fuel and a blind flange, tapped for a 1⅛-inch steam connection, was fitted on the end of the section between the furnace and the blower fan.

Live steam at a pressure of 120 pounds was turned into the line for 48 hours. The flange was then removed, the line connected up,
and the fan started without any coal being fed into it. The fire continued to burn, notwithstanding the amount of steam turned into the line. The return line was then cut out altogether, the open end of the feed line closed, and the coal fed directly into the furnace.

In connection with this incident, it may be said that there was a possible element of danger in connecting up the line and starting the fan after the steam had been turned off. It is true that no coal was fed into the fan; but some coal might have remained in the bottom of the pipe near the blower or, what is more likely, in that end of the return which had been cut out. When the circuit was again established and the fan started some of this burning coal might have been carried along until it reached the coal in the return, which would have been raised into a dust cloud by renewed action of the fan.

Fortunately this did not happen, but under similar circumstances it would appear to be much safer not to connect up the line but first to blow the steam and burning material out of the open end. Even then it would be safe practice to see that the steam had completely filled the entire section of the circulating line between the point at which it was cut and the blower, so that any dust remaining in the line would be so dampened that it would not be raised into a cloud. In addition, the section of the return line to the air separator should be thoroughly inspected for fire or hot, smoldering particles before the entire line is again connected.

In this same plant about six or seven months later an explosion did take place in the main return line. The explosion blew up the cyclone separator on top of the pulverizing house.

VARIATION IN MIXTURE OF COAL AND AIR

Similar fires and explosions in other plants have been investigated, and while the reason or reasons for an explosion occurring at one time and a fire at another, under apparently the same conditions, are not definitely known, it may be attributed to variation in the mixture of powdered coal and air in the circulating lines.

Some manufacturers of circulating systems provide an automatic regulator in connection with the screw feed to the fan. The claim is made, no doubt justly, that the amount of air and coal dust is maintained uniformly in the circulating system regardless of varying demands for fuel. Although a constant quantity of coal dust is provided per cubic foot of air, the density of the mixture is not necessarily homogeneous. This seems to be the crux of the whole matter.

The manufacturers also claim that the density of the mixture is so great that combustion will not occur. This claim may be also
true, but only if the density is homogeneous; the incontrovertible fact remains that in spite of the above claims fires and explosions do occur in the circulating lines.

TESTS IN DUST-EXPLOSION GALLERY

In order to ascertain the effect of a very dense cloud of coal dust on an open light the following test was made in the vertical dust-explosion gallery at the Pittsburgh experimental station (fig. 28). This gallery is practically the same in construction and dimensions as the horizontal gallery shown in Figure 11 and described on page 19, but it is so built that one side may be removed. A solid block forms the bottom of the gallery and the top is left open.

At uniform intervals along the entire length of one side of the gallery are nine holes into which are fitted three-quarters-inch pipe jets which project at an angle of 30° from a 2-inch ver-

Figure 28.—Bureau of Mines vertical dust-testing gallery
tical pipe extending along the side of the gallery. The bottom of this pipe is closed with a cannon having a capacity of 5 grams (0.176 ounce) of powder. A loose metal disk covers the discharge end of each jet, thus forming a pocket to contain the desired quantity of pulverized coal with which each hole was loaded. Each hole was covered by a small square of coarse heavy screen, that the dust might be diffused into a cloud of as uniform density as possible.

The gallery was loaded by pouring about three-fifths ounce of pulverized coal in each of the nine holes in the side of the gallery and placing the screens over each hole. The cannon in the end of the vertical pipe was loaded with about one-sixth ounce of black powder. A small bit of waste soaked in kerosene oil and an ordinary candle were placed on the bottom of the gallery. After the loading had been completed, the candle and waste were ignited and the cannon fired. The explosion raised a dust cloud in the gallery and the candle and waste were completely extinguished. If the cloud raised by the cannon shot was of uniform density, there would have been 2 ounces of coal to 1 cubic foot of air.

No satisfactory data on the maximum amount of coal dust per cubic foot of air which will explode are available; however, tests in the bureau’s experimental mine have shown that a well-formed dust cloud containing 1.3 ounces of coal dust per cubic foot of air ignited once in four times from a 4-pound shot of blasting powder. Ignition has been obtained with 0.55 ounce per cubic foot of air, as indicated in Bulletin 167 of the bureau.

**TESTS IN LABORATORY STEEL DUST GALLERY**

As some factors involved in dust explosions in the experimental mine might not be present in a dust explosion in a pipe line, and vice versa, tests were also made in the laboratory steel dust gallery (fig. 29), which represents as nearly as possible actual working conditions under which pulverized fuel is used. In general principle and in method of operation the gallery is very similar to the wooden gallery illustrated in Figure 11 (p. 20), with the exception that a steel pipe 8 inches in inside diameter and 17 feet long, consisting of a 12-foot section, a 3-foot section, and a 2-foot section, is substituted for the wooden box. The back end is fitted with a blind flange drilled to admit the mechanism used to ignite the dust cloud. The pipe is drilled to receive the pipe jets extending from the 2-inch pipe running underneath, in the same manner as in the wooden gallery.

The dust cloud is raised by the discharge, by means of a trigger valve, of 0.07 cubic foot of air at 100 pounds pressure. The length

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Figure 28—Bureau of Mines steel dust-explosion gallery.
of the flame is indicated by the burned or unburned condition of small pieces of guncotton suspended at given intervals from a metal frame inserted within the pipe.

**AMOUNT OF AIR USED AT VARIOUS INSTALLATIONS**

In a test at the Steelton (Pa.) plant of the Bethlehem Steel Co., these data were obtained: Air discharge from fan through a 12-inch pipe, 3,826 cubic feet per minute; quantity of coal delivered with air per minute, 29.68 pounds; air used per pound of coal per minute, 120 cubic feet, which is equivalent to 0.124 ounce of coal per cubic foot of air.\(^{14}\)

The smelter of the Nevada Consolidated Copper Co. at McGill, Nev., uses a mixture of 1 pound of coal for about 50 cubic feet of air or 0.32 ounce of coal per cubic foot of air.\(^{15}\) Mr. Longenecker, of the Bonnot Engineering Co., states that in the Holbeck distribution system about 60 cubic feet of air is used per pound of coal, or about 0.26 ounce per cubic foot of air.\(^{16}\)

Two of the statements were made by representatives of a prominent manufacturer of pulverized-coal apparatus and are doubtless absolutely reliable. If these three cases are typical of all installations, these mixtures are well within the explosive limit and therefore dangerous when brought in contact with open flames.

**EFFECT OF AIR CURRENTS**

The claim that the ordinary mixture is nonexplosive possibly arises from the fact that theoretically there is so much coal dust present in proportion to the amount of air that combustion can not take place.

Pittsburgh coal dust of an average fineness of 99 per cent through a 100-mesh screen, 88 per cent through a 200-mesh screen, and 79 per cent through a 240-mesh screen, requires, theoretically, the proportions of 0.123 ounce of dust per cubic foot of air for complete combustion and complete exhaustion of atmospheric oxygen,\(^{17}\) but would necessitate a theoretically uniform mixture of the dust and air which is practically never found. This would seem to be especially true in those distribution systems in which the circulating lines are made of spiral-riveted pipe. The spiral seams would tend to have the same effect on the air currents passing through the line

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\(^{15}\) Pomeroj, R. E. H., Coal-pulverizing plant at Nevada Consolidated copper smelter: Min. and Met., vol. 63, 1919-20, p. 13.


\(^{17}\) Rice, G. S., Explosibility of coal dust: Bull. 20, Bureau of Mines, 1911, p. 50.
that the rifling of a cannon has on the projectile, causing rapid rotation around its longitudinal axis.

Assuming that the above statement is correct—and it appears to be a logical statement, although "Unfortunately there is no means of obtaining the density of the dust cloud at the moment the explosion flame reaches a given space"—a coal dust and air mixture would probably vary (1) across the section of the circulating pipe; (2) with the velocity of the air current; (3) after passing any of the individual feed lines to the furnaces to which it is providing fuel.

In the first instance, due to the centrifugal force as a result of the spiral motion before mentioned, the dust particles probably tend to gather in greater density along the sides, top, and bottom of the line than in the center; in fact, there may be little or no dust along the center of the pipe. If this is true, layers of coal dust would undoubtedly accumulate from time to time on the bottom and possibly along the sides of the pipe.

The velocity of the air current (2) can be accelerated or diminished by opening or closing the feeders to the different furnaces, especially if there is no automatic regulator of the air supply. These changing air currents would also tend to deposit dust in small piles or layers along the bottom of the pipe line.

Under the conditions represented by (3), the variation in the mixture would be caused by pulverized coal being drawn from the line through the feeder to the furnace in proportion to the amount of air. If the cloud of dust in the main circulating line is denser near the sides, it would seem reasonable to believe that a greater proportion of dust than of air would be drawn through the furnace line, which would leave the remaining mixture with a much smaller percentage of coal dust. Where there are a number of furnaces and this operation is continually repeated, the final mixture would be rather explosive at almost any particular point in its cross section. This conclusion seems to be borne out by the fact that violent explosions have occurred at or near the air separator on the main return fuel line.

The above-described results of the tests and conclusions lead to the belief that layers of coal on the bottoms and sides of the circulating lines often become ignited, and the coal dust slowly smolders because the proportion of dust to air at that particular point is too great to cause an explosion. The dust may perhaps be carried along the supply line until a place is found where the percent-

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age of air is higher—not high enough to support combustion completely, but still high enough to allow the heated coal to glow and ignite surrounding particles. Finally the gaskets in the joints have burned out and smoke and flames burst out between the flanges. This theory seems to accord with the statement, made by persons who have witnessed the outbreak of fires in circulating lines, that fire was first observed coming out at joints in the line.

**Baffles and Deflectors**

Some manufacturers install a baffle or deflector at or near the feed lines from the main circulating line to the furnace to deflect the coal into the feed line when the valve is opened to allow the coal to pass to the furnace.

The main objection to baffles and similar devices is that such obstructions in the line form pockets in the current of coal-laden air which fill with coal. This coal, lying dormant, is very liable to ignite from spontaneous combustion or some other cause and in time make more or less trouble. It has also been found that coal adheres to the front of the baffle, probably through impact, and continues to build up slowly until the valve opening is closed. This entire mass is also liable to ignite.

For safety all circulating lines should be absolutely free from any obstruction on the inside of the pipe, so that there can be no chance of enough coal accumulating to ignite through spontaneous combustion or otherwise.

Some mills, when shutting down at the end of a day’s work, leave a small amount of coal lying in the bottom of the main circulating line. The men who run the furnaces claim that they can start them much more quickly than when the line has been blown clean the night before. This practice is rather dangerous, as the air-dust mixture is necessarily lean, perhaps at its most explosive combination, and if hot coal has gotten into the line an explosion will follow.

For safety, when the plant closes down at night all furnaces should be cut off from the main circulating line, and the line should be thoroughly cleaned by allowing the fan to force a current of air through it until all the pulverized coal is blown out.

**Coking Around Ends of Burners**

Coking around the ends of the burners is another source of trouble. The reason for this seems to be that the burner becomes hot at the extreme end from too much coal for the amount of air or the slowing down of the secondary air blower from power fluctuations. The coal then begins to stick on the burner and as the accumulation increases
the area of the burner is decreased and sometimes the burner actually becomes plugged. If the balance of pressure between the primary and secondary air currents is reversed, red-hot particles may be carried into the main coal-circulating line and start a fire. To avoid this contingency, the burners should be inspected often and, if the least tendency to coke is noted, they should be cleaned at once. Some steel mills employ men whose sole duty is to inspect and clean burners.

FAULTY BOOSTER-FAN INSTALLATIONS

If the main circulating system is very long and the load on the line resulting from the number of furnaces supplied is heavy, the air current tends to lose its carrying velocity; therefore a booster fan is installed in the main line at some plants. The main circulating line is connected to the intake side of the fan and the coal and air coming in from this part of the line are passed through the fan and out, via the discharge end, through the remaining section of the circulation system. In this type of installation there is an inherent danger against which it is difficult to guard. If for any reason the main fan does not supply enough air to meet the demands of the booster fan, the latter will draw its additional requirements from the place of least resistance—through the supply line of the nearest furnaces—thus reversing the air currents going into the furnace and creating a back draft that will carry with it burning particles from the furnace.

If the two fans are running independently, this situation may be brought about by the stopping or slowing down of the main blower because of power troubles, by the overloading of the coal-feed line by connecting it up with too many furnaces, or by the shutting down of the main fan before the booster is stopped.

ACCIDENT CAUSED BY BOOSTER FAN

This action of a booster fan was one of several possible causes of one of the most deplorable accidents in the history of modern pulverized-fuel systems. Six men were at work in various places in a coal-pulverizing plant when there was a sudden flash and flames and smoke poured from the building. This lasted but a short time, for the men were removed within a very few minutes; they died later.

The pulverized-coal installation was typical of the circulating system. The fuel was prepared in a separate brick building and the mixture of coal and air was blown around the mills through the circulating lines. The unused coal returned to the pulverized-fuel bin after passing through an air separator. To maintain the required velocity of air and coal in the distribution lines a booster
fan had been installed. The normal air pressure in the circulating line was about 9 ounces per square inch and in the secondary air line about 3 ounces. As far as could be ascertained before the accident, there had been no trouble in the distribution line due to stoppage from caked coal nor had the main fan ceased to operate. Either contingency would have tended to lower the pressure in the circulating line and cause a backfire from the furnaces.

The cyclone dust separator on top of the pulverizer house showed the only evidence of violence. A 10-inch hole had been blown in the side of the separator opposite the point where the 8-inch return line entered. The pitch and asphalt paint on the return line was melted off for some distance and the joints in the line that permits the air to escape from the separator were also melted (fig. 30).

The inside of the building and some of the pulverizing machinery showed evidences of fire; a sheet of flame had evidently spread widely through the building, as was also shown by the fact that the men who were fatally burned were working in different places.

CAUSE OF ACCIDENT

After careful consideration of evidence, the final conclusion was that the fire originated in some part of the return-coal line and, when it reached the end of the line, received enough additional air to cause a slight explosion. The side of the separator probably deflected the flames downward, where additional fuel was provided by the dust in the cyclone. In addition, the force of the wave may have raised into a cloud the dust lying in the pulverizing house, ignited it, and thus propagated the explosion throughout the building.

The lack of injury to the building indicates that little dust was in suspension. Had the building been very dusty, the force of the
initial explosion would have increased rather than diminished, the
doors and windows would have been shattered, and possibly other
marks of violence would have been in evidence.

The manner in which the fire first entered the circulating line
could not, of course, be determined exactly, but could have hap-
pened in two ways. The heated gases from the furnaces could
have been drawn into the line by a short circuit of the air, as de-
scribed on page 53, or the primary blower might not have been
supplying the booster fan with all the air needed; consequently the
additional air necessary to satisfy the partial vacuum produced by
the booster came through the furnaces, bringing incandescent par-
ticles with it. The fluctuation might be only a momentary one,
caused by the sudden turning on of the fuel to a furnace, but that
would be all that would be required. As far as could be learned the
primary fan was running normally and no stoppage of the line was
noticed; consequently the belief that the booster fan was to blame
seemed to carry the most weight.

**PRECAUTIONS AGAINST ACCIDENTS FROM USE OF BOOSTER FANS**

Precautions should always be taken to prevent a booster fan from
continuing to run when the main fan has for any cause been stopped.
The National Fire Protection Association code has this provision
under paragraph 23 (b):

> Motor circuits for primary blower and booster fan shall be protected by the
same circuit breaker switch or other protective device, so that the stopping of
either will cause the simultaneous stopping of the other.

These explosions in cyclone separators and many numerous fires
in the circulating lines raise doubts as to the safety of discharging
the returned fuel from the cyclone directly into the powdered-coal
bin to be fed again into the line. There seems to be an element of
danger in this practice, for it is undeniable that explosions and fires
do occur in the circulating lines and hot coal is bound to result. If
the mixture of coal and air in these lines is so rich when it reaches
the cyclone separator that no explosion takes place, should hot coal be
present due to a fire in the line, this hot coal is liable to be carried
into the pulverized-coal bin where it will heat other particles of
coal and possibly be blown into the line again.

Then, too, there is a potential danger that a primary explosion in
the separator will raise the pulverized coal in the storage bin into a
cloud and ignite it. Even though a storage bin has a cover, if
there is enough air space between the cover and the top of the
stored coal for the air and coal to mix in proper proportions, con-
fining the dust cloud would tend to increase the violence of the
explosion.
To have the cyclone separator discharge into a small hopper connected by a screw conveyer to the main storage bin, or possibly to have the coal in the separator flow by gravity to the main storage bin with a check door which would be automatically closed by any undue pressure that might occur in the separator, would seem practical.

In some plants bag separators allow the surplus air used in filling the bins with coal to escape, but at the same time retain the powdered fuel. Separators of this type should always be enveloped in tight metal containers and vented to an outside point remote from fire or hot metal. The wisdom of such a precaution is well illustrated by the following incident, an account of which is on record in the bureau's files: At the top of a hopper close to a furnace, a bag was connected to serve as a safety valve by relieving excess pressure due to blowing coal into the hopper. From some unknown cause the bag burst and the resulting dust cloud was ignited by a spark from the furnace.

HAZARDS DUE TO ELECTRIC ARCS AND ELECTRIC SPARKS

TESTS BY BUREAU OF MINES

The possible ignition of a cloud of pulverized coal by an electric arc has been investigated by electrical engineers of the Bureau of Mines and a brief summary of their findings has been published. The coal used in these tests was from the Pittsburgh bed and was fine enough to pass through a 70-mesh screen.

Proximate analysis, "as received" basis

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<th>Component</th>
<th>Per cent</th>
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<td>Fixed carbon</td>
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<tr>
<td>Ash</td>
<td>5.29</td>
</tr>
<tr>
<td><strong>Total</strong></td>
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APPARATUS

Figure 31 shows the apparatus for obtaining the dust cloud. An iron dust chamber, about 16 inches square, with an observation window was mounted over a blower driven by a direct-connected motor. The fan discharged into the funnel-shaped connection leading to the dust chamber. The dust passed through the outlet at the top of the chamber into a 6-inch pipe and returned to the inlet of the blower. Inside the dust chamber were two sliding rods connected to the circuit from which came the electric current. The

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electric arc was made by separating the ends of the two rods in contact. To supply the necessary current a 200-kilowatt direct-current generator was connected in series electrically with another generator of a booster set, so that any desired voltage up to 750 volts could be obtained.

![Image of a device for testing ignition of coal dust by electric arc]

**Figure 31.**—Gallery for testing ignition of coal dust by electric arc

**RESULTS OF TESTS**

Different densities of dust clouds were determined by the amount of light penetrating them. Tests showed that when the cloud was so thick that a lamp could not be seen through it, the mixture was readily explosive. Table 6 gives the results of these tests.
TABLE 6.—Ignition effects with various currents and voltages

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<th>Amperes</th>
<th>Number of flashes</th>
<th>Number of ignitions</th>
<th>Number of fresh dust mixtures</th>
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<td>10.00</td>
<td>10</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>220</td>
<td>10.00</td>
<td>50</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>220</td>
<td>15.00</td>
<td>50</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>220</td>
<td>20.00</td>
<td>12</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>220</td>
<td>40.00</td>
<td>14</td>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

These tests are very interesting because they show the uncertainty of the hazard. In the test with a current of 0.87 ampere at 665 volts potential but one ignition was obtained in 109 trials, yet the fact that even one ignition was obtained indicates the danger involved. A motor in a dusty plant may frequently spark and no effort be made to remedy the condition on the theory that because it “never has ignited the dust, therefore it never will,” although there is no knowing when the conditions may be right for producing a disastrous explosion.

Table 6 shows that with a 220-volt direct-current system and 40 amperes the percentage of ignitions was very high. This condition is approached in pulverizing plants when small direct-current motors are used for driving fans, conveyers, dryers, and small pulverizing mills.

INVESTIGATION BY THORNTON AND BOWDEN

An investigation by Thornton and Bowden\(^\text{20}\) has revealed some interesting facts. The writers record the results of about 1,800 trials and give numerous tables and curves. Tables 7 and 8, taken from their papers, are given here as of interest in connection with the coal-dust hazard in industrial plants.

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TABLE 7.—Least current which ignites coal dust when interrupted by a quick-break switch

<table>
<thead>
<tr>
<th>Volts</th>
<th>Direct current</th>
<th>Alternating current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inductive</td>
<td>Non-inductive</td>
</tr>
<tr>
<td></td>
<td>Ampere/s</td>
<td>Ampere/s</td>
</tr>
<tr>
<td>77</td>
<td>16.0</td>
<td>70.3</td>
</tr>
<tr>
<td>100</td>
<td>5.7</td>
<td>11.0</td>
</tr>
<tr>
<td>250</td>
<td>2.3</td>
<td>5.8</td>
</tr>
<tr>
<td>480</td>
<td></td>
<td></td>
</tr>
<tr>
<td>635</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8.—Quick break of current

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Least current</th>
<th>Certain current</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 direct current</td>
<td>70.3</td>
<td>270.0</td>
<td>3.80</td>
</tr>
<tr>
<td>240 direct current</td>
<td>11.0</td>
<td>44.2</td>
<td>4.00</td>
</tr>
<tr>
<td>480 direct current</td>
<td>6.8</td>
<td>13.0</td>
<td>2.00</td>
</tr>
<tr>
<td>1,000 alternating current</td>
<td>4.1</td>
<td>6.4</td>
<td>1.56</td>
</tr>
</tbody>
</table>

* Certain current is the value which will produce ignition on every flash.

Table 7 gives least current which ignites coal dust when interrupted by a quick-break switch. Bureau of Mines Report of Investigations 2365, cited on page 68, contains a number of other tables from Thornton’s paper.

CONCLUSIONS OF INVESTIGATORS

Study of the work done by Breth and Clark and reported by Ilsley and Gleim of the Bureau of Mines and of the investigations of Thornton and Bowden leads to the inevitable conclusion that when the proper mixture of coal dust and air is brought into contact with an electric arc under certain conditions an explosion is very liable to take place.

TYPICAL COAL-DUST EXPLOSIONS

Although Bureau of Mines representatives have not investigated any explosion of pulverized coal at industrial plants that was due to ignition by electric arcs, records are on file of such accidents at coal mines, which represent similar conditions. Two are cited below.

ACCIDENT TO TROLLEY FEED CABLE AND TROLLEY

At a western coal mine the trolley feed cable and the trolley wire carrying 250 volts, direct current, were torn down by a runaway trip
of cars and fell on the end of a mine car, causing an arc which ignited the dust cloud raised by the runaway cars. The resulting explosion caused enormous damage and killed more than 100 men.

**SHORT CIRCUIT IN ELECTRIC CABLE**

A somewhat similar accident in which about 90 men died is described in Coal Age. 21

A slope inclined about 30° and 850 feet long led downward from the tipple to the coal seam; upon this slope were two tracks—one for the loaded mine cars, the other for the empties. Along the side of the slope was a 3,300-volt armor-protected cable consisting of three No. 4 stranded conductors of copper wire, each conductor covered with varnished cambric and separated from the next by jute. Around the cable was about one-eighth-inch lead insulation and over the lead were two flat steel spirals, three-fourths inch wide, wrapped so that one covered the spaces left by the other.

Details of the construction are given because similar cables may be seen close to pulverized-coal apparatus and bins in industrial plants. At one plant, indeed, a pulverized-coal bin serves as a support for several high-tension lines. Moreover, it is desirable to point out here the danger from sudden breaking of an electric cable near a place where a cloud of pulverized coal may be created.

At the time of the accident a trip of mine cars that had been hoisted and dumped became uncoupled from the hoisting cable, ran down the slope, and at the bottom crashed into some loaded cars on the parallel track and was completely wrecked. In some way, probably by flying débris, the electric cable was flattened so that two strands of wire came in contact with each other, forming a short circuit. There can be no doubt that the arc so caused ignited the dust cloud formed when the runaway trip collided with the standing cars of coal.

**OTHER COAL-DUST EXPLOSIONS**

Attention has been called to a short circuit, at a steel plant, caused by the settling of dust on the terminals of an electric switch and resulting in partial wrecking of the switchboard in the power house. The damages might have been more serious had this happened in a building where the atmosphere was full of coal dust or in any place where pulverized coal could be raised into a cloud.

Sparking electrical apparatus caused an explosion at the New Brancepeth colliery, England. 22

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21 Forbes, J. J., High-power cable cut by cars that were uncoupled as a rotary dump explodes coal dust at Dolomite; Coal Age, vol. 23, No. 8, Feb. 22, 1923, pp. 331-332.

A pulverizer was operated by a 25-horsepower 500-volt d. c. motor which was inclosed but not explosion proof and stood on a platform about 6 feet above the floor.

A short circuit of one of the armature coils caused much sparking which finally ignited the coal dust accumulated inside the motor casing and initiated an explosion severe enough to blow off the sheet-iron cover over the commutator end of the motor. The flames thus produced ignited the fine dust held in suspension within the building and caused a second explosion, the flames from which extended 6 feet outside the open door and to a height of 15 feet inside.

**GRAIN-DUST EXPLOSIONS CAUSED BY ELECTRIC ARCS AND SPARKS**

Although it appears that "grain dusts can be ignited more readily and propagate flame more rapidly than coal dust," yet in view of the statement of Ilsley and Gleim that "The lesson from these tests is that coal dust in air * * * can be exploded with electric arcs," it may be well worth while to mention some of the electrical causes of grain-dust explosions.

**SPARK FROM BLOWN FUSE**

According to Price:

One explosion was caused by an electric spark from a blown fuse on a temporary switchboard at the very moment when a dust cloud was formed by the breaking of a belt 6 inches wide and running 5,000 feet per minute. From the testimony of eyewitnesses it appeared that when the belt broke a cloud of dust was formed by the dislodging of accumulations of dust on girders, machinery, and plant equipment.

**IGNITION BY EXPOSED FILAMENTS OF BROKEN LAMP**

**TESTS BY DEPARTMENT OF AGRICULTURE**

Incandescent lamps and their electric connections are a potential source of danger. The Bureau of Chemistry, United States Department of Agriculture, has made tests in cooperation with several leading lamp manufacturers to determine whether or not a dust cloud could be ignited by the exposed filament in a broken electric lamp. A socket to hold lamps of various sizes was placed in the bottom of

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23 An explosion-proof motor is a motor so constructed as to prevent the ignition of gas surrounding the motor by any sparks, flashes, or explosions of gas or of gas and coal dust that may occur within the motor casing. Fay, A. H., Glossary of mining terms: Bull. 89, Bureau of Mines, 1920, p. 256.


a chamber and a rod with a trigger release was arranged to smash the lamp when a dust cloud, produced by blowing dust from small shelves along the side of the chamber, had been formed. As this dust settled, the trigger was pulled and the rod sprang back to its normal position and broke the globe. Explosions were obtained with both vacuum and gas-filled lamps.\textsuperscript{27}

**EXPLOSION IN KANSAS CITY GRAIN ELEVATOR**

An example of how actual this danger may be is the $650,000 explosion in a Kansas City elevator in 1919 which killed 14 and seriously injured 10 men. Evidence indicates that a short circuit was caused by defective extension cords or by the breaking of an unprotected lamp bulb in the dusty atmosphere.\textsuperscript{28}

**EXPLOSION IN FEED-GRINDING PLANT**

An explosion of ground oat hulls occurred at a Buffalo feed-grinding plant in 1921, when an electric lamp being used by a workman was broken within the head of an elevator carrying the ground material to the top floor of the mill.\textsuperscript{29} A workman was using the light to inspect the elevator which had not been discharging properly. In some manner the steel buckets of the elevator struck the lamp which was protected by only a light wire guard. When this guard was crushed and the lamp broken, the hot filament ignited the fine dust and the explosion followed. The workman was only slightly injured in the explosion and was able to tell accurately what had occurred.

**BREAKING OF BULB IN PULVERIZED COAL**

The Bureau of Mines has a record of a slight explosion caused by the breaking of an incandescent light globe in a cloud of pulverized coal. A pulverized-coal bin which had no automatic signal to indicate the amount of coal delivered was being filled. It was the custom to note the rise of the pulverized coal by dropping an electric lamp attached to an insulated lamp cord through a small hole in the top of the bin. The lamp globe either exploded or was broken, and the dust cloud in the tank was ignited by the glowing filament or possibly by an arc in the connection to the lamp. The resulting explosion blew out through the observation hole, severely burning

\textsuperscript{27} Price, D. J., and Brown, H. R., Unprotected electric lights, a fire and explosion hazard in dusty industries: U. S. Department of Agriculture Circ. 171, 1921, p. 4.
\textsuperscript{28} U. S. Grain Corporation, Grain-dust explosion prevention; U. S. Department of Agriculture, Bureau of Chemistry, June, 1920, p. 22.
\textsuperscript{29} Price, D. J., and Brown, H. H., Dust explosions; theory and nature of, phenomena, causes, and methods of prevention. 1922, p. 215.
the man who was watching the filling of the bin. A more violent explosion was probably prevented by the preponderance of coal dust in respect to the amount of air in the bin.

Although explosions in establishments that handle grain do not conclusively prove that a broken incandescent lamp or short circuits due to defective connections can ignite pulverized coal thrown into a cloud, the work of Ilsley, Gleim, Thornton, and others, and the accident which actually occurred in a pulverized-coal bin demonstrate rather strikingly the potential dangers that should be guarded against.

**SPONTANEOUS COMBUSTION OF COAL DUST CAUSED BY LAMP BULB**

Leaving an electric light bulb in a place where it is liable to be covered with pulverized coal is a rather unsuspected but nevertheless real source of danger. To illustrate, a workman might repair a defective storage bin and leave a portable incandescent light therein by accident. The bin would be filled with pulverized coal, completely burying the lamp. In time the heat radiating from the lamp would so heat the coal that spontaneous combustion would result.

**TESTS BY BUREAU OF MINES**

At the Bureau of Mines Pittsburgh station some interesting tests have been made to show the possibility of igniting a body of fine coal in this manner.29a A 32-candlepower electric light was placed in a box of fine coal dust. In less than 30 minutes the bulb burst and the coal dust was found to be on fire. Following this a 16-candlepower electric lamp was placed in a nail keg half filled with Pittsburgh coal dust. Eighteen minutes later small puffs of smoke issued from the keg and at the end of 32 minutes the dust smoked steadily, continuing to burn after the lamp had been removed.

**RECOMMENDATIONS FOR SAFE USE OF ELECTRICAL EQUIPMENT**

In consequence of the fire and explosion hazards that have been discussed above it is strongly recommended that all electric wires and cables which are installed in and about pulverized-coal apparatus should as far as possible be carried in conduits.

Switches at a pulverizing plant should be placed outside any building where coal dust is liable to accumulate. If this is not

29a Price, David and Brown, H. R., A recently developed dust explosion and fire hazard: U. S. Department of Agriculture Circ. 171, 1921, p. 3.
feasible, they should be of the oil-immersed type. Provision should be made to cut off the power at some remote point in the event of an explosion or a fire in the pulverizer house, and thus avoid the need of entering the building.

Motors not properly inclosed or protected against ignition by sparks at the commutator have no place in a coal-pulverizing plant. Motors of the nonsparking type, preferably squirrel-cage motors, are the most nearly explosion proof now available. Even with such motors more or less trouble has been experienced because the dust accumulates in the windings and is liable to abrade or cut the insulation.

In its work to lessen fatalities in coal mines, the Bureau of Mines has drafted a schedule of requirements for the construction of electric motors to be used in dust-laden atmospheres. When motors have passed the tests described in this schedule they are classed as “permissible.” It is to be hoped that all users of pulverized-coal apparatus and all industries in which electric motors are used in dusty atmospheres will perceive the wisdom of installing “permissible” motors only.

When portable electric lamps are used to illuminate any place where a pulverized coal-dust cloud could form, the bulb should be protected with a heavy wire guard and all connections and the insulation of the cord carefully inspected for defects that would cause a spark by coming in contact with any metal. So far as possible electric hand lamps of the flashlight type should be used. It is perhaps unlikely that ignition would result from dust settling on the ordinary small electric light bulbs used in most plants if enough air is in circulation around them, but the danger is potential and no large amount of dust should be allowed to accumulate upon them.

STATIC ELECTRICITY

Static electricity is a hazard that should be taken into account in all plants where a mixture of dust and air is present. Many fires and explosions regarded as mysterious may be due to ignition of dust clouds by a spark from a charge of static electricity from some part of the machinery and dust-collecting apparatus in use.

Static electricity is ordinarily generated by the rubbing together of two bodies composed of dissimilar elements, one of these bodies taking a positive charge and the other a negative.

In industrial plants this is typified by the contact of rapidly moving parts of machinery, such as belts, rollers, and iron balls in pulverizing mills, the blades of fans in air-conveying systems, and

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particles of fine material which are being rapidly conveyed through chutes and spouts. If these moving parts are so constructed that there is an insulated or nonconductive body between them and the ground, disregarding the influence of a damp atmosphere, the electricity formed can not escape. In consequence, a charge is built up until its potential is strong enough to break down the atmosphere between it and some less highly charged body, leap across, and in so doing cause an arc between the two bodies. Under proper conditions, this hot spark will ignite a dust cloud with which it may come in contact. If, however, the moving parts mentioned above have an unbroken connection to the ground, the electricity, instead of accumulating, is led away as fast as it is generated and the danger of arcing or sparking is eliminated.

Generation of static electricity by small particles passing rapidly through chutes, spouts, and conveyers has an interesting phase because pneumatic and vacuum systems are being so widely used for conveying grain, sawdust, pulverized coal, and other fine material. Fires and explosions have occurred in bag and “cyclone” dust separators, and for some time the origin of such explosions was a mystery.

Rudge found that clouds of dust raised by the wind charged the atmosphere with considerable electricity and that finely divided material of different compositions will impart electrical charges to the dust and to the atmosphere when blown into a cloud by an air current.

Price and Brown deal with the practical side of this subject at length in connection with dust explosions in the grain industry.

INVESTIGATIONS BY BUREAU OF CHEMISTRY

The Bureau of Chemistry, Department of Agriculture, investigated the accumulation of static electricity due to the action of fine particles of dust blown through a dust collector and determined some rather interesting facts.

Several explosions, one of which seriously injured six men, occurred in a plant that manufactured dry lime-sulphur. After the lime-sulphur solution had passed through the drying process, the resulting dust was drawn from the drying room by a current of air and discharged into a collector of the suction-filter type, from whose outlet connection was made to the fan that induced the flow of air.

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28 Price, D. J., and Brown, H. H., Dust explosions; theory and nature of, phenomena, causes and methods of prevention. 1922, p. 137.
The dust-laden air, entering near the bottom of the collector, is compelled to make a turn in coming into the open lower ends of the bag. The bags were made of a special porous cloth suitable for holding the dust and permitting the purified air to pass through into the surrounding compartment. While the dust is being collected the air enters the lower end of the bag and passes through the cloth and out to the fan. During the process of cleaning, a valve at the top of the collector opens, permitting a counter current of air from the fan exhaust duct to pass from the outside to the inside of the bags, and thence into the adjoining compartments. At the same time the bags are shaken violently several times. This cleaning process takes place in each compartment successively about every two and one-half minutes. It was concluded that a static charge of high potential was accumulating on the bags of the filter dust collector. Some preliminary readings were made with an electrometer to determine the difference of potential between the bags and the shell of the collector which had been thoroughly grounded. In some readings the static voltage exceeded 20,000 volts. It was found that by grounding one of the rings of the filter bag the static voltage was reduced to 3,300 volts.

**ADDITIONAL DATA BY EDWARDS**

Edwards adds that more elaborate tests were made of one bag in each compartment and gives the results in the following table:

**Table 9.—Static voltages noted on dust collectors in dry lime-sulphur factory**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chain in stocking</td>
<td>Chain in stocking</td>
<td>Wire sewed on bag</td>
<td>Wire sewed on bag</td>
<td>Chain in stocking</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Not in operation.</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Cold air only.</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Temp., 122° F.</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Temp., 173° F.</td>
</tr>
<tr>
<td>5</td>
<td>1,300</td>
<td>400</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Spraying started, collectors not shaking.</td>
</tr>
<tr>
<td>6</td>
<td>0-5,000</td>
<td>0-2,000</td>
<td>0-200 (?)</td>
<td>0</td>
<td>0</td>
<td>Collectors shaking.</td>
</tr>
<tr>
<td>7</td>
<td>10,000+</td>
<td>10,000+</td>
<td>200</td>
<td>0</td>
<td>3,500</td>
<td>Collector door open.</td>
</tr>
<tr>
<td>8</td>
<td>500</td>
<td>0-1,500</td>
<td>0</td>
<td>0</td>
<td>300</td>
<td>Collectors shaking, temp. 196° F.</td>
</tr>
<tr>
<td>9</td>
<td>10,000+</td>
<td>10,000+</td>
<td>0</td>
<td>2,000-3,000</td>
<td>Collector door open, temp. 196° F.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Collector shaking.</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Open door.</td>
</tr>
</tbody>
</table>

1. Steel chain through center of bag grounded to shell of collector. Wire to electrometer connected to first ring at bottom of bag.
2. Steel chain through center of bag grounded to shell of collector. Wire to electrometer connected to two copper wires around bag at first and second rings, copper wires connected electrically.
3. Braided copper wire sewed to bag along lengthwise seam. Wire to electrometer connected directly to bag at a point midway between bottom of bag and first ring and on side opposite to seam.
4. Braided copper wire sewed to bag along seam. Wire to electrometer connected to bag at a point midway between first and second rings and on side opposite to seam.
5. Steel chain through center of bag grounded to shell of collector. Wire to electrometer connected to steel chain.

This table shows that under certain conditions extremely high static charges can be built up and that by properly grounding the filter bags in the dust collectors these charges can be eliminated.

Although the above illustration pertains to a material other than pulverized coal, it nevertheless serves as a warning to plants that have pulverized-coal installations with collectors of this type to see

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that proper ground connections are made. A spark caused by a high static charge might, if the proper conditions existed, ignite a cloud of coal dust and cause serious damage. Similarly, all parts of machinery that in any way are liable to build up a static charge, such as pulverizing mills and belt-connected conveyors, should be thoroughly grounded.

**SPONTANEOUS COMBUSTION AS POSSIBLE CAUSE OF FIRES**

One of the most serious troubles with which users of pulverized coal have had to contend has been the number of fires in dried-coal and pulverized-coal storage bins. It has been somewhat difficult to determine the exact cause of these fires, but there can be no doubt that spontaneous combustion has played an important part in some of them.

The writer has been unable to find that any work has been done to determine the rate of oxidation of coal under the actual conditions of use in pulverized-coal systems. However, investigations of the spontaneous combustion of coal under somewhat different circumstances have been made and it seems not irrelevant to utilize some results of these investigations in the study of fires in bins for dried and pulverized coal.

**EXPERIMENTAL WORK**

**WORK OF PARR AND KRESSMAN**

Parr and Kressman\(^\text{35}\) found that “coal in a fine state of division presents a much larger surface and brings a much larger quantity of reacting substances in contact with oxygen than when in solid masses.”

**WORK OF BUREAU OF MINES**

Experiments by the Bureau of Mines\(^\text{36}\) show that the rate of oxidation of coal increases rapidly as the temperature increases, as shown in the curve, Figure 32. It will be noted that the rate of oxidation, or in other words the heating of the coal, increases very rapidly above a temperature of 150° F.

**WORK OF THRelfALL**

Threlfall\(^\text{37}\) in England made some tests relative to the rate of heating of slack coal in storage. His experiment is especially interesting

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because the coal was stored in a bin somewhat as dried coal is stored in industrial plants.

A bin about 21 feet square by 21 feet deep was constructed of planking somewhat irregular in shape, so that the spaces between the boards were large enough to permit a certain amount of ventilation to pass over the coal inside, but not large enough to allow the fine coal to run out. A galvanized-iron roof about 4 feet above the level of the top of the coal covered the bin. The temperature of the

![Graph](image)

**Figure 32.—Rate of oxidation of Illinois coal at different temperatures**

coal was taken at different points, and the results were plotted. Figure 33 shows the comparative rate of heating of the coal; an inspection of the curve will show that after the temperature reaches 150° F. it rises very rapidly.

**STOEK’S CONCLUSIONS**

Stoek states that “One very safe rule is to be ready to remove the coal if the temperature reaches 150° F.”

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PRESENT WORK AT PITTSBURGH STATION, BUREAU OF MINES

Some work now being done at the Pittsburgh station of the Bureau of Mines on spontaneous combustion of coal has shown that if coal is dry and pulverized and the heat insulation is perfect spontaneous combustion is almost certain to occur at temperatures around 150° F.

SPONTANEOUS COMBUSTION OF FINE COAL DURING TESTS

During washing tests of Illinois coal at the Bureau of Mines Central District experiment station, some washed screenings were dried on a steam-jacketed drying pan. The coal screenings were placed on the pan on Friday afternoon and on Monday morning when they were inspected to ascertain whether or not they were dry it was found that they were burning. The hot spots were removed and an hour later temperatures of the coal were taken; the thermometer readings were 240° F., 250° F., and 293° F.

An experiment described by Parr and Kressman is especially applicable to this proposition. The coal, of about 200-mesh fineness, was placed in an oven where the temperature was within a constant range of 107° to 118° F. In 48 hours from the time the coal was placed in the oven its temperature had risen to about 288° F., or about 170° C. The original temperature at which this coal was placed in the oven, 107° to 118° F., is considerably less than that of the pulverized coal which, in some industrial plants, is transported to the storage bins.

A rather remarkable part of this test was the fact that this same coal was cooled for three days, then put in an oven whose temperature was about 112° F., and a rise of only about 11° F was observed. The coal was then placed in a high-temperature oven.

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that was heated to about 215° F. for three days, when a rise in temperature above oven temperature of about 91° F. was obtained. Parr and Kressman state in concluding that "If this fine coal had been put into this oven first, without any preheating, it would undoubtedly have taken fire at once, that is, in 24 or 36 hours."

Fires in Stored Coal

At one cement plant where an explosion occurred (p. 43), it was stated that at times the dried-coal bin of steel construction became red hot and that the dried coal sometimes attained a temperature of 230° F. These circumstances would seem to indicate that spontaneous combustion occurred due to the high temperature of the dried coal.

Stoek,40 in an account of a fire in a coal-storage pile, says "A temperature of 170° F. was recorded shortly before the fire broke out in the pile, the highest temperature being recorded usually 5 feet below the top of the pile."

Inasmuch as the wisdom of limiting the temperature of dried coal not intended for immediate use to 150° F. has been questioned, the foregoing incidents are especially illuminating.

Location of Storage Bin

The location of the storage bin41 may be an additional cause of spontaneous combustion.

It has been proven beyond doubt that oxidation * * * is greatly accelerated and in certain phases directly dependent upon an increase of temperature. What may be external or physical causes of heat, and thus presumably avoidable, are suggested by the following:

(1) Contact of the mass with steam pipes, hot walls, or floors under which are placed heat conduits of any sort.

Bullock42 reviewing 20 years' experience with stored coal, during which time 12 fires occurred, says:

In six instances the primary cause was clearly from heat being communicated to the mass from external sources, such as being against a wall that got heat from furnaces on the other side, being over a hot flue, and from a steam pipe the covering from which had become broken.

Some furnaces that are supplied with fuel directly from bins near by have had trouble with fires in the fuel bins. At a large Ohio plant the heating furnaces were supplied with fuel from bins

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that were close to the furnace, and in which fires were constantly occurring. The trouble was finally eliminated by moving the bins away from the heat radiating from the furnaces.

Greenwood 43 says that:

It has been found that with some kinds of bins for storage the coal will adhere to the walls in the angles, and this building up will extend until one or more sides of the wall are covered for a considerable area, and the formation will be exceedingly dense. It will adhere to the walls so that, in some cases, it can not be jarred off by hammering on the outside.

Caked coal in contact with the side of a bin that is exposed to the heat of a furnace may absorb enough of this heat to raise its temperature to the critical point. From that time on, oxidation may progress rapidly until the loose coal, or that which is easily discharged into the burner, is also on fire.

CONTROLLING FIRES IN PULVERIZED-COAL BINS

About the only method of controlling a fire in a pulverized-coal bin is to cut off the feed to the furnace and empty the bin as quickly as possible, with care to avoid raising a dust cloud that might be ignited by contact with the burning coal.

Some manufacturers of pulverized-coal apparatus, however, equip their pulverized-fuel bins with airtight valves which may be closed in case of fire in the bins, completely sealing the bins and preventing the admission of air. This provision has been effective at least twice.

Fire was discovered late one afternoon in a bin that fed a pulverizing mill. Immediately the valves were closed and left overnight. Upon examination the next morning no live coal was found, although the coal was warm.

At another mill fire was discovered in a bin that also supplied a pulverizing mill. This bin was also sealed; and when it was opened after about one week, no signs of fire were detected.

When a fire in a bin that feeds a pulverizing mill has been extinguished by sealing, or in fact by any other method, extreme care must be exercised to see that no live coal is present when the mill is again started. Even one piece of burning coal going into a mill is liable to cause disaster if it should come in contact with the proper mixture of air and finely pulverized coal.

The custom of covering burning coal with fresh coal is of questionable safety and can not be recommended.

SHIPMENT OF POWDERED COAL BY RAIL

There is developing in recent years a demand for a main central pulverizing station, from which the pulverized fuel, packed in sacks, can be shipped by rail to the various points of consumption. If coal is to be shipped in this manner, precautions should be taken to see that the temperature of the coal as shipped is not high. A large number of fires in railroad cars have been reported, some of such serious proportions that the cars had to be cut from the train and sidetracked, and the fire department from the nearest town called to extinguish the flames.

Two such fires are cited below:

Smoke was noticed coming from a box car and the side doors were opened for ventilation and the entire load was found to be hot and smoke was rising from the surface of the coal. Three hours later one end of the load appeared to glow and an effort was made to transfer the load, but the dust was so hot that the laborers were almost suffocated in trying to handle it and the dust ignited where the men were shoveling, making it impossible to stay in the car.44

About 13 hours after a box car had been closed and sealed it was discovered on fire. The car was only slightly damaged and the greater part of the loss was confined to 135 paper bags of pulverized coal and 50 cases of near-hazardous articles.

After the fire was extinguished and while employees were working in the car to recondition the lading, fire again developed in the pulverized coal. It was necessary to move the car to a side track and flood it before the second fire was extinguished. Several bags of the coal that did not appear to be damaged were piled out in the driveway and 20 minutes later they too were afire and destroyed.44

When pulverized coal is to be shipped in bags, precautions should be taken to see that the coal is not at a high temperature when packed.

SPONTANEOUS COMBUSTION OF BROWN COAL

German brown coal when heated and dried is said to be very susceptible to spontaneous combustion, so that the problem of cooling is considered an essential technical problem in the process. If brown coal is allowed to flow very slowly through vertical louver structures that present a cooling and aerating surface, this treatment will avoid the possibility of spontaneous combustion.

The action that probably takes place is the adsorption of gases on the fresh surfaces under such conditions that the resulting heat is carried away. By the time the material has cooled its surfaces have been partly satisfied and no longer have an avidity for oxygen.

EFFECT OF PACKING ON SHIPMENT

There seems to be a field for developing a practicable means of cooling pulverized coal at plants from which large quantities of this fuel are to be shipped.

44 Report No. 11 of the Chief Inspector for the Bureau for the Safe Transportation of Explosives and Other Dangerous Articles.
Some authorities believe that the manner in which the coal is packed in bags has something to do with its firing; that when the coal is allowed to flow into the bag loosely a large quantity of air is carried with it, which would be favorable for spontaneous combustion. To obviate this condition the suggestion has been made that the bags while being filled be set on a jarring machine, which would tend to shake the small particles together and drive out the air.

In a report 45 on the ignition in transit of a shipment of foundry facings made from pulverized coal, the laboratory of the Bureau for the Safe Transportation of Explosives and Other Dangerous Articles makes the following comment:

The only positive prevention of spontaneous ignition of this material is to store it, and ship it in tight metal containers instead of bags • • • the temperature of the coal as it comes from the drier should not exceed 150° F.

RECORDS OF FIRES IN CARLOAD SHIPMENTS

Figure 34 shows the distribution by months of fires in carload shipments of pulverized coal for several years. The interesting point in connection with this curve is that its peak occurs during the hot season, leading to the inference that the sun may heat the interior of the car while the car stands in the railroad yards, and the car in turn will heat the coal enough to start spontaneous combustion. This inference has not been definitely proved but provides a basis for further investigation.

It has been recommended that pulverized coal be shipped in tightly closed metal containers, or possibly loaded in bulk in tank cars so constructed that the supply of air would be limited. The cars would be unloaded by means of a vacuum process similar to that used in unloading grain and other fine material. Whether or not such practice would avoid the danger of spontaneous combustion is problematical, but pulverized coal so shipped would not be more liable to ignite than when shipped in paper bags in box cars, as is the present practice.

HAZARDS IN USE OF PULVERIZED COAL AT CEMENT PLANTS

Cement-manufacturing plants were among the first users of pulverized fuel, having installed this method of burning coal for heating the kilns. At cement plants the coal is usually prepared practically the same as in other industries. Operation of the kilns is, however, attended by hazards which merit special attention.

45 Report No. 12 of the Chief Inspector of the Bureau for the Safe Transportation of Explosives and Other Dangerous Articles.
One hazard peculiar to the industry is the liability of explosions within the kiln. Sohm \(^{46}\) describes an accident of this nature. The operator started a fire inside a rotary kiln about to be placed in operation after a shutdown, using for this purpose kindling wood some of which was damp and would not ignite readily. Without waiting to see whether conditions were right for igniting the coal as it came from the burner, he turned on the mixture of air and coal. Inasmuch as the kindlings were smoldering, this mixture did not ignite but, carried along by the current of air, collected at the extreme end of the kiln near the chimney. The wood fire near the burner soon blazed up and ignited the dust cloud, which immediately exploded, wrecking the chimney.

Such accidents are not necessarily confined to cement kilns, but they may happen in boilers, furnaces, and other installations in which pulverized coal is used as a fuel. It is hardly conceivable that

one would turn a valve admitting gas into the combustion chamber of a furnace without assuring himself that the gas would be ignited at once. If the same care is used in igniting a pulverized-coal burner that is ordinarily used in lighting a gas burner, then pulverized coal is no more dangerous than gas.

AIR AND COAL ENTERING KILN WITHOUT OPERATOR'S KNOWLEDGE

Sohm also mentions a rather unusual accident caused in another cement plant by the air and coal being turned into the kiln without the operator's knowledge. The kiln had been stopped and cooled for repairs and the supply of coal had been shut off, but the blower that supplied the air for combustion continued running. While the repairs were being made the kiln was revolved from time to time, which, with the vibrations due to the operation of the blower, caused the gears of the screw feed supplying the coal to the burner to become engaged and consequently discharge the coal into the interior of the kiln. There still remained in the kiln some of the hot "clinker" which had cooled only on the surface. When the operator, not knowing that the coal was being blown into the kiln, started the kiln revolving again, the red-hot "clinker" on the bottom was exposed and came into contact with the cloud of pulverized coal, which immediately ignited. The explosion that followed partly wrecked the kiln.

OPERATION OF COAL BLOWER CONTINUED WHEN AIR BLOWER STOPPED

The same writer cites an accident in a furnace of a chemical-manufacturing plant. Evidently there were two blowers in the installation, one for blowing the pulverized coal through the burner and the other for supplying the additional air needed for complete combustion. The latter ceased to operate, but the coal continued to be blown into the furnace. As there was no air for oxidation the fire was soon extinguished, although the supply of fuel was not diminished. The operator, perceiving that his fire was black, opened the door in the ash pit, letting in air and causing the glowing mass to burst into flame. An explosion instantly followed.

Sohm attributes this explosion to the distillation of gas from the coal by the intense heat of the furnace. While this may be true, it is highly possible that the draft induced by opening the ash-pit door not only caused the hot mass to be reignited, but also supplied enough air for the powdered coal, which was being forced in, to form an explosive mixture. When the smoldering coal was fanned into flame this explosive mixture was ignited.

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47 Sohm, Michel, work cited, p. 36.
In installations where two blowers are used, one for coal and one for air, or where one is used as a booster for blowing pulverized coal to the point of consumption, both should be so designed that the stopping of one will stop the other.

EXPLOSION DURING CLEANING AND REPAIRS

An explosion at a large cement plant in this country killed several workmen. While a coal-grinding mill was being repaired one of the workmen rammed a stick with waste on the end into the part he was cleaning, and the waste caught fire as it was pulled out. There was a sudden hiss, and the stream of fire traveled the length of the room, downstairs, and back several times in layers, without any other sound than the hissing, burning off all the clothes from the workmen, who later died from their injuries.

There appeared to be no clue to the origin of the ignition of the waste. It seems evident, however, that fine particles of coal remaining in the mill had been stirred into a cloud during the process of repairing and cleaning and the burning waste ignited this cloud. Fine coal dust had probably accumulated on the various pieces of machinery and on the floors, rafters, and windows of the building, which was raised into a dust cloud and ignited by the "flare up" in the grinding mill. This theory seems to be supported by the statement that the flames traveled the length of the room and back.

SEPARATION OF COAL-TREATING PROCESSES FROM KILNS

Coal should not be crushed, dried, and pulverized in the building that contains the kilns unless a fireproof partition separates the coal-treating operations from the kilns. The explosion which severely burned a man at a cement plant in England was caused by sparks from a rotary kiln igniting fine coal dust in the pulverizing plant.

Leaky bins, conveyers, and pulverizing mills are more common in cement-manufacturing plants than they should be, and it is the dust that sifts through these leaks which settles around the building ready to cause havoc and death. An explosion in a western plant that killed eight men and injured one was evidently caused by inattention to the danger of coal dust escaping into the atmosphere. It is evident that considerable fine coal dust had accumulated, for the reason that in the cleaning of the plant a dense cloud of dust came in contact with the fire in the kilns or with a sparking motor and exploded with great violence. If the grinding and pulverizing rooms had been entirely separated from operations in which furnaces or

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kilns are used, or if attention had been paid to leaks in the machinery so that the mills, elevators, and conveyors had been made dust-tight, this explosion would have probably been avoided, and these men’s lives might have been saved.

Mention has already been made of the fatal explosion in an Indiana cement-manufacturing plant due in all probability to overheated coal being delivered into the pulverizing mills. Another similar accident is reported from a plant in one of the eastern States; six men were killed and five men badly burned. It was pretty well established that a fire started in one of the coal-storage bins and hot coal was carried to the pulverizer where it came in contact with the proper mixture of air and fine coal dust and exploded.

**DIRT AT CEMENT PLANTS**

Holly 40 comments on the dusty and dirty conditions in the average cement plant, stating that:

All grinding plants, regardless of the sort of mill used (tube or roll) are producers of a large amount of dust which freely mingle with the air of the grinding room. Thick layers of dust cover all the machines, while around the neighborhood this dust may be found.

The writer can not agree with the first part of this statement, as there are many plants for the preparation of pulverized fuel in which it is almost impossible to find a trace of dust. Construction of all conveyors, elevators, and other equipment for handling dust should be so heavy that all joints are absolutely tight and there should be no openings that would allow dust to escape. Accumulations of dust should not be permitted.

**PLANT CLEANLINESS**

Many explosions of coal dust at industrial plants have been more violent and destructive than they would have been had the plant been kept clean. Generally speaking, a primary explosion occurs in some part of the pulverizing machinery, such as the pulverizer or the drier. An atmospheric disturbance is created by this primary explosion which raises the dust accumulations near by into a cloud. This dust cloud is in turn ignited by the burning gases of the primary explosion, and causes other dust clouds to be formed and ignited until a tremendous pressure is built up.

Figures 23, 24, 25 and 26 illustrate well the effects of a primary explosion in which the pulverizer was first wrecked; flames which swept through the entire building followed almost immediately.

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If a building is kept absolutely free from coal dust the chances are that ignition of coal dust in any of the apparatus will cause only a local explosion.

**VACUUM-CLEANING SYSTEMS**

Elaborate vacuum cleaning systems have been installed in some huge American grain elevators to keep them free from accumulations of explosive grain dust, and portable vacuum cleaners are in use in certain coal-pulverizing plants.

Figure 35 shows the practical application of a vacuum cleaner in an industrial plant. Inclined and vertical as well as horizontal surfaces are cleaned. Figure 36 shows a vacuum unit and dust collector.

When a vacuum-cleaning system is installed it should be so planned that the dust which is collected can not come in contact with an igniting medium, such as a spark from the driving motor or from static electricity. Preferably a dust collector should be placed between the fan and the source of the dust. If bags are used for dust collectors they should be thoroughly grounded, as in fact should the entire collecting system, to avoid the building up of a charge of static electricity.

Price and Brown\(^5\) treat the subject of dust collection and removal quite thoroughly.

It is possible that reported failures of vacuum-cleaning apparatus in industrial plants can be traced to improperly designed suction tools and to the installation of inadequately powered vacuum producing units. Systems of this type should be designed and installed by specialists in this line of work.

**DANGER OF USING COMPRESSED AIR**

Dust around pulverizing plants, boiler plants, coal-storage bins, or coal-handling plants should not be blown away by compressed air, because the air raises a dust cloud which may be ignited. An incident which is described by Hansen\(^6\) shows this plainly.

The tops of the boilers in a steam-generating plant were covered 4 to 6 inches deep with coal dust and soot. An attempt was made to clean off the accumulation with compressed air. Naturally the dust was immediately put into suspension and came in contact with an open flame, was ignited, and then exploded. Fortunately no one was hurt, but this might not be so another time.

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\(^6\) Hansen, C. M., *Dust explosions in the boiler room; Power and the Engineer*, Dec. 5, 1908, p. 1017.
Figure 36.—Vacuum unit and dust collector
The cement-plant accident that killed eight men, cited on page 88, is also an example of the danger of raising the dust into a cloud when cleaning it up.

DEPOSITION OF COAL ON RAFTERS AND WINDOW LEDGES

It may be assumed that if a building has adequate ventilation, either through windows and doors open to the outside or by artificial drafts induced by fans, the dust hazard will be avoided, but this assumption is not entirely true. The writer would not in the least minimize the utmost importance of light and ventilation, but when a number of currents of air at different velocities are passing through and around a pulverizing plant, much of the dust carried in suspension will be deposited on rafters, roof trusses, and window ledges, consequently some method of cleaning should supplement an adequate ventilation system.

ARRANGEMENT OF COAL-PULVERIZING PLANT

The general arrangement of the units in a coal-pulverizing plant has much to do with its safety. If the equipment is arranged systematically, with due regard to a logical routing of the coal from the crusher to the transport system, and if the space between each unit is ample to allow inspection of the machinery and removal of accumulations of dust, the psychological effect of such an arrangement upon the men employed in and around the plant is of no little importance. It furnishes an incentive for them to take pride in the general appearance and cleanliness of the plant and thereby tends to prevent an accumulation of dust.

VALUE OF WHITEWASHING

By the somewhat common practice of whitewashing or painting white the interior walls, steel columns, and machinery foundations, much is added to the cleanliness and thereby the safety of the plant.

On the other hand, in a dark dim building where the equipment is placed here and there without order and pulverized coal is pouring out of leaky joints and loose connections, and these conditions are supplemented by bad lighting and ventilation, there is no incentive, and generally no effort made, for cleanliness.

CLEANLINESS AND ECONOMY

There is an economic side to the question of plant cleanliness. It has been estimated that in some plants as high as 2½ per cent of the coal handled is lost in dust.52 If this estimate is correct, a

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plant using 200 tons of coal per day would pay for 5 tons which goes off in dust and is wasted. If coal has a value at the plant of $4 per ton this means a loss of $20 a day, which would go a long way toward rendering a plant practically dustproof. Plants can be made absolutely dustproof; the author has been in plants where 150 tons of coal a day are pulverized, yet hardly a speck of dust could be seen, even by drawing the tip of the finger along the walls.

CONSTRUCTION OF BUILDING

The type of construction used for the buildings that house the pulverizing plant can do much to lessen the dust hazard. Although window ledges and flat surfaces upon which dust can settle should be avoided as far as practicable, where unavoidable they should be beveled steeply enough to counteract, as much as possible, the tendency of dust to pile up on a flat surface.

Some plants are built with a light framework covered with metal sheathing. With this type of construction, the inside of the framework should also be sheathed. If corrugated iron is used the corrugations should be placed vertically, to avoid collecting the dust which may be suspended in the air.

ADVANTAGES OF LIGHT CONSTRUCTION

There is gradually developing among engineers the idea that buildings which are subject to explosions should be of rather light construction, as this type has proved effective in releasing explosion pressures and localizing the effect of the explosion.

REGULATIONS OF NATIONAL FIRE PROTECTION ASSOCIATION

The fire-insurance authorities have recognized this idea in the National Fire Protection Association's "Tentative regulations for the installation of a pulverized-fuel system," adopted at the Chicago meeting, in May, 1923, and later made a part of the regulations of the National Board of Fire Underwriters.

Section 26 of the general regulations states that:

The frame should be preferably of steel with light nonbearing walls (except fire walls), constructed of such materials as stucco on metal lath, tile, metal, or other similar incombustible material and with roof of monitor or gable type, and all secured in such a manner as to give way readily under pressure of explosion.

Section 2(d) reads:

In order that the venting of explosions may be more readily facilitated in buildings of brick, concrete, or similar heavy construction, a portion of the exterior walls and roofs (considered in lieu of an exterior wall) equal to not less than 10 per cent of the inclosing walls shall be of glass.
The main object of these regulations is to provide an outlet for the forces generated by a possible explosion and thus avoid the building up of the pressures.

EXAMPLE OF VALUE OF LIGHT CONSTRUCTION

The advantage of this type of construction is exceedingly well illustrated in the recent starch-dust explosion at Pekin, Ill. The primary explosion originated in a building constructed with a very large window area. A second explosion, an immediate effect of the first, occurred in a building with a less proportionate window area.

In the first building affected by the explosion only a little damage was done to the walls and floors, although, of course, the glass in the windows was blown out. The second building was completely wrecked.

WINDOWS

Windows should be of the steel-sash type, and those near the ground should not be glazed with wire glass, because in an emergency they might be the only means of escape for the men in the plant. It might be advantageous to adopt the practice of some manufacturers of explosives, to provide the lower windows with safety catches, and so hang them that in an emergency they may be swung open and the workmen enabled to make a quick exit from the building.

LOCATION OF PULVERIZING PLANT

The main pulverizing building should be so situated that there will be no chance of sparks from locomotives, furnaces, or boilers getting into the building through open windows, ventilators, or doors. If conditions are such that it is impracticable to locate the pulverizing building as indicated above, then all windows and ventilators through which a chance spark might enter should be carefully screened. That this is not an imaginary hazard is shown by the fact that in the "year ending April 30, 1919, of 78 elevator fires * * * 15 were caused by locomotive sparks." 53

This reference is made because grain elevators are closely akin to pulverized-coal plants as dust-explosion hazards.

SIZE OF COAL BINS

All pulverized-coal bins should be of a size reasonably close to actual operating requirements, providing only for a few hours’

reserve supply for emergencies, in order to avoid storing for pro-
tracted periods. The bins should be tightly covered to eliminate
the possibility of a dust cloud being raised when the bin is being
filled or at any other time. Manholes with tightly fitting covers
should be provided and if possible the bins should be vented to the
outside air so that pressure can be released in case of a slight ex-
plosion. This vent should have a valve which can be closed when-
ever the bin is out of operation, yet contains an appreciable amount
of fuel. In this way, the liability of spontaneous combustion is
decreased because the air supply is cut off. All joints should be
welded, and in actual practice it has been found that if the corners
are well rounded the coal is less liable to cake and adhere to the sides.

As has been stated before, the safety of a coal-pulverizing plant
depends largely on its cleanliness, and cleanliness, in turn, depends
on good and careful construction, especially of those parts of the
equipment that confine the dust. Tightly fitting coverings for eleva-
tors, conveyers, and bins are absolutely essential, and the expense
of such workmanship is fully justified by the additional security
which they furnish.

**SUMMARY**

Even though the coal-pulverizing system is efficiently designed
and the most effective safety devices are provided, much of the value
of these safeguards is lost if plant operatives are not educated to
note and avoid potential dangers. Several of the incidents men-
tioned in the preceding pages illustrate this fact—for example, the
accident caused by the lighting of a torch in the elevator of a crush-
ing plant and that caused by the firemen neglecting a drier furnace
until hot coal was carried from the drier to the pulverizer.

It is of the utmost importance that the men in the plant, and also
those who are in and around furnaces or boilers which are using
pulverized coal should be impressed with the idea that coal dust is ex-
plorative and inflammable when in a cloud and mixed with the proper
amount of air, and that it should be treated just as carefully as
natural gas.

A small stream of coal leaking from a defective joint in a coal-
transport line or a storage bin will perhaps not attract attention,
yet even a very small leak in a gas line would be repaired at once.
Let this little stream of coal be blown across an open flame or red-
hot metal and the effect would be the same as placing a lighted
match to the leak in the gas line.

One steel company thought it was so important to educate its
men that it sent a number of the foremen connected with its
coal-crushing plant to the Bureau of Mines' experimental mine where they witnessed a demonstration of the inflammability of a coal-dust cloud made especially for their benefit.

OPERATING REGULATIONS

To those who are interested in the use of pulverized coal as a fuel, the following summary of the preceding pages is given as a basis for regulations looking to the safer operations of pulverized-fuel plants.

There should be absolute cleanliness and freedom from any accumulations of dust, both in the pulverizing plant and in the buildings in which the pulverized coal is used as fuel.

Accumulations of dust on the floor or machinery should never be brushed or swept up without either the dust being wetted or thoroughly mixed with an excess mixture of fine incombustible material.

All coal-pulverizing plants should be adequately ventilated and lighted, and when practicable, some method of cleaning by vacuum system should be installed.

All open lights in and around coal-pulverizing plants should be prohibited, and employees should not be allowed to smoke while in the building. This rule should apply to superintendents and other officials who casually visit the plant, as well as to the regular attendants.

The drier and drier furnace should be separated by a fireproof partition from the pulverizing mills, conveying machinery, and storage bins.

Where furnaces and boilers are equipped with individual fuel bins, these bins, if possible, should be isolated from the boilers or furnaces.

All pulverized-coal bins should be tightly closed, and never opened if there is any possibility of ignition from an open flame. Bins should be equipped with automatic indicators to indicate the amount of coal in the bin.

Only men of known reliability should be intrusted with the direct operation of a drier. It may be more economical in the long run to pay a higher wage to a careful man than a smaller wage to an unreliable man or boy.

Especial care should be taken not to overheat the coal in the drier, and recording pyrometers should be installed to enable the officials of the plant to check the operation of the drier.

The operation of the drier should never be stopped while it contains a charge of coal.

Fire in the drier furnace should never be started with paper, shavings, or any light combustible material.
Because of the liability of spontaneous combustion, dried or pulverized coal at a temperature over 150° F. should never be stored in a bin over 18 hours. For the same reason, storage bins for pulverized coal should never be placed in close proximity to furnaces, boilers, steam pipes, or flues.

If fire is discovered in a fuel bin, the bin should be tightly sealed and the fire allowed to die for want of oxygen. Fresh coal should not be discharged into a bin in which there is burning coal.

In opening a bin which has been sealed to extinguish a fire, care should be taken not to ignite any inflammable gas which may have been generated during the time the bin was sealed.

Whenever a plant is to be shut down for a few days all storage bins should, if possible, be emptied of coal. When it is not possible to empty the bins they should be thoroughly inspected for hot coal before the plant is again put in operation.

In the circulating system of using pulverized coal the primary air pressure should always be maintained at a pressure much higher than that of the secondary air.

If a coal-circulating line becomes plugged the furnaces should be immediately cut out and the secondary air stopped.

After the line has been cleaned it is essential that no smoldering particles of coal are left in the line, and before the fan is started a thorough examination of the line should be made.

Burners should be frequently inspected, and any coke burned thereon should be removed.

Circulating lines should be blown clean of coal when the plant is shut down at the end of the day's work.

The mixture of air and coal in the furnace should never be ignited by a man reaching in or by opening the doors.

All conveyers and elevators should be tightly inclosed and should never be opened while running; before they are opened the machinery should be stopped and the dust allowed to settle.

Whenever pulverized coal becomes caked in bins, transport lines, or conveyers it should not be jarred off by hammering, because of the liability of causing leaking joints.

A coal-line compressed-air tank, or storage bin should never be opened in the vicinity of a flame or open light.

All electric wires and cables should, as far as possible, be inclosed in conduits, preferably rigid iron conduits.

All switches should be placed outside the pulverizing plant or in dustproof casings.

Nonsparking motors or motors in dustproof housings should be used in the pulverizing plant.

Precaution should be taken against sparks from static electricity in all rapidly moving machinery by having it thoroughly grounded.
Dust should never be allowed to accumulate upon electric-light bulbs, and the bulbs of all portable lights should be protected by heavy wire guards. Care should be taken to prevent arcing from loose socket connections or imperfectly insulated cords.

All leaks in pulverized-coal circulating lines or storage bins should be stopped as quickly as leaks in gas lines.

All the men should be educated to the dangers of pulverized-coal dust.

The use of pulverized coal as a substitute for natural gas as fuel in industrial plants, especially in those plants using different types of heating furnaces for the manufacture of steel products, will no doubt increase as the supply of gas decreases. This increase should develop safer and more efficient methods in the preparation and distribution of powdered fuel.

**PUBLICATIONS ON POWDERED COAL**

A limited supply of the publications of the Bureau of Mines is available for free distribution until the edition is exhausted. Requests for publications should be addressed to the Director, Bureau of Mines.

The Bureau of Mines issues a list showing all its publications available for free distribution, as well as those obtainable only from the Superintendent of Documents, Government Printing Office, on payment of the price of printing. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest list.

**PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION**


**PUBLICATION THAT MAY BE OBTAINED ONLY THROUGH THE SUPERINTENDENT OF DOCUMENTS**

Bulletin 217. Preparation, transportation, and combustion of powdered coal, by John Blizard. 1923. 127 pp., 4 pls., 38 figs. 20 cents.
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