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Is Dust, As Such, Explosive?

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What are the Chemical Reactions and the Most Efficient Preventatives?

BY

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The subject which has been assigned to me is one that has disturbed the keenest minds of our profession for a century or more, and it may be unnecessary to state that this paper does not assume to explain the problem fully, nor with complete satisfaction.

By dust, I take it, is meant such particles of coal which are transported from their original position by the air current. The sizes of the particles so affected will vary with kind of coal and velocity of current. The term "dust" has in past literature had a very loose definition, in fact a satisfactory one has not been discovered. No experiments, at least no results of experiments, are reported as to the size of particles which are maintained in suspension by air currents of certain velocities. The definition of dust, if it ever will be developed, will be flexible and amendable depending on conditions of which velocity of air currents will be the most important. Recent French writers in conducting their experiments on dust have used the size that passes through a two hundred mesh screen. In this country, (probably merely as a starting point), a 100 mesh screen was adopted and in some cases an 80 mesh screen. By actual experiment it was determined that such coal which will pass through an 80 mesh and over a 100 mesh, is not maintained suspended in a velocity of 1200 feet per minute, which is a comparatively high velocity when considering mine currents, and it would appear from this that our standard of 100 mesh is still too coarse.

However, this need not enter into the discussion, as we know that in case of an explosion there is no discrimination as to the size of the particles affected. In fact I am satisfied, in my own mind, that the bulk of the force of the Monongah explosion originated in the solid coal. From a strictly technical standpoint I would say that dust is not explosive, no more so than solid coal.

An explosion is defined as rapid combustion. How rapid it does not state, but we know that it must be almost instantaneous.

If it were possible to get ten parts of air by weight in immediate contact with one part of coal, an explosive mixture would be obtained. This, however, is impossible, as one volume of coal by weight is equal to 1065 volumes of air by weight. It would, therefore, require 10,650 volumes of air, each particle of which to be in intimate contact with one volume of coal. Furthermore, the temperature of volatilization of coal is less than that of ignition, therefore, coal dust would become coal gas and coke before the temperature, where explosion is possible, is reached. The argument then is this, that the explosions which are attributed to coal dust are really explosions of coal gas. This distinction, in so far as the results are concerned, is slight, but it is essential nevertheless, for no investigation of dust can be successful without accounting for the volatile gases, and furthermore, there are other sources of coal gas, the solid coal, which might be overlooked if dust alone was considered the source of all the danger. With this explanation we can repeat that "dust, as such," is not explosive.

All coals when exposed to a temperature of over 250 deg. Fahrenheit will liberate gases, the amount so liberated will depend on the character of the coal, the temperature and the time of such exposure. If such temperatures should occur in a mine, combustible gases would be formed and the formation of explosive mixtures highly probable. It is not to be inferred, however, that gas or high volatile coals are the most dangerous. It is a question of how much coal is effected rather than the amount given off by each particle, and a very low volatile coal may give off some gas just as readily as a higher volatile one.

Some time ago some experiments were made to determine the rate of burning and amount of heat given off in successive units of time, in which three kinds of coal were used: first, a high volatile gas coal of about 35% of volatile matter; second, a semi-bituminous coal of about 20% volatile matter; and third, anthracite coal with about 3% of volatile matter. While the experiments were made in the furnace of a steam boiler for the purpose of purely practical results, and therefore lack the accuracy of labratory determinations, yet they show the tendency, if not the exact measure of the reaction involved.

Among other data of interesting and useful application elsewhere, there were developed these facts pertaining to the subject in hand. The first 5% of the total volatile matter given off by anthracite coal had a heating value of 27,000 B. T. U. per pound of volatile matter.

For the semi-bituminous this figure was 19.300 B. T. U; and the gas coal but 16,600 B. T. U. This would indicate that irrespective of other conditions, the first gases given off by anthracite are the most powerful explosively, and the general statement can be made that the lower the volatile matter in a coal, the higher the calorific power of the first gases given off. Following the curve further, we find that at 23% of total volatile matter given off, the value of the gas of the anthracite and semi-bituminous are the same at 20,400 B. T. U., while the gas coal volatile was 16,600 B. T. U. At 38% of total volatile gas the anthracite had dropped to that of the gas coal at 16,900. The semi-bituminous was not determined.

These results will warrant the statement that if an equal quantity of gas is given off from these three kinds of coal in the first unit of time, the anthracite will, by far, produce the most violent explosion. Anthracite is not immune from dust explosion, and while the conditions are difficult and improbable they are not impossible, and should ideal conditions for an explosion present themselves in an anthracite mine we may prepare ourselves for the most violent explosion that has yet occurred.

The probability of favorable conditions are decidedly minute with anthracite, as compared with semi-bituminous or bituminous coals, and should dust explosions occur in the future, as they probably will, we will likely find them in coals of the bituminous or semi-bituminous class.

The composition of the gases given off is extremely variable and a discussion of all the different combinations that are possible would be an endless task and but little could be learned from it, but a single case can be taken and its physical and chemical features discussed, and for such an example we will take a gas which is the complete volatilization of a high volatile coal.

The subject requests that reactions be given, but as there are problems of stoichiometry involved, which are both laborious and uninteresting the reactions which can be readily reproduced will be omitted.

The composition of such coal gas is approximately as follows:

		By volume	*By weight*
Illuminants	C_2H_4	2.8%	6.1%
Marsh Gas	CH_4	25.1	30.7
Hydrogen	H	41.3	6.3
Carbon Monoxide	CO	7.2	15.4
Carbon Dioxide	CO_2	2.3	7.7
Oxygen	O	.4	.9
Nitrogen	N	5.4	11.6
Moisture	H_2O	15.5	21.3

The first so called illuminants (because of its high illuminating power) is mostly Ethylene, a combustible gas of high heating power. Marsh gas which is the same as the principal gas of the miners "fire damp" is also combustible. Hydrogen is a very light gas of high heating power, it combines with the oxygen of the air forming water. Carbon Monoxide which is the miners "white damp" is not only combustible but highly poisonous when inhaled. Carbon Dioxide or "black damp" is the result of the combination of carbon or such gas which contains this element; it is non-combustible. Oxygen and Nitrogen are the two elements of the air. The Water is the evaporated moisture of the coal, together with its combined water.

In some of the literature which has referred to gas given off by coal, it is stated that carbon monoxide is the principal gas so given off. This, I believe is in error, for at no time during the complete volatilization of coal is carbon monoxide, the principal ingredient of the gas mixture. A failure to find any considerable quantity of this gas after an explosion would by no means be evidence that the coal was not volatilized.

The illuminants, marsh gas, hydrogen gas and water vapor would, in all probability form the bulk, if not all of the gases previous to their explosion.

The combination of these gases is combustible, with a steady supply of air and explosive within certain percentages in a mixture with air. For an explosion of maximum intensity, it requires by volume one part of gas to four and one-half parts of air.

Under the conditions of perfect mixture and ignition three manifestations of force are in evidence,—a rise in temperature, an increase in pressure and an expansion in volume. If there is no space for expansion and the volume remains constant a temperature of about 4300 deg. Fahrenheit would be theoretically reached, with a pressure approximating 134 lbs. to the square inch. If, however, there is room to expand under atmospheric pressure the volume would be increased to about nine times the original volume.

These manifestations of force are all reciprocal, and none of the above theoretical figures are even approximated. The pressure depends on the temperature, the size of the area affected and the area of escape from the explosion center. The volume depends on the temperature and the quantity of gas exploded, while the temperature, which is really the initiative, is widely effected by the quality of the gas and quantity of air with which the gas is mixed. Radiation, conduction and convection, all antagonistic to temperature, tend towards a decided diminution from the maximum.

The maximum pressure of a theoretical mixture is alarmingly high; but with all these counteracting forces it is my opinion that 50 lbs. to the square inch would cover the maximum pressure encountered in actual explosions, at least those which have come under my observations. While such a pressure is capable of enormous power, it is still within human control.

Air, as has been previously stated, is a necessary element for an explosion. Coal and coal dust are always in excess and the amount of gas that could be given off is incalculable. The air, however, is limited and the quantity is readily determined by a measurement of the volume of the mine from which coal has been displaced and the roof intact. From this it can readily be seen that the quantity of air, rather than the quantity of dust or coal, is really the measure of the magnitude of an explosion.

There is considerable difference in the physical results of an explosion from "fire damp" and from coal gas. "Fire damp" at its maximum will develop a theoretical temperature, pratically the same as the gas coal, we have previously discussed, the difference between the two, however, is in the character of the products of combustion.. The gases which result from the explosion of coal gas when cooled down to their original temperature and pressure occupy 10% less volume than the original explosive mixture, while from an explosion of "fire damp" they occupy 19% less than the original volume. This would explain, in part, the greater violence of so called dust explosions and would also show that they would not be followed by a "back lash" to the extent of a "fire damp" explosion. Another very important feature about a coal gas explosion is that it is able to regenerate itself; that is, after an explosion has occurred it can continue to volatilize gas and explode if it should come in contact with air. This could continue until the temperature was below the volatilization point or until the mine was on fire. With a pure "fire damp" explosion this could not occur, for, after the gas is once exploded there is nothing further to feed it.

Coal dust has the property of absorbing and holding moisture when surrounded by favorable conditions in the atmosphere.

A direct mixture of dust and water is very difficult and practically impossible. It appears that the time element has considerable to do with the absorption of water by dust, and moist atmosphere is necessary for it to retain the water so absorbed. A series of experiments were carried out to determine the amount of water which dust will absorb and retain. In normally dry atmosphere the dust which was experimented on contained about 1.50% of water. In the return air-way of a mine in which the air was held to its highest point of saturation, dust was collected from the side walls of the entry where it had lodged on the small projections of the solid coal. The results as obtained were extremely variable, running from four per cent moisture as a minimum to 42% as a maximum, with an average of 25%. The atmospheric conditions surrounding each particle being practically the same there should be more uniformity in the results, if the water so determined was one of the physical properties of the dust. As this was not the case, however, it was concluded that the minimum was more nearly the absorptive power of the coal, while any additional water, over the minimum, was merely mechanically held in contact.

For all practical purposes it is immaterial whether the water is chemically or mechanically held; its effect is the same. The quantity is surprisingly large and it is a most fortunate circumstance. If such conditions could be maintained uniformly throughout a mine, a very formidable obstacle, if not a preventative is placed in the way of possibility of volatilization and explosion of coal dust.

The difference in calorific intensity of the volatile gas of dry coal and that of wet dust, (containing 25% of water), is insignificant from a practical view point. It is in the quantity of heat necessary to volatize coal and to bring the gas to the ignition point that is the most important consideration. If we assume the average per cent of moisture (25%), which we have determined, it would require two and one-half times as much heat to bring the wet coal and dust to the critical point as with dry dust. Considering the comparative infrequency of dust ignition this additional obstacle can be accepted as of considerable magnitude. In addition to its effect as a preventative the water so contained would have a marked effect on the force of the explosion as well as a cooling effect on conditions subsequent to the explosion, when danger from fire is always imminent.

It has been asserted by some few that a wet condition in a mine is a source of danger, that explosions are more liable to occur and that conditions for propagation of an explosion are more favorable. Such a statement is incomprehensible to me, as I can find no law in physics or chemistry that would substantiate it. Water either as liquid or vapor has the highest specific heat of any matter, either as liquid, solid or gas, which can occur in any considerable quantity in a mine, and it therefore requires more heat with a corresponding greater drop in temperature. The argument is evidently based on the decomposition of water vapor forming hydrogen and oxygen.

That the decomposition of water vapor by heat and temperature is possible we do not deny, but it is not only heat and temperature but also pressure which enters into the conditions. Under ordinary pressure the temperature necessary for such decomposition is very high and with 50 lbs. to the square inch pressure this temperature would have to be enormously increased and in my opinion to an extent beyond practical possibility. I do not question the records of facts and observations which have lead up to this opinion, but I do question the interpretations that have been put on these observations, and am of the opinion that other conditions, perhaps unnoted, occasioned such misinterpretations. Water has been, and always will be, the most efficient and by far the most economical material that can be introduced into a mine as a preventative of initial, as well as the propagation of an explosion.

With no further thought on the subject the question would be simple indeed, but there are several physical properties and characteristics of coal dust that must be considered. The effect of a spring rain on a duck's back is proverbial. To make mud out of coal dust by the direct application of water is practically impossible. Coal when in a finely powdered form has some of the characteristics of oil, and it is probable that if the mineral ingredients were completely removed it would make a lubricant of some value.

Water by direct application is obstinately resisted by coal dust, yet we know that it has some absorptive power, and this leads one to suspect that the element of time and temperature as well as the manner of application play important parts in the operation. Water vapor has the property of greater penetration than the liquid, and it is in this form of water that practical results may be realized. A saturated atmosphere at a high temperature, and in constant contact would be the most efficient method. Saturation to a certain degree can be attained but the temperature of a mine is fixed with but slight variation between the seasons of the year. A change in this temperature would be impractical and objectionable for various reasons. The best that can be done would be to maintain the uniform temperature of the mine and hold it to the highest point of saturation. This would fulfill the requirements for maximum absorption. The mines with which I am most familiar have a temperature of about 60 deg. Fahrenheit; with a complete saturation, the mine air would contain nearly 10 gallons of water per 100,000 cubic feet. Complete saturation can hardly be attained by practice and 85% would probably be more nearly the best results that could be attained, this would mean about 8.8 gallons of water per 100,000 cubic feet.

As a cause of explosions I have no faith in the theory of occluded gas. in the distant discharge of explosive mixtures by pressure, in the combustion of coal by friction or the unknown atmospheres generated by electric current.

The causes of mine explosions, I believe are well within the present knowledge of chemistry and physics, but it is the lamentable ignorance in the interpretation of the multitudinous and therefore complicated conditions which exist, each of which, simple of comprehension in itself, but enormously complicated in the aggregate, that has so far prevented a rational explanation of all.

It would be advisable then, to study more the conditions which are possible to occur, rather than to call on the mysterious or supernatural for new theories.

In proposing "Efficient Preventatives," which the subject calls for, we confine ourselves strictly to coal dust. The first and by far the most effective is "Keep the atmosphere of the mine saturated by whatever means practicable." Sprinkling in itself is not very effective, local and intermittent in application as it necessarily must be it does not supply the moisture uniformly, nor in its most available form, yet it must be admitted in the absence of other methods it can be considered as a precautionary measure. The system of water sprays, which is elaborate and expensive is probably more effective, but still falls short of complete success, unless the temperature of the mine is under control. A third method which has so far given much promise, is the preheating of the intake air with saturation by exhaust steam. This method in its preliminary trials has given satisfactory results. A thorough study of the process is now under way,—the results of which will appear in a subsequent paper on the "Control of Humidity of Mine Air."

Removal of dust should be carried out as thoroughly as practicable, so many considerations exist outside of danger, from a sanitary and economical standpoint that no argument is needed.

The suggestion recently made to abandon mining machines on account of the dust made is a statement based on lack of knowledge of conditions. The quantity of dust (as we understand the term) produced by puncher, chain and pick mining has been investigated recently, and the conclusions reached were that the amount of dust produced was practically the same for all these methods of mining.

I do not believe any conditions which might arise from the presence of an electric current, by short circuit or otherwise are capable of affecting dust to such an extent as to make an explosion possible. The volume of application of the temperature is too limited and the quantity of heat supplied insufficient.

Ventilation has no bearing on the question of danger from dust explosions, nor need safety lamps be considered in this connection. In fact the absolute preventative for a dust explosion is to prevent an initial explosion from some other source, for under no other circumstance can dust be considered dangerous.

Outside of the efforts of the individual operators, our hopes of safety lie in the mining laws and in the intelligent and faithful interpretations, and enforcement of such laws by the District Mine Inspector.

Intelligent, honest, experienced and broad minded men are needed, men fully appreciative of the authority vested in them and comprehensive of the responsibility that rests upon them. Compensations for such Mine Inspectors should be such as to attract the best men in the mining profession in the State.

The State should through its Department of Mines establish and maintain in each mining district instruments for recording the condition of the atmosphere, this would furnish the District Mine Inspector with facts instead of opinions as regards the atmosphere, and would enable him to caution the operators on short notice of any unusual or dangerous conditions. As an example it might be remarked here, that during four weeks in September, of the present year, such an unusual condition of circumstances existed. During this time the atmosphere was unusually dry, and it was estimated, from the records of recording instruments, that during this period the return air ways carried out fully 20% more water than was furnished by the atmosphere in the intake, which in an ordinary sized mine would represent a loss of about 3,000 gallons of water per day.

In the operation of a mine the area under active development should be held to a minimum. I do not mean by this that the total acreage to be worked out by one opening should be limited, but that the working places should be contracted to within as small a space as possible.

We have sufficient evidence to believe that an explosion once started may spread to every nook and corner of the mine, and by minimizing the area the chances for such local explosions are reduced as well as the ultimate magnitude diminished. The panel system should be adopted throughout, abandoned panels which are not pillared (because of surface rights or other causes), should be closed by substantial brattices capable of withstanding the pressure of an explosion.

The present method of mine rating used by some railroads in which the number of working places is the principal factor should be condemned, as it encourages or even forces overdevelopment, which, in our opinion, is dangerous practice.