MINE EXPLOSIONS

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What is an Explosion?

- Explosion is a sudden combustion process of great intensity.
- It is accompanied by release of large quantities of heat energy and development of pressure.
- In explosion, the original gas (methane) and solid substance (coal) is converted instantaneously into gaseous products.
- An explosion is also invariably accompanied by violence on a large scale.

MINE EXPLOSIONS

- Mine explosions are generally regarded as a serious and constant hazard in underground coal mines.
- In coal mines, explosions are caused
  - By ignition of firedamp (Fire damp explosion) or
  - By ignition of coal dust (Coal dust explosion) or
  - By both (Mixed explosion)
- In metal mines, explosions are due to sulphide dust (iron pyrite).

- In India, between 1900 and 1980, 21 explosions occurred.

- The worst disaster due to mine explosion took place in Dhori Colliery (1965) when 268 miners were killed.

3.4 CHARACTERISTIC PROPERTIES OF METHANE

Methane is also known as Carbureted hydrocarbon, firedamp, and marsh gas. High methane concentrations can cause oxygen-deficient atmospheres, flammable situations, or explosive environments. When methane enters the atmosphere as a point source, it can be readily ignited if the concentration exceeds 5 percent. Atmospheric methane can ignite at concentrations between 5 and 15 percent at Standard Temperature and Pressure (STP). Higher levels can quickly dilute to flammable levels. In either case, if methane is allowed to accumulate in an enclosed area, an explosive environment may develop. An explosive environment exists when a mixture of gases can self-propagate a flame throughout the mixture, independent of, and away from, the source of ignition. An ignition source can be an electrical outlet, pilot light, well pump, or match. Combustion requires fuel (methane), oxygen, and a source of ignition (Figure 3.2). Most methane problems are usually associated with confined spaces or enclosed structures where the gas can build up to explosive levels.

The explosive range for methane in air is normally quoted as 5 to 15% by volume, with the most explosive (stochastic) mixture occurring at about 9.8%. While the lower limit remains fairly constant, the upper explosive limit reduces as the oxygen content of theair falls. The flame will propagate through the mixture while it remains within the flammable range. Figure 3.3 illustrates a well-known diagram first produced by H. F. Coward in 1928 (McPherson, 1993).This can be used to track the flammability of air: methane mixtures as the composition varies.

In zone A, the mixture is not flammable but is likely to become so if further methane is added or that part of the mine is sealed off. In zone B, the mixture is explosive and has a minimum nose value at 12.2 percent oxygen. Zones C and D illustrate mixtures that may exist in sealed areas. A mixture in zone C will become explosive if the seals are breached and the gases intermingle with incoming air. However, dilution of mixtures in zone D can be accomplished without passing through an explosive range.

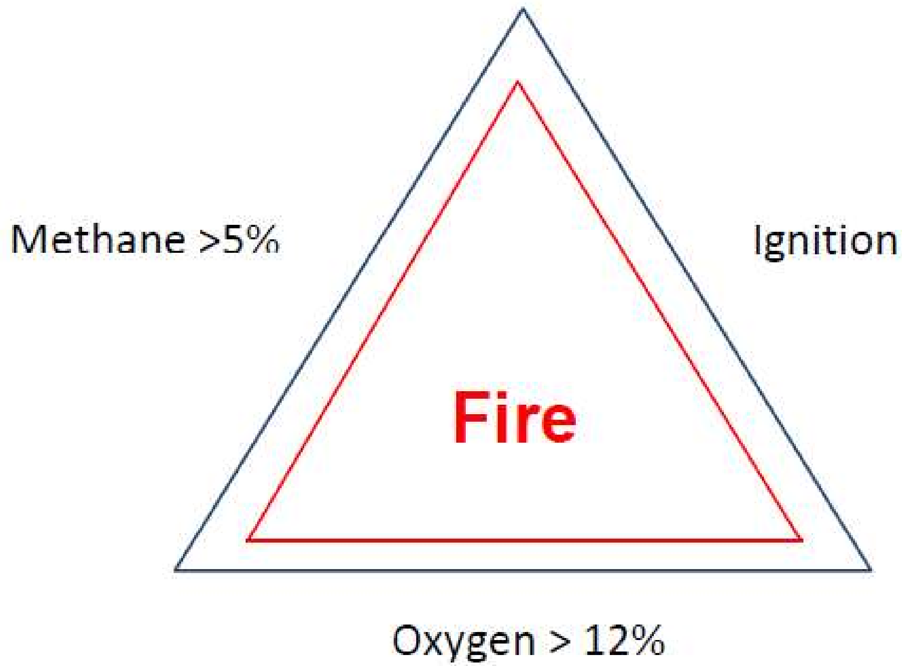


Figure 3.2 Fire Triangle for Methane

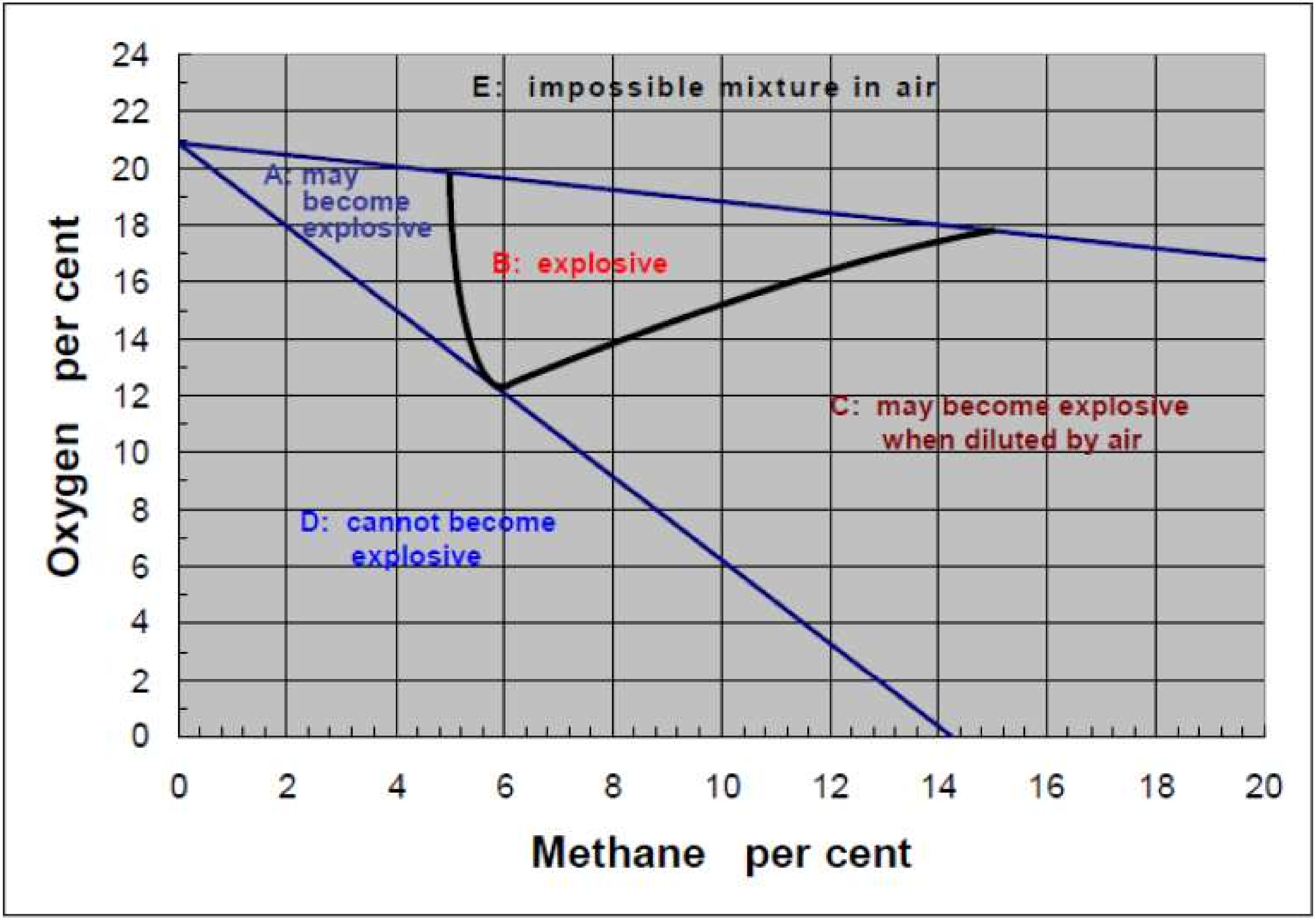


Fig. 3.3 Coward's Diagram for Methane in Air (McPherson, 1993)

FIREDAMP EXPLOSIONS

Firedamp:

- The term firedamp refers to the natural gas mixtures emanating from the strata of coal mines.

- Such gas mixture consists chiefly of methane (CH_4), with small traces of other combustible gases like ethane (C_2H_6) and ethylene (C_2H_4).

- Therefore, firedamp is often considered synonymous with methane.

- Methane burns in air when ignited with a pale blue flame but when it is mixed with air, it can explode on ignition.

- The combustion or explosion takes place according to the equation

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

Two factors are essential to cause a firedamp explosion:-

- Firedamp in inflammable explosive proportions, i.e. mixed with the right amount of air should be there and

- A suitable igniting agent should be present.

Inflammable Mixture:

- Inflammable mixture is that which contains CH_4 and air at certain proportions, and which, when ignited will allow the flame to be self propagated throughout the mixture in all directions, independent of, and away from, the source of ignition.

Limits of Flammability, Flammable Limits, or Explosive Limits:

- The flammable limits of methane-air mixtures are the limits of conc. of CH_4 in air between which a flame can be propagated throughout the mixtures.

- The boundary-line mixtures with min. and max. conc. of CH_4 in air, which if ignited, will just propagate flame are known as the lower and upper flammable or explosive limits.

- The lowest % of CH_4 in air that yields an inflammable mixture is called the **lower flammable limit (LFL).**

- The highest % of CH_4 in air that yields a similar mixture is called the **upper flammable limit (UFL).**

The flammable limits of firedamp in air:

- **Lower limit of inflammability:** 5% (33 g/m^3) of CH_4 in air
- **Higher limit of inflammability:** 15% (100 g/m^3) of CH_4 in air

- Presence of other combustible gases like ethane, CO, H_2 etc. reduces the LFL of the mixture.

- LFL of mixture of gases can be determined by the **Le Chatelier relation:**

$$\frac{100}{L} = \frac{P_1}{L_1} + \frac{P_2}{L_2} + \frac{P_3}{L_3} + ------$$

Where

P1, P2, P3….. are the percentages of the component gases in the mixture (P1 + P2 + P3 + …… = 100) and

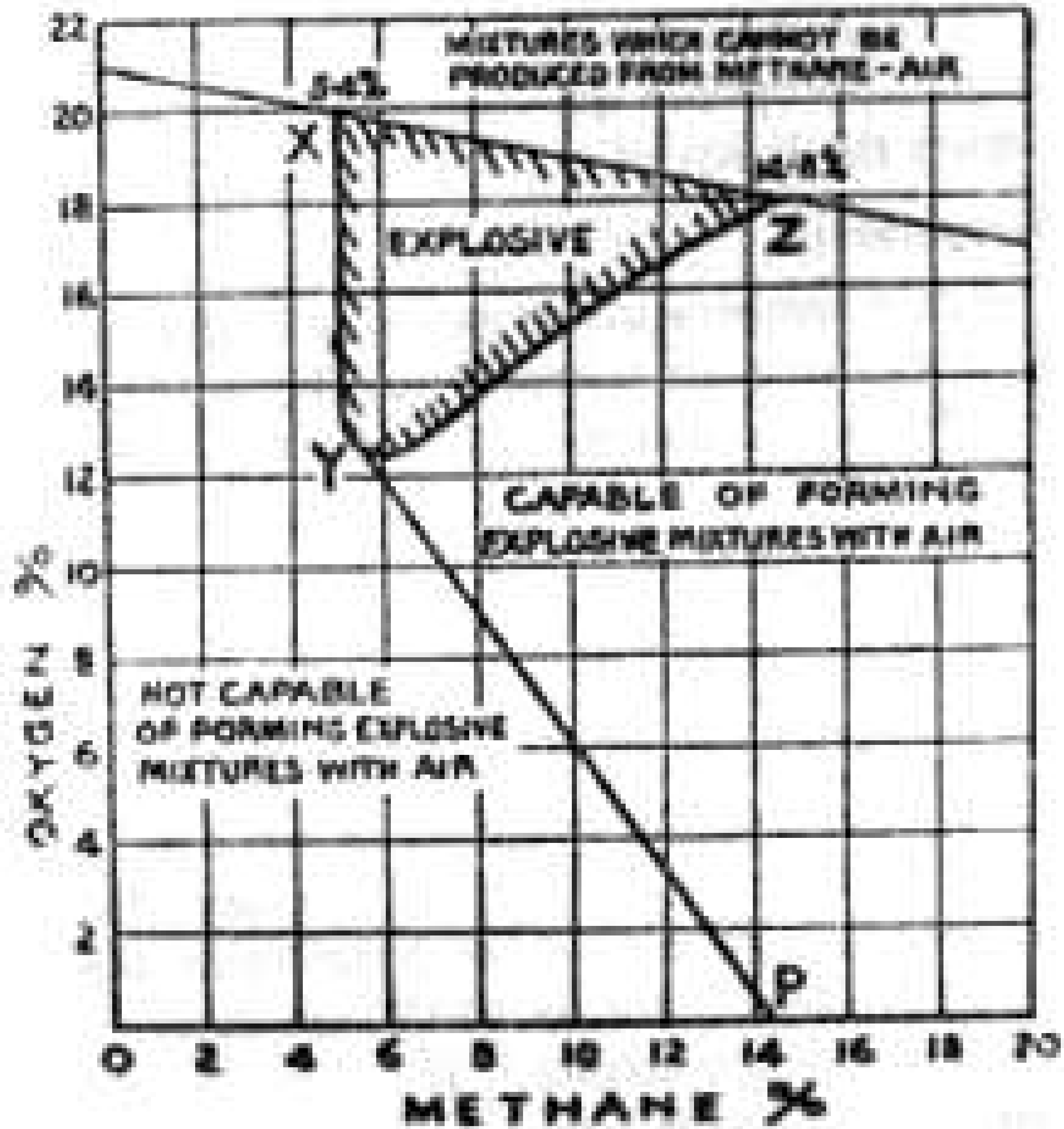
L1 , L2, L3 ….. their percentage lower limits.

Flammable limits of combustible gases

Gas	*% by valume*	
	Lower limit	Upper limit
Acetylene (C_2H_2)	2.5	80
Carbon monoxide (CO)	12.5	74
Ethane (C_2H_6)	3.2	12.5
Ethylene (C_2H4)	3.1	32
Hydrogen (H_2)	4.1	75
Hydrogen sulphide (H_2S)	4.3	46
Methane (CH4)	5.4	14.8
Ammonia (NH3)	15	28

Coward's Diagram

- Shows the limits of explosibility with different percentages of firedamp and oxygen.
- It has significance
  - during sealing off a fire in a gassy mine, and
  - when reopening a sealed off area.



MIXTURES WHICH CANNOT BE PRODUCED FROM METHANE - AIR
EXPLOSIVE
CAPABLE OF FORMING EXPLOSIVE MIXTURES WITH AIR
NOT CAPABLE OF FORMING EXPLOSIVE MIXTURES WITH AIR
X
Y
Z
P
OXYGEN %
METHANE %

Coward's Diagram

- All mixtures lying within the triangular area XYZ, are in themselves explosive.
- All mixtures lying to the right of PYZ contain too much CH_4 to explode, but they will form explosive mixtures when mixed with the right amount of air.
- All mixtures lying to the left of PYX are neither explosive, nor capable of forming explosive mixtures with air.
- Lower limit of explosibility remains almost constant at about 5.4% for all percentages of O_2 down to about 12.5%.
- The higher limit of explosibility gradually decreases from 14.8% to about 6% with decreasing O_2 %.
- No percentage of firedamp is explosive when the O_2 % is 12 or less.
- A firedamp-air mixture may become explosive when diluted with an appropriate quantity of air which brings the new mixture within the limits of the triangle XYZ.

Factors affecting the inflammable limits:

- The limits of flammability are not fundamental characteristics of the gas but depend on the experimental conditions.

- The limiting percentages or limiting mixtures of flammability are influenced by
  - Presence of other combustible or inert gases
  - Temperature, pressure and intensity of turbulence
  - Diameter of the experimental tube
  - Direction of flame propagation
  - Oxygen concentration
  - Intensity of igniting source
  - Presence of coal dust

Ignition Temperature:

- The lowest temp. to which an inflammable mixture must be raised in order to set the mixture aflame is called the ignition temp. or ignition point.
- The ignition point of pure methane in oxygen is 550°C.
- Ignition temp. of firedamp-air mixtures usually taken as 650 to 750°C.

- It is not a definite temperature but depends upon the
  - nature of the source of ignition whether flame, spark, etc.
  - shape and size of the of space where ignition occurs
  - methane content
  - temperature of the surroundings
  - pressure
  - oxygen concentration
  - presence of other gases
  - turbulence

The Lag on Ignition

- The firedamp air mixture doesn't immediately burst into flame when it has been raised to its ignition temp.

- The later temp must be maintained for a definite interval of time to ensure that flame will appear.

- The interval of time that elapses between the exposure of a CH_4 air mixture to an igniting source and the appearance of flame is called the **preflame period** and duration of this period is called the **lag on ignition**.

- During this period the rate of heat production progressively increases and the temp rises.

<u>The lag on ignition is not constant but varies with:</u>

- Temp. of the igniting source
- CH_4 % in the gas mixture
- Higher the source temp., shorter the lag on ignition.
  - 6.5% of CH_4 – source 700 °C – Lag 11 seconds
  - 6.5% of CH_4 – source 1175°C – Lag 0.01 second

Direct Blast and Backlash

Methane explosions are characterised by two distinct phases:

- the direct blast and
- the indirect blast or backlash.

- In **direct blast**, a pressure wave of great force and speed travels ahead of explosion flame.
- The **backlash** is caused by the vacuum arising out of cooling of explosion gases and condensation of water vapour.
- It is of less intensity than the direct blast and traverses the same path backwards.

Explosion flames

- When the concentration of CH_4 is greater than 9.5%, two types of explosion flame occur, the **primary** and **secondary flames**.
- Primary flame propagates at a greater velocity and consumes the entire available oxygen.
- The secondary flame is produced by the burning of unburnt gas with the help of the oxygen supplied by the backlash. It propagates slowly in the opposite direction to that of the primary flame at a lower velocity.

Effect of high press and temperatures

- By suddenly compressing the gas mixture, both temp. and press. are raised simultaneously, and it has been found possible to ignite in this way a mixture containing as little as 2% and as much as 75% of methane.

- If the press of gas mixture raised to 125 atm., the higher limit is about 46%.

- This is important, because it shows that the press. waves or hot compressed gases, of an explosive may during shot firing, ignite a wider range of firedamp air mixture, in brakes or cavities behind the face

Effect of black damp on inflammability:-

- Black damp (a mixture of CO_2 and excess N_2) has very little effect in diminishing the danger of an explosion

- For all % of excess nitrogen or of ordering blackdamp upto about 35%, the lower limit of inflammability remains unaffected, being between 5% and 6%.

- Higher inflammability is 14.8 when no black damp is present and it gradually falls to about 6% as the % of black damp increases upto 35% .

- The upper limit and the lower limit then coincide.

- When the % of blackdamp > 35%, the atmosphere becomes non-inflammable with any % of methane

- If the blackdamp consists solely of CO_2 (a condition never met with in a mine) at least 25% of CO_2 would be required to render the mixture non-inflammable with any % of methane

EXPLOSION CHARACTERISTICS

- ***Explosion flame temperature***
- ***Explosion pressure***
- ***Flame length***
- ***Velocity of propagation of flame or Flame velocity***

FLAME TEMPERATURE

- It is the temp. which occurs just at the moment of explosion of a flammable firedamp-air mixture.

- It depends upon 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.

- The adiabatic flame temperature for a stoichiometric methane air mixture is 2,200 °K.

EXPLOSION PRESSURE

- It depends upon the flame temp and confinement.

- The maximum explosion pressure of methane-air mixture (760 mm Hg, 20°C) when ignited in a closed vessel is given as 7.2 bar.

- In mine workings, explosion pressure is much higher than this; because the shockwave travelling ahead of explosion flame compresses any fire damp accumulation encountered on its way to a press greater than 1 bar.

- Upon ignition of such an accumulation, the resulting explosion pressure will be much greater than 7 bar.

- Therefore, severe damage due to explosions does not occur at the seat of explosion but away from it.

FLAME LENGTH

- Experiments in the USBM Experimental Coal Mine showed that the length of flame increases as the gas concentration in a gas zone increases

- It increases from the lower limit of flammability to about 12%, after which it decreases.

- Length of flame is directly proportional to the
  - volume of the zone and
  - Concentration of firedamp in mixture

- For a given roadway cross section, the total flame length is
  - 4.5 times the length of the gas zone for 9.5% mixture and
  - 5 times the length for 12% mixtures.

VELOCITY OF PROPAGATION OF FLAME
OR
FLAME VELOCITY

It depends upon the following factors:

- ***Methane content of mine air:***

- Velocity of flame propagation increases with increasing firedamp content from the lower flammable limit upwards.

- After reaching the maximum value at the optimum concentration, the velocity decreases.

- ***Condition of gas mixture whether at rest or in motion:***

- From experiments it was found that maximum velocity of propagation is not greater than 0.6 m/s.

- On the other hand, when the gas mixture is in motion, the velocity may quickly increase to few hundreds of m/s.

Point of ignition:

Location of the point of ignition within the body of gas mixture markedly affects the velocity of propagation.

- If ignition takes place at the close end of a roadway filled with a gas mixture, the speed of propagation and severity of explosion are greater than when ignition takes place at the outbye end of the roadway.

- When ignited at the outbye end, rapid burning rather than explosion develops.

Length of gas zone:

- Experiments in gas zones in the USBM Experimental Coal Mine showed that

- Velocity of flame propagation increases from zero at the point of ignition to a maximum at a distance of about twice that of the original length of the gas body.

- The maximum velocity for the 7.5m zone is about 99 m/s and that for the 15m zone is 533 m/s.

➢ *Presence of Obstacles in the Path or Change in Area of Roadway Cross-section:*

- Obstacles cause turbulence of the air and greatly increase the speed of the flame.

- Presence of objects or obstacles in roadway e.g.
  - props,
  - tubs,
  - doors,
  - brattice cloths etc. decreases its area of cross-section and the velocity of propagation rises to a few hundreds of m/s.

CAUSES OF FIREDAMP EXPLOSIONS IN MINES

- 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
- Making fire
- Opening of flame safety lamps, etc.

resulting in ignition of firedamp causes firedamp explosions.

Use of damaged safety lamps and their improper handling:

A safety lamp is safe only when

- its various parts are clean,
- in good condition,
- all parts are properly assembled, and
- is properly handled.

Blasting:

- Blasting in coal, roadhead rippings represented a dangerous source of ignition of firedamp in the past.

- **Effects of Blasting:**

  - **Flame produced by the explosive**: lasts very short time – so no chance of burning

  - **The hot gases emitted:** Cooled down rapidly –no chance of burning firedamp air mixture.

  - **Heat of compression:** Sudden compression of a gas by 20 fold increases the temperature of the gas and ignite the gas.

- With development of new and safer explosives and improved blasting techniques, the number of explosions due to this cause had decreased considerably.

Mine fires:

- Mine fires can easily bring about ignition of flammable firedamp – air mixtures in contact with them.

Friction :

- Frictional heating and frictional spark can ignite flammable firedamp-air mixtures.

- The frictional ignition hazard depends on the
  - nature of the contacting materials
  - composition of the flammable gas mixture
  - rate of energy release, and
  - type of frictional contact of the materials.

- Frictional ignition may take place due to:
  - Friction between metal and metal
  - Friction between metal and rock
  - Friction between rock and rock

Metal to metal friction

- Degree of ignition hazard from metal-to-metal contact depends on the properties of more readily oxidizable metal.

- Extensive research carried out in Germany and U.K. clearly shown that ignition hazard from incendive particles of iron is extremely less.

- Danger may be feared from aluminium and its alloys.

Incendive definition: Able to ignite, or cause ignition.

Metal to rock friction

- **It poses the greatest ignition hazard in mines.**
- Frictional sparking during cutting and drilling operation in seams containing hard siliceous bands or inclusions of iron pyrite nodules attributed several firedamp explosions in mines.
- Nature of rock particularly quartz content and its grain size far more important than types of picks or bits used.
- The coal cutter pick generate brilliant spark of 200°C to 300°C which can ignite iron pyrite (FeS_2) dust and produces flame which in turn burns methane air mixture.

Rock and rock friction

- Some of mine explosions in the UK and Canada were attributed to friction between rocks caused by fall or caving of sandstone roof rocks.
- Experiments conducted in the UK showed that the ignition of firedamp-air mixture by the impact of rocks take place by its contact with the hot patches on the contacting rock surfaces.
- Particularly, siliceous or quartz bearing sandstones can produce ignitions.

Electric sparks:

- Electrification of coalmines has introduced into the mines an everpresent source of ignition by electric sparks of flammable firedamp-air mixture.

- Electric sparks of sufficient energy and long duration can ignite the firedamp-air mixture.

- Sparks may be produced from
  - switch gear
  - damaged cables
  - signalling apparatus
  - faulty electrical equipment
  - shot firing magneto exploders.

- The minimum energy of a spark causing ignition of flammable fire damp mixture varies with
  - Methane concentration
  - Humidity
  - Oxygen content of atmosphere
  - Temperature
  - Pressure
  - Turbulence

- Most flammable mixture for ignition by an electric spark occurs at 8.3% CH_4 irrespective of the type of spark and

- The minimum igniting energy is as low as 0.28 mJ (mWs).

Other special causes:

- Sparks of static or frictional electricity having adequate energy capable igniting firedamp-air mixture.
  - Ordinary belt passing over pulleys can accumulate static charges sufficient to produce sparks.
  - Dust laden air passing through ducting can electrify ducting by friction.
  - When dust particles are blown through and projected from a compressed air pipe or nozzle, the dust cloud may become electrified and under certain conditions, the electrostatic discharge they result may be capable of igniting firedamp.
- Methane blowers, when catch fire, can become a cause of explosion.
- Tungsten filament of an incandescent electric lamp (even a 2 volt lamp) is capable of igniting a firedamp air mixture if the enclosing bulb become accidentally broken.

PREVENTION OF FIREDAMP EXPLOSIONS

- No practical measures exist for arresting firedamp explosions in coal mines.

- Only protective measures against this hazard can be adopted.

The various measures against firedamp explosion hazard in mines can be divided into the following three groups.

1. **Measures against accumulation of dangerous firedamp mixtures in mine workings**

2. **Measures against ignition of flammable firedamp mixtures**

3. **Control of firedamp emission**

1. Measures against accumulation of dangerous firedamp mixtures in mine workings from the beginning:

- Provide adequate ventilation to dilute the firedamp below limits and carry it away to surface.
- Frequent sampling of mine air for methane at several points in the mine.
- The important points to be noted for adequate ventilation:
  - Mine should be mechanically ventilated.
  - Where methane emission > $5m^3$/te. of daily output, a standby main fan having an independent drive and power circuit should be provided in mines.
- Main fan to be so placed, it will not be damaged by explosion.
- Automatic alarm or signal device to alert persons on duty – should it stop or slow down.

- Mine equivalent orifice should be as large as possible ($> 2m^2$).

- The entire mine should be ventilated by the exhaust ventilation method.

- Ventilation of development headings should be done by utilising mine ventilating pressure as far as practicable.

- Auxiliary fans should be installed and located in such a manner that air is delivered within 5m of the face and recirculation of air is eliminated.

- In all idle days, the mine should be ventilated by primary ventilation only to prevent accumulation of firedamp.

- Ventilation doors should be correctly located and kept closed except when men, equipment, and trains are passing through them.

- The mine ventilation system to be planned so that simple, effective, and reliable ventilation of all workings is assured.

- The method of working or extraction should be selected so that it guarantees an easy and safe ventilation of the faces with adequate velocities in the face and the waste edge.

- The seams to be depillared top downward to decrease methane content in lower seams.

- Air leakage should be kept to a minimum.
- High standard of ventilation should be maintained in districts liable to outbursts.
- Bleeder system of ventilation to be adopted to drain out the gases behind stopping.
- Roof cavities to be filled up with approved sealant or ventilated to avoid accumulation of firedamp.

- Air currents and methane emission should be controlled by systematic measurements of air quantities and their methane concentration.

- Special examinations for firedamp layering should be made during periods of falling barometric pressure in roadways adjacent to old workings.

- Check methane emission in ascensionally ventilated face – layering index to be judged by Middendorf formula (GlukauF – 1965)

$$S_{\text{index}} = \sqrt[3]{\frac{23V^2}{C\sqrt{F}}}$$

V = Mean air velocity, m/s
C – Mean methane content (% CH4)
F – Cross-sectional area of airway at the measuring station, m2
Sindex < 2, there is probable danger of methane layering
> 2, no danger

2. Measures against ignition of flammable firedamp mixtures:

- All persons should be prohibited from carrying smoking articles, matches or other spark or flame-making devices.
- 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.
- Only approved types of flame and electric safety lamps should be used.

- Following precautions should be taken when using flame safety lamps:
  - The lamp should be carried in vertical position.
  - The glass should be protected from splashes of water.
  - The lamp should not be set down on the floor but should be hung from a substantial support.
  - The lamp should not be left unattended in the mine.

- The lamp should not be exposed to strong air currents to prevent the flame from ‘going out’.

- No combustible material should be ignited by the lamp.

- When the flame of a safety lamp indicates a dangerous percentage of gas in the atmosphere, the lamp should be withdrawn slowly, carefully, and promptly to prevent the flame from going out.

- If the flame is extinguished suddenly, the lamp should be withdrawn carefully and promptly and should be taken into fresh air and allowed to cool before relighting it.

- Only certified flameproof and intrinsically safe apparatus should be used in coal mines.

- The apparatus should be properly installed, protected, operated, and maintained.

An ***intrinsically safe light source*** *is one in which the current feeding the light has very little energy so that any short in the circuit will not produce a spark which can ignite the methane gas.*

In ***an explosion proof lamp****, any explosion triggered by the lamp's electrical activity will be contained within the device. In addition, the device itself will not become hot enough to cause an explosion.*

- **To prevent ignition from electricity**
  - In a district, if electrically-operated equipment is not in immediate use and men are not working there, power should be cut off in that district.
  - Trailing cables vulnerable to damage should be suspended from hangers and suitably protected against damage.
  - **To prevent ignition from electrostatic charges:**
  - all ventilation ductings should be earthed.
  - only antistatic polythene sheeting, hoses and belts used to prevent accumulation of electrostatic charges.

- In endangered mine workings, a reliable methane monitor with cut-out that will be automatically cut off power supply to the electrical apparatus when the methane concentration reaches the prescribed maximum value, may be installed.

- If the main fan is stopped for any reason, electric power supply should be cut off in return airways.

- Auxiliary ventilator not to be operated when main mine fan is stopped.

- 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 source until the ventilation is restored.

- The auxiliary fan should be so maintained that the impeller does not strike the casing.

- Excessive frictional heat produced from conveyors, brakes and bearings should be avoided by good ventilation and proper maintenance.

- Frictional sparks produced by metal-to-rock contact as with face-cutting, drilling, continuous mining and longwall power-loading equipment should be avoided.

- The cutting bits of mining machines, when they are worn or broken, are especially hazardous if they scrape against instead of cutting into the material.

The precautionary measures against frictional sparking during cutting of seams by jib coal cutters :

- selecting appropriate cutting horizon and lower pick speeds
- wet-cutting using external water sprays directed at the ingoing and outgoing picks
- providing a water mist in the cut
- introducing inert gas such as CO_2 and N_2 into the cut, or ventilating the cut
- adequate ventilation of the cut using compressed air

- Frictional ignition by ripper-type continuous miners can be considerably reduced by using carefully engineered back sprays on the ripper drum applied directly at the coal cutting bits.

- Materials constructed of light alloys to be avoided in underground coal mines to eliminate incendive sparking.

- Spontaneous heating of coal should be controlled by proper planning of mine development as well as coal extraction, good ventilation system and inspection.

- Blasting with explosives should be restricted to a minimum.

- Welding, flame cutting, grinding, and soldering operations etc. must be done U.G. only after checking concentration of CH_4 before and during such work and taking proper precautions

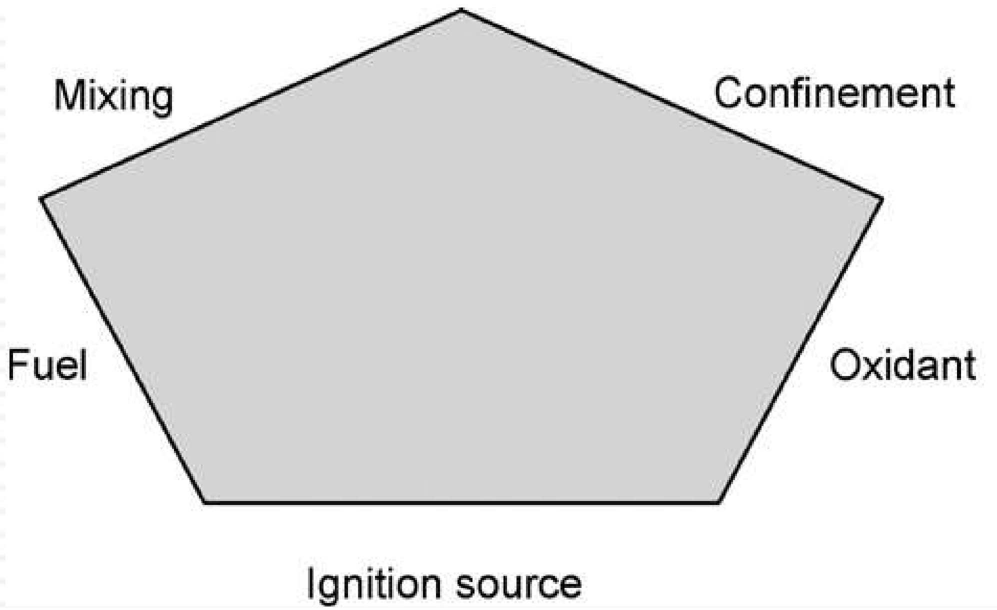
- All mobile diesel-powered equipment must be inspected and maintained in approved condition in accordance with the instructions furnished by the manufacturer.

3. CONTROL OF FIREDAMP EMISSION

- Seams with high methane content at great depth, should be intensively worked by high production methods.

- Methane drainage techniques to be applied where it is not possible to control methane concentration by general ventilation.

COAL DUST EXPLOSIONS



The dust explosion pentagon

While fire is caused when three factors – fuel, oxidant, and ignition – come together to make what has been called 'the fire triangle', a dust explosion demands two more factors: mixing (of dust and air), and confinement (of the dust cloud). The 'dust explosion pentagon' is formed when these five factors occur together (Fig. 1):

Fig. 1. The dust explosion pentagon

(i) presence of combustible dust in a finely divided form;
(ii) availability of oxidant;
(iii) presence of an ignition source;
(iv) some degree of confinement;
(v) state of mixed reactants.

A point to be noted here is that even partial confinement of an ignited dust cloud is sufficient to cause a highly damaging explosion. In this sense, too, dust clouds behave in a manner similar to clouds of flammable gases.

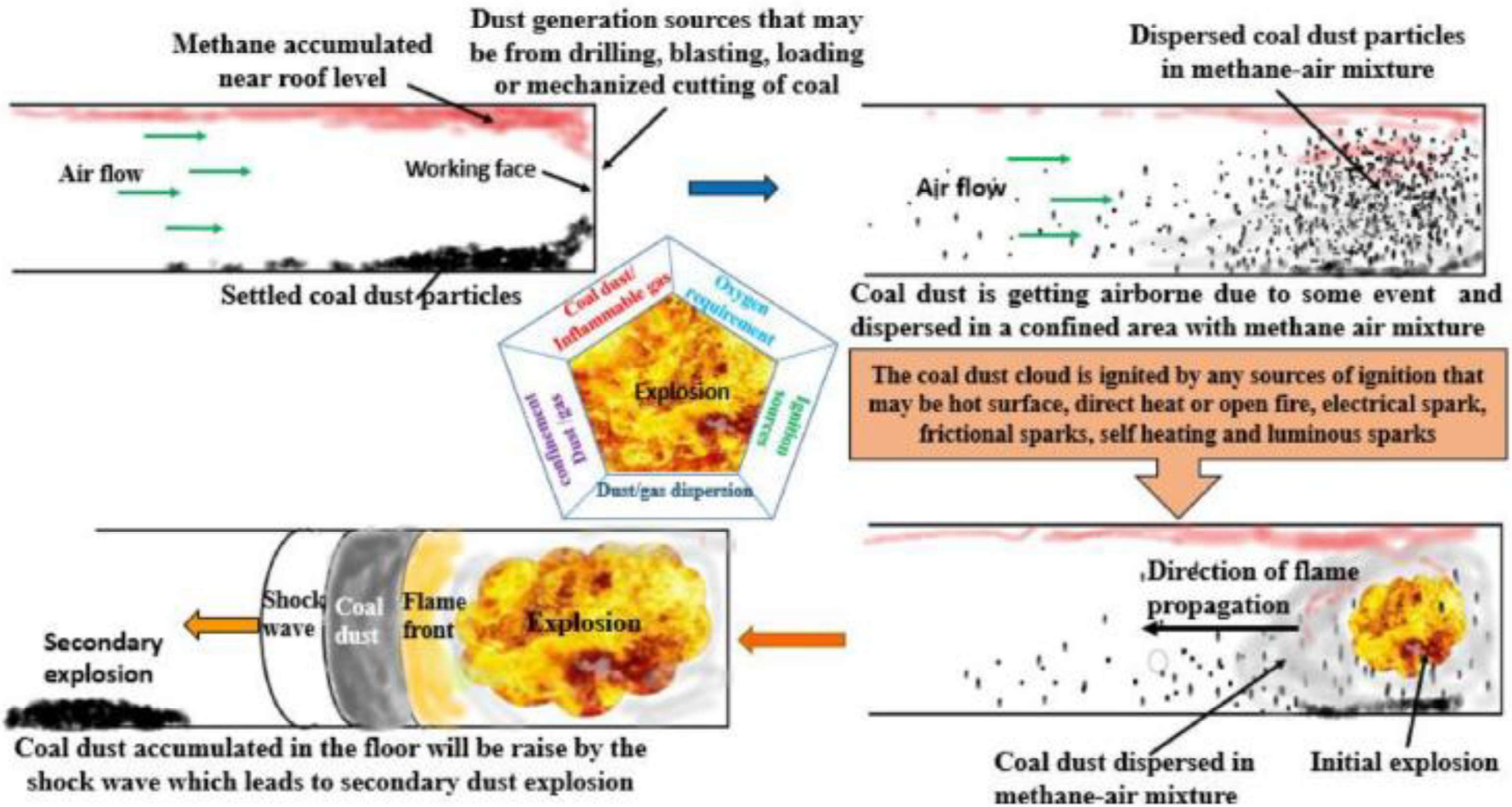


Fig. 1. Graphic representation of an explosion in underground coal mines.

Table 3
Characteristics of coal dust explosions in underground mines.

Characteristics Combustible dust	Oxygen	Ignition source	Dust dispersion	Dust confinement	Outcome
✓	✓	✓	×	×	No explosion
✓	×	×	✓	✓	No explosion
✓	✓	✓	✓	×	O nly flash fire
✓	✓	×	✓	✓	No explosion
✓	×	✓	✓	✓	No explosion
✓	✓	✓	×	✓	No explosion
✓	✓	✓	✓	Partially	Explosion may propagate
✓	✓	✓	✓	✓	High-intensity explosion

- Coal dust, when suspended in the air as a cloud, is capable of bursting into an explosion and propagate it, even in the absence of firedamp.

- For a coal dust explosion to take place:
  - Coal dust must be of a composition which includes sufficient VM.
  - Coal dust should be of necessary fineness.
  - They should be in a dispersible condition in the form of a thick cloud.
  - The dust cloud should be so dense that one can't see through it. The quantity amounts to 30 to 40 g/m^3 .
  - A source of ignition of sufficient intensity should be present.

Such circumstances generally exist after a firedamp explosion.

Development of coal dust explosion

- **Exact ignition mechanism not known**

- **Common view –**
  - Surface oxidation of coal dust particles
  - Ignition of flammable mixture of air and gases present in between the dust particles
  - combustion of solid coal particles

Coal dust explosion develops in stages.

First stage of ignition or 'Puff'

- It is a sudden combustion process of a part or whole of air-borne dust marked by a very high temp. but without any dynamic effects.
- If the whole of the dust is consumed, the combustion of dust-air mixture ends with a puff.

Main explosion

- If the whole of the dust is not consumed, the puff may lead eventually to an intense main explosion.
- During the transition from Puff to explosion, due to transfer of heat of combustion to the surrounding unburnt layers mainly by radiation, an increase of pressure in the burning layers takes place.

- When the pressure exceeds a certain value, a full fledged explosion is developed in which the combustion takes place at a rapid rate.

- The pressure wave developed passes through the unburnt layers ahead of explosion flame and stir up the deposited dust creating necessary fuel in the form of a thick cloud for the following flame.

- Thus the dispersion of dust and flame propagation processes are intercoupled.

Flammability or Explosive Limits of coal dust

- It is defined as its ability of coal dust, when in the form of a cloud, to spread or propagate ignition to all points where dust-air mixtures of corresponding concentration are present.

- The range of flammable limits or explosive limits is very wide, much wider than in the case of firedamp mixture.

- Lower flammability is not an absolute quantity.

Lower limit of flammability depends upon

- Particle size
- The chemical composition of dust
- Nature and intensity of igniting source
- Time of contact with the source
- Turbulence of the dust cloud
- Uniformity of dust dispersion
- Purity of the sample
- Composition of atmosphere especially methane and oxygen contents

- Bituminous coals have LFL varies widely between 30-300g/m^3.

- Most violent explosions are produced when the concentration is about 10 times the lower limit (400 to 500 g/m^3)

Ignition of coal dust-air mixture

- Ignition of coal dust-air mixture is not so rapid as with gas-air mixture

- A larger source of heat is required for coal dust-air mixture.

- The ignition temperature of coal dust cloud depends on
  - **The rank of coal:** The ignition temperature decreases as the rank of coal decreases from the anthracites to sub-bituminous coals.
  - **Nature and intensity of ignition source:** It varies between 900 °C and 600 °C for relatively low-ash coals
  - **Particle size**
  - **Moisture and ash contents :** Moisture in dust particles and in surrounding atmospheres raises the ignition temp. of the dust because of heat absorption and vaporization of the moisture.
  - **Oxygen concentrations :** With decrease in oxygen concentration, the ignition temp. increases.

Factors affecting development of coal dust explosions

- The flammability or explosibility of coal dust-air mixtures had been the subject of many investigations carried out in
  - Laboratories
  - Surface experimental galleries and
  - Experimental coal mines

The experimental work was centered around the

- Origin
- Propagation and
- Control of coal dust explosions

Factors affecting flammability or explosibility of coal dust-air mixtures

- Particle size
- Dustiness of mine workings
- Volatile matter content
- Percentage of ash
- Percentage of moisture
- Oxygen Concentration
- Nature and intensity of ignition source
- Presence of firedamp in mine air
- Turbulence
- Surrounding Conditions

Particle size:

- The finer the dust, the greater is its surface area per unit mass and greater is its inflammability.

- Coal dust particles up to 750 to 1000 μm take part in explosions depending upon the

  - rank of coal,
  - nature and intensity of ignition,
  - oxygen concentration.

- Most dangerous particle sizes lies between 10 to 100 µm.

- Below 10 µm size, flammability reduces to a certain degree due to
  - Chemical decomposition of coal dust
  - Tendency to agglomerate and
  - Rapid oxidation on initial exposure to air thereby becoming less easily ignitable

Dustiness of mine workings:

- The dust cloud must be dense immediately surrounding the ignition source so that one can not see through it.

- Minimum density of a dust cloud which will propagate an explosion depends on the
  - Nature of the ignition source
  - Fineness of the dust
  - Rank of coal

A mine working is dangerously dusty if it contains 100 – 120 g/m^3 and most violent explosions occur at 300 to 400 g/m^3.

- The thermal ignitability curve for a coal dust showing the relationship between Ignition temp and coal dust concentration shows that the minimum value of the ignition temp. approaches asymptotically at the higher dust concentrations.

Volatile matter content:

- Flammability increases with increasing combustible volatile content.

- The volatile matter is usually calculated on dry, ash free basis by the formula

$$\% \text{ VM} = \frac{\% \text{ VM (From analysis) x } 100}{100 - \%\text{ash} - \%\text{, moisture}}$$

right hand side of above formula may be written as

$$\frac{\% \text{ VM}}{\% \text{ VM} + \% \text{ FC}}$$

Known as volatile – Combustible ratio or simply volatile ratio of coal

Several investigations had shown that coal dusts with

- VM $<$ 10% - non-inflammable
- VM $\rightarrow$ 10 – 14% - less inflammable
- VM $>$ 14% highly inflammable

Percentage of ash

- Increase in ash content or presence of inert foreign material reduces the ignitibility or flammability of coal dust because of heat of absorption.
- Stone dusting in coal mines functions on this principle which is a practical application of the use of inert dust to prevent an explosion from taking place.

Percentage of moisture

- Moisture in dust particles raises the ignition temperature of the dust.
- It exerts a cooling effect because heat is absorbed during its heating and vaporization, thereby reducing the energy available for ignition of the dust cloud.
- coal dusts containing 25 to 30% moisture tends to wet and agglomerate the fine particles and reduces their dispersability.
- Effect of moisture on flammability is unimportant below < 10%.

Oxygen Concentration

- Variation in O_2 conc. affect the ease of ignition of dust clouds and the explosion pressure.

- With decrease in O_2 concentration, the ignition energy required increases, ignition temp. increases and maximum explosion pressure decreases.

Nature and intensity of ignition source

- The nature and intensity of ignition source e.g.
  - temperature,
  - size of spark or flame etc.

exert a great influence on the flammability of mine dust as they determine the dust-raising capacity and turbulence induced within the cloud.

- Explosions initiated by strong sources develop faster and cause more damage than explosions initiated by weak sources.

Presence of firedamp in mine air

- The flammability of coal dust increases almost directly in proportion to the % of firedamp.

- Presence of firedamp in air in % less than its lower limit reduces the lower explosive limit of coal dust.

- 1% CH_4 (by vol.) in 1m^3 of air is equivalent to about 12 g of coal dust.

Turbulence

- The rate of combustion reaction depends on how intimately dust and O_2 are mixed.
- Turbulent mixing of dust and air result in most violent explosion.

Surrounding Conditions

The surrounding conditions e.g.

- The size,
- shape,
- constrictions,
- obstructions,
- branching,
- length and nature and condition of the surfaces of mine workings

exert an important influence on the coal dust explosions as they increase or decrease the progress of flame by holding or releasing the pressure.

Causes of coal-dust explosions in mines

- 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 flame must be present.

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

- Naked flames
- Friction
- Electrical sparks
- Firedamp explosions

Naked flames

- It is the easiest means of igniting a dust cloud as the source of heat is of considerable size and a large part of the dust can be heated.

Friction

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

Electric sparks

- Sparks from short-circuiting and arcing at electrical equipment or overheated trolley wire may ignite an explosive dust-air mixture.
- 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.
- Under suitable conditions, a discharge or sudden recombination of separated positive and negative charges can occur which can act as a source of ignition.

Firedamp explosions

- It is the commonest source of initiation of a coal-dust explosion.

- Besides posing the danger of 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 firedamp mixture (approx. 0.4 m^3 vol.) may thus bring about a much bigger coal-dust explosion.

- 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

- It is much easier to prevent a coal dust explosion being initiated than arrest one.

- The measures for prevention and suppression of coal-dust explosion can be divided into the following three groups:

1. Measures which prevents or reduce formation and dissemination of coal dust underground

1. Measures against ignition of dust accumulation

1. Measures against explosion propagation

1. Measures which prevents or reduce formation and dissemination of coal dust underground

- Elimination of coal dust in mines is the logical means of eliminating coal-dust explosion hazard.

- The following important measures should be adopted to reduce the formation, distribution, and accumulation of dust in mine workings

WATER INFUSION

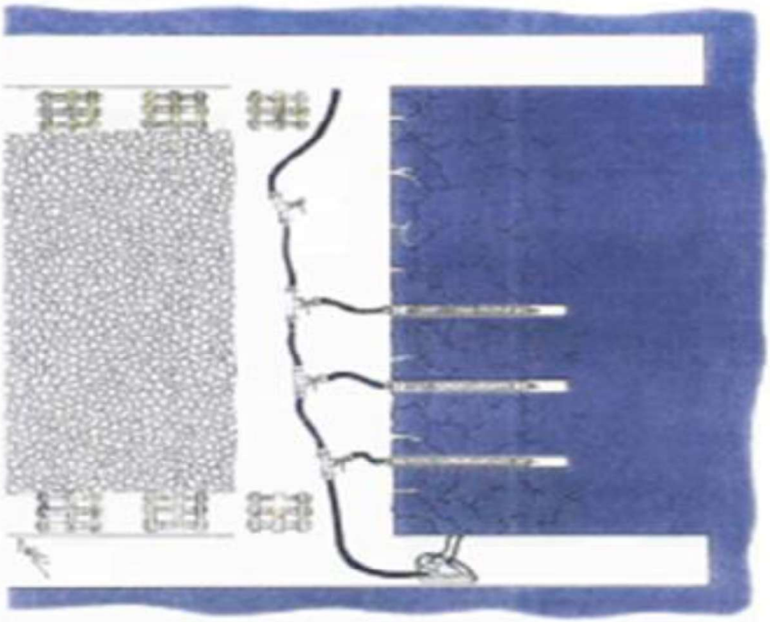
- Water infusion of the coal face at normal (5-20 atg) or high (80-250 atg) water pressure.

- The effectiveness of coal face infusion depends on the amount of water injected and its uniform distribution in coal.

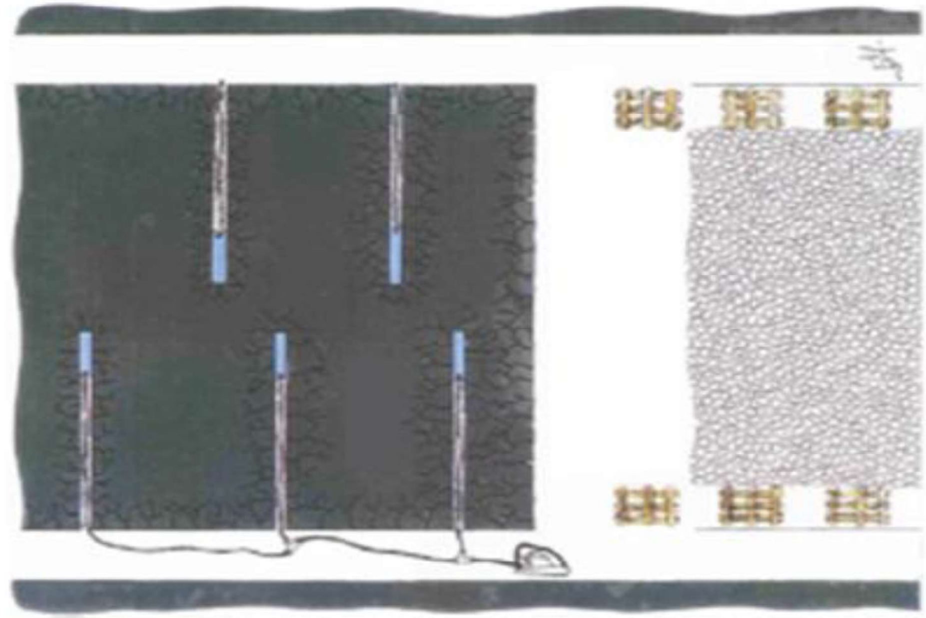
- The amount of water required lies between 8 and 10 litres per solid cubic meter coal.

Water infusion is the process of injecting water with or without surfactant under a certain pressure into the coal seam ahead of working face. The liquid infuses into the seam along coal seam cleats and fractures and penetrates a considerable distance from the hole radially.

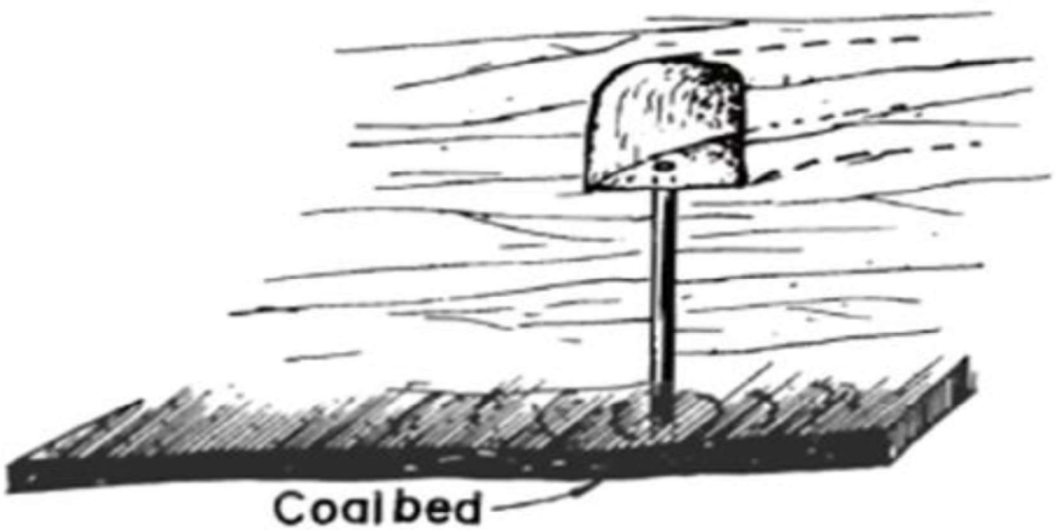
In Fig. 1a, horizontal holes are drilled into the face to a depth of about the daily advance (about 3 m) of the panel (shallow infusion). Under some circumstances, holes are drilled to about 12 m (deep infusion). The spacing of these holes is approximately 1.5–2 times the length of the holes. In Fig. 1b, water is injected into coal seam from pre-drilled holes in coal ribs from gateroads. Hole depth ranges from 18 to 36 m and the sealed depth ranges from 14 to 18 m. The third method is known as remote infusion or infusion from outside of the mined coal seam, as shown in Fig. 1c. If there is a roadway above the panel being mined, holes are drilled downward from this roadway into the panel and infused continuously. Face infusion has serious operational limitations in that it requires large numbers of holes to be drilled and infused in one shift otherwise production shift can be delayed. Remote infusion requires more expensive and difficult drills and this method is not widely used. Drilling and infusion from gateroad shows promise by solving operational problems. Completion of the infusion process of a hole is determined by regular inspections of water seepage on both sides of the panel. However, seepage may be difficult to find at the ribs because mining induced fractures parallel to the rib will prevent water from migrating to the entry. Water may be observed at all places along the ribs and seeping from the panel near the floor. Another sign that the infusion process may be complete is a drop in infusion pressure, accompanied by an increase in flow rate, which usually indicates that the water has reached the rib or is short-circuiting along the path of the least resistance.



(a) Face infusion [13]



(b) Gateroad infusion [13]



(c) Remote infusion [12]

Fig. 1. Illustrations of various coal seam infusion methods

- ‘**Wet winning**’ of coal using wet pneumatic picks.

- With machine cutting,
  - using sharp picks of suitable type,
  - selecting optimal cutting traveling speeds of the machine,
  - using wet-cutting.

- **During blasting** in coal

- use of stemming cartridges of CaCl2 powder containing 82-85% CaCl2 and 15-18% water reduces dust production.

- **With power loading, using conventional shearer loader**
  - by using sharp picks of suitable type and pick lacing,
  - selecting suitable drum design, optimal rotational speed of drum, traveling speed of the machine and proper direction of drum rotation;
  - introducing water to the pick clearance line through hollow drum shaft
  - flushing the cutting edge of the picks from jets located either in or close to the pick boxes,
  - using external water sprays during cutting.
  - Internal water sprays with a water pressure greater than 15 kg/cm^2 have been found to be more effective than external water sprays.

- Wetting through coal pile before it is manually or mechanically loaded.
- Using proper type of conveyors with which the dust production is minimum.
- Covering the total length of conveyor with a hood.
- Water spraying at transfer and loading points and improving their design.

- **Preventing spillage and degradation of coal during transport in roadways by**

  - Using undamaged dust tight cars
  - Avoiding overloading so that it will not spill in transit
  - Water spraying the full and empty trains during their transit.
  - Maintaining the haulage track in good condition

- **On coal conveyor roadways, reducing spillage by**
  - selecting suitable capacity conveyor as well as proper belt width and speed
  - providing adequate bunker capacity at loading points, and
  - centralizing the flow of coal.

Proper ventilation

- Restricting velocity of air current in mine airways to less than 3 m/s.
- Adopting homotropal ventilation.

- **Preventing dust accumulations in mine workings by**
  - dry suction at loading and unloading points at which large quantities of dust are produced and can not be suppressed in the ordinary way.
  - Cleaning systematically and regularly main haulage roads and main return airways of dust (3 to 4 times a year) by transportable roadway suction apparatus.
  - Regularly cleaning at and near transfer and loading points.
  - Locating dry coal preparation plants far away from down cast shafts (not less than 80m)

- Selecting a method of winning with which the dust production is less.

- Controlling caving of roof coal in thick seam mining using sub-level caving method.

- Consolidating the floor dust to prevent it from being raised.

2. Measures against ignition of dust accumulation

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

3. Measures against explosion propagation

The protective measures which have been found in practice to have varying degree of effectiveness in arresting explosion propagation are:

- generalized wetting of coal dust
- generalized stone-dusting
- stone dust barriers
- explosion stoppings
- salt zones
- water barriers
- triggered barriers

Generalized wetting of coal dust

- It is an effective means of arresting propagation of coal-dust explosions in dry mine workings.

- For water to be effective it must be present in sufficient quantity and be mixed intimately with coal dust.

- The percentage of admixed water required to prevent propagation of a coal-dust explosion depends on

  - ✓ The fineness of the dust
  - ✓ Strength of the igniting source
  - ✓ Volatile content of coal and
  - ✓ Amount of stone dust present

- It should not be less than 50%.

- In practice, coal dust is wetted by washing excessive deposits of it on the side and roof surfaces to the floor by means of hoses, thereby converting the dust into mud.

- To increase the wettability of coal dust which does not absorb water readily, a wetting agent may be added to the water.

- The disadvantage of water as an inert for neutralizing the coal-dust explosion hazard are:

  - Requires sufficient quantity of water streams for continuous wetting.
  - Relative humidity of mine atmosphere is increased.
  - Heaving of floor, if soft, occurs.
  - Cost of the plant is high as the entire mine workings must be equipped with water mains.

GENERALIZED STONE-DUSTING

- It consists of applying stone dust on the sides, roof, and floor of all mine workings except those within 10 m or less of all working faces so that it overlays the deposited coal dust and thus prevents the latter from being ignited or taking part in an explosion.

- Stone-dusting is not required in a mine or part of it if
  - it is naturally ‘too wet’ (condition wherein water exudes if a ball of dust is squeezed in the hands) or
  - It is too high in incombustible content to propagate an explosion.

- In 1891, British Engineer W. Garforth first observed that an explosion did not propagate to a part of a mine which was well stone dusted.

- With this observation, stone-dusting began in Britain and officially adopted in 1920.

- Stone-dusting was officially adopted in France in 1911 and in Germany in 1926.

- Today, generalized stone dusting is done in mines of almost all coal-mining countries of the world.

The value of stone-dust application is due to the following facts:

- When coal dust is mixed with enough incombustible dust, it will not explode or assist in propagation of an explosion.
- When incombustible dust is raised into an explosion flame in a sufficiently dense cloud, it gets heated up taking away heat from the flame.
- Greater the amount of stone dust in the flame, greater is the cooling effect.
- The incombustible dust also serves to shield or blanket the coal dust particles from heat of radiation so that they do not take part in combustion any more.

- As coal dust is constantly produced as a result of mining operations and get deposited by ventilating currents in mine workings, one application of stone dust will not suffice to keep the mine workings immune from explosions.

- Stone-dusting must be applied at regular intervals of time after it has been first applied.

- Minimum incombustible content (by mass) required by the coal dust depends on
  - Characteristic of the coal especially its VM content
  - Fineness of the dust and
  - Percentage of CH_4 present in the mine atmosphere
- Requirement of min. incombustible matter in coal dust
  - In India – 70%
  - In FRG – 80% and
  - In USA – 65%

- For a given coal, the quantity of stone dust to be applied in mine workings can be calculated from the following relation:

- $$\frac{0.01a + x}{1 + x} = \frac{b}{100}$$

Or

$$x = \frac{b - a}{100 - b}$$

where

x = quantity of stone dust required (kg of stone dust/kg of mine dust)

a = percentage of incombustible matter already present in the mine dust

b = prescribed minimum percentage of incombustible content

- **About 3 to 7 kg stone dust per tonne of coal output is required.**

Characteristics of suitable stone dust

- Fineness
- It should not be hygroscopic so that it does not cake.
- Dispersibility: Should be readily dispersible into the air when blown by mouth or by suitable appliance.
- Combustible matter present
- It should be soluble in the fluids of the lungs.
- It should be as light in colour as possible and preferably white.

Table: Specifications of stone dust in some countries

	F.R.G.	U.S.A.	U.K.	India
Fineness	100% through sieve 144 mesh/cm^2 and at least 50% through sieve 6400 mesh/cm^2, by mass	100% through 20-mesh per linear inch sieve and at least 70% through 200-mesh sieve, by mass	100% through BS 60-mesh sieve and at least 75% through 240 mesh sieve, by mass	100% through 60-mesh and at least 50% and not more than 75% through 240-mesh sieve by mass
Combustible matter	< 3%	< 5%	Not specified	Not specified
Total free and combined silica content	< 10% by mass in fraction < 20μ 5% in the respirable fraction < 5μ	< 4%	Not specified	Free silica < 5%

Standard stone dust is prepared in special mills out of

- Shale
- Dolomite
- Gypsum: Most effective of all
- Limestone: most commonly used in mines throughout the world due to its
  - Cheapness
  - Easy availability
  - White colour
  - Low silica content and
  - Little tendency to cake

Stone dust application

- Stone dust can be applied
  - By hand or
  - By mechanical means using stone dusting machines

Hand stone-dusting

- A man can stone dust 15 to 20 m of a roadway, 9 to 11 m^2 in cross-section, per shift.

Hand-dusting by hand scoops is

- Cumbersome
- Has low capacity
- Does not ensure even distribution of stone dust over the roof and sides and
- Not suitable for large or mechanised mines.

Mechanised dusting/mechanised spreading of dust

- It is ideal for large and mechanised mines.
- It is most economical
- Efficient and
- Rapid method

Stone dusting machines/stone dust distributors

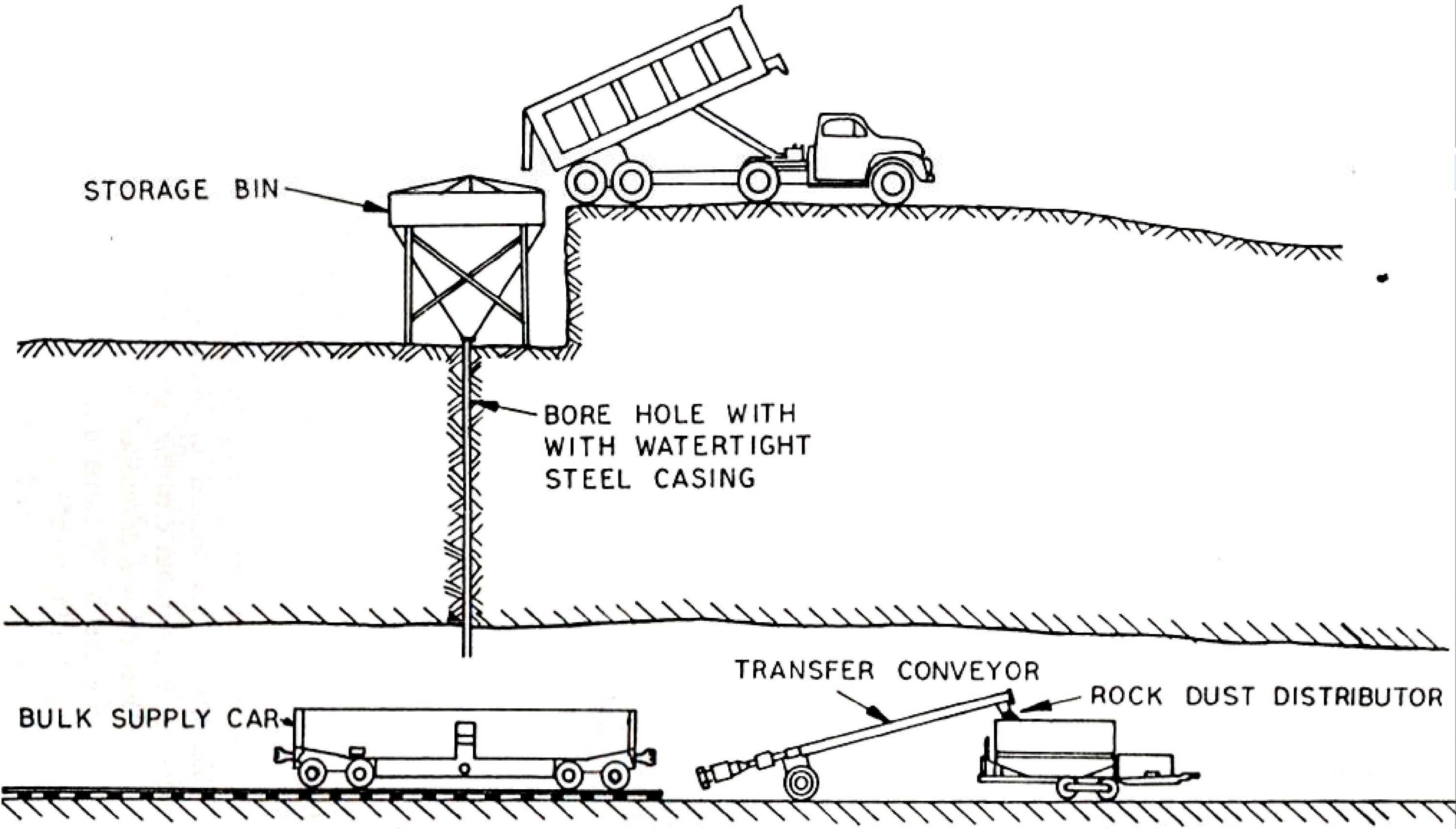
- They blow fluidised dust on to mine surfaces through tubing or hose of up to 200 m long.

- They may be of

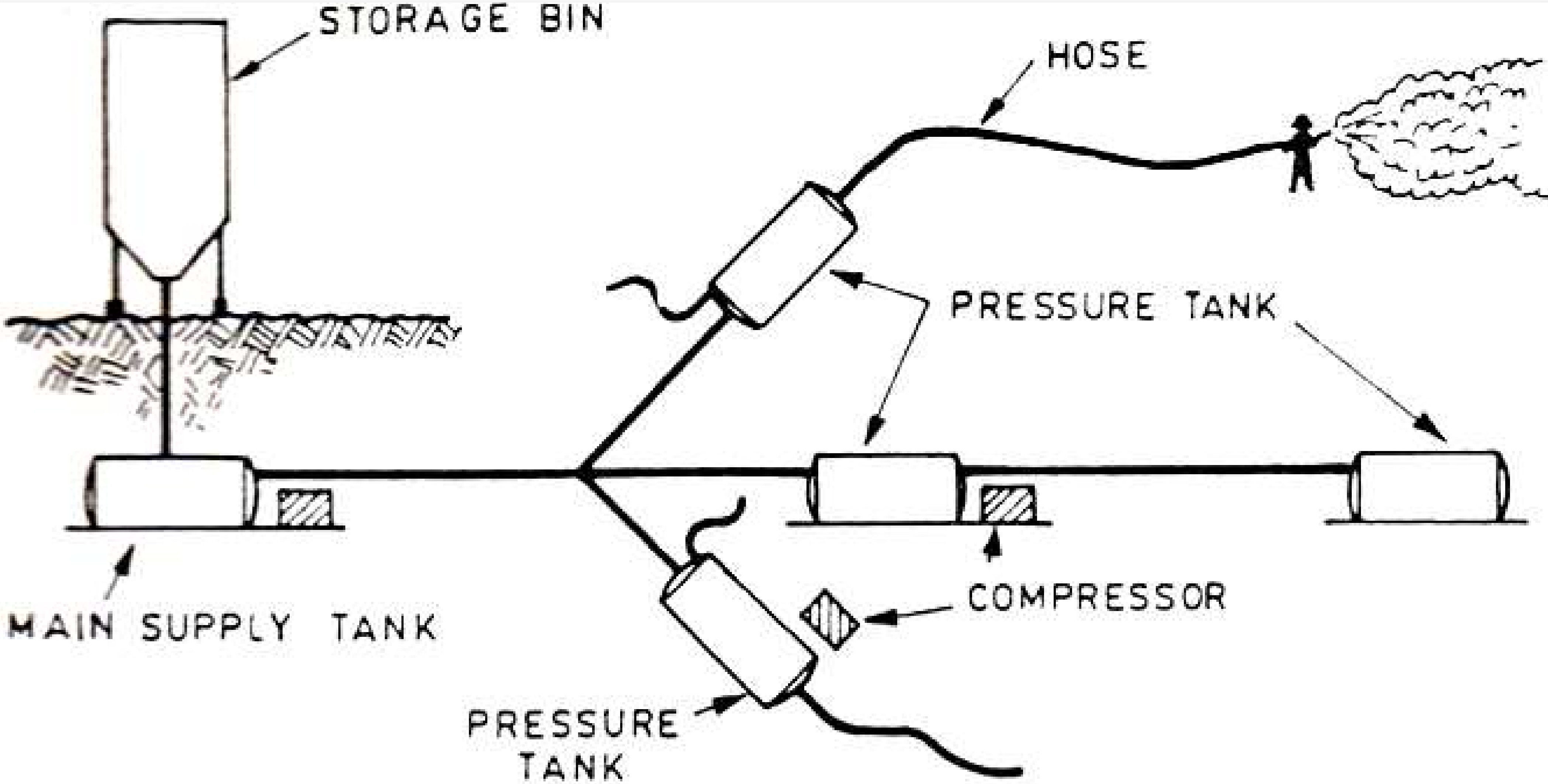
  - **Low pressure type**: portable machines which can be moved from one face to another for face-area stone dusting as soon as a face is loaded out.

  - **High pressure-machines:** have dust capacities up to one tonne per minute.

    - Used for applying dust in intake and return airways as well as in face areas.



MSA bulk rock-dusting system



MSA pressure tank automated rock-dusting system

Effectiveness of wet stone dusting in arresting propagation of explosion:

Experiments carried out in US Experimental Coal Mine has shown that:

- A mixture of 20-30 litres of water with about 45 kg dust gives good results from the standpoint of adherence.
- Wet stone dust should be applied at a rate of not less than 0.92 kg/m^2 of surface area to yield a good covering of the side-roof surfaces.

- Rate of drying of the stone dust varies with the air velocity and relative humidity.

- With normal air currents and relative humidity below 80-90%, it dries in about a week.

- Wet stone dusting is less effective than dry stone dusting in arresting the propagation of an explosion.

STONE DUST BARRIERS

Stone dust barrier is a device which uses the dynamic pressure of explosion to release and disperse a mass of stone dust in the form of thick cloud into the path of an on-coming explosion flame thereby smothering the flame.

- Stone dust barriers, the means of suppression of coal dust explosions, were first proposed by M. J. Taffanel and today extensively used in Indian and many overseas mines.

Location of stone dust barriers

Installed at strategic locations of the mine such as

- Roadways leading from shafts or pit bottoms.
- In all levels and inclined roadways including gate roads and development heading and
- Near roadway junctions

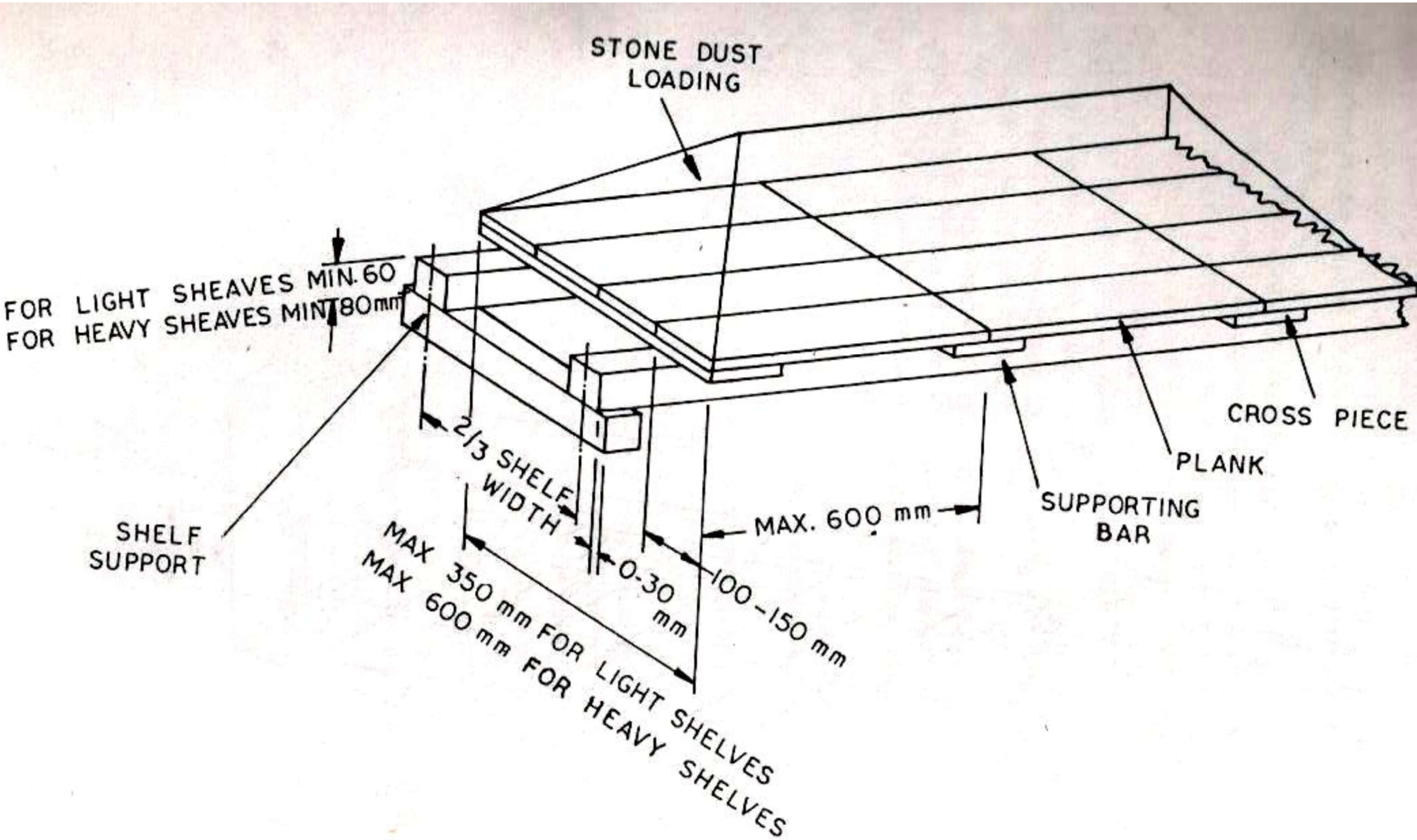
Barrier design

- The shelf barrier consists of a no. of dust-laden shelves.
- Independently supported transverse to and along the roadway in which it is installed.
- It occupies a length of 25 to 40 m of the roadway.
- Two design of shelves are commonly used in mines

- **The German shelf** and
  - Consists of several loose planks, max. 60 cm long and10-15 cm wide
- **The Polish shelf**
  - Consists of several short planks 35-50 cm long and 10-15 cm wide

In German mines, both German and Polish shelves are approved.

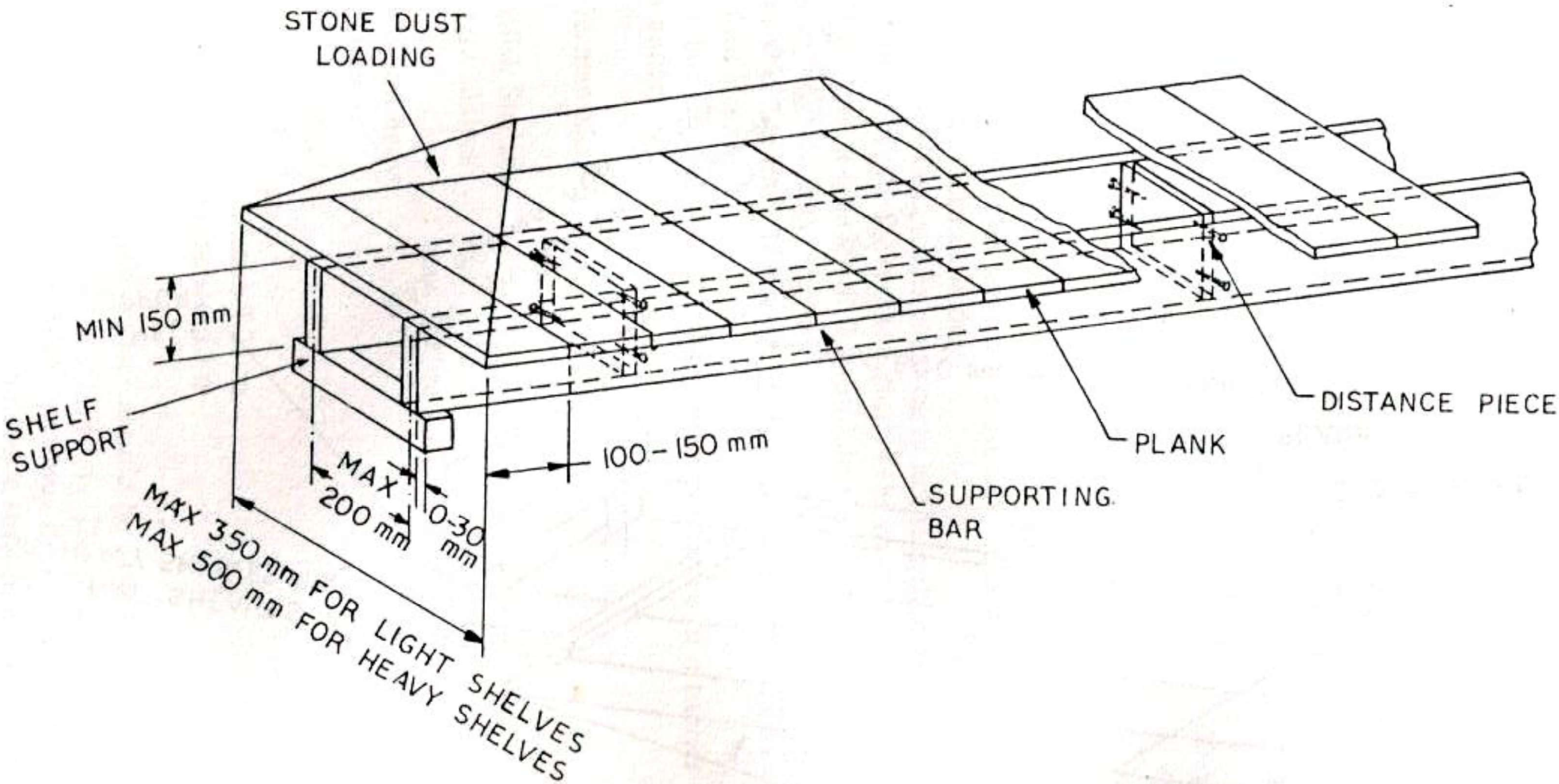
In UK and India, Polish shelves are only permitted.



German Shelf

Specifications of the light and heavy German shelves

	Light	Heavy
	Shelves	
Width of shelves	max. 35	60 cm
Width of planks	10–15	10–15 cm
Length of planks	max. 60	60 cm
Height of supporting bars	at least 6	8 cm
Distance between supporting bars (centre to centre)	2/3 of shelf width	
Mass of shelves/m length of shelf	max. 15	20 kg/m
Deflection of supporting bars	Max. 2 per cent span width	
Dust loading on shelf	at least 50	150 kg
	max. 100	300 kg



Polish Shelf

Specifications of the light and heavy Polish shelves

	Light	Heavy
	Shelves	
Width of shelves	max. 35	50 cm
Width of planks	10–15	10–15 cm
Length of planks	max. 35	50 cm
Height of supporting bars	at least 15	15 cm
Distance between supporting bars (centre to centre)	max. 20	20 cm
Mass of shelves/m length of shelf	max. 15	15 kg/m
Dust loading/m length of shelf	at least 30	60 kg/m
	max. 35	70 kg/m

Rules for erection of stone dust barriers in German Mines

- A stone dust barrier must carry not less than 400 kg stone dust/m2 of the roadway in which it is installed.
- Distance between the adjacent shelves of a barrier :

German shelves

- Min. 1.5 m and Max. 2.0 m

Polish shelves

- Light shelves: min. 1.0 m and max. 2.0 m
- Between heavy shelves or between a heavy and a light shelf: min. 1.25 m and max. 2.5 m

- Bottom of the shelves should be at a height greater than half the roadway height but not exceed 2.6 m.

- Clearance between the ends of the shelves and the sides of the roadway should be at least 5 cm.

- Brackets supporting the entire shelf must be rigidly fixed to the ground or roadway support.

- The shelf should never be suspended from chains or wire ropes which tend to swing.

- The shelf supports at the brackets must be horizontal and have a smooth bearing surface.

- They should not project beyond the shelf supports more than 3 cm.

- The supporting bars must be rectangular in section.

- The gaps between the planks must be covered with thin strips having max. width equal to the width of the planks.

- The clear space between the top of the dust loading and the inner edge of the roof bar or crown segment of the steel arched support may be at least 15 cm.

- Dust loading must be approx. symmetrical with respect to the centre of the roadway and must occupy atleast two-thirds of the max. width of roadway.

- Dust loading on the shelves must not be covered.

- In the vicinity of a barrier, ventilation ducting, overhung belt conveyors, pipes and other obstructions which seriously affect the effectiveness of a barrier must not be present.

- Barriers should not be installed at roadway junctions, curves, or in widened places. They can however, be installed near roadway junctions.

- Distance between barriers should not exceed 200 m in gate roadways of longwall faces and 400 m in main roadways.

Efficiency of stone-dust barriers

- Studies shown that efficiency of a stone dust barrier depends on the time interval between dust discharge and flame arrival which depend upon

  - The design and location of the barrier.
  - Presence of firedamp-air mixture and
  - Intensity of explosion

- A weak explosion may not through the shelves off their support.

- If the time interval between dust release and flame arrival is too long, a greater part of the dust falls to the floor. If it is too short, the dust does not get adequately dispersed.

- A time interval of 0.1 to 0.2 s is sufficient enough to create a flame quenching cloud.

Failure of stone-dust barrier

- When barrier itself lies in a flammable firedamp-air mixture or firedamp occurs at the as a roof layer.
- When flame velocities are high (more than 500 m/s) as when an explosion is initiated by a powerful firedamp explosion.
- When the barrier is located less than 40-60 m or far from a face or other potential point of ignition so that the dynamic pressure is less than the min. required and normally lies between 3-5 Kn/m2.
- When an explosion is initiated by a weak ignition source and sufficient dynamic pressure is not built up.

Water Barriers

- Since the early 1960s, water barriers, also called water-trough barriers are being used as alternative to stone-dust barriers for suppression of coal-dust explosions in mines.

- At present, water barriers are widely used in the West German coal mines.

- Performance tests of water barriers carried out in **Tremonia Experimental Mine, FRG** showed that
  - in quenching explosion flame, water barriers are roughly equivalent to the stone-dust barriers.
  - 200 litres of water per sq. m of roadway cross-section has the same effect as 400 kg stone dust per sq. m on German shelves.

Advantages of water over stone dust

- Its heat capacity (latent heat of water = 539 cal/g) is about 5 times that of dust.
- Efficiency is not affected by underground climatic condition.
- Easily available in all mine roadways.

Constructional features of water barrier

- Consists of a no. of water-filled troughs or containers of suitable material supported on horizontal shelves in the vicinity of the mine roof.

- The containers shatter or burst under the action of 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.

Types of water barrier

Depending on the method of support of troughs, two types of barriers have been approved

- **Type 1**
  - Troughs are supported with their total upper lip surface resting on transverse supporting frames.
- **Type 2**
  - Troughs are placed over transverse bars.

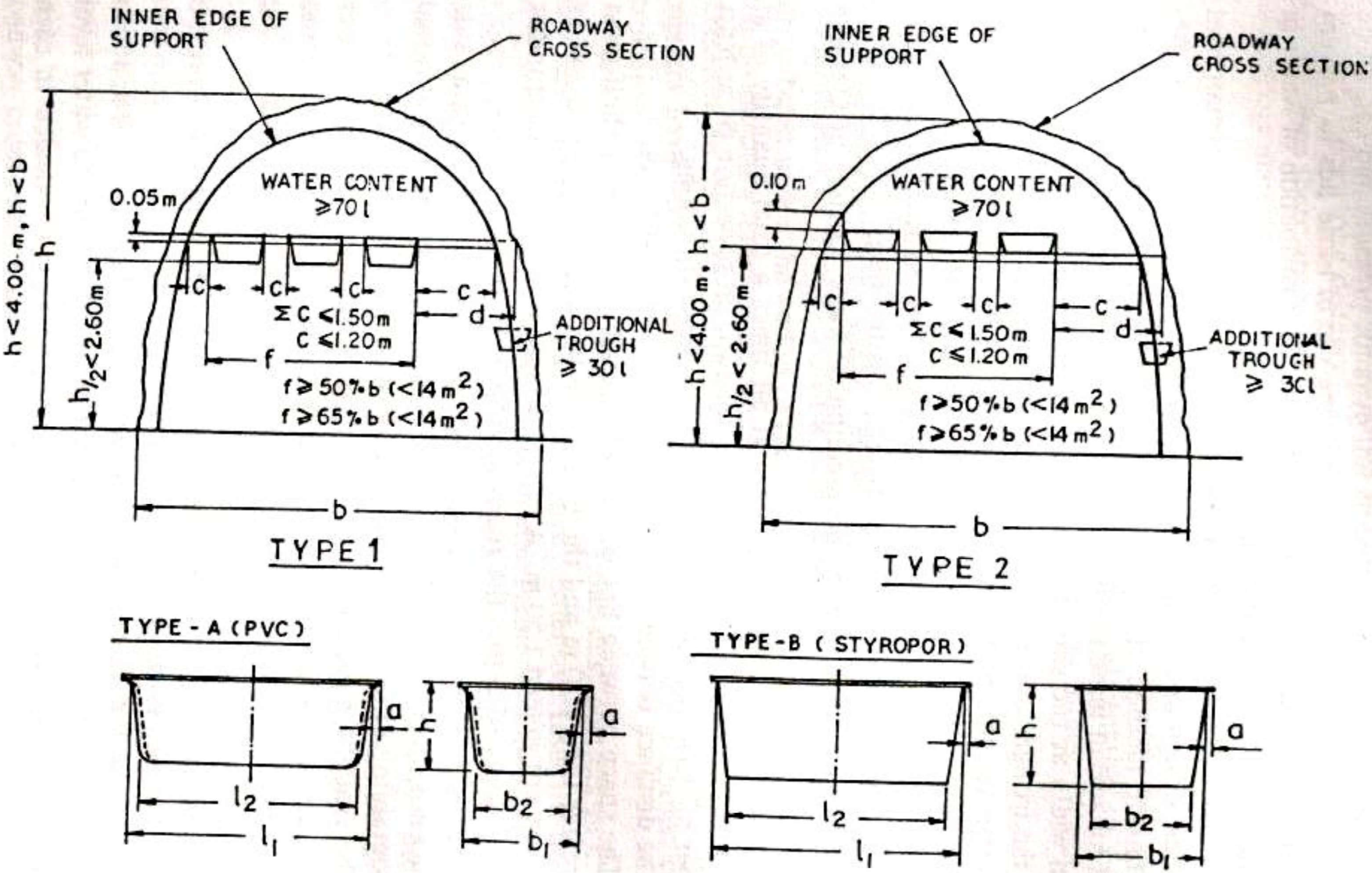


Fig. 2.45: German Water (trough) Barrier (schematic)

$l_1 = 760$ $l_1 = 720$ $a = 25$ $b_1 = 500$ $b_2 = 450$ $h = 270$ Vol ≈ 83 l

Fig. Water Barriers

- Shattering of the water troughs is influenced by
  - Magnitude of the dynamic pressure
  - Trough material used
  - Trough shape
  - Method of installation and
  - Trough lid or covering

- Troughs made of certain verities of hard PVC or foamed polystyrol have been found most suitable.

- They are easily shattered at low wind pressures giving good water distribution.

Design and installation of water-barrier

- Troughs must be designed so that they maintain their shape.
- Troughs with approval certificates should only be used.
- Method of installation of the troughs in roadway cross-section exercises a great influence on the shattering of the troughs.
- Troughs placed with their longer axis at right angles to the roadway axis offer greater frontal area to the dynamic pressure than they are placed parallel to the axis of the roadway.
- Troughs supported in the roadway with their edges resting on transverse supporting frame have been found to shatter easily than troughs supported on transverse bars.

Rules for erection of water barriers in German Mines

- Water barriers must contain at all times atleast 200 liters of water per sq. m roadway cross-section or at least 5 liters per m^3 roadway volume and at least 20 m long.
- Distance between two shelves must be at least 1.2 m.
- Space between lips of adjacent troughs carried by a shelf must not be greater than 1.2 m and total space between troughs in a row of troughs must not exceed 1.5 m.
- Distance between outer troughs of a row and roadway side or rib must not exceed 1 m.
- Where this distance exceeds 1 m, an additional trough containing 30 liters of water must be installed at the rib.

- At the site of installation, troughs must cover at least 50 % of max. roadway width for roadway cross-sections up to 14 m^2, and 65% for roadway cross-sections exceeding 14 m^2.

- Bottom of the troughs must be at a height of at least half the roadway height but not exceed 2.6 m.

- When the top lip or edge of the troughs is higher than 1.7 m above the roadway floor, arrangements must be made for recognizing water level by marked graduations or float provided in each trough.

- With Type 2 barriers, the space between the top edge of the trough and the inner edge of the roof support must be at least 10 cm.

- Troughs must carry at least 70 litres of water.

- At all places where barriers are installed, water from a water pipe must be available. Water hoses must be provided.

- Water barriers must be located at least 100 m away from stone-dust barriers.

- Distance between the barriers must not be greater than 200 m in gate roadways and 400 m in main roadways.

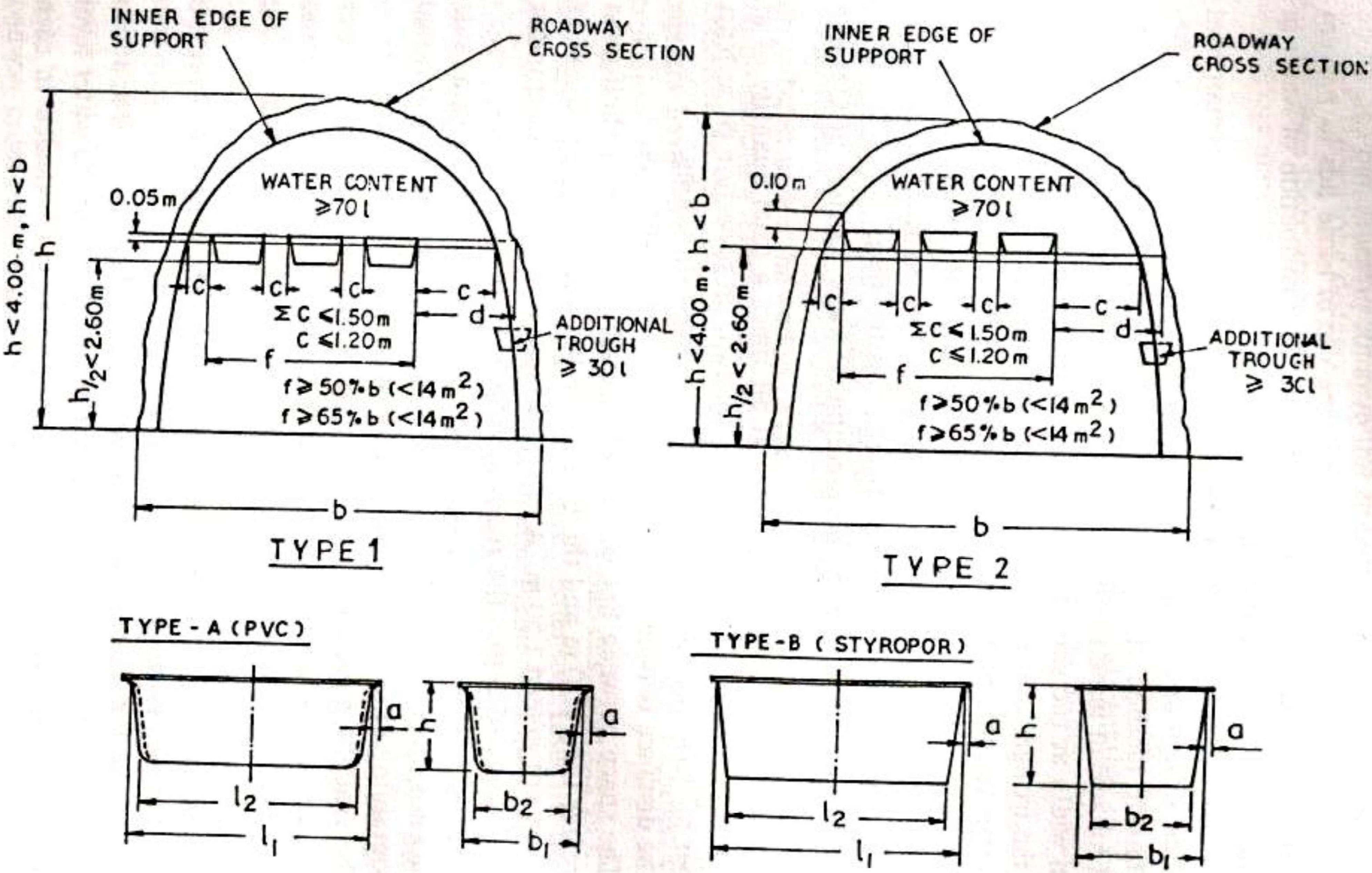


Fig. 2.45: German Water (trough) Barrier (schematic)

$l_1 = 760$ $l_1 = 720$ $a = 25$ $b_1 = 500$ $b_2 = 450$ $h = 270$ Vol ≈ 83 l

Failure of water barriers

Water barriers can be ineffective when

- An explosion initiated close to (less than 40 m) or far from the barrier.
- When an explosion is initiated by a weak ignition source resulting in a weak or slow-moving explosion with flame speed less than 76 m/s.
- When an explosion is very strong or violent so that the time lapse between the arrival of pressure wave at the barrier is too short (less than 0.1 s) to disperse water into the roadway cross section.
- When an explosion spreads in to an adjacent roadway through interconnecting crosscuts.

Triggered Barriers

- Stone-dust and water barriers suffer from the disadvantages that they depend for their action on the dynamic pressure generated by the explosion.

- Triggered barriers started in 1966 whose operation is independent of pressure.

Constructional features:

- Consists of
  - A sensor or detector
  - A disperser and
  - An extinguishing agent

The sensor or detector

- It is located upstream of the disperser.

- It detects a developing explosion and sends a signal to the disperser which disperses the extinguishing agent into the path of the explosion flame.

- Of two types:

  - Photo-electric (IR and UV) sensors and

  - Thermocouple sensors.

- The sensor should be sufficiently sensitive to react to temperature change or to radiation from the flame of any size of explosion.

- On the other hand, it should not react to extraneous effects and influences, viz. due to
  - mechanical shock,
  - cable faults,
  - air-blast shocks produced from blasting,
  - mine lighting and
  - heat from flame lamps or other sources.

- Its performance should not be impaired by dust, oil or water.

- Ultraviolet sensors have been found to be unreliable in operation with coal-dust explosions, in which unburnt cloud of coal dust between the flame and sensor may attenuate the UV radiation to an insignificant level.

The disperser

- The disperser disperses the extinguishing agent into the path of the explosion flame.

There are two types of extinguishant dispersion systems:

1st system:

- The extinguishing water contained in a trough or
- The extinguishing powder held in polythene bag.
- They are dispersed by a detonating cord.

2nd system:

- The extinguishing agent (water or powder) is contained in the disperser under stored force (pressurized nitrogen gas or Halon) and

- It is dispersed when a detonator bursts the sealing disc of a quick-release valve of an inverted high pressure steel cylinder containing the suppressant water or powder and nitrogen at a pressure of 30, 60 or 120 bar.

The extinguishing agents

- It is essential that the extinguishant is discharged at a high rate and
- Time interval between the onset of discharge and flame arrival does not exceed the time necessary for full discharge.
- Commonly used extinguishants are:
  - $KHCO_3$
  - Water
  - Dry powders
  - Halon (CF_3Br)
  - Water mixed Halon (CF_3Br)

- The relative effectiveness of the extinguishing agents has been found to be as follows:

$$KHCO_3 < \text{Water} < \text{Water mixed Halon } (CF_3Br) < \text{Halon } (CF_3Br)$$

Advantages of triggered barriers:

- They are applicable in all regions of a mine.
- They find particular application in thin seams where there is insufficient headroom for passive barriers.
- They can be used to suppress firedamp explosions.
- Much less extinguishant is required.
- Minimum barrier maintenance.

Investigation of Mine Explosions

The evidences that may be available and collected immediately after an explosion are

- Displacement of loaded mine cars, strong steel supports, machinery or other heavy objects, and

- bending of steel beams may serve as the guide for ascertaining the direction in which the explosion force had traveled through the mine workings.

- Charring or burning of materials sensitive to flame viz. paper, fibres of torn timber, and pieces of clothing may give valuable information on the passage of explosion flame.

- Formation of traces of coke crust or globules on roadway supports may give indication of passage of coal-dust explosion flame and intensity of explosion.

- Layering of soot deposit on horizontal surfaces would indicate the passage of coal-dust explosion flame.

- Nature of death or injury of the victims whether by burning, violence, suffocation or poisoning by afterdamp may give clue to the type of explosion that have occurred.

- Position of dead bodies and equipment may give valuable information on the operations being carried out.

- Defective electrical apparatus and machinery or defective or damaged safety lamps which may pinpoint the cause of origin of explosion.

- Discovery of contrabands, such as matches or other flame making devices may indicate negligence of miners as a possible cause of ignition.

- Signs of blown-out shots may locate the seat of explosion.

- Analysis of air samples collected and analyzed immediately after the explosion may give a clue to the type of explosion that might have occurred.

- Immediate past history of mine and affected parts thereof from official reports/records, especially

  - The ventilation difficulties

  - Operation of ventilation appliances and

  - Dust hazards may give general appreciation of explosion hazard existing in the mine.

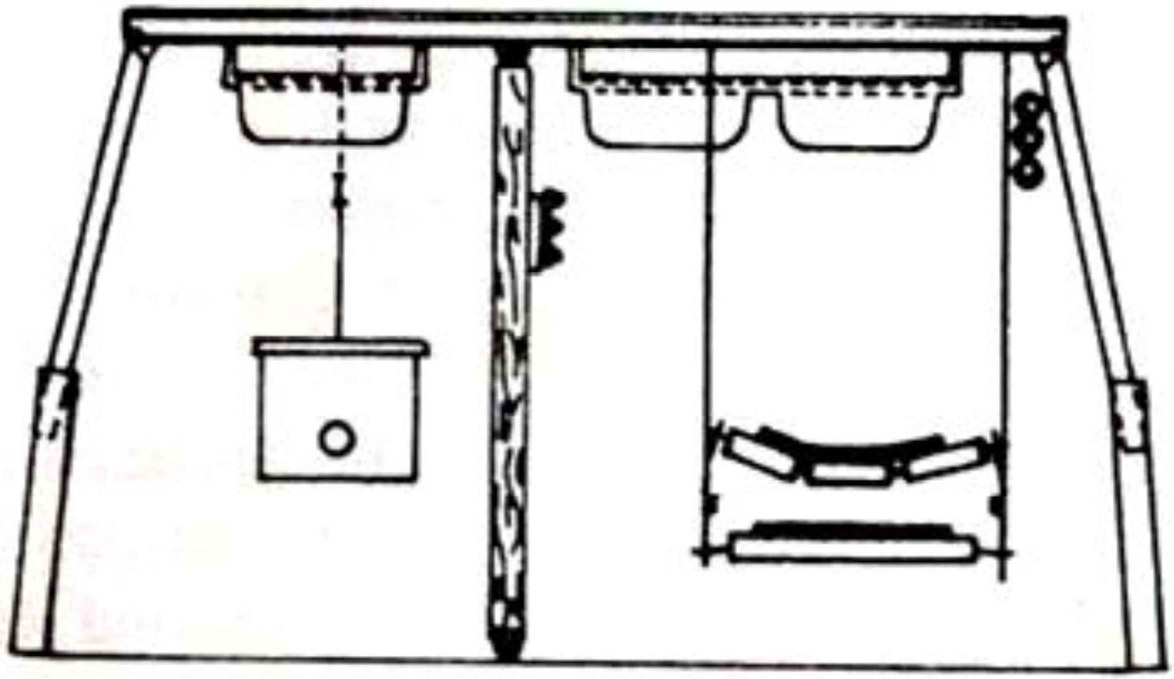


Fig. 2.46: Water troughs in the cross-section of the gate road of an advancing longwall face

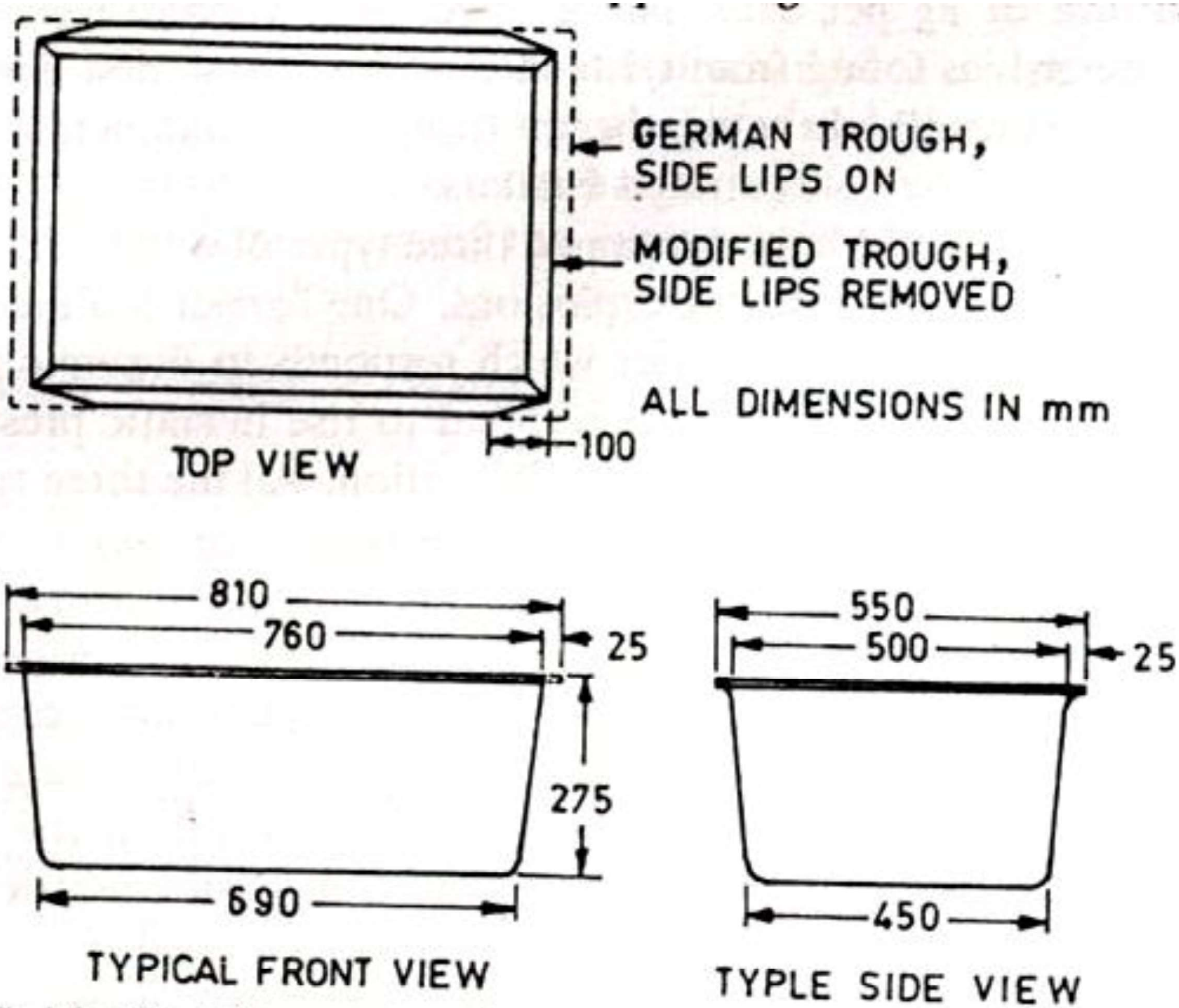


Fig. 2.47: Modified German trough