FUEL RESEARCH INSTITUTE OF SOUTH AFRICA

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MINE EXPLOSIONS

by

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INTRODUCTION

The methods of preventing mine explosions are well known to coal mine workers, but virtually all explosions are the result of human fallibility, that is, carelessness and the disobeying of the safety rules. Through education and strict discipline these failures can be eliminated to a great extent.

One of the major hazards in coal mining is the occurrence of firedamp. It may be released from newly exposed coal faces or freshly broken coal, from accumulations in waste or old workings, from breaks in the strata or from adjacent seams.

Methane-air mixtures are inflammable when the methane content of the mixture lies in the range of 5% to 15%. If this mixture is ignited, a variety of modes of burning may occur. It may be slow, or the flame may spread rapidly and create blast waves. If blast waves occur, there is usually a potential danger of a coal-dust explosion.

Only in this century was it discovered that coal dust plays a rôle in mine explosions. The full importance of coal dust was recognized when the Courrieres explosion in France occurred during 1907, causing the death of 1,100 men.

Up to 1910 hardly any attempt was made to remove coal dust from mine workings. Ventilation was poor and small volumes of methane were disregarded, sometimes with disastrous results.

During the past fifty years mining techniques and methods for the prevention of explosions have become much more effective, but coal mine explosions, with a resultant loss of life, still occur. It is, therefore, necessary to maintain the strictest control to eliminate all factors that might combine to cause even a small

ignition/...

ignition of gas or dust.

To achieve an even greater measure of safety, further studies are being conducted in laboratories, in galleries and in coal mines to obtain information on the causes, the development and the prevention of mine explosions.

DEFINITION OF TERMS CONNECTED WITH EXPLOSIONS

The following is a brief description of terms used in firedamp and dust-air explosion work.

The ignition temperature[22] of a combustible mixture is usually defined as the temperature at which the rate of heat evolution due to chemical reaction exceeds the rate of heat loss from the system.

The temperature at which an explosive mixture ignites can only be defined with respect to the system in which the determination is made. Thus, different ignition temperatures are obtained in flow systems, static systems and vessels of different materials.

A detonation[22] is that process in which an exothermic reaction takes place in a high-pressure wave moving with supersonic velocity with respect to the unreacted material.

An explosion[22], properly an effect and not a cause, is the rapid release of pressure without regard to the source of the pressure.

A coal-dust explosion[2] can be defined as any combustion of a coal-dust cloud in air, provided the combustion or explosion extends beyond the influence of the heat or flame of the igniting source.

The relative flammability[2] of a dust cloud is the percentage of inert required to suppress flame propagation in a dust cloud under otherwise favourable conditions.

A stone-dust barrier[1] is a device intended to extinguish an explosion in a coal mine by smothering the flame with a dense cloud of incombustible dust.

If a combustible gas is added continuously to a given quantity of air, the concentration of the gas eventually reaches a value known

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as the lower limit of flammability[3]. With further addition the upper limit of flammability is reached. Gas-air mixtures whose concentrations are below and above these two limits are not flammable.

Methane has a lower limit of 5% and an upper limit of 14% by volume in air, and in oxygen the limits are 5.15% and 60.5% respectively.

THE FACTORS INFLUENCING GAS EXPLOSIONS

Explosions in coal mines are generally initiated by the ignition of methane gas that is liberated from coal.

Methane[2, 3, 5, 28] is a colourless, odourless, non-toxic gas, lighter than air (s.g. = 0.554), which has lower and upper explosion limits of ± 5% to 15%. The optimum mixture is 9.5%.

With natural gas[2, 28] (83% CH_4 + 16% C_2H_6 + 1% N_2) the ethane tends to increase the hazard by lowering the ignition temperature and increasing the explosion pressure and rate of pressure rise. The optimum concentration for natural gas is 8.6%.

At elevated temperatures[3, 4, 22, 24] the limits of flammability are wider than they are at ordinary temperatures. As the temperature rises, the lower limit drops and the upper limit rises. Temperature also affects the reaction rates, flame speed, tendency to auto-ignite and final product temperature.

Pressure[2, 3, 4, 22] affects the reaction rate, limits of flammability, flame speed and tendency to auto-ignite. A mixture of methane and air, which is compressed before ignition (as may be presumed to occur when an explosive is the cause of ignition) is much more readily ignited than when no compression occurs. There is a minimum pressure below which the mixture will not explode.

The ignition temperature[3, 4, 22] is influenced by the pressure, oxygen content of the mixture, volume of the container of the mixture, and the surface material of the container, and also by the factors which influence the rate of the gas reactions.

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The minimum electrical energy[2, 28] of a spark causing ignition varies with the gas concentration, humidity, oxygen content of the atmosphere, the temperature, and turbulence.

The minimum gas concentration[5, 6] required for ignition decreases linearly from 5% to zero as the airborne coal-dust concentration increases from zero to 0.07 oz/cu. ft.

To ignite firedamp[3, 4, 7, 22, 24] there must be a source of heat of sufficient size, intensity and duration. A heated surface at 650°C can ignite a mixture of methane and air in an enclosed space, but if there is a free circulation round the heated surface the temperature must be 900° to 1000°C.

FACTORS INFLUENCING DUST EXPLOSIONS

To have a dust explosion there must be enough inflammable dust, a means by which the dust is raised as a cloud in the air, and a source of flame or heat intense enough to ignite the dust cloud. These are only the main factors and the following are other factors that influence and control dust explosions.

Explosibility increases with reduction in particle size[2, 8, 11, 19, 21, 26] because fine particles are more readily dispersable, they remain in suspension longer, and their greater surface per mass provides better contact with oxygen, so that they are easier to ignite. However, cohesion forces increase with increase in specific surface so that very fine particles tend to agglomerate, thus placing a limit on the influence of fineness. Increase of the specific surface of the dust increases the rapidity of evolution of the volatile matter.

The composition of the dust[2, 8, 11, 12, 13, 18, 19, 21, 26] has an important effect on the explosibility of the dust. The explosibility increases almost linearly with the increase in the volatile matter content, but above 25% the explosibility rises only slightly with increase in volatile matter content. Increase in the ash and moisture contents is accompanied by a reduction in explosibility. The effect of moisture is unimportant below about 10%.

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The explosibility of coal dust increases almost linearly with the percentage of inflammable gas in the atmosphere[2,8,21,22,24,26,27,28]. The presence of small amounts of natural gas enhances the ease of ignition. The minimum explosive concentration of dust decreases almost linearly as the concentration of methane increases from zero to 5%. Small amounts of methane increase the explosion pressure with low dust concentrations (0.1 - 0.4 oz/cu. ft.), but with a further increase in dust concentrations (0.5 - 2.0 oz/cu. ft.), small amounts of methane decrease the explosion pressure.

The minimum explosive concentration[3, 8, 11, 22] of fine, bituminous coal dust in air was determined to be of the order of 0.05 oz/cu. ft. The exact value depends somewhat on the nature of the ignition source, the fineness of the dust and other parameters. The total amount of coal burnt is generally limited by the quantity of oxygen available.

Coal dust, unlike mine gas which, in the case of longwall mining, normally occurs only near active faces and in limited volumes at other points in a mine, may be present on all surfaces in the mine in sufficient quantities to propagate an explosion[2, 8, 11, 18]. Coal dust deposited on rib and roof surfaces and on overhead timber is generally of finer size, is more readily dispersable and ignitable, and constitutes a greater explosion hazard than coal on the floor. Once an explosion has developed, the forces are great enough to disperse considerable dust off the floor and thus increase the coal-dust concentration in the atmosphere.

The temperature, energy and size of the source of ignition are important factors[2, 8, 21, 28]. Explosions initiated by strong sources develop faster, do more damage and are more difficult to arrest than explosions initiated by weak sources. The principal sources of ignition of mine explosions forty to fifty years ago were open lights, black powder and dynamite. In recent years electric arcs from trolley wires and from improperly maintained mining machines and power cables have become the chief hazard.

Increases in the initial pressure of the gas and also of the surrounding temperature increase the explosion hazard.

Physical/...

Physical Properties

The main effects[19, 27, 28] of an explosion are the blast, causing damage and disturbance extending often far beyond the limits of the flame, the spread of the flame, which is customarily taken as defining the extent of the explosion, and the afterdamp, containing the products of combustion, mainly CO, CO_2, steam and N_2, with smoke and dust.

Pressure development[11, 19, 22, 28] during a methane explosion is caused by the heating of the atmosphere during the oxidation reaction. The quantity of the gas in the atmosphere remains unchanged, the reactions of methane with oxygen produce equivalent volumes of CO_2 and H_2O vapour. In small-scale laboratory equipment the maximum pressure developed by the explosion of various combustibles and air is roughly 4 to 10 times greater than the pressure before the explosion. In methane explosions in mines the gases expand more or less 5 times their original volume.

The temperature attained[19] during the reaction depends on the concentration of the methane, the uniformity of the mixtures, turbulence, and heat losses. The temperature of the gaseous products in the flame front is of the order of 1900°C to 2000°C. As the burnt gas behind the flame cools, there is a general contraction which tends to pull the flame back.

The minimum amount of coal dust[14, 18, 19, 26] which can propagate an explosion is ± 1/40 oz/cu. ft. The speed of propagation of a coal dust explosion can vary from about 10 yd/sec to over 1,000 yd/sec. Experiments have shown that in the great majority of cases flame speeds do not exceed 550 yd/sec.

A flame tends to accelerate[14, 17] when passing from a closed towards an open end because the expansion of a firedamp-air mixture pushes the flame front and the unburnt gases forward. If the blast raises a cloud of dust and a dust explosion follows, it will continue to propagate until the composition or density of the dust becomes unfavourable.

Causes/...

CAUSES OF EXPLOSIONS

More or less 50% of explosions in coal mines are caused by electricity. Open lights, smoking and unsafe blasting practices contribute another 20%. Thus, during the periods 1929 to 1944 and 1944 to 1950, 44% and 40% respectively of the explosions registered in the United States of America were caused by electricity, while 33% and 20% respectively of the explosions were ascribed to open lights and smoking[7, 8, 15, 16, 17, 25].

The hazards that contributed to explosions in the past were:

1) Failure to provide and maintain continuous ventilation[15, 16], including movement of gas accumulations from unventilated areas into working sections.

2) Failure to test for gas[15] before and while working in haulage ways, face regions, or areas adjacent to where methane was known to be liberated.

3) Use of open-type electric equipment[15, 16, 17] without providing constant adequate ventilation to prevent the accumulation of explosive mixtures.

4) Unsafe methods of blasting[15], including the use of non-permissible explosives.

5) Smoking in mines[15, 16] or the use of open lights.

6) Damaged or improperly adjusted flame safety lamps[15, 16].

7) Inadequate rock-dusting[2, 8, 9, 15, 18] permitted the propagation of an explosion.

PREVENTION

The most universal measure to minimise the danger of firedamp explosions is mine ventilation[3, 5, 6]. Inflammable gases are diluted to harmless levels by mixing them with the ventilation air. When methane is emitted at the roof of a ventilating tunnel, it may form a layer along the roof which may mix only very slowly with the ventilation air. The layer may have a motion of its own,

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different from that of the ventilation air. The best action against methane roof layers is to increase the velocity of the ventilation air or to reduce the methane emission.

To lessen the probability of a coal dust explosion, an inert dust[1,2,8, 9, 10, 11, 12, 13, 14, 18, 20, 25] is used to make the dust cloud non-inflammable. Limestone is slightly more effective than shale, and gypsum is twice as effective as shale. Stone dust is supposed to cover the coal dust and should remain dry so that in the event of a blast wave it will be dispersed first.

When two dusts are laid in strips, both are raised into the air but they do not mix adequately, and an explosion can still travel along the roadway. This situation is analogous to that found in coal conveyor roads.

Stone-dust barriers[1, 14] are used to stop a coal-dust explosion, but they cannot be relied upon to stop a firedamp explosion. Barriers are designed to operate by the blast that travels some distance ahead of the flame during an explosion. A dense cloud of stone dust is then created in the air just before the flame arrives.

Spraying with water[2, 8, 10, 18, 19, 20] alone may not always add to the safety of a roadway, but spraying with a wetting solution does increase the safety of a mine roadway. However, a violent gas explosion can raise the wet dust into the air and when raised, such dust will propagate an explosion.

To prevent and minimise gas and coal-dust explosions, the following measures have been suggested[2, 7, 19, 20] :

1) All coal mines must be rock dusted.

2) Rock dust must be distributed upon the top, bottom and sides of all underground openings to within 40' of all working faces.

3) Rock dust must be maintained in such a quantity that the incombustible material in representative samples will not be less than 60%.

4) The coal face and working place 40 feet therefrom must be kept free of coal dust by the use of water.

5) The machine cuttings must be wetted as cutting is being done.

6) The tops of loaded cars in the working place must be wetted.

7) Adequate ventilation must be provided at the coal face.

8) Enough air and water must be used in the cuts.

9) The gas in the atmosphere must frequently be checked.

10) Mining machines must be so designed and used that the rapid removal of gas is facilitated.

11) The overheating of cutting and other machines must be avoided.

12) Hard rocks must also be avoided during cutting and drilling.

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PRETORIA,
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REFERENCES

1. Coward: Safety in Mines Res. Establishment, Res. Report No. 51, 1952.
2. Rice and Greenwald: Bureau of Mines, Tech. Paper 464, 1929.
3. Scott, Kennedy and Zabetakis: Bur. of Mines, I.C. 7601, 1951.
4. Lewis and Von Elbe: Fifth International Conference of Directors of Mine Safety Res., Sept. 20-25, 1948.
5. Bakke and Leach: The Mining Eng. No. 22, 1962, p. 3924.
6. Bakke and Leach: Safety in Mines Res. Est., Res. Report No. 195, 1960.
7. Hartmann: Bur. of Mines, I.C. 7727, 1955.
8. Hartmann: Bur. of Mines, I.C. 7785, 1957.
9. Hartmann, Howart and Nagy: Fifth International Conf. of Directors of Mine Safety Res., Sept. 20-25, 1948.
10. Hartmann, Nagy, Rauschenberger and Mitchell: Bur. of Mines, R.I. 5264, 1956.
11. Hartmann, Jacobson and Williams: Bur. of Mines, R.I. 5052, 1954.
12. Mason and Wheeler: Safety in Mines Res. Board, Paper No. 33, 1927.
13. Mason and Wheeler: Safety in Mines Res. Board, Paper No. 79, 1933.
14. Coal Industry National Consultative Council Safety and Health Committee: Report on Stone Dust Barriers on Coal Conveyor Roads, May, 1961.
15. Fene and Humphrey: Bur. of Mines, I.C. 7661, 1953.
16. Forbes, Fene and Humphrey: Bur. of Mines, I.C. 7572, 1950.
17. Harrington and Fene: Bur. of Mines, I.C. 702, 1939.
18. Tideswell: Fifth International Conf. of Directors of Mine Safety Res., Sept. 20-25, 1948.
19. Rice: Bur. of Mines, Tech. Paper 448, 1929.
20. Hartmann and Greenwald: Bur. of Mines, I.C. 7131, 1940.
21. Greenwald: Bur. of Mines, Bulletin 365, 1932.
22. Van Dolah, Zabetakis, Burgess & Scott: Bur. of Mines, I.C. 8137, 1963.
23. Nagy and Portman: Bur. of Mines, R.I. 5815, 1961.
24. Safety in Mines Res. Board Publications, Vol. 4, 1928.
25. Special Report by Safety in Mines Res. Board, June 1943.
26. Cybulski: The 7th International Conf. of Directors of Safety in Mines Res., July 7-12, 1952.
27. Tideswell: Transactions: Institution of Mining Eng., Vol. 112, 1952-53, 158.
28. Nagy and Mitchell: Bur. of Mines, R.I. 6344, 1963.