

**LABORATORY INVESTIGATIONS OF THE IGNITION OF  
COAL DUST.**

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**INTRODUCTORY STATEMENT.**

Although perhaps laboratory experiments had no great share in bringing about the general knowledge of the explosive character of coal dust, they are a valuable means of gaining information in advance of experiments carried out on a scale large enough to simulate mining conditions. The acceptance of the theory has come about only through such large-scale experimental work, which has shown conclusively that coal dust alone may be the cause of serious disasters or may propagate and prolong a comparatively harmless explosion caused from some other source, so as to produce a disaster extending through great areas.

The object of this part of the report is to describe in some detail the work which has been done on a laboratory scale bearing on the question of coal-dust ignition and inflammation. Many of the experiments on a somewhat larger scale are excluded, but some such early

experiments are mentioned because of their historical interest and some of the most recent on account of their great importance in furnishing quantitative data.

#### EARLY EXPERIMENTS OF GALLOWAY.

Galloway<sup>a</sup> was one of the first to study this question from the experimental side. His experiments were carried out in a wooden box 5.71 meters long and 0.305 by 0.0152 meters cross section, through which a regulated current of air was passed. A hopper placed at one end served to introduce the dust, which was then carried by the air current 2 meters to a naked flame. Two kinds of coal dust were used, of the following composition:

*Composition of coal dusts used in Galloway's experiments.*

	1.	2.
Carbon (C).....	85.3	82.6
Hydrogen (H <sub>2</sub> ).....	5.0	5.4
Oxygen (O <sub>2</sub> ).....	1.3	1.6
Nitrogen (N <sub>2</sub> ).....	.6	1.0
Sulphur (S).....	.7	.8
Moisture.....	.6	.7
Ash.....	6.5	3.5
Volatile matter.....	22.0	15.0

Galloway's first conclusion is thus stated by him:

The results of these experiments and others which I have since made indicate in a conclusive way that a mixture of air and coal dust is not inflammable at ordinary atmospheric pressure.

However, on investigation he concluded that suspended coal dust could cause the explosion of a mixture of air and amounts of methane too small to be explosive in the absence of the dust.

#### IGNITION OF DUST FALLING ON FLAME.

Marreco and Morison<sup>b</sup> record certain crude observations made by persons whose names are not given, in which the tendency of coal dust to inflame was studied by allowing 5 liters of the powder to fall from a height of 6 meters upon a strong gas flame and noting the effect. Some of the dusts were ignited, and flame emitting much heat rose at times to a height of 10 meters. Other dusts were less inflammable, while still others failed to ignite at all. Professor Abel made certain experiments on ten different samples of coal dusts in an apparatus similar to that used by Galloway, with results entirely negative.

<sup>a</sup> Proc. Roy. Soc. London, 1876, p. 168; Annales des mines, ser. 7, vol. 11, 1878, p. 229; Bull. Soc. ind. minérale, ser. 2, vol. 6, 1877; vol. 7, 1878, p. 617; vol. 9, 1880, p. 157.

<sup>b</sup> North of England Inst. Min. and Mech. Eng., 1879, p. 92.

## EXPERIMENTS OF VITAL.

While investigating the cause of a certain mine explosion Vital<sup>a</sup> concluded that coal dust had been an important factor in the accident, and he accordingly began certain laboratory experiments to see if it were not possible to ignite coal dust.

His apparatus (fig. 5) consisted of three parts—an explosion gallery, a gas burner of special construction, used as the source of ignition, and a device for measuring the violence of the explosion. The explosion gallery was a straight glass tube (*g*) 3.5 centimeters in diameter and 2 meters long. The end of this tube at which the ignition took place was somewhat enlarged, the opposite end somewhat constricted. Along the outside of this glass tube was pasted a strip of paper marked in 2-centimeter divisions in order to measure the distance to which the flame was propagated. Inside of the tube, at distances of 1.5 to 1.75 meters from the larger end, were placed small pieces of lead wrapped in paper to serve as indicators of the character of the flame traversing the tube. The ignition was brought about by

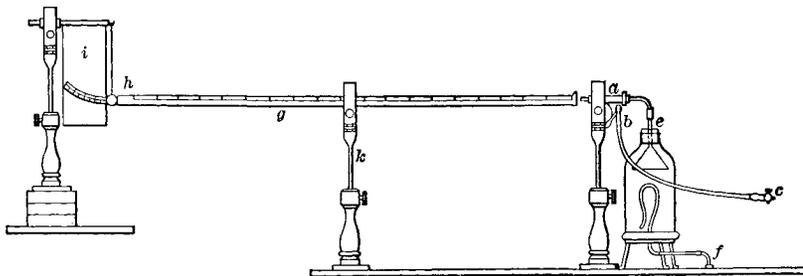


FIGURE 5.—Coal-dust ignition apparatus of Vital.

means of a specially constructed gas burner (*b*) situated at the larger end of the gallery tube. The gallery was movable, so that the flame from the gas burner could, at the proper instant, be directed momentarily into the larger end of the glass tube along its axis. This gas burner was operated by a foot bellows (*f*). Intervening between the bellows and the lamp was a glass reservoir into which the air entering from the bellows was directed toward the bottom. By this arrangement the gas burner could be operated by pure air by direct connection with the bellows or it could be fed by a dust-laden atmosphere by placing dust on the bottom of the reservoir beneath the opening from the bellows. At the opposite end of the gallery was placed the arrangement used for estimating the violence of the explosion in the gallery. This consisted of a light pith ball (*h*) 2 centimeters in diameter, the surface of which was coated with a layer of ivory black. This ball was placed against the open end of the gallery and rested against the front of a graduated circle (*i*), the divisions on which were 2 degrees each.

Before the apparatus was used the following facts were ascertained: With the gas unlighted, the air blast carrying coal dust laid a heavy deposit of it on a porcelain plate set a few centimeters from the end of the tube. With the gas lighted, burning with pure air, the burner gave a blue flame, scarcely visible, 5 centimeters long. When the blast was operated with air containing coal dust in suspension a bright blue flame was obtained which showed many brilliant sparks of burning carbon, but did not deposit soot. With the two indicators in position, the gallery free from dust, the flame of the lamp fed by dust-laden air and directed into the gallery, the flame did not change color, but elongated about 2 centimeters. The indicators were not charred; the pendulum recoiled, but without shock.

These preliminary facts having been ascertained, the gallery was charged successively with dusts 1, 2, 3, and 4. When the dust-fed flame was directed into the tube, a red flame traversed the gallery rapidly, and the tube was left filled with fumes. After these were removed the walls were found to be covered with a coating of dust impregnated with water and bituminous matter. The indicators were burned, and the pendulum received a shock. The results of these experiments are given in the following table:

*Results of Vital's experiments.*

Observations.	Dust 1.	Dust 2.	Dust 3.	Dust 4.
<b>Flame:</b>				
Length.....	1.78 m.....	1.46 m.....	0.15 m.....	1.73 m.....
Conduct.....	Regular.....	Regular.....	Regular.....	Regular.....
Color.....	Red without brilliant particles.	Red without brilliant particles.	Blue and red without burning particles.	Red without brilliant particles.
<b>Indicators:</b>				
No. 1.....	Burnt.....	Burnt.....	Intact.....	Burnt.....
No. 2.....	do.....	Charred.....	do.....	Do.....
Angular motion of pendulum.	14°.....	11°.....	2°.....	13°.....

Dusts 1 and 2 when removed from the tube had lost their black color and become reddish. No crystalline particles were observed, but globules composed largely of water were found on the inside of the tube. The crucible tests on these dusts before and after the experiments gave the results contained in the following table:

*Analyses of dusts before and after ignition in Vital's experiments.*

	Dust 1.		Dust 2.	
	Before (a).	After (b).	Before (c).	After (d).
Moisture.....	0.31	11.3	0.29	9.7
<b>Dry dust:</b>				
Volatile matter.....	34.1	21.2	34.8	23.5
Ash.....	24.2	29.7	24.4	28.2
Fixed carbon.....	41.7	49.1	40.8	48.3
	100.0	100.0	100.0	100.0

The coke residues from *a* and *c* were hard and brilliant, while those from *b* and *d*, collected after the explosion, were found to be pulverulent. A sample of reddish dust charred by an explosion in the mine from which the dusts used in the experiments came gave the following analysis:

*Analysis of coal dust charred by mine explosion.*

Volatile matter.....	27.2
Ash.....	26.1
Fixed carbon.....	46.7
	100.0

The conclusions reached as the result of this and additional experiments were:

- (1) Certain finely divided dusts, rich in gas, take fire when brought into the air by a blown-out shot. These dusts, being decomposed, yield an explosive gas mixture which would take fire from the powder.
- (2) The flame is instantaneous; it burns or alters the small amount of coal dust raised in its path and goes out.
- (3) The intensity of the phenomenon is intimately connected with the character of the dust and becomes practically nil if the size of the particles is increased to an appreciable part of a millimeter.
- (4) Other things being equal, the violence of the explosion would depend essentially on the physical conditions which determine the raising of the cloud of dust and its subsequent conduct.
- (5) The presence of an excess of free carbon in the powder facilitates the production of an explosion.

Certain experiments were performed by the Soci t  de l'Industrie Min rale in a gallery used for testing lamps. During the experiments an air current was kept circulating through the apparatus. The inflammation was produced by igniting 50 grams of powder contained in a lead cartridge, after coal dust had been placed in the gallery. A second series of experiments was made in a gallery constructed for the purpose, the length of which could be varied. In this set of experiments the ignition charge was 30 grams of powder placed on the bottom of the gallery in a paper or lead cartridge.

In the first series of experiments it was noticed that the flame from the powder was elongated from 3 meters to 6½ meters. In the second series, when the gallery was 4 meters long and the ignition charge was placed 2 meters from the orifice a large flame shot out of the tube on the ignition of the charge; when the gallery was 8 meters long the flame did not emerge. Thus they were able to secure the ignition of the coal dust in this way, but the amount of such ignition must have been small, as paper was not ignited at 3 meters from the cartridge.

## EXPERIMENTS OF HALL AND CLARK.

Hall and Clark <sup>a</sup> performed certain special experiments to study the effects of blown-out shots. They were the first to carry out experiments under conditions approaching those existing in mines. They ignited various charges of powder at the bottom of an inclined gallery along which was placed the coal dust under investigation. The length of the flame was determined by suspending pieces of inflammable cloth at regular intervals along the gallery. In many of their experiments the flames were voluminous.

This work is mentioned in more detail elsewhere, and is repeated here merely because it forms the beginning of the great amount of work which has been done on an extensive scale, and because it was repeated on a smaller scale shortly after by Marreco and Morison.<sup>b</sup>

These investigators carried out experiments on a much smaller scale than those of Hall and Clark, but otherwise there was some similarity in their method of working. The apparatus used consisted of a long rectangular box divided longitudinally into two compartments by a vertical partition reaching nearly to the bottom of the box. One of the longitudinal chambers thus formed was 3.6 meters long, the other 3 meters. One end of the apparatus was closed, and at the second end of the longer gallery was attached a connection for introducing a regulated current of compressed air. The second end of the shorter gallery was left open. Two small cannons were placed at the closed end, each directed along the axis of one of the galleries. They were discharged electrically and the connections so made that they could be fired either simultaneously or one at a short interval after the other. The air current which came into the longer gallery passed under the partition and through the shorter one and had a velocity of  $1\frac{1}{2}$  to 3 meters. The charges of powder used were not given, nor the composition of the coal.

The results of the work showed that dusts conducted themselves very differently under these conditions, according to their nature. With some the flame issued from the box, with others the flame was only a small fraction of the length of the box. The greatest effects were produced when the cannons were fired at short intervals apart, the first shot serving to charge the air of the second gallery with dust. The shot then fired into the second gallery produced more violent explosions. In many of their experiments the box was burst open.

As the result of these experiments they concluded that if they had been able to perform their experiment on a sufficiently large scale, the results would have been comparable in every way with a mine explosion.

<sup>a</sup> Communicated to the North of England Inst. Min. and Mech. Eng., June, 1876.

<sup>b</sup> North of England Inst. Min. and Mech. Eng., 1879, p. 85; Annales des mines, ser. 7, vol. 15, 1879, p. 374.

## EXPERIMENTS OF ABEL.

Abel <sup>a</sup> attempted to secure the explosion of coal dust on a small scale by means of a charge of 26 grams of powder placed on the bottom of a wooden box, which was used as the explosion chamber. He judged the effect of the dust by the extent to which the flame of the powder was elongated by the burning of the dust. His results were negative, as the length of the flame was sometimes longer but sometimes shorter than the flame of the powder alone. But he concluded that possibly with the large flame and violent agitation from a blown-out shot dust alone would propagate a flame farther than the experiments on a small scale seemed to indicate.

## EXPERIMENTS OF MALLARD AND LE CHATELIER.

In 1882 Mallard and Le Chatelier <sup>b</sup> published the results of their work. In the course of this work the authors undertook a study on a laboratory scale of many of the important conditions influencing the ignition and the explosive character of coal dust. This work is of great historical interest, because of the conclusions reached by its authors and the influence which these conclusions have exercised in the development of the coal-dust theory. The work is also of great scientific interest because of its scope and the number of problems of a fundamental character which the authors have undertaken to investigate. Their experimental work is prefaced by a summing up of the evidence in support of the theory, both the evidence furnished by laboratory experiments and that obtained from mine accidents where coal dust had been assumed to be a factor.

Their own laboratory experiments are divided in the following way:

Chapter I. The study of the phenomena presented by the mixture of coal dust and air containing no methane.

Chapter II. The study of the phenomena presented by mixtures of coal dust with air containing an amount of methane too small to form an explosive mixture.

Chapter III. The study of the phenomena presented by mixtures of coal dust with an explosive mixture of air and methane.

Our interest in this work, for the present, centers in Chapter I. This chapter is subdivided into the following six sections:

Section 1. A study of the influence of the size of the flame.

Section 2. A study of the influence of the velocity of the air current.

Section 3. A study of the influence of the size of the dust particles.

Section 4. A study of the influence of the nature of the coal.

Section 5. A study of the influence of the relative proportions of dust and air.

Section 6. The velocity of propagation of the flame.

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<sup>a</sup> *Annales des mines*, ser. 7, vol. 20, 1881, pp. 121-159.

<sup>b</sup> *Idem*, ser. 8, vol. 1, 1882, pp. 5-98.

The experiments were made in two forms of apparatus. The first resembled that previously used by Galloway, Morison, and Abel. It consisted of a wooden box, 4 meters long, 0.4 meter high, and 0.15 meter wide. One extremity communicated with a ventilator capable of giving a pressure of 5 centimeters of water. At 50 centimeters from this end was a device to regulate the flow of air, the velocity of the ventilator being maintained uniform. At a point 25 centimeters farther there was placed on top of the main box or gallery a second box, perforated for the introduction of coal dust. The arrangement of the regulator with reference to the point of introduction of the dust was such that the eddy produced at the regulator served to disseminate the dust through the air. At 2 meters farther a removable glass window was placed, which permitted the introduction of a lamp and the observation of the results. The other end of the gallery was open to the outside air, 50 centimeters beyond this window. When the dust burned it gave a large flame, filling the whole section and extending out of the orifice.

The second form of apparatus used was simply a cubical wooden box of 50-centimeter dimensions. At the center was placed a gas flame directed downward in order to spread it out. In testing the dust in this form of apparatus a double handful of the dust was held about  $1\frac{1}{2}$  meters above the box, and was allowed to fall between the fingers in such a way as to subdivide it as much as possible. In falling the columns of descending dust carried along a considerable amount of air by the time the dust reached the flame, and the eddy produced in the box by this air kept the atmosphere charged with the dust. If the sample was inflammable, it ignited at the gas flame.

The sources of heat investigated by the authors were, first, the normal flame of the Davy lamp; second, the same after regulating its flame to a height of 5 centimeters; third, a large gas flame; fourth, a large roll of burning paper.

With finely powdered coal of an inflammable character it was found that in the first form of apparatus described above inflammation took place instantly when the last three sources of heat were used. With a normal flame of the Davy lamp flashes occurred, after which the whole was inflamed, the duration of this phenomenon being only about two seconds.

Coal dust collected in the gallery of the same mine, but less finely divided, took fire immediately on contact with the gas flame and roll of burning paper, and after the end of some seconds it ignited from the flame of the Davy lamp, burning 5 centimeters high. But with the normal flame of the Davy lamp, ignition occurred only after some time, or not at all.

The coarser dust collected from the floor of a gas works ignited after some seconds from the third and fourth sources of heat, but not

from the others. Another sample of a different dust was found to be inflammable from all four sources.

The conclusion of the authors was that an inflammable mixture of coal dust and air required for its ignition a flame of a certain minimum volume, varying with the nature of the dust. The same is true of explosive mixtures of gases ignited by an electric spark, a certain minimum spark being necessary, varying with the character of the gas mixture. The great difference is the enormous size of the source of heat necessary to ignite the dusts as compared to the electric spark. By increasing the size of flame above this minimum the rapidity of inflammation is increased and for a certain volume becomes practically instantaneous and nothing is gained by increasing the size of the flame beyond this volume. This maximum volume seemed to be less than a cubic decimeter for the dusts investigated.

Some indication of the effect of the size of the dust particles is seen from the above-described experiments, in which it was found that the more finely divided were the dusts the more inflammable they became and the smaller was the size of the flame necessary for their ignition. Yet in many tests these authors thought that fineness of division was a secondary matter. Some coals were found inflammable whatever the size of the particles. This fact is not opposed to the principle of greater inflammability of finely divided coals, for the authors explain that the dusts used by them were not screened to a certain size, and in all samples there was a sufficient amount of the fine dust that remains longest in suspension to cause ignition on arrival at the source of heat. In this way the occurrence of fine dust in a sample, the average size of whose particles was large, would mask the effect that might be anticipated from the relatively large average size of the particles. For instance, two samples of dust may be very different with respect to fineness when introduced into the apparatus, but in the course of their passage to the flame, situated some distance away, the largest particles are deposited and only the particles smaller in size reach the flame, so that at this point both dust clouds are very similar as regards the size of the particles remaining in suspension.

The velocity of the air current which carried the dust in suspension was found to have a great influence on its degree of inflammability. One of the samples studied ceased to inflame for velocities under 1 meter or above 4 meters. The reason appeared to the authors to be that with the weak air current dust was deposited from suspension before reaching the flame, while with currents faster than 4 meters the particles traversed the flame too rapidly to become ignited.

In the course of the experiments mentioned above the authors established the fact that dusts of certain coals might be considered inflammable while others yield noninflammable dust. Many authors

have previously attempted to connect the inflammability of the dust with the gaseous character of the coal from which it was derived, without, however, giving any experimental evidence of such connection. The authors took up this question and employed for the investigation both forms of apparatus described above, after having shown previously that the behavior of each dust was similar in both forms of apparatus. As a result of this investigation the authors were able to arrange the coals investigated into two groups, first, those whose dusts were inflammable, second, those whose dusts were noninflammable. These results are summarized as follows:

*Percentage of volatile matter in inflammable and noninflammable dusts.*

Inflammable dusts:		Noninflammable dusts:
Sample 1.....	32.0	Sample 1..... 19.5
Sample 2.....	35.0	Sample 2..... 24.6
Sample 3.....	39.0	Sample 3..... 19.0
Sample 4.....	50.0	Sample 4..... 18.0

In stating their conclusion the authors say that a coal to yield an inflammable dust must contain 30 per cent or more volatile matter. The last sample investigated was a lignite, containing 50 per cent volatile matter. It was also found to be the most inflammable of all.

In stating that a coal dust is noninflammable the authors do not mean that the coal dust does not burn, but that under the conditions of the experiment the dust suspended in the air is not capable of propagating the combustion much beyond the confines of the source of inflammation. The propagation of the flame they consider to be a complex function of the temperature of combustion, of inflammation, of distillation, etc. It is conceivable that this combustion could be arrested under certain conditions and that the air and dust mixture would not inflame, while in other circumstances it would burn more or less easily. It is for an analogous reason that a mixture of air with methane in amounts insufficient to form an explosive mixture can be rendered explosive merely by raising somewhat the temperature of the mixture. The dusts of all coals are certainly combustible under the proper conditions, but only a certain number are inflammable under the conditions set by the authors. The proportion of volatile matter, according to the authors, is not the only cause of the inflammability of coal dust, as they consider that those volatile constituents which have already been partially oxidized would be expected to be more inflammable than those same substances unoxidized, just as alcohol vapor is more inflammable than vapors of petroleum. In other words, the authors believe that the inflammable character of the coal dust depends not only on the amount of volatile matter contained in the coal, but also upon its character. A further influence on the inflammable nature of a

coal dust would be the ease with which the volatile matter is expelled.

The authors confirm the conclusions of Galloway that the amount of dust suspended in the air must be considerable to render the mixture inflammable—that the dust clouds should be very dense, such that a thickness of 50 centimeters of the mixture in bright daylight intercepts completely the light from a candle placed in it. The authors made no special measurements in this connection, but conclude from their experience that Galloway was correct in assuming that the amounts of suspended dust most likely to give an inflammable mixture would be 1 kilogram per cubic meter of air.

Berthelot has stated that such an excess of dust is necessary because the only part of the dust particle that enters into action is its surface, whereas in gases the mixture exploding most violently contains the constituents in proper proportions for complete combustion.

The authors consider that to put in suspension such a quantity of dust and keep it suspended would require a violent agitation in the air, because the density of such a mixture is nearly double that of the pure air, and hence only a considerable force can overcome the tendency of the two to separate; besides, the dust would be deposited soon after the cause of agitation ceased. As previously mentioned, the authors show that according to their experiment a velocity of 1 meter a second is not sufficient to keep the air charged to the point of inflammation.

In studying the velocity of propagation of the flame the authors attempted to use the same method by means of which they measured the velocity of propagation of the flame in gas mixtures, but they found that in mixtures of coal dust and air not much agitated there was no appreciable velocity of propagation of flame, and conclude that if it exists it must be less than 1 centimeter. The propagation appears to be effected by the internal movements of the air instead of by conductivity or radiation.

When the air and dust mixture is agitated by considerable internal movements, the velocity of propagation is still small, less than 1 meter, which shows the great difference between the velocity of such a flame and that in an explosive mixture of gases. In confirmation of this statement the authors call attention to the fact that when coal dust was ignited in their long apparatus a sheet of paper which covered the hole in the side of the gallery was not broken and was scarcely puffed out by the pressure within.

In applying their results to mining conditions the authors say that the accidents that can be attributed to dust alone are very rare, not dangerous, and that the flame does not extend farther than 50 meters. The dangerous explosions occur mostly in gaseous

mines, and whether the dust is inflammable or not the conditions do not permit doubting the presence of methane. Lignite mines which are slightly gaseous, if at all so, but which contain dusts more inflammable than coal dust, have never suffered from serious explosions. Further, all the accidents attributable to dust alone are caused by blown-out shots directed to the floor of the mine. The results of their experiments have confirmed these facts by showing the reason for them—the slight inflammability of the coal dust.

According to Galloway and to Mallard and Le Chatelier, the quantity of dust which must be suspended in the air to give an inflammable mixture is far beyond what could possibly be in the air even in the most dusty parts, and it requires a very violent agitation to bring such an amount of dust into the air and maintain it in suspension. Further, the authors have shown that dusts are precipitated very rapidly from the air whenever the causes which brought them into the air cease to operate. Their experiments on the velocity of propagation of the flame in air and dust mixtures show it to be practically zero. These two facts tend to limit the extent of a dust explosion, because before the flame can travel an appreciable distance there ceases to be a sufficient amount of dust suspended in the air to propagate the inflammation. They conclude, therefore, that coal dust alone is of very little danger in mines, but in the presence of small amounts of methane the danger is much increased. Coal dusts play an important part in mine accidents only by lowering the explosive limit of an air and methane mixture.

#### LATER EXPERIMENTS BY GALLOWAY.

After his first investigation on the question of the explosion of mixtures of air and coal dust, Galloway performed a number of other experiments, as a result of which he altered his first opinion, which was stated above in discussing his work. His first conclusion was that coal dust, to be a factor in mine explosions, must be suspended in air that contains at least some methane. His later work led him to the conclusion that coal dust alone mixed with air would under the proper conditions form an explosive mixture, and that in all probability it figured at times as the sole cause of certain mine explosions.

#### EXPERIMENTS OF THORPE.

From this time on work on the question of coal-dust explosions was done on a comparatively large scale. Interest was then taken in the matter by several European governments, and special commissions were appointed by these to investigate the question by instituting experiments to demonstrate conclusively the explosive character of a mixture of pure air and coal dust. These experiments

have been discussed in another portion of this bulletin. Before describing certain experiments carried out under conditions which have been particularly well controlled attention will be called to several demonstrations of the explosive character of coal dust made on a laboratory scale as lecture experiments. A number of such experiments have been described, and of these one described by Thorpe,<sup>a</sup> with which it is possible to illustrate many features of a dust explosion, will be taken up first.

The apparatus (fig. 6) consists of a long wooden gallery in two parts, A and B, which together are 3.66 meters long, each 12.7 centimeters square in cross section. These two parts fit into opposite sides of a similar gallery (C) placed at right angles to A and B and intended to represent a second gallery of a mine crossing the main one at right angles. Each of these galleries is covered for its whole length by a hinged top in two parts, which during the experiment are tightly clasped down. The box should be made of 1-inch oak and screwed together. A shutter (*a*) fits in the slot *s*. This end of A slips into

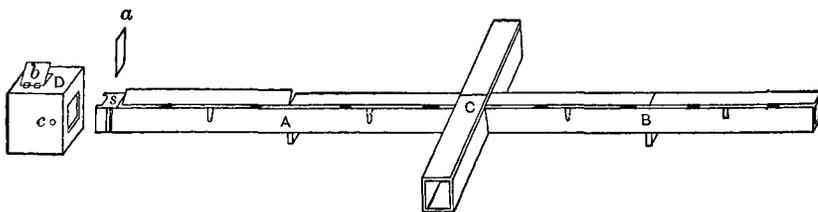


FIGURE 6.—Coal-dust ignition apparatus of Thorpe.

a quadrangle box D, 22.86 centimeters square, which is provided with a door (*b*) and a small hole (*c*), through which a tube can be inserted.

The coal dust is put into the box D and a blank cartridge is fired from a small pistol through *c*. The dust raised by the concussion ignites from the flame of the powder, and the flame of the burning dust goes several feet out of the ends of the box. To illustrate the effect of a local explosion of methane, D is filled with an explosive mixture of methane and air, with *a* in place; *a* is then withdrawn and a flame applied at *c*. The resulting gas explosion charges the air with dust and ignites it, and the flame rushes along the gallery and shoots out at the end, being propagated the length of the gallery and 4 or 5 feet out into the air. The success of the experiment depends on the nature of the coal dust and the character of the initial cause. Some dusts are not brought into the air by concussion and the flame soon dies out. The condition of the coal dust with respect to dryness and fineness of division has a great influence on the character of the explosion.

By the use of lycopodium powder instead of coal dust, Thorpe states, one can observe with this apparatus the phenomena of a dust explosion. For example, it is possible to show how the charred dust is found lodged in greatest proportion behind obstacles and not on the face presented to the advancing air wave, as frequently observed after mine explosions. By putting small pegs in the floor of the experimental gallery it can be shown that the lycopodium powder is swept away clean from in front of the pegs and heaped up behind them.

Thorpe says it is well known that dust explosions increase in violence with the distance from the source of the explosion. At the point of origin the disturbance is small, while a few hundred yards away the violence of the explosion is remarkably greater. This fact also is useful in determining the point of origin of the explosion.

#### REDUCTION OF PRESSURE FOLLOWING EXPLOSIVE WAVE.

It has been said by some that mine explosions are frequently so violent that the diminution in pressure at places is great enough to draw out methane inclosed in the coal. This statement has obtained many believers. The only experimental evidence in regard to it was obtained by Greenwell.<sup>a</sup> The apparatus used for his experiment was a box closed at one end and open at the other. The box is 3 feet long, and at right angles to this and opening into it is another box smaller than the first and fitted with a valve on which the outside atmosphere acts. When a charge of dust was fired in this apparatus the violent outrush of air drew out some of the air in the small box connected to the side of the larger one, and the valve was driven in because of the diminished pressure produced in the small box by the withdrawal of a portion of the air which previously filled it at atmospheric pressure. This does not show a diminution of pressure in the main gallery, according to the author, as the position of the side box would cause the withdrawal of part of the air it contained by the principle on which an injector operates. By a special manometer, which he devised to show that an area of low pressure exists around the flame of a Bunsen burner, Thorpe was able to demonstrate that no diminished pressure exists along the side of the gallery during an explosion, but that on the contrary there was always considerable pressure against the sides and top of the box. Hence the statement that gas is brought into a mine from the face of the coal because of diminished pressure produced in certain areas during an explosion does not receive confirmation by this experimental work.

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<sup>a</sup> Trans. Manchester Geol. Soc., vol. 10, 1870, pp. 20-27.

## EXPERIMENTS OF ENGLER.

In 1907 Engler<sup>a</sup> published a description of a form of apparatus designed to demonstrate the explosion of coal dust on a laboratory scale. He showed that substances like bituminous coal, meal, and naphthalene, which are capable of giving gas, can be exploded by an electric spark. He showed also that substances such as soot and charcoal do not ignite in air alone, but will explode in a mixture of air with a small amount of combustible gas, even a mixture that would not ignite in the absence of the dust. Thus in air containing 2.5 to 3.5 per cent of methane the presence of soot or charcoal dust brought about the explosion of the mixture, and this explosion was increased in violence by the use of dust from bituminous coal. A bituminous coal dust that does not explode when mixed with air will do so if the air contain a small percentage of methane. The apparatus which Engler used to demonstrate the explosion of coal dust is shown in figure 7. A is a flask of 250 to 500 cubic centimeters capacity. A quantity of coal dust is put into B, a small amount of which can be introduced into A by elevating B. The wires *c c* lead from an induction coil, the spark gap being between the two platinum wires at *a*. By blowing air into *b* in jets from a rubber bulb the dust is brought into suspension, and as the cloud passes (*a*) the ignition of the dust takes place, if the dust is that of the proper kind of bituminous coal. In a similar piece of apparatus filled with a mixture of air and 2.5 to 3.5 per cent of methane, or even less, no explosion takes place when the mixture is sparked in the absence of dust, but on introducing a small amount of a coal dust that has been found to be nonexplosive, and blowing it into the air as before by means of a rubber bulb, the contents of the vessel explode with great violence, and the stopper is blown out of the vessel or the glass flask is shattered. The same is true when soot or powdered charcoal is used in place of the nonexplosive coal dust.

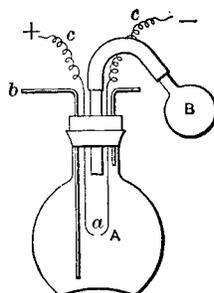


FIGURE 7.—Coal-dust ignition apparatus of Engler.

## LECTURE EXPERIMENT OF BEDSON AND WIDDAS.

A simple lecture experiment to show the inflammable character of finely ground coal dust is described by Bedson and Widdas.<sup>b</sup> Their apparatus is shown in figure 8. It consists of two glass tubes, *a* and *b*, each 3.81 centimeters in diameter, *a* being 7.62 centimeters

<sup>a</sup> Chem. Zeitung, vol. 31, p. 358; Jour. für Gasbeleuchtung und Wasserversorgung, vol. 50, p. 488.

<sup>b</sup> Trans. Inst. Min. Eng., vol. 32, 1907, p. 531.

long and  $h$  30.48 centimeters. The tubes  $a$  and  $h$  are connected by a collar ( $f$ ) which holds in position the cotton gauze  $e$ , on which is placed a quantity of dust ( $g$ ). Into the other end of  $a$  is fitted a stopper ( $b$ ) through which passes the glass tube  $c$ , the upper end of which ( $d$ ) comes a short distance below  $e$ . By means of an air blast blown through  $c$ , the dust is blown from the gauze and disseminated as a cloud, which is carried upward by the air blast to the open end ( $i$ ) of the tube  $h$ . When a naked flame is applied to  $i$  the cloud of dust ignites and the flame of combustion travels down the tube.

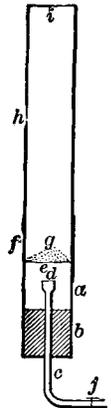


FIGURE 8.—Apparatus of Bedson and Widdas for use in lectures.

#### EXPERIMENTS OF HOLTZWART AND MEYER.

In 1891<sup>a</sup> the attention of Rud. Holtzwardt and Ernst von Meyer was directed to an investigation of the cause of explosions which had occurred frequently in factories where lignite briquets are manufactured. The principal result of their work was a study of the explosive character of lignite dusts mixed with air. Their apparatus (fig. 9) consisted of an explosion tube (E) of 50 cubic centimeters capacity, having two platinum wires sealed through its side about midway the length of the tube. These wires ( $i$   $i$ ) are about 3 to 4 millimeters apart. The spark used as the source of ignition was obtained from an induction coil operated by two strong Bunsen elements. In one end of this tube ( $k_2$ ) is fitted a one-hole rubber stopper, through which passes a glass tube bent downward at a right angle. The longer limb of this tube ( $m$ ) is immersed under water. A weighed quantity of dust is placed against the stopcock H. A is a glass bottle of 600 cubic centimeters capacity; B, a bottle of 3 liters capacity. C is a reservoir of water placed at a height of 1.5 meters above the level of the water in B. In each of the experiments performed 0.18 gram of the dust was used. Water from the reservoir (C) is allowed to flow into B, compressing the air contained in B to a pressure equal to the difference in the level of the water in

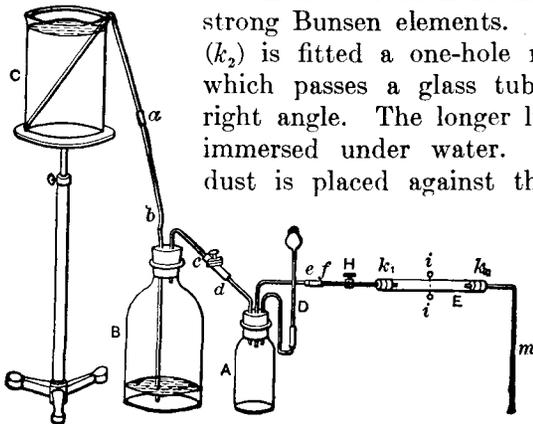


FIGURE 9.—Coal-dust ignition apparatus of Holtzwardt and Meyer.

each of the experiments performed 0.18 gram of the dust was used. Water from the reservoir (C) is allowed to flow into B, compressing the air contained in B to a pressure equal to the difference in the level of the water in

the two vessels. The screw cock *c* is then opened until the air contained in A is compressed to a definite pressure indicated by the manometer D. This pressure was varied in the course of study of each sample. After the proper pressure was secured in A and the apparatus was connected up as indicated, the passage of the spark between the terminals *i i* is started. H is then quickly opened and closed and the character of the explosion observed. The character of the explosion is indicated somewhat by the behavior of the water closing the open end of *m*.

Eight samples of dust were tested. The results of these experiments and the analyses of the dusts are given in the two following tables. The samples were collected from various parts of the briquetting plant, put through a fine sieve, and dried for a long time over sulphuric acid. To remove the last of the moisture the samples were heated to 60° or 70° before analysis.

*Results of experiments by Holtzward and Meyer with explosions of lignite dust.*

Sample No.	Results of tests for specified pressures of air in A in centimeters of mercury.				Remarks.
	2 centimeters.	3 centimeters.	4 centimeters.	8 centimeters.	
1	2 negative, 1 very weak.	1 negative, 1 weak.	2 negative...	Negative...	Tendency to explode small; in 8 experiments 6 negative.
2	2 negative...	2 negative...	.....do.....	.....do.....	No explosion.
3	2 negative, 1 very weak.	.....do.....	.....do.....	.....do.....	Dust not inclined to explode.
4	2 very violent.	2 very violent.	2 very violent.	2 very violent.	
5	2 negative...	2 negative...	2 negative, 1 weak.	Negative...	In 7 experiments 6 negative.
6	2 negative, 1 weak.	2 rather strong.	2 rather strong.	2 rather strong.	Sample inclined to explode; in 9 experiments 7 positive.
7	2 strong.....	2 strong.....	2 strong.....	2 strong.....	Dust explosion very strong.
8	2 strong, 1 negative.	.....do.....	.....do.....	.....do.....	Do.

*Analyses of lignite dusts used in experiments by Holtzward and Meyer.*

	Ash.	C.	H <sub>2</sub> .	N <sub>2</sub> .	S.	O <sub>2</sub> .
1 (Complete.....)	15.93	56.93	5.16	0.93	4.13	16.92
1 (Ash-free.....)		67.70	6.14	1.10	4.90	20.16
2 (Complete.....)	14.05	57.72	4.73	.74	3.16	19.60
2 (Ash-free.....)		67.16	5.5	.86	3.68	22.80
3 (Complete.....)	9.44	60.76	5.22	1.15	2.00	31.43
3 (Ash-free.....)		67.09	5.76	1.27	2.21	23.67
4 (Complete.....)	6.12	61.33	4.66	1.11	.63	26.15
4 (Ash-free.....)		65.33	4.96	1.21	.68	27.82
5 (Complete.....)	7.08	59.56	4.53	1.22	.60	27.01
5 (Ash-free.....)		64.10	4.88	1.33	.65	29.04

A glance at the above table shows a great difference in the conduct of the coals with respect to their inflammability. There is, however, no apparent connection between their explosive character and their

elementary composition. Coal No. 4 is chemically very closely related to No. 5, but their conduct with respect to their explosive character is entirely different. It is probable that the inflammable character of the dust is related to the condition of the surface as well as to the bituminous matter of the coal. Coals Nos. 4, 6, 7, and 8 are seen by inspection of the analyses to be very explosive, while No. 5, chemically very similar to these, is not explosive. Nos. 2 and 3 were found to be nonexplosive, and No. 1 exploded only once. The character of the explosion could be judged by the eye. With Nos. 1 and 3, as propagation of the flame was very slow, its passage through the tube could be readily followed by the eye, appearing to have a velocity very much like that of propagation of a flame in a mixture of carbon monoxide and oxygen near its explosive limit; but in Nos. 4, 7, and 8 the explosion was sudden, and the whole tube filled with a flash of light. In case of such violent explosions much gas escapes from the tube (*m*), while in weak explosions no gas escapes. The experimenters failed to secure an explosion of lignite dust except when the dust was blown in as indicated above. When the dust was placed in the tube E, and the tube was shaken while the spark was passing, no explosion was obtained even with the most explosive dusts. This shows the great importance which the method of introducing the dust can exercise on the character of the explosion. To the authors the character of the explosion of lignite dust under these conditions appeared very similar to that of an explosive gas mixture.

In one experiment, A and E were filled with a mixture composed of 10 per cent carbon monoxide and 90 per cent air. This amount of carbon monoxide and air was just below the explosive limit for these gases. A sample of coal No. 4, which was one of the most explosive coals investigated, was exploded in this mixture. When the coal was blown into the apparatus the explosion which resulted was not noticeably stronger than when the coal was used with air alone.

Their study was confined entirely to lignites, but they considered that a similar study of bituminous coals would be of greatest importance in furnishing data regarding the explosive character of such coals.

They further investigated the gases which were evolved from lignites when heated. Even at 400° C. the gases which were given off were found on analysis to be in such small amounts and of such nonexplosive nature that they could not be considered as a source of the explosions which so frequently occur in briquetting plants; the real cause of the explosions, according to the authors, must be the coal dust.

LABORATORY EXPERIMENTS OF BEDSON AND WIDDAS.

Convinced of the utility of the method adopted by Holtzwardt and Meyer in their investigations of the explosive character of lignite dusts, Bedson and Widdas<sup>a</sup> undertook a similar investigation of mixtures of coal dust and air. The apparatus they used for this work differed in certain respects from that used by Holtzwardt and Meyer. In place of the electric spark used by those authors as the source of ignition they substituted in certain experiments a gas flame or a spiral of platinum wire heated electrically. The apparatus shown in figure 10 consists of a bottle (*a*) of about 1,900 cubic centimeters capacity, closed by a three-hole rubber stopper, through which pass three glass tubes (*b*, *c*, and *e*). The tube *b* was connected with a foot bellows, *c* with an open manometer (*d*), and *e* with the chamber in which the explosion takes place. This chamber in the first form of apparatus is a cubical tin box (*f*) of 10.16 centimeters dimension, provided with mica windows (*g*) at the front and back. On two opposite sides of the box are openings 3.81 centimeters in diameter, provided with collars permitting the attachment of the glass tubes *l* and *m*. The glass tube *e*, communicating with the bottle *a*, is provided with a stopcock (*p*) and was bent downward (inside of the glass tube *m*)

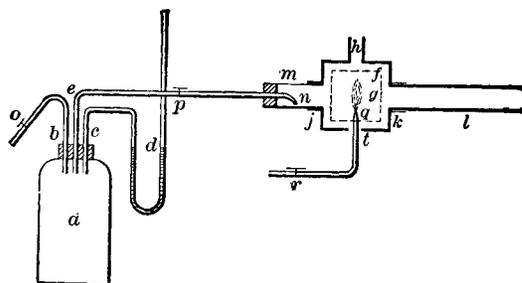


FIGURE 10.—First coal-dust ignition apparatus of Bedson and Widdas.

at *n*, in front of which is placed the weighed sample of dust. Two other openings (*h* and *t*) into the top and bottom of *f* are for the introduction of the gas flame or other source of ignition.

The operation is carried out in the following way: A weighed quantity of dust is placed in front of *n*, in the glass tube *m*. The air in the bottle *a* is compressed to the desired pressure by means of the foot bellows connected to *b*. After placing the gas jet (*q*) in position the stopcock *p* is quickly opened. The outrush of air from *e* blows the dust into the air and carries it to the source of ignition, where the behavior of the dust is observed through the windows. The first series of experiments was made on finely ground samples of lignite. The sources of ignition used were an electric spark, electrically heated platinum wire, and a small gas flame. The second series of experiments was a study of finely ground dust of each of the following materials: Brown coal, bituminous coal, dant (slack), charcoal, wheat flour, wood sawdust, lycopodium powder, metallic aluminum, and

<sup>a</sup> Trans. Inst. Min. Eng., vol. 32, 1907, p. 529.

metallic magnesium. The source of ignition used in each case was a small gas flame, the amount of dust 1 gram. In every material except dant and charcoal inflammation took place.

In a second paper<sup>a</sup> the same authors record the results of further experiments on coal dust with apparatus (fig. 11), somewhat different from that described above. In order to secure better control of the conditions of ignition they substituted a coil of platinum wire for the gas flame and electric spark used in some of their earlier experiments. They could in this way obtain a considerable range of temperature, and could measure approximately the temperature of the coil during any experiment by measuring the current passing through the coil. Below is given the current that was found necessary to produce inflammation of each of the dusts named:

*Current required to produce ignition in specified dusts.*

	Amperes.
Brown coal.....	10.5
Busty seam, bright coal.....	11.5
Hutton seam, coal.....	11.5
Lycopodium.....	11.5
Brockwell seam, cannel.....	12.5
Harvey seam, splint.....	17.0

A current of 17 amperes was insufficient to produce an ignition with anthracite or dant. The samples used in these experiments were passed through a 100-mesh sieve and were air dried. To show the effect of drying on the temperature of ignition of those same coals, experiments were carried out in the same way as those described above, except that the coals were dried. The results were as follows:

*Current required to produce ignition of dried dusts.*

	Amperes.
Brown coal.....	9.8-10.0
Busty seam, bright coal.....	11.0-11.5
Hutton seam, coal.....	11.0-11.5
Brockwell seam, cannel.....	11.5-12.6
Harvey seam, splint.....	13.0-15.0

Further experiments were made on the effect of moisture by exposing the coal dusts under a bell jar over water. Brown coal dust, after seventy-two hours' exposure, and Hutton seam coal dust, after ninety-six hours' exposure, required, respectively, 12.2 and 13.5 amperes. In another set of experiments, the freshly ground dust was mixed with water to a thin paste and allowed to dry for six days in the air. At the end of that time it was found to contain 3.1 per cent moisture, and to require 13.5 amperes for its ignition. The coal was mixed with water the second time and left to dry, and on the fifth day it was found to contain 3.77 per cent moisture, and to require

<sup>a</sup> Trans. Inst. Min. Eng., vol. 34, 1908, pp. 91-97.

13.8 amperes for its ignition. At the end of eight days it contained 1.78 per cent moisture, and required 13.8 amperes for its ignition. The conclusion of the authors regarding the effect of moisture on the inflammability of coal dust is that in order to prevent an ignition of an inflammable dust it must be made so damp that it can not be blown into the air as a cloud by a jet of air, but that an increase of moisture tends to raise the temperature of inflammation.

It was also found that exposure to air rendered freshly ground dust less inflammable. A sample of dust which in the beginning required 12.5 amperes for ignition required 14 amperes at the end of seven-teen days.

Experiments were also made to test the effect of incombustible dusts on the inflammability of coal dust. The result of these experi-ments, summed up in the table below, was to show that the tem-perature of ignition of such a mixture was higher than that of the coal dust alone.

*Effect of mixture of sand with coal dust on current required for ignition.*

Character of coal.	Amount of sand to 1 gram of coal.	Current required for ignition.	Remarks.
	<i>Grams.</i>	<i>Amperes.</i>	
Brown coal.....		12.5	
Do.....	1	13	6 trials, 4 ignitions. 4 trials, 3 ignitions.
Do.....	1.5	13.5	
Do.....	2	15.5	
Hutton seam.....		12.5	
Do.....	.5	13	
Do.....	1	14	
Do.....	1.5	14	
Do.....	3	15	No inflammation.

While these results afford evidence of the difference in conduct of different coals regarding their temperature of ignition, they give no measure of the relative inflammability of the dusts, as the only means available of judging the results was by the eye, and they could only be classified as no ignition, a slight puff, or a violent inflammation. An attempt was made by these authors to gain more exact information on this point with the use of the piece of apparatus shown in figure 11. It consists of the explosion vessel *a*, of 2 liters capacity, and provided with 3 tubulures, *b*, *k*, and *o*. In *b* is inserted a stopper, permitting connection to a coil of platinum wire (*f*). The dust is introduced through *k* in much the same way as in their first experiments, while *o* is attached to the apparatus used for registering the pressure developed in *a* by the inflammation of the dust. The apparatus constructed to register the pressure consists of a three-necked Wolff bottle, one opening of which is connected with the explosion vessel and the second with a closed manometer containing

colored water. The third opening contains a glass tube, the upper end of which is closed by a short piece of rubber tubing and a pinch cock. Any sudden pressure generated in the explosion vessel produces a movement of the liquid in the manometer, the extent of which is noted by means of a scale attached to its side.

Equal weights of the same coal dust gave practically the same pressure in the apparatus. Equal weights of different dusts, when the same current was used for ignition, produced quite different pressures. These pressures, the authors consider, indicate the explosive character of the dust mixture. Several samples of dusts were examined in this way; some of these were collected from a mine, while others were ground in the laboratory. These are designated in the table below as natural and artificial dusts, and all were put through a screen of 100 meshes to the inch. The weight of dust used in each experiment was 2 grams, the pressure of the air used to project the dust into the vessel was 8 inches of mercury, and the wire was heated by a current of 15 amperes. The results are given in the following table:

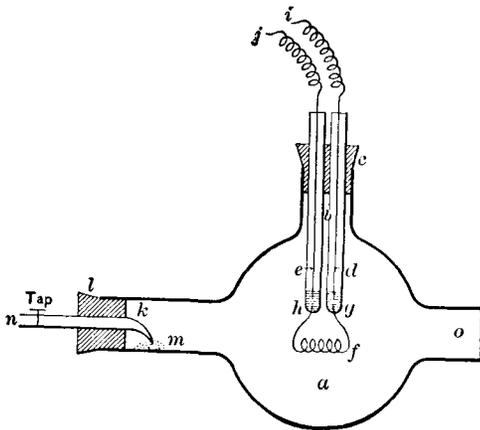


FIGURE 11.—Later coal-dust ignition apparatus of Bedson and Widdas.

These are designated in the table below as natural and artificial dusts, and all were put through a screen of 100 meshes to the inch. The weight of dust used in each experiment was 2 grams, the pressure of the air used to project the dust into the vessel was 8 inches of mercury, and the wire was heated by a current of 15 amperes. The results are given in the following table:

*Explosive character of coal dusts of stated composition as shown in experiments by Bedson and Widdas.*

No. of experiment.	Nature of dust.	Composition of dust.						Pressure. <sup>a</sup>
		Moisture.	Volatile matter.	Fixed carbon.	Ash.	Ratio of fixed carbon to volatile matter.	Ratio of fixed carbon and ash to volatile matter.	
1	Artificial .....	14.86	45.77	35.87	3.50	0.78	0.81	<i>Inches.</i>
2	.....do.....	1.52	34.01	58.55	0.94	1.50	1.51	5
3	.....do.....	6.08	38.22	52.85	2.85	1.38	1.46	5
4	.....do.....	8.58	31.89	57.78	1.81	1.81	1.86	2
5	Natural.....	1.07	27.49	63.72	7.72	2.32	2.59	4
6	.....do.....	5.20	29.05	42.22	23.60	1.45	2.27	1.5
7	.....do.....	5.01	28.38	37.08	29.60	1.30	2.35	1.5
8	.....do.....	6.00	21.70	7.63	64.67	.35	3.33	0
9	.....do.....	4.14	21.31	12.06	62.55	.56	3.50	0

1. Ground brown coal. 2. Ground coal from Hutton seam. 3. Ground coal from Grey seam coal. 4. Ground coal from yard seam coal. 5. Screen dust from Busty seam. 6. Dust from timber baulks and haulage roads in yard seam. 7. Dust from stone in roof of yard seam. 8. Dust from top and bottom of timber baulks and roof of Grey seam. 9. Dust from sides of haulage roads and pillar sides of Grey seam.

<sup>a</sup> The length of the sealed limb of the U tube above the level of the water in the tube is 12 inches. The pressure of 5 inches, therefore, would represent a compression sufficient to reduce the volume of air to seven-twelfths of its original volume, etc.

The authors in concluding their paper call attention to the influence which the proportion of volatile matter in the dusts exercises on their inflammability and explosive character, and assert that the method affords a ready means of judging the character of a coal with respect to these qualities. They express the hope of being able to contribute further results of a similar character.

In some of his work Bedson has made use of a different method for obtaining the relative pressures produced by the explosion of coal dust. This is a modification of the method used by Vital in his experiments.

EXPERIMENTS AT LIÉVIN, FRANCE.

A series of interesting experiments carried out in a comparatively small gallery at the Liévin station in France will next be considered. These experiments have been mentioned in another portion of this

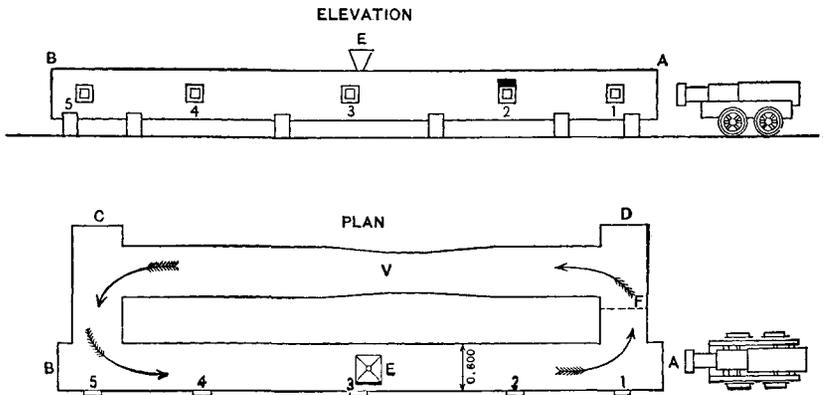


FIGURE 12. Coal-dust ignition apparatus used at Liévin.

bulletin (pp. 47-48) but they can scarcely be passed over here, because they embody the features of laboratory experiments together with those of actual mining conditions. They are, therefore, doubly interesting in this connection as bearing on both the quantitative side of the problem and its practical side. The experiments were performed in a small gallery (fig. 12), made of sheet-iron pipe, 0.6 meter in diameter, and arranged so as to form two galleries parallel to each other and connected at each end, so that the two galleries formed a closed circuit in which the air is made to circulate at regulated speed by means of a ventilator (V) placed near the middle of one of these galleries. The length of the gallery was about 7 meters. At the points A, B, C, and D were openings, which were closed during the experiment by means of paper diaphragms. The long side of the gallery A-B had five observation windows, numbered 1 to 5. Ignition was brought about by firing a cannon into the end

A or B, the muzzle of the cannon having first been placed against the diaphragm closing the end. In this way the ignition could be brought about either against or in the direction of the current of air in A-B. The shot was always fired with the ventilator in operation. The dust was introduced through E during the circulation of the current of air. The introduction was regulated by hand, so as to secure uniform distribution of the dust throughout the gallery. The time required to introduce the dust by hand was sufficient to permit the circulation of the air from five to fifty times around the closed circuit formed by the two galleries. The dust used throughout these experiments was passed through a 200-mesh sieve without any attempt to screen it to a certain size. The velocity of the air current used was from 4 to 5 meters a second, a velocity that was relied on as sufficient to maintain in suspension all of the dust of this degree of fineness. The total capacity of the apparatus was 4.5 cubic meters, and the density of the dust was determined by the amount introduced considering the whole amount as suspended at uniform density throughout the galleries.

When the cannon was fired into the gallery devoid of dust a rapid flame was seen at the first two windows, and at the same time all four paper diaphragms were ruptured. Identical results with a dust-laden air in the system indicated no inflammation. When inflammation occurred a red flame advanced at different velocities to various points of the gallery, or in some tests projected out the end opposite the cannon. Lacking the facilities for such work, the experimenters did not attempt to measure the velocity of propagation of the flame, but, judging by the eye, they were able to express the velocity as very slow, slow, or rapid. After each experiment the tubes were carefully cleaned.

In the course of this work eight different samples of dusts were examined. By varying the density of the dust, beginning with densities too low for inflammation to occur, they were able to arrange the dusts in the order of their inflammability under these conditions. The fact was brought out by this work that the order of inflammability is the same as that of the content of volatile matter in the coal. The same conclusion, as we have seen, was reached by other investigators, namely, Vital, Mallard and Le Chatelier, Holtzwardt and Meyer, and Bedson and Widdas. Further factors considered by the author as determining the inflammability of dust are the character of the volatile matter and the percentage of ash in the coal; but the dusts as prepared for use in this investigation were of somewhat similar composition with respect to ash, so that the content of volatile matter was found to exercise a preponderating influence, and to determine the order of inflammability. Attention is also called to the influence which the ash exercises, both by increasing the weight of the particles,

and by furnishing inert matter which must be heated up before inflammation occurs. The results, summed up in a table, have been given in an earlier part of this bulletin (p. 48). It is seen by inspection of this table, that of the eight dusts investigated, inflammation was obtained in all but the anthracite and Lens 2. The inflammability of the others was found to be greater according as they contained more volatile matter. The four types richest in volatile matter ignited at low densities, and the violence of the inflammation increased with the density of the cloud of dust. The point of greatest interest in connection with this work is the fact that inflammation and propagation of the flame throughout the available length of the gallery took place with a comparatively low density of dust, such as in mining conditions would be considered as indicating a comparatively dust-free gallery.

Since the publication of the preliminary bulletin containing the results of work done in the small gallery, further work has been done in this same gallery, and in one much larger. This work, however, is considered in another part of this bulletin (pp. 86-90).

In discussing the results of his work, Taffanel enters somewhat into the chemistry of dust explosions. No measurements of the pressure produced in the gallery, or of the velocity of propagation of the flame were obtained, because the necessary apparatus was lacking, but analyses of samples of gas taken from the gallery during the explosion have thrown much light on some of the problems involved.

Attempts to obtain samples of the gas after the explosion gave uncertain results because of the reentrance of fresh air. The method that was found satisfactory was to introduce into the gallery a closed glass tube, which communicated with an evacuated vessel outside of the gallery. By means of a detonator and instantaneous fuse, which was ignited by the passing flame, the closed glass tube was broken, and the evacuated vessel was filled with gas from the gallery in a fraction of a second. Analysis of this gas showed the presence of nitrogen, carbon monoxide, carbon dioxide, oxygen, and at times small quantities of methane. The distribution of the oxygen consumed between the carbon and hydrogen of the dust was obtained by deducting from the oxygen present in the beginning that consumed by the carbon plus that remaining free. The amount of carbon and hydrogen burnt per unit volume being known, and the amounts of the various constituents to be heated by this combustion, it was possible to calculate the theoretical temperature of the flame. This calculation gave a temperature ranging from 1,000° to 1,700° C.

The amount of carbon dioxide found, except when large amounts of dust were used, was much greater than the amount of carbon monoxide, and the absorption of heat, which takes place in the

reduction of carbon dioxide to carbon monoxide, was not as great as had been expected. This is especially true in the flame itself, as the amount of carbon monoxide there is very small. It requires a certain amount of time to bring about the reduction of carbon dioxide, and the amount of carbon monoxide became appreciable only after elapse of such a period.

At first it was impossible to explain the part played by finely divided schist in retarding the propagation of the flame, as 100 grams of that material should lower the theoretical temperature only  $50^{\circ}$  C. Even after allowing for the absorption of heat that takes place when the chemically combined water of the schist is expelled, the calculated temperature was higher than the temperature in certain experiments in which propagation was obtained with coal dust alone.

The explanation given for this discrepancy is the difference in the screening action of coal dust and an inert dust. The effect of a dust cloud in front of the flame is to form a screen. With respect to coal dust, the greater the concentration the greater the surface of this screen per unit of volume, and the more favorable are the conditions for propagating the flame. But with a dust cloud composed partly of inert particles, these serve the same screening purpose, but do not take part in the combustion. They do not act like an excess of carbon, but merely by their screening effect they exercise a retarding influence in addition to that of the heat which they absorb in attaining the temperature of the flame.

By a careful interpretation of the analyses of gas taken during the explosions, it was demonstrated that certain particles of the coal were completely consumed, while others participated only to the extent of their volatile matter. For the propagation of the flame it is necessary that the proportion of substances undergoing rapid combustion—that is, the fine dusts and the distilled gas—should be somewhat more than enough to make the mixture inflammable, so that a sufficient amount of heat shall be disengaged to raise the dust cloud in front of the flame to the temperature of ignition. This may result from the volatile matter, or from the finest coal dust, or from a combination of the two. These, however, are complicated questions to be dealt with only by further experimental work.

#### FIRST SERIES OF EXPERIMENTS AT PITTSBURG TESTING STATION.

During the past year the writer has studied a number of coals with respect to their relative absorption of oxygen from oxidizing agents, especially standard solutions of chromic acid, with the thought that the amount of absorption would be indicative of the relative tendency

of the different coals to take up oxygen from the air or to undergo spontaneous combustion.

In this connection it seemed desirable also to determine, if possible, the relative inflammability of some of these same coals, and quite recently, with this in view, a series of experiments was carried out on some of the same dusts used in studying the rate of oxidation. The apparatus used for this work is a modification of that of Bedson and Widdas described above.

Plate VIII, *A*, shows the form of apparatus used. *A* is an ordinary 2-liter aspirator bottle. *B* is a small filter flask of about 250 cubic centimeters capacity, connected at *a* by rubber tubing with *C*, a glass bulb of about 150 cubic centimeters capacity, and through the rubber stopper with the open manometer *c*. *D* is a glass tube 6.5 millimeters in internal diameter and 20 centimeters long, passing through holes in opposite sides of a box support, and set in firm and level position with plaster of Paris.

Through a rubber stopper in the mouth of *A* pass two large copper wires, which form the terminals for the platinum coil *d*. Through a hole in the same stopper passes a glass tube 13 millimeters in internal diameter, which is closed at the top, and to which is sealed a side tube (*e*) of the same diameter as *D*. This side tube is connected closely, end to end, with *D* by means of a short rubber tube. The platinum coil *d* is made from about 120 centimeters of No. 26 platinum wire, is suspended in two sections from a small perforated porcelain plate, and is connected with the copper terminals. The porous plate serves not only as a support for the coil but as a protection to the rubber stopper above from too high heating during the experiment, and also tends to disseminate the dust more uniformly in the upper part of the flask. The platinum coil when in position hangs slightly above the center of the bottle.

The tube *f* passing through the stopper in the tubulure at the bottom of the bottle is bent at a right angle and is made funnel-shaped at one end. The end carrying the funnel is directed upward inside the bottle toward the platinum coil, and directly under and within about 5 centimeters of it. In this funnel is placed the coal dust which it is desired to examine. The funnel and the fine wire gauze with which it is covered aid in securing a more complete dissemination of the dust when it is ejected from *f*. By means of a rubber tube *f* can be connected with *C*. Pinchcocks are at *g*, *h*, and *j*.

The terminals of the coil *d* are connected in series with an ammeter and rheostat. The relative pressure produced by the ignition of different dusts is measured by the distance to which a small steel ball (*b*) is projected, when this ball is placed at a definite point in *D* and in which it fits snugly.

Before each experiment the bottle *A* is thoroughly cleaned out and fresh air aspirated through it. Fresh air is also forced into *B* and *C* through *g* (pinchcock *h* being also open) until the desired pressure of mercury is indicated in the manometer *c*. The cock *h* is then closed and remains closed during the remainder of the experiment. The stopper carrying the coil is put in place, and the tubes *e* and *D* are connected. The tube *f*, containing the coal dust, is inserted in its proper place and connected with *C*.

To secure comparable results the coil is always heated the same length of time, three minutes, before the dust is scattered from *f*. The same current is used each time, and is kept perfectly constant the entire three minutes. With the coil used in these experiments a current of 6 to 7 amperes has been found satisfactory.

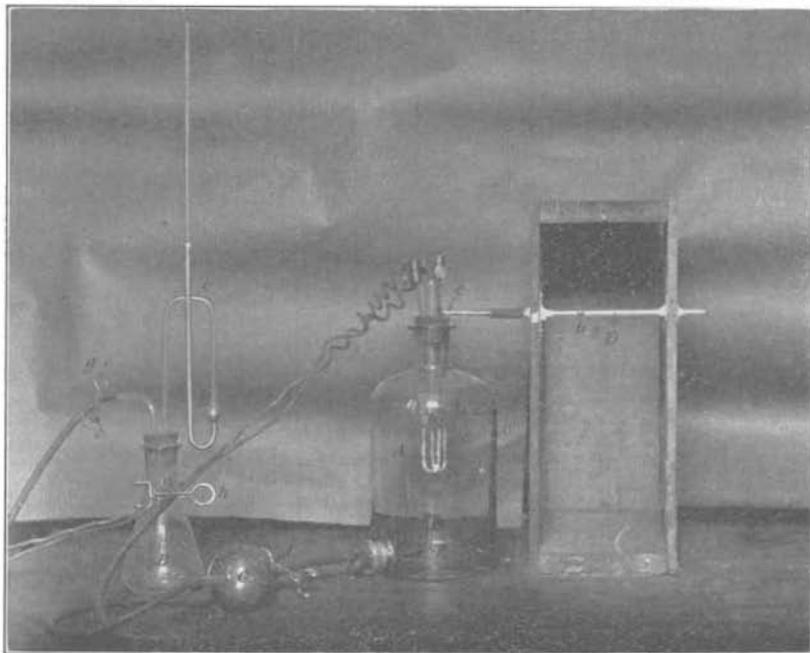
Just before scattering the dust the steel ball is placed exactly in position. At the end of the three minutes the cock *j* is released instantaneously, and the air entering *A* puffs the dust into the bottle and about the coil. It has been found better for the operator to replace the cock *j* and pinch the tube with his fingers before releasing, as the instantaneous release can be accomplished much more certainly in this way. The pressure in the bulb *C* of 150 cubic centimeters capacity being 165 millimeters of mercury, the pressure resulting therefrom in *A* would be only about 12.7 millimeters.

With the apparatus and method of procedure described above, the ignition of a number of coals has been studied. In every experiment ignition has taken place readily, except those with anthracite, natural coke, and charcoal.

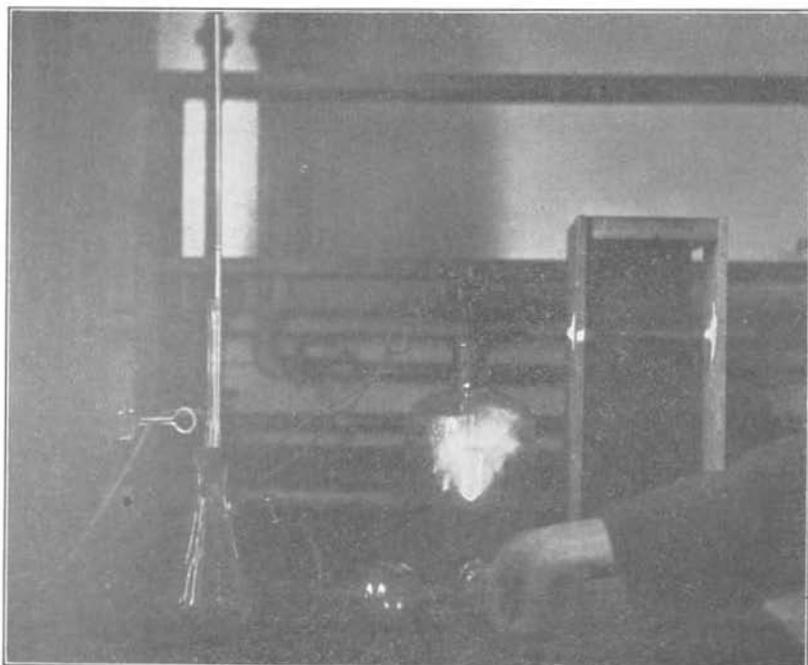
With a pressure in *C* of 165 millimeters of mercury, and a current of 6 to 7 amperes, 0.04 gram of dust was found quite sufficient for producing decided inflammation with all the coals investigated, with the exception already noted, and with some coals even less than this amount was required to produce measurable results.

In the table below are given the results of experiments with 11 coals of varying character and from different sources. In each experiment 0.04 gram of dust was used, dust meaning coal finely ground and passed through a 100-mesh sieve. The current employed was 6.4 amperes; the pressure in *C* was 165 millimeters of mercury.

In the first column of the table is given the character of the coal, while the third column shows, in centimeters from the end of the barrel *D*, the distance to which the metal ball was projected.



A. COAL-DUST IGNITION APPARATUS USED AT PITTSBURG.



B. APPARATUS USED AT PITTSBURG, SHOWING IGNITION OF DUST.



*Results of laboratory experiments with explosive coal dusts at Pittsburg station.*

Character of coal.	No. of experiment.	Distance ball was projected.	Character of coal.	No. of experiment.	Distance ball was projected.
		<i>Cm.</i>			<i>Cm.</i>
Pennsylvania bituminous....	1	318	New Mexico bituminous.....	1	323
	2	325		2	312
	3	325		3	307
Illinois bituminous, noncoking.....	1	281	Kentucky cannel.....	1	317
	2	262		2	309
	3	284	Texas lignite.....	1	353
	4	277		2	339
Illinois bituminous gas coal...	1	326	Dakota lignite.....	1	321
	2	335		2	293
Montana bituminous.....	1	306	Colorado lignite.....	3	295
	2	312		4	295
	1	302		5	309
West Virginia bituminous....	2	320		6	319
	3	315		1	312
Alabama bituminous.....	1	323		2	363
	2	326		3	343

In the above tabulation no account is taken of the moisture or ash in the coals, nor of any deterioration of any of the samples that may have taken place before or after powdering and storing in bottles. As is shown in the table, lignites generally exhibited greater irregularity of results. The coals are not greatly differentiated here, probably because the heat supplied by the wire was too great in comparison with that supplied by the dust in burning, so that the differences of the dusts were masked.

The photograph reproduced in Plate VIII, *B*, was taken during one of the experiments. The flame observed has been in every test apparently confined to the upper half of the 2-liter bottle, as shown here. Consequently, the density of the mixture of dust and air at which the ignition occurred is not 0.04 gram of dust in 2 liters of air, but greater than that, 0.04 gram in less than 1 liter. Furthermore, the phenomena can not be considered as indicating indefinite propagation of the flame in an atmosphere containing the same density of dust, but only indicate propagation in the available space, and under the conditions of these experiments. It may be desirable to add that the inflammation was in all tests practically instantaneous and similar in appearance to the ignition of a slightly explosive gas mixture.

A great deal more work would have to be done before any positive statement could be made concerning the relative behavior of different coals. The same is true with respect to the effect of variations in the current used, and in the pressure with which the dust is brought into the bottle. A definite strength of current does, however, seem to be required for complete ignition, and beyond that strength variation of current has no effect. The initial pressure of the ignition mixture is probably of considerable importance.

An objection to the use of a platinum coil as a source of ignition is the possible catalytic action of the platinum.

It is hoped that further experiments can be performed on the ignition of coal dust by the use of pressure alone. It should be understood that the record given above is to be taken as a preliminary report of a few experiments performed under limited conditions, which are to a large extent repetitions of previous experiments, with some minor alterations of apparatus and method of manipulation.

#### SECOND SERIES OF EXPERIMENTS AT PITTSBURG TESTING STATION.

A second series of experiments is now in progress in which the pressures developed in the explosion vessel are measured by a different method. This method was adopted because the maximum pressure in many cases is not developed instantaneously, and the method previously used would on that account not give a true measure of the force of the explosion. The explosion vessel now in use is a 1,500-cubic centimeter glass globe with two tubulures on opposite sides. The dust is puffed into the vessel through the lower opening in much the same manner as in the experiments described above. Into the top opening is inserted a stopper carrying the same platinum coil used in the previous work. The measurement of the pressure is accomplished in the following way: A brass tube of 7 millimeters diameter is passed vertically through the rubber stopper which carries the connections of the platinum coil. (See Pl. VIII, A.) The top of this tube is ground so that a  $\frac{5}{16}$ -inch steel ball fits on it practically gastight. The pressure developed within the explosion vessel is measured by ascertaining by several trials the smallest weight which must be placed on the steel ball to prevent it from being lifted. Thus the total pressure exerted on a known area is obtained directly. The experiments have given concordant results, as the table below shows. The above method of testing the inflammability of coal dust is being used in the Bureau of Mines laboratory at Pittsburg, Pa.

*Results of second series of experiments with explosive coal dusts at Pittsburg station.*

[In all tests the amount of dust used was 0.04 gram.]

Source and proximate analysis of coal dust used and pressure developed in tests.	Results of tests.		
	Weight applied.	Equivalent per sq. cm.	Effect on steel ball.
	Grams.	Grams.	
1. Bituminous coking coal from Hastings mine, Las Animas County, Colo. (Lab. No. 9780):	300	779	Not lifted.
Moisture..... 1.43	275	714	Do.
Volatile matter..... 33.98	250	649	Do.
Fixed carbon..... 57.46	225	584	Do.
Ash..... 7.13	200	519	Do.
Sulphur..... .57	175	454	Do.
Pressure developed, less than 454 grams per square centimeter.			

*Results of second series of experiments with explosive coal dusts at Pittsburg station—Cont'd.*

Source and proximate analysis of coal dust used and pressure developed in tests.	Results of tests.		
	Weight applied.	Equivalent per sq. cm.	Effect on steel ball.
2. Bituminous free-burning domestic coal from Chandler mine, Fremont County, Colo. (Lab. No. 9778): Moisture..... 6.49 Volatile matter..... 35.69 Fixed carbon..... 52.25 Ash..... 5.56 Sulphur..... .49 Pressure developed, 666 grams per square centimeter.	Grams. 250 260 255 258	Grams. 649 675 662 670	Lifted. Not lifted. Lifted. Not lifted.
3. Bituminous, noncoking steam or domestic coal, with cubical or round fracture, from Maitland mine, Huerfano County, Colo. (Lab. No. 9784): Moisture..... 4.74 Volatile matter..... 38.24 Fixed carbon..... 49.32 Ash..... 7.70 Sulphur..... .60 Pressure developed, 751 grams per square centimeter.	250 270 272 280 285 290 288 290	649 701 706 727 740 753 748 753	Lifted. Do. Do. Do. Do. Not lifted. Lifted. Not lifted.
4. Noncoking, bituminous coal of "nigger head" or round formation from Ravenwood mine, Huerfano County, Colo. (Lab. No. 9781): Moisture..... 3.49 Volatile matter..... 37.46 Fixed carbon..... 49.62 Ash..... 9.43 Sulphur..... .99 Pressure developed, less than 390 grams per square centimeter.	275 260 290 150	714 675 519 390	Not lifted. Do. Do. Do.
5. Bituminous coking coal from Delagua mine, Las Animas County, Colo. (Lab. No. 9785): Moisture..... 2.15 Volatile matter..... 34.45 Fixed carbon..... 53.42 Ash..... 9.98 Sulphur..... .48 Pressure developed, 647 grams per square centimeter.	250 259 240 245 250 248	649 649 623 636 649 644	Not lifted. Do. Lifted. Do. Not lifted. Lifted.
6. Bituminous coking coal from Bowen mine, Las Animas County, Colo. (Lab. No. 9779): Moisture..... 1.44 Volatile matter..... 31.84 Fixed carbon..... 50.88 Ash..... 15.84 Sulphur..... 3.21 Pressure developed, 652 grams per square centimeter.	250 270 260 255 252	649 701 675 662 654	Lifted. Not lifted. Do. Do. Do.
7. Bituminous coking coal, high carbon, from Sun No. 2 mine, Fayette County, W. Va. (Lab. No. 9783): Moisture..... 0.96 Volatile matter..... 21.08 Fixed carbon..... 73.38 Ash..... 4.58 Sulphur..... .51 Pressure developed, 426 grams per square centimeter.	250 230 200 150 160 170 165 163	649 597 519 390 415 441 428 423	Not lifted. Do. Do. Lifted. Do. Not lifted. Do. Lifted.
8. Bituminous coking coal from Ansted mine, Fayette County, W. Va. (Lab. No. 9787): Moisture..... 1.83 Volatile matter..... 33.61 Fixed carbon..... 58.94 Ash..... 5.62 Sulphur..... .74 Pressure developed, 800 grams per square centimeter.	320 310 305 307 309	831 805 792 797 802	Not lifted. Do. Lifted. Do. Not lifted.

Results of second series of experiments with explosive coal dusts at Pittsburg station—Cont'd.

Source and proximate analysis of coal dust used and pressure developed in tests.	Results of tests.		
	Weight applied.	Equivalent per sq. cm.	Effect on steel ball.
9. Bituminous coal, coking, from Gem mine, Campbell County, Tenn. (Lab. No. 9782):			
Moisture..... 3.58	250	649	Not lifted.
Volatile matter..... 34.18	170	441	Do.
Fixed carbon..... 54.98	140	363	Do.
Ash..... 7.26			
Sulphur..... .74			
Pressure developed, less than 140 grams per square centimeter.			
10. Bituminous coal, steam and domestic, from Wooldridge mine, Campbell County, Tenn. (Lab. No. 9786):	250	649	Lifted.
Moisture..... 2.73	300	779	Do.
Volatile matter..... 35.85	320	831	Not lifted.
Fixed carbon..... 54.88	310	805	Lifted.
Ash..... 6.84	312	810	Not lifted.
Sulphur..... 1.07			
Pressure developed, 808 grams per square centimeter.			
11. Bituminous coking, high carbon coal from Jed mine, McDowell County, W. Va. (Lab. No. 10034):	250	649	Not lifted.
Moisture..... 1.01	100	259	Do.
Volatile matter..... 14.52			
Fixed carbon..... 77.65			
Ash..... 6.82			
Sulphur..... .71			
Pressure developed, less than 259 grams per square centimeter.			
12. Bituminous coking, high carbon coal from Elk Ridge mine, McDowell County, W. Va. (Lab. No. 10035):	250	649	Not lifted.
Moisture..... 0.97	100	259	Lifted.
Volatile matter..... 17.57	120	311	Not lifted.
Fixed carbon..... 77.65	110	286	Do.
Ash..... 3.81	105	272	Do.
Sulphur..... .58	102	265	Do.
Pressure developed, 262 grams per square centimeter.			
13. Bituminous, noncoking coal from Woodside mine, Sangamon County, Ill. (Lab. No. 9774):	250	649	Not lifted.
Moisture..... 13.13	225	584	Do.
Volatile matter..... 35.00	200	519	Lifted.
Fixed carbon..... 41.53	210	545	Do.
Ash..... 10.24	212	550	Not lifted.
Sulphur..... 3.48			
Pressure developed, 548 grams per square centimeter.			
14. Bituminous, noncoking coal from Little Vermilion mine, Vermilion County, Ill. (Lab. No. 10037):	250	649	Not lifted.
Moisture..... 13.92	150	390	Lifted.
Volatile matter..... 33.24	200	519	Do.
Fixed carbon..... 45.39	202	524	Not lifted.
Ash..... 7.45			
Sulphur..... 1.05			
Pressure developed, 522 grams per square centimeter.			
15. Subbituminous noncoking coal from Navajo mine, N. Mex. (Lab. No. 10038):	200	519	Lifted.
Moisture..... 12.65	230	596	Do.
Volatile matter..... 39.57	250	649	Do.
Fixed carbon..... 37.67	260	675	Do.
Ash..... 10.11	280	727	Do.
Sulphur..... .47	285	740	Not lifted.
Pressure developed, 730 grams per square centimeter.	282	732	Do.

*Results of second series of experiments with explosive coal dusts at Pittsburg station—Cont'd.*

Source and proximate analysis of coal dust used and pressure developed in tests.	Results of tests.		
	Weight applied.	Equivalent per sq. cm.	Effect on steel ball.
16. Subbituminous, noncoking coal from Weaver mine, N. Mex. (Lab. No. 10039):			
Moisture..... 12.14	Grams. 282	Grams. 732	Not lifted.
Volatile matter..... 38.82	230	597	Lifted.
Fixed carbon..... 37.78	240	623	Not lifted.
Ash..... 11.26	235	610	Do.
Sulphur..... .52	232	602	Do.
Pressure developed, 606 grams per square centimeter.			
17. Subbituminous, noncoking coal from Superior mine, Wyo. (Lab. No. 10040):			
Moisture..... 10.45	290	519	Lifted.
Volatile matter..... 38.28	225	584	Do.
Fixed carbon..... 45.06	250	649	Do.
Ash..... 6.21	260	675	Do.
Sulphur..... .85	270	701	Do.
Pressure developed, 718 grams per square centimeter.	280	727	Not lifted.
	275	714	Lifted.
	278	722	Not lifted.
18. Subbituminous, noncoking coal from Superior mine, Wyo. (Lab. No. 10041):			
Moisture..... 5.17	250	649	Lifted.
Volatile matter..... 43.23	300	779	Not lifted.
Fixed carbon..... 52.77	275	714	Lifted.
Ash..... 1.83	290	753	Do.
Sulphur..... .68	295	766	Do.
Pressure developed, 760 grams per square centimeter.	300	779	Not lifted.
	297	771	Do.
19. Subbituminous, noncoking coal from Weaver mine, N. Mex. (Lab. No. 10042):			
Moisture..... 12.81	278	722	Lifted.
Volatile matter..... 38.83	300	779	Do.
Fixed carbon..... 43.06	305	792	Not lifted.
Ash..... 5.30	302	784	Lifted.
Sulphur..... .59			
Pressure developed, 782 grams per square centimeter.			

The experiments recorded in the table were made on equal weights of the dusts, and each sample was ground to pass through a 100-mesh sieve. These results are interesting chiefly for two reasons. First, they show what degree of accuracy may be expected from this method of examining the explosive character of dusts. From experience it may be stated that the pressures developed in almost all of the tests could be measured to about 3 per cent of the total pressure developed. Second, the results are of most importance in showing the care which must be taken in preparing the dusts in order that the results obtained with different coals may be strictly comparable. Each sample of coal was ground in a ball mill, so that the whole of the sample passed through a 100-mesh sieve, and efforts were made to have them ground as nearly as possible to the same degree of fineness. But this object was not attained by any means. It was shown that fully 90 per cent of those dusts which developed the greatest pressures in the explosion vessel would pass through a 200-mesh sieve, whereas of some samples only about 30 per cent would

pass through the same sieve. To obtain comparable results it will be necessary to impart to all of a sample such a degree of fineness that the whole amount introduced into the explosion vessel will take part in the explosion. A series of experiments is being conducted on the same coals that were used in the tests described above. The samples used in this series were ground so that the whole passed through a 200-mesh sieve. The following results of experiments are given for comparison of the pressures developed in the previous experiments with the pressure developed by the same samples ground to pass through a 200-mesh sieve.

*Comparison of pressures developed by 100-mesh and 200-mesh coal dusts of like composition.*

		Grams per sq. cm.
Coal No. 9780	{ 100-mesh.....	Less than 454
	{ 200-mesh.....	549
Coal No. 9778	{ 100-mesh.....	666
	{ 200-mesh.....	703
Coal No. 9784	{ 100-mesh.....	751
	{ 200-mesh.....	774
Coal No. 9781	{ 100-mesh.....	Less than 390
	{ 200-mesh.....	626
Coal No. 9785	{ 100-mesh.....	647
	{ 200-mesh.....	667

If it is not possible to obtain dust sufficiently finely divided to get comparable results it will be necessary to screen the samples used for the tests with more than one sieve and to use in each test only dust whose particles are between certain sizes. This process may change somewhat the composition of the dust from that of the original coal and will not be used except as a last resort.

#### SIGNIFICANT POINTS IN EXPERIMENTS.

In closing this short summary of the laboratory experiments on the ignition of coal dust, it may be well to call attention to certain facts which they show. In the first place, the phenomenon of ignition is very complex, and for that reason it is necessary to have the proper conditions in order to demonstrate the ignition of coal dust on a laboratory scale. It has been pretty well demonstrated by these experiments that the order of inflammability of a coal dust is a function of the amount and character of the volatile matter which is expelled, the ease with which it is given up, the fineness of division of the dust particles, the density of the cloud, the character of the source of ignition, the amount of water and ash, and, finally, the pressure prevailing in the neighborhood of the flame. It does not seem that sufficient attention has been given to the last condition. Several facts brought out in the experiments support this statement.

Unless there is an exceptionally large amount of dust in the air, experience shows that ignition does not take place from a naked flame.

This fact is illustrated by the work of Galloway, and that of Mallard and Le Chatelier (who used for the source of ignition different kinds of naked flames, and accords with the conclusions which they reached as a result of their work. It will be recalled, too, that Holtzwardt and Meyer drew attention to the fact that no ignition was obtained if they introduced lignite dust into their apparatus, and, after establishing the spark between the terminals within, disseminated the dust in the air by shaking the tube. But when the dust was puffed between the terminals by compressed air ignition occurred. Dust explosions in mines and in successful experiments in galleries specially designed for these investigations are preceded by violent compressions simultaneously with the production of a large flaming area by the charge of explosive (the means of ignition always used). Attempts will be made to ascertain the effect of pressure alone on coal dust suspended in air and in some inert gas.

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JOSEPH A. HOLMES, DIRECTOR

THE  
EXPLOSIBILITY OF COAL DUST

BY

GEORGE S. RICE

WITH CHAPTERS BY

J. C. W. FRAZER, AXEL LARSEN, FRANK HAAS,  
AND CARL SCHOLZ

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