Mine Ventilation and Environmental Hazards

Mine Explosions

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FIREDAMP EXPLOSIONS

Methane present in coal mines is a by-product of the coalification process during which the coal was formed from vegetable matter. It exists in the coal seam both in an adsorbed state, adhering to the internal micropore surface of the coal matrix, and in a compressed state in the fracture system of the seam. It is also present in the adjacent strata compressed in the fracture system of the rock.

When the seam is mined, the equilibrium that existed in the coal seam and the surrounding strata under the confining pressure is disturbed and the gas is liberated from both the seam being mined and the adjacent strata, thereby posing a serious hazard unless sufficient air quantity is circulated through the mine to dilute its concentration in the general ventilation to less than the safe prescribed limit.

The amount of methane stored within the coal increases with the coal rank, depth of cover over the seam, and the reservoir pressure. The volume of methane released as the coal is being mined forms the *'base emission'* while the emission from other sources forms the *'secondary emission'*.

Methane bums in air when ignited with a pale blue flame, but, when it is mixed with air, it can explode on ignition. The combustion and explosion take place according to the equation

$$CH_4 + 2(O_2 + 4N_2) = CO_2 + 2H_2O + 8N_2$$

One volume of methane requires two volumes of oxygen or 10 volumes of atmospheric air for its complete combustion. Theoretically, therefore, the optimum or stoichiometric mixture is formed at 9.5 per cent methane. Methane, however, forms flammable mixtures with air over a range of approximately 5 to 15 per cent.

If the methane content of a methane-air mixture is greater than 9.5 per cent, the oxygen present will not be sufficient for its complete combustion and if it is less than 9.5 per cent, oxygen or atmospheric air will be in excess.

A pure firedamp explosion does not extend over a wide area *unless* there has been emission or accumulation of large quantities of methane.

Limits of flammability, flammable limits, or explosive limits

The flammable limits of methane-air mixtures are the limits of concentration of methane in air between which a flame can be propagated throughout the mixtures. The boundary-line mixtures with minimum and maximum concentration of methane in air, which if ignited, will just propagate flame are known as the **lower and upper flammable or explosive limits**.

The lower and upper flammable limits (LFL and UFL) are approximately 5 (33 g/m^3) and 15 (100 g/m^3) respectively. Explosions at the flammable limits are rather weak and slow-burning, while at the stoichiometric concentration, they are most violently explosive.

The lower flammable limit of methane is found to be independent of oxygen concentration above 20 per cent. It decreases linearly from 5 per cent to zero as the air-borne coal dust concentration increases from zero to its lower limit of flammability.

The presence of other combustible gases like ethane, carbon monoxide, hydrogen, etc., which have, like methane, lower and upper flammable limits also reduces the lower limit which can be determined by using the Le Chatelier relation:

$$\frac{100}{L} = \frac{p_1}{l_1} + \frac{p_2}{l_2} + \frac{p_3}{l_3} + ...$$

where p_1, p_2, p_3 ... are the percentages of the component gases in the mixture ($p_1 + p_2 + p_3 + \ldots = 100$ per cent) per cent) and l_1, l_2, l_3 ... . . their percentage lower limits.

The presence of *inert gases* has a damping effect on the flammability of methane-air mixtures. Carbon dioxide is more effective than nitrogen.

Ignition point or ignition temperature

The ignition point of flammable firedamp-air mixtures is given as 650° to 750°C. The ignition point is the minimum temperature to which a portion of the mixture must be raised in order to initiate or cause a rapidly accelerating reaction in the whole of the accumulation with the accompaniment of a flame. It does not refer to the temperature of the igniting source which must obviously be at a higher temperature. It is not a definite temperature but depends upon the nature of the source of ignition. The ignition point of pure methane in oxygen is 550°C.

A characteristic property of firedamp is that when it comes into contact with an igniting source, the temperature of which is comparatively a little above its ignition point, a certain time must elapse before it is ignited. This period is known as the 'ignition lag' or induction time and it depends on the temperature, pressure, gas concentration and presence of other combustible gases.

Explosion characteristics

- **Flame temperature** The flame temperature of a flammable firedamp-air mixture is the temperature just at the moment of its explosion. It depends on the concentration of firedamp, uniformity of the mixture, turbulence, confinement, and heat losses. It is maximum at the stoichiometric concentration and is less at the lower and upper flammable limits.

- **Explosion pressure** The explosion pressure depends on the flame temperature and confinement. The maximum explosion pressure of a methane-air mixture (760 mm Hg, 20°C) when ignited in a closed vessel is given as 7.2 bar(g), In mine workings, however, the explosion pressure may exceed this value.

- **Flame length** The length of flame increases as the gas concentration in a gas zone increases from the lower limit of flammability to about 12 per cent, after which it decreases; the limited data indicate that the length of the flame is directly proportional to the volume of the zone and, for a given roadway cross-section, the total flame length is four-and-a-half times the length of the gas zone for 9.5 per cent mixtures and five times the length for 12 per cent mixtures.

- **Velocity of propagation of flame or flame velocity** The velocity of propagation of a firedamp explosion flame is very small.

Estimation of hazard due to firedamp in mines

The hazard posed by firedamp to mine safety may be estimated by:

- determining the gas emission indices or rates in return air currents (m^3 CH_4/t and of r.o.m or saleable output) in coal mines;
- determining the concentration of methane at working faces; and
- the number, type and size of firedamp accumulations.

The gas emission index or emission rate is determined by using the formula

$$q_{CH_4} = \frac{c\,x\,60\,x\,24\,x\,Q_{air}}{100\,x\,O\,x\,K} = \frac{c\,x\,14.4\,x\,Q_{air}}{O\,x\,K}$$

where c = methane content in return air current (Vol. %)

Q_{air} = return air current quantity (m3/min)

O = mined or saleable output (t/d)

K= a factor given by the ratio (max conc. of methane on any day in a week/average concentration of methane in the week)

It varies between 1 and 2, depending on the degree of mechanization; for mechanized faces, K lies between 1.5 and 2.

On the basis of the gas emission index, coal mines in different countries have been classified into degrees/categories of gassiness.

Indian Classification

Degree of gassiness	Gas emission index (m^3 CH_4/t output)
I	< 1
II	1 - 10
III	> 10

Causes of firedamp explosions

The greatest number of firedamp explosions occur in active mine workings in face areas and headings. The various causes of firedamp explosions in mines may be grouped under the following headings:

- Negligence of miners
- Use of damaged safety lamps and their improper handling

- Blasting
- Mine fires
- Friction
- Electric sparks
- Other special causes

Negligence of miners

Smoking, starting fires or opening of flame safety lamps on the part of miners had in the past resulted in firedamp ignitions.

Blasting

Blasting in coal and roadhead rippings and drifts represented a dangerous source of ignition of firedamp in the past.

Mine fires

Mine fires can easily bring about ignition of flammable firedamp-air mixtures in contact with them. When fighting a fire in a gassy mine, care should be taken to prevent firedamp content of mine air from rising to flammable proportions.

Friction

Frictional heating and frictional sparks can, under certain circumstances, ignite flammable firedamp-air mixtures. Frictional ignition in mines may take place due to: (a) friction between metal and metal, (b) friction between metal (especially steel) and rock, and (c) friction between rock and rock.

Frictional heating are seldom the cause of ignition of flammable firedamp-air mixtures.

Electric sparks

The electrification of coal mines has introduced into the mines an ever-present source of ignition - electric sparks igniting not only combustible materials but also flammable firedamp-air mixtures. Sparks may be produced from switchgear, damaged cables, signalling apparatus, and faulty electrical equipment. Although electric sparks usually have a much higher temperature than ordinary flames, it may happen that a spark has a very short life and its electrical energy is not sufficient to cause ignition of the mixture in that time. The minimum energy of a spark causing ignition of a flammable firedamp mixture varies with methane concentration, humidity, oxygen content of the atmosphere, temperature, pressure and turbulence.

Prevention of firedamp explosions

Measures against accumulation of dangerous firedamp mixtures in mine workings from the beginning (Ventilation specific)

The most effective method of preventing firedamp explosions in mines is by providing adequate **ventilation** which will dilute the firedamp, besides other harmful gases, to well below limits that may be prescribed for different mine workings and carry it away to the surface. Frequent sampling of mine air for methane at several points in the mine is, therefore, an important measure for prevention of firedamp explosions.

The following important points should be borne in mind:

- The mine should be mechanically ventilated by the exhaust ventilation method.
- The mine equivalent orifice should be as large as possible (> 2 m^2)
- The ventilation of mine workings greater than 3 m in length should not be done by diffusion alone.
- The ventilation of development headings should be done by utilizing the mine ventilating pressure as far as practicable. Air which has passed through any abandoned area which is inaccessible or unsafe for inspection should not be used to ventilate any active workings in a mine.
- Ventilation doors should be correctly located and kept closed except when men, equipment and trains are passing through them. They should always be in good repair and be self-closing.
- The mine ventilation system should be planned so that simple, effective, and reliable ventilation of all workings is assured. Where multiple main fans are used, the ventilation system should be so arranged that no adverse air reversal will occur in the event of failure or stoppage of any fan or fans.
- Seams should be extracted, as a rule, from top downwards to decrease the methane levels in the lower seams.
- The method of extraction should be selected so that it guarantees an easy and safe ventilation of the faces by air dilution with adequate velocities at the face and at the waste edge. In high-capacity longwall faces with strong methane emissions and high ventilating air requirements, faces laid with W-ventilation system will enable larger air quantities to flow through them besides providing a middle gate for drilling additional methane drainage holes.
- A particularly high standard of unit ventilation by separate ventilation splits should be maintained in each mechanized mining section and in districts/panels liable to gas outbursts.
- In bord and pillar and longwall retreating panels in very gassy seams worked with caving, the firedamp content in the goaves behind the active faces must be controlled by in-mine local or central drainage of goaves or drainage through surface ventilation boreholes.

- Mining with backfilling or solid stowing of the waste/goaf, especially hydraulic filling, prevents formation of methane reservoirs in goaves.
- Horizontal methane drainage holes drilled into a seam in advance of a panel must be sealed before they are intercepted during extraction of the panel to prevent methane from being discharged forming flammable methane mixtures.
- Air currents and methane emission should be checked by systematic measurement of air quantities and their methane concentration. If, at any time, the air at any working place contains a methane accumulation, changes or adjustments in ventilation should be made at once so that such air contains less than the prescribed value.
- For judging the possibility of formation of methane layering, the Middendorf formula may be used to calculate the 'layering index':

  $$S_{index} = \sqrt[3]{\frac{24v^2}{c\sqrt{F}}}$$

  where v is the mean velocity (m/s); c is the mean methane content of air current (% CH_4); F is the area of the cross-section of the airway at the measuring station (m^2).

  If $S_{index} < 2$, there is probable danger of methane layering

  $S_{index} > 2$, there is no danger of methane layering.

  A correction factor must be used for the rising inclination and change in the cross-sectional area of the airway.

Measures against ignition of flammable firedamp mixtures (Electricity specific)

The various preventive measures to be taken against ignition of flammable firedamp mixtures in mines are:

- All persons should be prohibited from carrying smoking articles (pipes, cigars, cigarettes, tobacco other than chewing tobacco or snuff), matches or other spark- or flame-making devices into the workings.
- All coal mines should be treated as safety-lamp mines as a number of explosions in the past had occurred in the so-called naked-light mines. In short-life naked-lamp mines where naked lights are to be retained, special attentions should be paid to ventilation, gas-testing, and to precautions against coal dust.
- If, in a district or part of a mine, electrically-operated equipment is not required for immediate use and men are not working there, power should be cut off in that district or part of the mine. Tests for methane should be made immediately before the equipment is energized.
- Trailing cables which are vulnerable to damage should be suspended from hangers, specially provided for the purpose, and, if they are present in the face area, should be suitably protected against damage from any cause.

- To prevent ignition from electrostatic charges, all ventilation ducting should be earthed and only antistatic polythene sheeting, hoses, and belts used.
- A reliable methane monitor or cut-out that will automatically cut off power supply to the electrical equipment when the methane concentration reaches the prescribed maximum percentage may be installed in endangered mine workings.
- A methane monitor should be installed, when available, on any electric face-cutting equipment, continuous miner, longwall face equipment, and loading equipment to automatically de-energize equipment or give a warning automatically when the concentration of methane reaches the maximum prescribed limit. The methane monitors shall be properly maintained to keep them operative and checked at regular intervals for operating accuracy.
- When a main fan is stopped for any reason, electrical power should be immediately cut off in return airways. After the fan has been restarted, the power shall not be switched on unless normal ventilation and safe conditions have been restored.
- In places where auxiliary fans are used, the auxiliary fans should not be operated during stoppage of normal mine ventilation. Accumulations of methane should be removed after restoration of normal mine ventilation before the fans are operated. In a place ventilated with an auxiliary fan, if the auxiliary fan is stopped or fails, electrical equipment operating in the place should be stopped and the power disconnected at the power source until the ventilation is restored. The auxiliary fan should be maintained so that the impeller does not strike the casing.
- Changes in ventilation affecting the main air current or any split thereof should be made only when the mine is idle. The power supply should be cut off from the affected area before changes are made.
- A **flameproof enclosure** is used for electrical apparatus at higher voltage exceeding 25 volts. A flameproof enclosure is not gas tight, but it is so designed and constructed that during its normal operation, even if a gas explosion takes place inside the apparatus, the cover withstands such explosion and the hot gases coming out from the rough-machined flanges of the cover are sufficiently cooled so that they do not ignite gas-air mixture outside the apparatus because of lag on ignition. An intrinsically safe apparatus is one which is so constructed that during its use, the spark produced by it is not of such high temperature as to cause ignition of gas. This construction is possible with apparatus operated by voltage upto 25 volts. Signalling bells, telephones, exploders and relays are of intrinsically safe construction.

If the gas emission is very high, as may sometimes occur in very deep mines, it is a safe practice to substitute electric power by compressed air, or to arrange for methane drainage. This has already been elaborated in the earlier chapters.

COAL DUST EXPLOSIONS

A coal-dust or any industrial dust explosion is a sudden combustion process of great intensity characterized by mechanical destructive effects through pressure and heat. For an ignition to take place, the combustible dust must be present in the form of a thick cloud having a definite mixing ratio with oxygen, and a source of ignition of sufficient intensity in the form of flame must be present to initiate a combustion wave.

Comparison of coal dust and firedamp

Coal dust and firedamp have many common properties besides their characteristic features:

- Both have lower and upper limits of flammability. Explosions of limit mixtures are weak.
- The ignition temperature of firedamp is 650° to 750°C while that of dry airborne dust is 600° to 900°C.
- The heats of combustion and explosion temperatures are nearly the same.
- The flammability of firedamp is generally the same throughout the mine. On the other hand, the ignition and flammability of dust in mine workings vary greatly, depending on fineness, volatile matter, ash, moisture, etc.
- The propagation of firedamp explosions takes place due to conduction of heat. With coal-dust explosions, on the other hand, radiation of intense heat by the pressure wave as well as the explosion flame plays an important part in their propagation.
- The maximum pressures developed in some dust explosions are higher than in firedamp explosions. The rates of pressure rise are, however, generally lower than those obtained in firedamp explosions.
- Coal-dust explosions are frequently more disastrous in their effects than firedamp explosions because of their longer duration.
- With firedamp explosions, carbon monoxide is frequently found. With coal-dust explosions, on the other hand, carbon monoxide is always found.
- The ignition of a coal-dust explosion even with the strongest igniting source requires at least 100 ms, while with a firedamp explosion only 1 to 2 ms is required.
- The velocity of propagation of coal-dust explosions is generally higher than that of firedamp explosions.

Causes of coal-dust explosions in mines

In practice, the causes that bring about ignition of flammable dust-air mixtures are very similar to those operating in the ignition of flammable methane-air mixtures, but the explosion hazard, in general, is rather greater as coal dust is a normal accompaniment of the coal winning process and can be easily raised into the mine air as a dust cloud, particularly in winter when danger of dust explosions is likely to be more when the mine air is drier. For a coal-dust explosion to take place in mines, two conditions must be fulfilled. The dust must be present as a dense cloud and a source of ignition in the form of a flame must be present.

The various causes of direct ignition of a dust cloud can be classified as

- naked flames
- friction
- electric sparks
- firedamp explosions

Naked flames

A naked flame is the easiest means of igniting a dust cloud as the source of heat is of considerable size and a larger part of the dust cloud can be heated.

Friction

Hot surfaces as a result of mechanical friction, such as overheated bearings, may ignite surrounding explosive dusty atmospheres.

Electric sparks

Electric sparks from short-circuiting and arcing at electrical equipment or overhead trolley wires may ignite an explosive dust-air mixture. Sparks of higher voltage and amperage are necessary than in the case of flammable firedamp mixtures.

Static electric sparks can also ignite explosive dust-air mixtures. Fine particles of dust may readily become electrified by friction with air or ducting through which they pass. As the electric charge on a body resides on the surface, a dust cloud has a very large capacity. Under suitable conditions, a discharge or sudden recombination of separated positive and negative charges can occur which can then act as a source of ignition. With increasing humidity, however, the electric potential falls.

Firedamp explosions

A firedamp explosion is the commonest source of initiation of a coal-dust explosion. Besides posing the danger of such direct ignition, a firedamp explosion may raise the deposited dust from the mine floor, sides, or roof into mine air very quickly before its flame has ceased and then propagate as a coal-dust explosion. A very small gas explosion initiated by accidental ignition of a small quantity of flammable firedamp mixture (approximately 0.4 m^3 volume may thus bring about a much bigger coal-dust explosion. This danger is particularly great in long headings than on long coal faces due to the low air velocities and a lack of adequate pressure relief except in one direction towards the entrance of the heading. An explosion in pure coal dust may not develop when layered gas is ignited or when the gas is ignited at the outbye end. It is significant that most firedamp explosions do not develop into coal-dust explosions due to their failure to raise a sufficiently dense dust cloud.

Prevention and suppression of coal-dust explosions

Measures which prevent or reduce formation and dissemination of coal dust underground

- On longwall faces, water infusion of the coal face to reduce respirable dust at low or high water pressures where the seam and adjacent strata allow.
- Wet winning of coal using wet pneumatic picks where used.
- With machine-cutting by means of coal cutters, using sharp picks of a suitable type, selecting optimal cutting and travelling speeds of the machine, using gummer and wet-cutting; with continuous miners by using scrubbers on them.
- When blasting in coal, use of stemming cartridges or ampoules of calcium chloride powder containing 82 to 85 per cent $CaCl_2$ and 15 to 18 per cent water of crystallization reduces considerably the dust produced by shotfiring due to the formation of a large number of droplets.
- Thoroughly wetting the coal pile before it is manually or mechanically loaded. Using such types of conveyors with which the dust production is minimum.
- Using large-capacity mine cars.
- Water spraying full and empty trains during their transit.
- With rope haulages, raising the haulage ropes by correct siting of the rollers to prevent contact with the floor containing dust.
- Preventing spillage and degradation of coal during transport on haulage roads.
- Restricting velocities of air currents in mine airways to less than 3 m/s if possible.
- Adopting homotropal ventilation where the ventilating air travels in the same direction as the coal to reduce dust pick-up.
- Preventing dust accumulation in mine workings.
- Selecting a method of coal winning with which dust production is the least. Winning by coal ploughs produces much less dust than by shearer loaders.
- Controlled caving of roof coal in very thick seams mined by the sub-level caving method using close-fitting shields.
- Consolidating the floor dust to prevent it from being raised.

Dust modelling

At the mine planning stage, for dust control in mines, predictive dust models using computers have been developed for major contributions from both point and non-point sources taking into account the given meteorological data over the area to predict dust impact. Appropriate dust control options are provided. Owing to inaccurate estimate of the various variable factors, the control options should be tested before their acceptance.

Measures against ignition of dust accumulations

- Measures against ignition of flammable firedamp mixtures;
- Neutralization or consolidation of dust at working coal faces within a radius of 10 to 20 m before shotfiring by means of water or inert dust; and
- Neutralization of dust in roadways by means of water, inert stone dust, and hygroscopic salts.

Measures against explosion propagation

The protective measures which have been found in practice to arrest explosion propagation in the coal mines so that an explosion is confined to the part of the workings in which it might occur are:,

- Generalized wetting of coal dust
- Generalized stonedusting (rock dusting)
- Stone dust (rockdust) barriers
- Explosion stoppings
- Salt zones
- Water barriers
- Triggered barriers

Stone Dust Barriers

Stone-dust barriers as a means of suppression of coal-dust explosions are today extensively used in Indian and many overseas mines. A stone-dust barrier is a device which uses the dynamic pressure of an explosion to release and disperse a mass of stone dust in the form of a thick cloud into the path of an oncoming explosion flame, thereby smothering the flame.

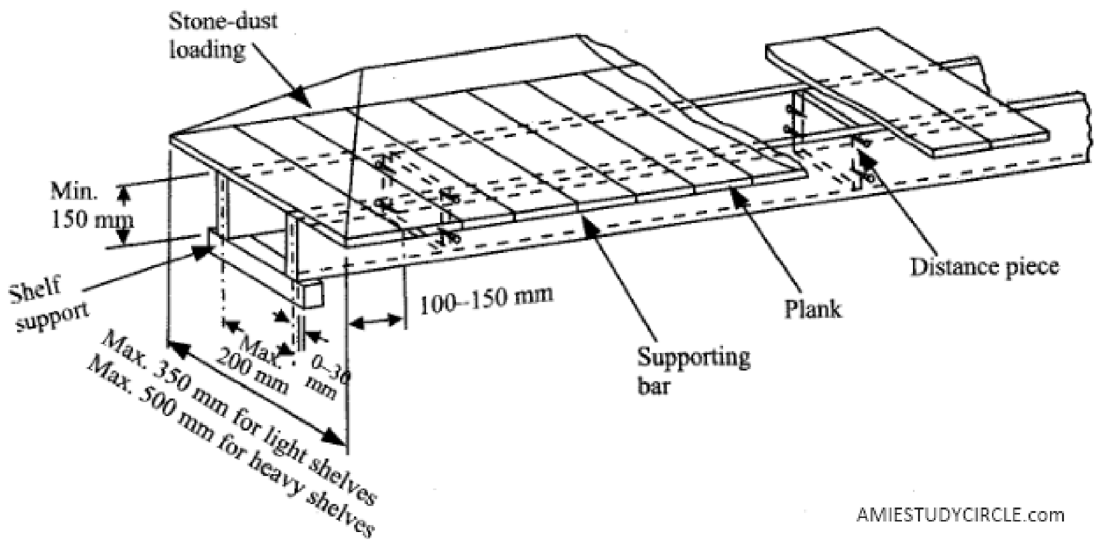
Barrier design

The shelf barrier, consisting of a number of dust-laden shelves independently supported transverse to and along the roadway in which it (the barrier) is installed, is the most practical design, being less difficult to install and maintain. It occupies a length of 25 to 40 m of the roadway.

Stone-dust barriers are installed in strategic areas of the mine such as roadways leading from shafts or their pit bottoms, in all level and inclined roadways including gate roads and development headings, and near roadway junctions.

Two designs of shelves are commonly used in mines, the German (Improved Dortmund-type) Shelf and the Polish Shelf.

The Polish Shelf (see figure) is composed of several short planks, 10 to 15 cm wide and 35 to 50 cm long, laid alongside one another in the direction of the roadway.



Polish Shelf

In India, only the Polish Shelf is the officially approved one.

Two types of Polish Shelves are used. The light shelf the width of which should not exceed 35 cm, has a dust loading not more than 29.8 kg/m shelf length, while the heavy shelf, the width of which should not be less than 35 cm and not more than 50 cm, is loaded with not more than 59.6 kg/m. The light barrier carries a total dust loading of at least 107.4 kg per square metre of average roadway cross-section and comprises all shelves of the light type. The intermediate barrier carries a dust loading of 195.3 kg per square metre roadway cross-section and comprises not more than one-third of the shelves of the heavy type.

The heavy barrier carries a dust loading of at least 390.6 kg per square metre of average roadway cross-section comprising not less than one-third of the shelves of the light type.

The distance between the adjacent shelves are:

Light shelves

min. 0.91 in max. 2.10 in

Between heavy shelves or between a heavy and a light shelf

min. 1.22 in max 2.59 in

All stone-dust barriers depend for their *effective* operation on the formation of a thick cloud of stone dust by the pressure wave of a coal-dust or firedamp explosion before being passed by the flame of the explosion. Studies and experience with explosions in experimental and operating coal mines had shown that the force of an explosion and the time interval between dust discharge and flame arrival at the barrier, which depend upon the design and location of the barrier, the presence of flammable firedamp-air mixture, and the intensity of the explosions, determine the efficacy of a stone-dust barrier. A weak explosion may not throw the shelves off their supports. If the time interval between dust release and flame arrival is too long, a greater part of the dust falls to the floor but if it is too short, the dust does not get adequately dispersed. Investigations have shown that a time interval of 0. 1 to 0.2 s is sufficient enough to create a flame-quenching cloud.

Failure of Stone-dust barriers

In practice, stone-dust barriers may fail under any one of the following circumstances:

- When the barrier itself lies in a flammable firedamp-air mixture or firedamp occurs as a roof layer;
- When flame velocities are high (exceeding about 500 m/s). as when a dust explosion is initiated by a powerful firedamp explosion or is assisted by firedamp during its propagation;
- When the barrier is located less than 40 to 60 m or far from a face or other potential point of ignition, so that the dynamic pressure is less than the minimum required, which normally lies between 3 and 5 kN/m^2 ; and
- When an explosion is initiated by a weak ignition source and sufficient dynamic pressure is not built up.

Explosion-proof stoppings

Unlike stone-dust barriers, explosion-proof stoppings *localize* firedamp or coal-dust explosions by isolating completely the area from the rest of the mine. An explosion-proof stopping must, therefore, withstand, without being damaged, the full explosion pressure and also bring about extinction of the explosion flame by starving it of oxygen. It is mainly used for localizing explosions in parts of a mine in which there is less likelihood of widespread propagation of an explosion such as development workings in coal and stone. In practice, explosion-proof stoppings are frequently erected in sealing off fire areas where there is danger of explosion due to firedamp or fire gases.

The stoppings may be constructed of brickwork, concrete, or timber. Wedge stoppings of brick, concrete blocks and wood have been successfully used. Frequently, heavy single-wing steel doors about 20 mm thick erected in a solid stopping are used. They have the advantage that they can be closed quickly. They can also be used as ‘blasting dams’ in mine development work in gassy mines.

Water barriers

Since the early 1960s, interest has revived in the use of passive water barriers, also called water-trough barriers, as an alternative to stone-dust barriers for suppression of coal-dust explosions in mines.

Water has the following advantages over stone dust:

- its heat capacity is about five times that of dust;
- its efficacy is not affected by underground climatic conditions; and
- it is available in all mine roadways.

A water barrier consists of a number of water-filled troughs or containers of suitable material supported on horizontal shelves in the vicinity of the mine roof as in the case of a stone-dust barrier. The containers shatter or burst under the action of the pressure wave or shock wave ahead of the propagating flame of an explosion releasing and dispersing water in all directions in the path of the explosion flame. In some countries, water barriers have become the principal means of protection against coal-dust explosions.

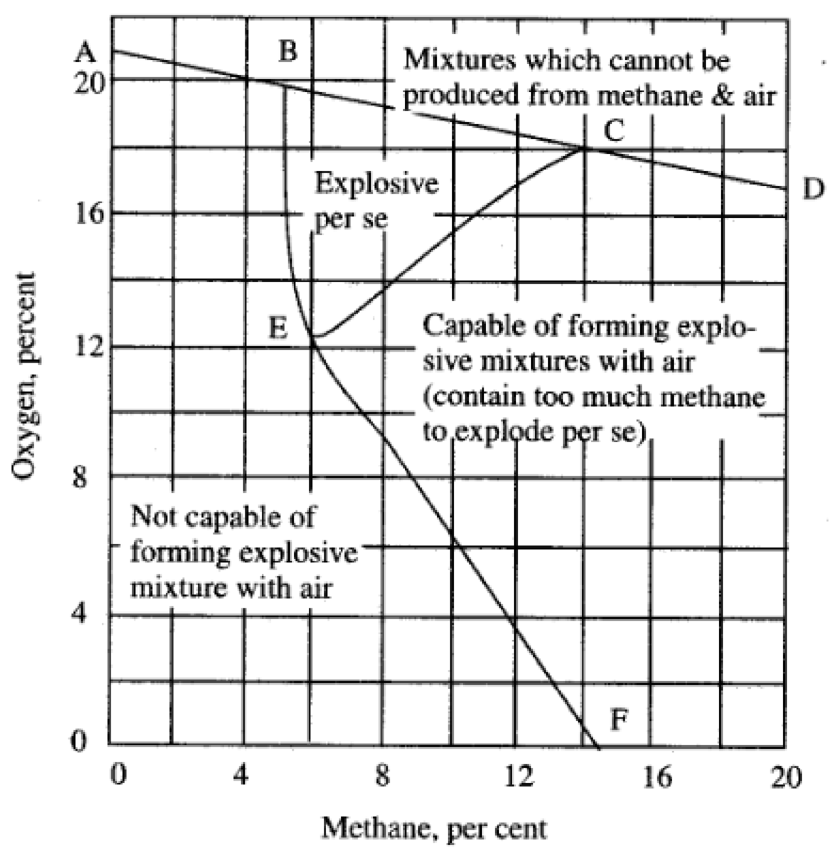
FLAMMABILITY OF ATMOSPHERE IN SEALED-OFF AREAS

In gassy mines, it is important to know before attempting recovery of a sealed-off area whether the firegases in the area would form a flammable mixture when admixed with air. The composition of the firegases which depends, within limits, upon the development, extent, and intensity of fire at the time of sealing as well as upon dilution through methane and leakage air, consists in general of CO, O_2, CO_2, N_2, and CH_4.

A given mixture of firegases can be considered as consisting of combustibles, suppressors of combustion, and oxygen. It is the combustible constituents of the firegases, notably methane, that combined represent an explosion hazard in a fire area during its sealing or unsealing.

Coward method

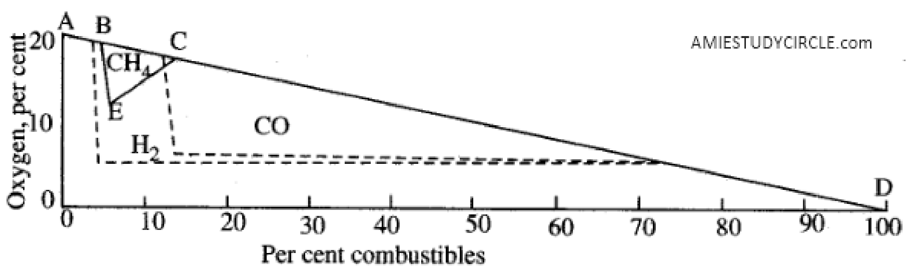
Coward was the first to represent graphically the relationship between the quantitative composition and the flammability of mixtures of methane and air. In the diagram (See figurte) one distinguishes the following four areas:



1. An area above the line AD in which no mixture of methane and air is possible impossible mixtures range). The point A represents the normal air of 20.93 per cent O_2 and 79.07 per cent N_2 and CO_2.
2. An area to the left of the line BEF in which methane does not form any flammable mixture with air at all (non-flammable or safe range). The line BE represents the lower limits of flammability of methane-air mixtures.
3. An area to the right of the line CEF in which too rich methane can form flammable mixtures when mixed with air in suitable proportions (possible flammable range). The line CE represents the upper limits of flammability of methane air mixtures. As the oxygen content of the mixture decreases, BE and CE approach each other and meet at, E which is called the 'nose flammability limit'.
4. A triangular area BEC known as the Coward triangle, in which any methane-air mixture is flammable (flammable range). The shape of the Coward triangle does not alter with the percentage of CH_4 in the sample.

It can be seen from the diagram that no mixture that contains less than about 12.1 % oxygen is explosive by itself.

Coward triangles for gases other than methane can also be drawn. Following figure shows the diagram with flammability triangles for CH_4, CO, and H_2.



ASSIGNMENT

Q.1. (AMIE W11, 4 marks): Calculate the maximum water pressure for an arc dam from the following data:

External radius of arc ring = 80 m

Internal radius of arc ring = 76 m

Safe compressive stress of material used = 200 N/m^2

Radial thickness of arc ring = 4 m

Q.2. (AMIE S13, W13, 10 marks): What are the distinguishing differences between the coal dust and the firedamp explosions? How do stone dust barrier help in arresting explosions in coal mines? Enumerate various types of stone dust barriers.

Q.3. (AMIE W11, 5 marks): Explain how stone dust barriers help in handling explosions in underground coal mines. Under what circumstances and at what locations these are installed?

Q.4. (AMIE S13, 20 marks): Write short notes on the following:

(i) Limits of explosibility of firedamp

(ii) Water gas explosion

(iii) Explosion-proof stopping

(iv) Fresh air base

Q.5. (AMIE S14, 15 marks): Write short notes on the following:

(i) Coward diagram

(ii) Bulk head door

(iii) High expansion foam plug

Q.6. (AMIE W15, 10 marks): With reference to Coward flammability diagram, what do you understand by "nose limit"? Based on this diagram, how do you rate an atmospheric composition with 20% methane and 15% O_2.

Q.7. (AMIE W14, 10 marks): What is your interpretation for the region termed as "potentially-explosive" in a Coward flammability diagram? A sealed-off atmosphere in a coal mine has the following composition: Normal air: 90.0%, CH_4: 7.0% and CO: 3.0%. With respect to individual gases in the presence of normal air, following is known for CH_4 and CO:

Explosive gas	LEL, %	UEL, %
CH_4	5.0%	15.0%
CO	12.5	74.0

Comment on the explosibility status of the sealed-off atmosphere.

Q.8. (AMIE W17, 10 marks): Construct the Coward flammability diagram and classify the following samples of "normal air and methane mixtures" in terms of their explosibility characteristics:

(i) CH_4: 5% andO_2: 12%

(ii) CH_4: 10% and O_2: 10%

(iii) CH_4: 7.5% and O_2: 16%

(iv) CH_4: 10% and O_2: 20%

Q.9. (AMIE W14, 10 marks): Identify the precautions/methodologies to be adopted for the control of fire damp explosions in a coal mine with respect to (i) ventilation system (ii) usage of electricity.

Q.10. (AMIE W15, 10 marks): How one can ascertain the explosibility status of a gas mixture of normal air combined with more than one inflammable gas? Explain the approach.

Q.11. (AMIE W15, 10 marks): What is degree of gassiness of a coal seam? Explain. Outline the ventilation-related precautions one has to take when the coal seam being mined is classified as degree III.

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