

UNIT 1: MINE FIRE

DR PATITAPABAN SAHU

ASSOCIATE PROFESSOR, DEPARTMENT OF MINING ENGINEERING, IIT(ISM) DHANBAD

Fire:

Fuels, in the form of solids, liquids or gases undergo rapid chemical change by interacting with oxygen or oxidants releasing large amounts of energy at fast rate that results in the form heat and light.

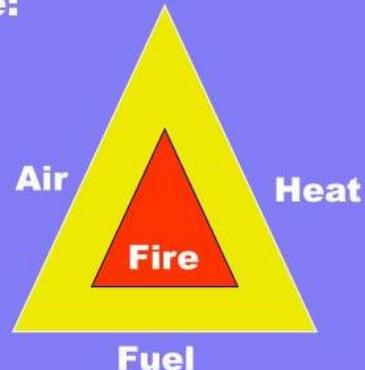
The Fire Triangle

Three factors make a fire triangle:

Fuel

Heat

Oxygen



Fuel

Solid

Liquid

gases

**Timber
Coal
Solid waste
Rubber like
conveyor belts**

**Petrol, paraffin,
Hydraulic fluids**

Butane, Methane

Ignition sources:

Exogenous fires (ignition from external source)

- **Frictional heating**
- **Over heating**
- **Open flames**
- **Sparking from electrical equipment**

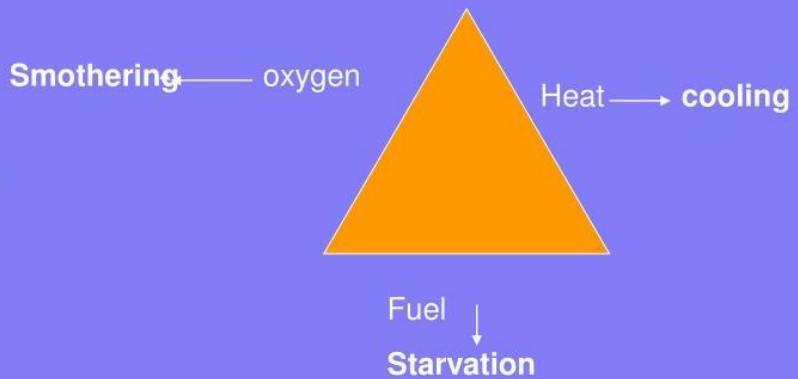
Endogenous fires (ignition from spontaneous heating)

Spontaneous combustion

Requirements for sustenance of a fire

- Availability of fuel
- Adequate quantity of heat for exothermic reaction
- Necessary supply of oxygen for supporting exothermic reaction

Control of fire



Classification of fires:

Type A fires:

Fires involving solids combustible materials of organic nature like wood, rubber, plastic, paper, etc.

Type B fires:

They involve inflammable liquids like gasoline, lubricating oils, greases, fuel oils, etc.

Type C fires:

All electrical fires such as fires like electrical motors, transformers, trolley wire, battery equipment fires, etc.

Type D fires:

Fires involving combustible metals like Mg, Al, Zn, Na, K, Zr, Ti, etc.

Control:

Type A: cooling effect of water

Type B: blanketing effect (cutting off oxygen supply)

Type C: Inert gas , powder extinguishers

Type D: special media to extinguish due to danger of chemical reaction

Extinguishers

Portable fire Extinguisher

- Soda acid extinguisher
- Water co₂ Extinguisher
- CO₂ gas extinguisher
- Dry powder extinguisher
- C. T. C extinguisher (Carbon tertrachloride)
- Foam extinguisher

Classification of Fires and Extinguisher

Class A

Fire involving solid material of organic nature like wood , rubber ,paper etc



Fire Extinguisher

Soda , CO₂ , Dry powder , water CO₂ ,
Foam ,C.T.C extinguisher .



Class B

They involve in inflammable liquid like oils, petrol etc.



Fire Extinguisher

Dry powder , CO₂, C.T.C,
Foam extinguisher are use .



Class C

Fire involve in inflammable gases fuel like LPG , Methane , butane.



Fire Extinguisher

Dry powder and CO₂ extinguisher
are use



Class D

The fire involve in metal fire like melting iron etc.



Fire Extinguisher

Dry powder and CO₂ Extinguisher are use.

Class E

The fire involve in electrical equipment like motor, generators, oil filled transformers.



Fire Extinguisher

Dry powder and CO₂ Extinguisher are use.

FIRE FIGHTING

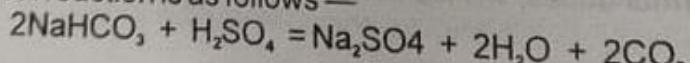
FIRE EXTINGUISHERS : Mine fire in their early stages may be extinguished by use of suitable fire extinguishing appliances. They are extremely handy when fighting fires at places which can not be served with water mains. They have greater extinguishing ability than water but suffer from the limited supply of extinguishing agent. The principles on which they function are—

- (a) Cooling effect of water.
- (b) Fire extinguishing effect of Carbon dioxide.
- (c) Blanketing effect of foam.
- (d) Smothering effect of solids.
- (e) Combination of more than one effect.

There are various types of fire extinguishers suitable for use in mines :

1. Soda-acid extinguishers.
2. Water-carbon dioxide extinguishers.
3. Foam extinguishers —
 - (a) Chemical foam, (b) Air foam.
4. Carbon dioxide gas extinguishers.
5. Dry-powder extinguishers.

Soda-Acid Type : This contains two separate chemical liquids, sulphuric acid and a solution of sodium bi-carbonate which, on mixing, produces a large volume of carbon dioxide which, being confined within the container creates a high pressure. The chemical reaction is as follows —



The acid is usually placed in a glass phial at the top of the container while the sodium bi-carbonate solution (10 litres) fills the greater part of the remaining space. A striking knob on the outside is used to break the phial to allow the release of the acid, after which the container is shaken and resulting jet is directed as required. The pressure is sufficient to project the liquid through a distance upto 14m and a duration of 90 minutes. Cooling action of water is the main factor here in quenching the fire and carbon dioxide helps it only partially.

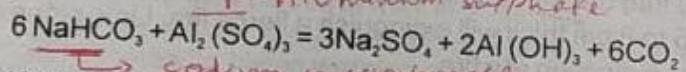
The soda acid types is suitable for free-burning materials such as coal, timber or brattice, but it not suitable for oil fires or electrical fires involving risk of shock. It is prohibited by the mines regulations for fighting oil or electrical fires.

Water-Carbon Dioxide Extinguisher : It consists of a copper or copper-lined steel cylinder containing water and a small copper cylinder of carbon dioxide compressed to some 60 atmospheres. When the copper seal of the cylinder is broken, the gas pressure expels a jet of water which can be thrown up to a distance of 10 to 12 meters. It can be quickly re-charged underground and does not deteriorate with age.

It is suitable for free burning fires. But it is not effective on oil fires and is not safe against electrical fires, in which cases its use has been prohibited by the regulations.

Foam Extinguisher : These can be used on oil fires for smothering the fire and cutting off the air supply.

Chemical foam—In the chemical foam type the foam is formed by mixing a suitable acid solution with an appropriate alkaline solution so as to form bubbles containing CO₂. The foam is then spread over the surface of blazing liquid and the blanket of CO₂ smothers the flames. The acid solution filled in an inner container is aluminium sulphate and the alkali solution sodium bicarbonate in an outer container. To one of these solutions is added a foaming or frothing agent such as liquorice, glue or glucose. When the solutions intermix, generally by upending the extinguisher, CO₂ is entrapped in tiny mass of bubbles forming a tenacious foam which serves to retain the CO₂. The chemical reaction during the process producing carbon dioxide is as follows—



With the 10-litre size extinguisher, about 80 litres of foam are produced. The foam acts as an extinctive blanket which spreads over the burning material excluding air and putting out the fire. There is, however, danger of electric shock with this type of extinguisher if used on electrical fires.

Air foam — This type of extinguisher, also known as 'mechanical foam' type has the advantages that it can be charged simply by filling the outer container with water and inserting a sealed metal charge holding foam concentrate and a propellant

charge of CO₂ under pressure. When the latter is released by the plunger, the charge is forced into the water and the resulting foam is ejected through a nozzle.

Carbon-Dioxide Gas Extinguisher : This extinguisher consists of a charge of carbon dioxide, 1 kg to 6 kg according to size, stored under pressure in a steel cylinder fitted with a wheel or a lever valve. When the valve is operated, the carbon dioxide emerges as a mixture of CO₂ gas and CO₂ snow which is particularly suitable for dealing with fires involving electrical risks or with oil fires in the undercut.

Disadvantages of this extinguisher are that the cylinder must be recharged at maker's works, periodical weighing is needed to make sure that the charge has not been partially used and the carbon dioxide is rapidly dispersed in well ventilated roadway, so reducing its effectiveness.

Dry-Powder Extinguisher : This contains a special fire-quenching powder which can be shot out of the container either by the detonation of a small charge as in the pistol type or by an excellent charge of carbon dioxide as in the large cylindrical containers.

Dry powder extinguishers are suitable for electrical fires, or for oil fires, or for fires involving conveyor belts, free burning materials, etc. They are readily recharged underground.

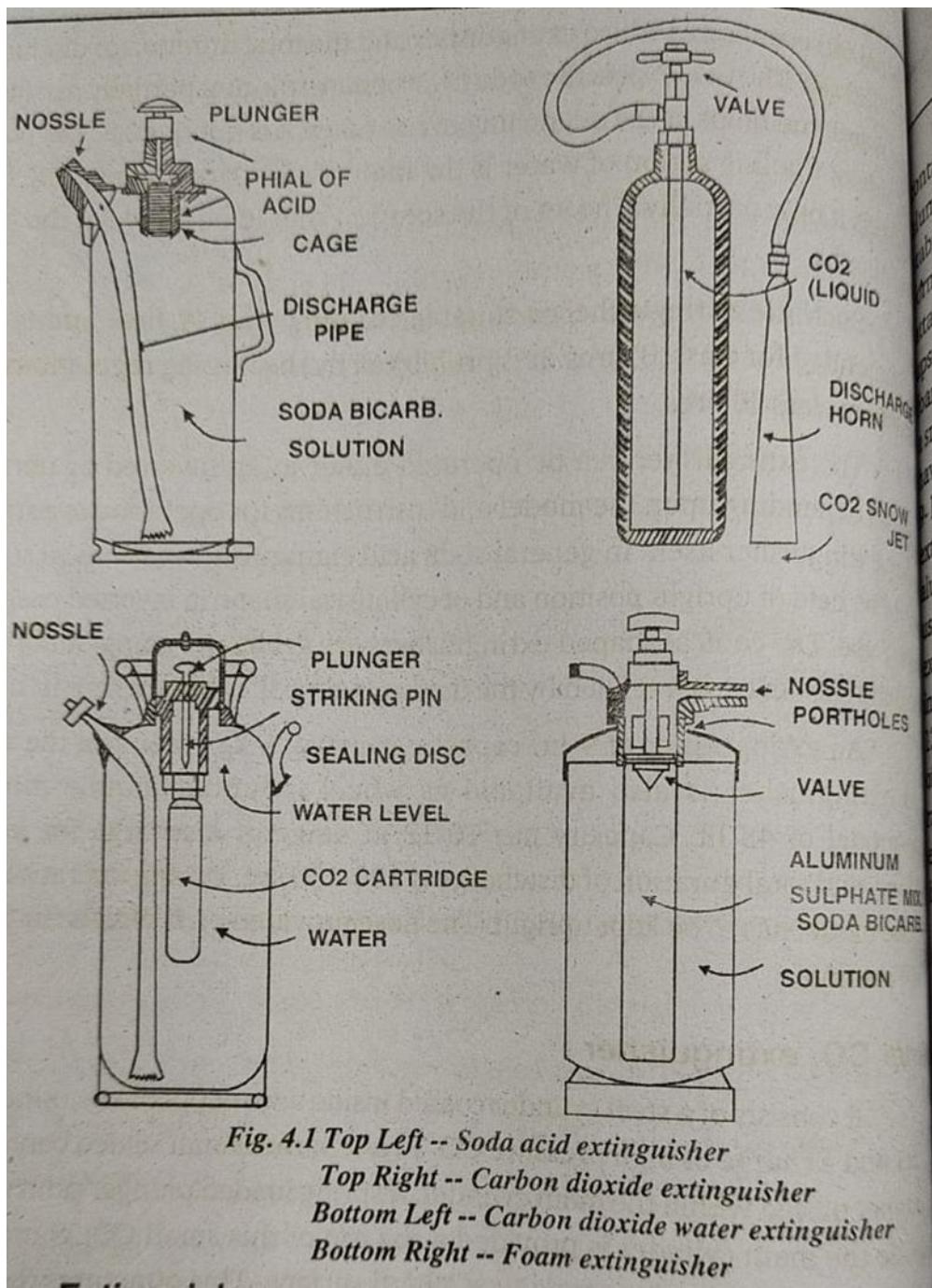
General Types of Agent for Fire-Fighting : These are (i) Sand, (ii) Stone-dust, (iii) Water, (iv) Foam plug.

Sand : The use of sand a recognised method of subduing fires of electrical origin. Sand should be clean and dry otherwise there is a tendency for subduing fires is the simplicity of its application. It is only necessary to spread a thin layer of sand to arrest combustion and smother the flame.

Stone-dust : The use of stone dust as a substitute for sand in fire-fighting has frequently been appreciated while it might appear that stone dust is more effective due to its fineness and less porosity than sand. It suffers a disadvantage that it is more readily dispersed into the air stream and therefore is more difficult to apply. A blanket of stone dust 5 to 8 cm thick will extinguish a fierce fire. Lime stone dust is a regarded to be better for extinction of a fire.

Water : Experience has shown that the most effective way of subduing a fire is by drenching it with water, although it has disadvantage of producing large volumes of steam which hinder progress. Water mains generally lead from surface to inbye districts. Rubber hose with nozzles or 8 cms fine hydrants are generally used to deliver water to fires at 20 atmospheric pressure.

Foam Plug : It is achieved by erecting a brattice sheet of not to close a weave across the roadway section some distance from the fire and directing foam from a suitable generator on to the surface of the brattice. The ventilating current passes through the brattice taking with it the foam. In a few minutes a foam plug is produced on the other of the sheet (fire side), the plug completely filling the road way. When the foam reaches the fire it cools and subdues the fire rapidly. The plug can extend to about 180m. and men applying this method are not working in heated atmosphere. The quantity of water used is minimum and there is less liability of damage to roof and floor when using the foam plug.



SPONTANEOUS COMBUSTION

Spontaneous combustion or spontaneous ignition is a type of combustion which occurs by the process of self-heating (increase in temperature due to exothermic internal reactions) of coal or other carbonaceous material, followed by thermal runaway (self-heating which rapidly accelerates to high temperatures) and finally, ignition.

The occurrence of spontaneous combustion in coal mines may be seen when the following three conditions are available:

1. Coal must be in a form which can oxidize readily at ambient temperature.
2. Oxygen must be available to support the oxidation.
3. Favorable conditions for accumulation of heat must be available.

MECHANISM OF SPONTANEOUS HEATING

- Coal is a heterogeneous and stratified organic rock, with carbon content varying from nearly 70% in the lignite stage (young coal) to 96% in anthracite (mature coal) with sub-bituminous and bituminous coals lying in between.
- Coal is constituted of petrographically homogeneous components (macerals) formed from transformation of vegetable matter by biochemical and geochemical processes, sometimes under rigorous extraneous conditions of heat and pressure.
- **Coal reacts with O₂ present in the air even in ambient conditions resulting in an exothermic reaction. The reaction is caused by a progressive series of adsorptive, absorptive and chemical processes** (Hudak, 2002).
- **The heat generated, if greater than that dissipated, gives rise to an increase in the temperature of the coal. As the temperature of the coal rises, the reaction becomes progressively faster and thermal runaway may take place to the point of ignition** (Stracher et al., 2004). This process is known as spontaneous heating or auto-oxidation of coal.
- **The ignition temp. of bituminous coal is nearly 160-170°C and of anthracite coal nearly 185°C.**
- However, when the dissipation of heat is more than accumulation, then coal temperature does not reach up to critical temperature and results in its weathering.
-
- The heat from oxidation normally varies from 2.0 to 4.0 cal/ml of O₂ sorbed at N.T.P.
- There are **other factors that assist in the generation of heat, viz. oxidation of pyrites present in coal, bacterial action, crushing of coal due to earth's movements and sorption of water (H₂O) vapour in coal**. But it is the oxidation of carbonaceous matter in coal that is primarily responsible for the initiation of spontaneous combustion.

- The exact mechanism of spontaneous heating of coal is still obscure. Unless the chemical constitution of coal is fully established, it would be difficult to clearly understand the mechanism. However, most researchers have recognized it to be essentially a surface combination, the nature of which may be dependent on the oxidation time, temperature and type of coal.
- **The spontaneous heating or auto-oxidation of coal is a complex physico-chemical process, which is accompanied by the absorption of oxygen, formation of coal-oxygen complexes and their decomposition leading to the liberation of heat.** This complexity of the process is enormous because of the great diversity in the coal substance with the associated mineral matter and the conditions of oxidation. OR

It may be defined as a complex physico-chemical process by which the freshly exposed coal at ordinary atmospheric temperature when comes in contact with oxygen catches fire due to auto-oxidation and without the application of heat from any external source.

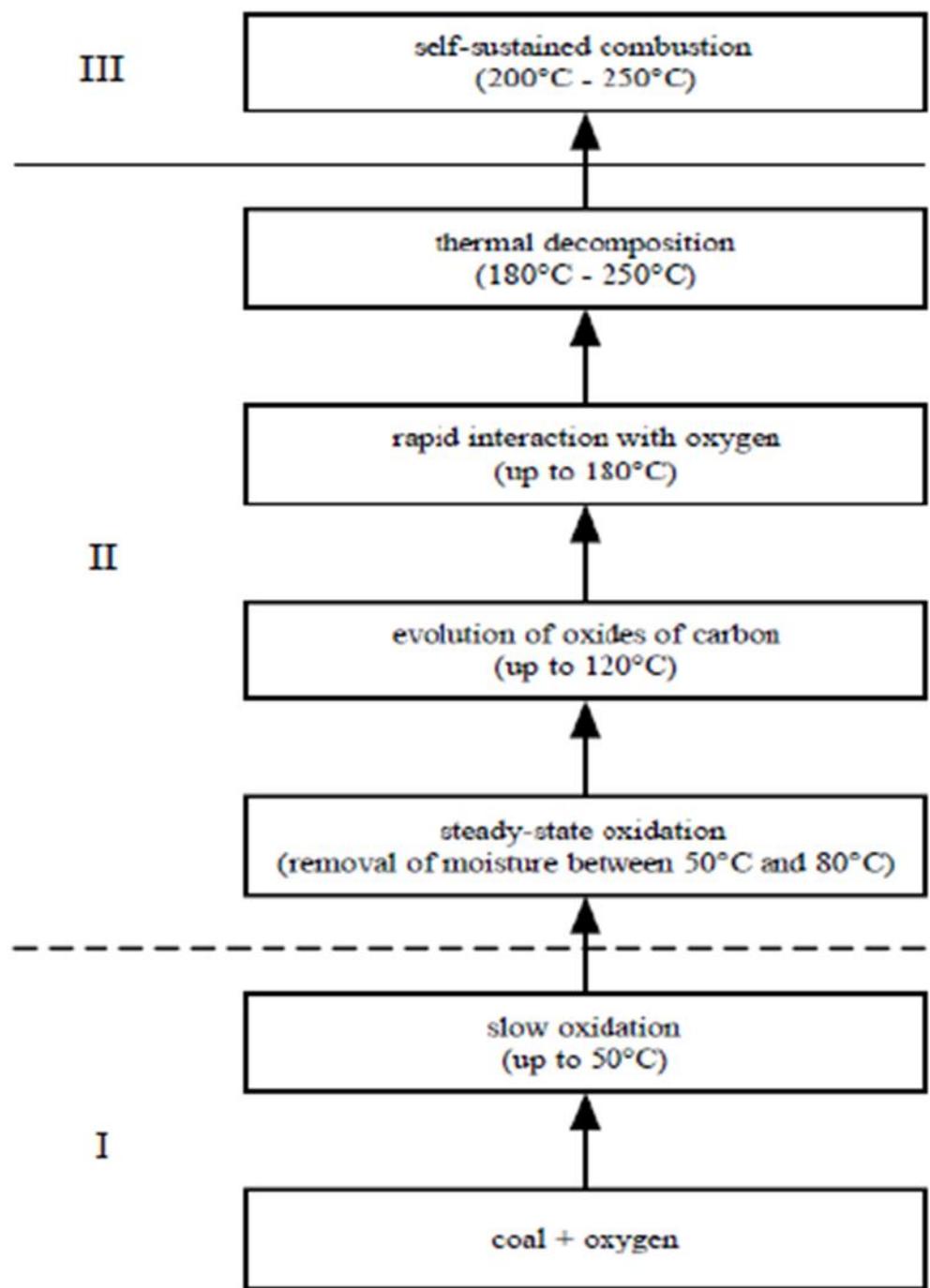
- During the oxidation of the heterogeneous mass, concurrent and overlapping reactions take place, which are very difficult to separate out. The rate of oxidation at ambient temperatures gives a measure of the proneness of coal to auto-oxidation. This low temperature aerial oxidation of coal is not a singular chemical process, but a complex phenomenon generally comprising of several simultaneous and interacting chemical processes which result both in erosive material removal and structural alternation of the organic matter.
- A large number of stable chemical chain reaction takes place due to several oxidation states of carbon and a variety of strong carbon oxygen bonds are formed.
- The observable elemental, compositional and structural changes reveal that the reaction of O₂ with solid coal is a time-dependent dynamic process.
- Observable changes in coal molecular structure and composition arise from prolonged sequence of events whose components exhibit complex interrelationships. The oxidation of coal is heterogeneous in character in which the diffusion of O₂ in the fine pores of the coal and the chemical reactions occurring at the same time influence the rate of reaction.
- At low temperature (80°C), the physical adsorption of O₂ in coal is dominant but plays a minor role from above 0°C. Chemical reactions set in at a temperature of 10°C and lead to the evolution of carbon monoxide (CO), carbon dioxide (CO₂) and

H_2O , starting between 42–55°C. This shows that chemisorption process takes place in the very early stages of the sorption process (Sevenster, 1961). Oxidation is very slow below 50°C and accelerates above 50°C, but above 80°C, a period of steady state is maintained, probably due to the removal of moisture of coal. Removal of oxides of carbon begins from 120°C. The interaction of O_2 with coal accelerates rapidly up to 180°C and thermal decomposition starts from 180°C to 250°C. The self-sustained process of combustion begins in between 220°C to 275°C with very rapid rise of temperature until the ignition point is attained. The active combustion sets in above that temperature.

Sequential stages in the spontaneous combustion of coal

- **1st Step:** Formation of coal-oxygen complexes and heat generation.
- **2nd Step:** Decomposition of these complexes, yielding of CO_2 and H_2O molecules and formation of more sensible groups [carboxyl (COOH), carbonyl (C=O) and phenolic (OH)] and heat generation.
- **3rd Step:** Decomposition of these groups too (at temp. $> 100^\circ\text{C}$), production of CO , CO_2 , H_2 , H_2O and high degree hydrocarbons (ethane, ethylene, propylene) and heat generation.
- **4th Step:** Decomposition of aliphatic structure (saturated & unsaturated hydrocarbons), production of CO , CO_2 , H_2O .

SEQUENTIAL STAGES IN THE SPONTANEOUS COMBUSTION OF COAL



STAGES OF SPONTANEOUS COMBUSTION

One recognizes three stages of spontaneous combustion of coal in coal mines:

- ✓ the incubation period
- ✓ the indication period
- ✓ open fire

1. The incubation period

- ✓ It is the period between the onset of first oxidation and the time point when one can detect by the senses.

- ✓ In a broader sense, it denotes the period between the beginning of coal extraction in a district or panel and the appearance of first signs of heating.
- ✓ During incubation period, one does not detect heating during one's passage through mine workings.

The incubation period varies widely depending on

- characteristics of the coal
- seam thickness
- nature of the immediate roof
- method of working and method of roof control
- regularity and continuity of working
- air leakage and the heat accumulation in the environment

- ✓ For low-rank coals, the incubation period generally varies between 3 and 6months.
- ✓ With high-rank coals it varies between 9 and 18 months.
- ✓ Under adverse conditions, the period can be less than 2 weeks, especially with low-rank coals.

2. The indication period

- The end of the incubation period is the beginning of the indication period.
- It is marked by ‘sweating’ and haze which is caused by the warmed up air from a fire area cooling on coming in contact with the cooler coal, rock and metallic surfaces and depositing moisture.
- The indication period is often of very small duration lasting sometimes only a few hours and end with the appearance of ‘fire stink’.
- The fire stink can be easily recognized by its characteristic petrolic smell.

3. The open fires

- After the indication period, open fire with visible active combustion breaks out.

- In open fires, seams seldom burn with a bright flame but they glow developing bluish-white clouds of smoke.

FIRE INDICES / SUSCEPTIBILITY INDICES OF SPONTANEOUS COMBUSTION

Based on the compositional analyses of mine environment, a no. of ratios or fire indices have been suggested, to detect not only the onset of heating in mines, but the degree of it as well.

They assist in the interpretation of fire gases.

Some of these gas ratios or indices used in interpreting trends of gas concentrations produced by mine fires are given as follows:

Ratio	Name
• $CO/\Delta O_2$	Graham's Ratio or Index for Carbon Monoxide (ICO)
• $CO_2/\Delta O_2$	Young's Ratio
• $CO/(Excess N_2 + CO_2 + combustibles)$	Willett's Ratio
• $(CO_2 + 0.75CO - 0.25H_2)/\Delta O_2$	Jones and Trickett Ratio
• CO/CO_2	Oxides of Carbon Ratio

• A feature of several of the ratios is the *oxygen deficiency*, ΔO_2 . This is a measure of the O_2 that has been consumed and is based on two assumptions;

✓ First, that the air has been supplied with 20.93% O_2 and 79.04% inert gases (excepting 0.03% CO). That 79.04 per cent contains traces of other gases but is referred to simply as N_2 .

✓ Secondly, it is assumed that no N_2 has been consumed or added (except from the air) through the area under consideration.

If no O_2 is consumed, then the O_2/N_2 ratio would remain at $20.93/79.04 = 0.2648 \approx 0.265$ irrespective of the addition of other gases. For any measured values of O_2 and N_2 , the conc. of O_2 that was originally in place can be calculated as

$$\frac{20.93}{79.04} N_2$$

Hence, the amount of O_2 that has been consumed, or O_2 deficiency is given as

$$\Delta O_2 = 0.265 N_2 - O_2 \quad \text{per cent}$$

Graham's Ratio

- It is the most widely used indicator of an incipient heating in coal mines and has often given warnings several weeks before any odour could be detected.
- It is recognised that coal on being exposed to air, even at room temperature, consumes O₂ and gives rise to gases like CO and CO₂ as oxidation products.
- As CO₂ may be produced from other sources or may be lost in air due to sorption by coal or by solution in water, CO is the most reliable indicator of heating.
- By 1914, Ivon Graham recognized the importance of CO as an early indicator of sp. heating of coal and the equally vital influence of O₂ that was consumed.
- He first suggested the index CO/ΔO₂, now known as *Graham's Ratio* or *Graham's Index* or the *Index for Carbon Monoxide* (ICO).
- It has the significant advantage that it is almost independent of dilution by leakage of air as this affects both numerator and denominator equally.

ling points should also be as possible to the suspected site of heating to avoid parallel leakage paths.

6. Different sampling points might indicate varying composition. Therefore the trend in the ratio in one sampling point may not be similar to another.

7. The use of diesel equipments and shot-firing may effect on the true value of the ratio.

CO₂/O₂ deficiency ratio :

When a fire becomes active, the Carbon monoxide produced may be consumed by the normal process of combustion. Under such conditions the CO₂/O₂ deficiency ratio becomes a useful guide of the magnitude of the fire. But this ratio is less reliable than the CO/O₂ deficiency ratio in the initial stages of heating because oxidation of coal and pyrites produce some CO₂, it is also given off from the strata.

Alarm for Mine Fires : Tele-monitoring systems have been installed in a number of mines for detection of carbon monoxide the help of sensors. EMCOR (M.S.A.) COMOWARN (Drager), ECOLYZER (E.S.), etc. are used as a continuous monitor to give an indication of fire or spontaneous combustion with visible and audible alarms.

Detection of heating by analyses of Mine Air

To interpret the results of an analysis, that a sample of the return air from a district liable to heating gave the following results :

Gases	Percent	Pure Air	(Normal Air)
Oxygen—	20.20	O ₂	=20.39%
N ₂	78.74	N ₂	=79.04%
CO ₂	0.31		
CO	0.003	CO ₂	=0.3%
CH ₄	0.75		
			=100.00%

When N₂ is 79.04

O₂ is 20.93

when N₂ is 1

$$O_2 \text{ is } \frac{20.93}{79.04}$$

when N₂ is 78.74

$$O_2 \text{ is } \frac{20.93}{79.04} \times 78.74 = 20.84$$

Vol. of oxygen absorbed

$$= 20.84 - 20.20 = 0.64 = 0.64\%$$

CO₂ produced

$$= 0.31 - 0.03 = 0.28\%$$

$$\text{Ratio } \frac{CO_2 \text{ produced}}{O_2 \text{ absorbed}} = \frac{0.28}{0.64} \times 100 = 43\%$$

$$\text{Ratio } \frac{CO \text{ produced}}{O_2 \text{ absorbed}} = \frac{0.003}{0.64} \times 100 = 0.47\%$$

MINE VENTILATION

80

Of the two ratios, the later is the most important. It is essential that the normal state of the air from each district should be known because the progressive increase of the CO/O_2 ratio indicates the development of a heating.

An air sample taken from the return airway of a district in a seam of coal liable to spontaneous combustion shows the following analysis.

CO_2	=	0.04%
CH_4	=	1.17%
O_2	=	19.92%
N_2	=	78.49%
CO	=	0.02%

The given analysis of the air in the return airway of a mine subject to spontaneous combustion, indicates clearly that the O_2 is low and that gases CO , CO_2 , CH_4 are formed. It is, therefore, apparent that a heating is in progress in an advanced stage, and active fire might be expected at any moment at some point in the workings.

Normal air contains	O_2	=	20.93%
	N_2	=	79.04%
	CO_2	=	0.03%

$$\text{When } \text{N}_2 \text{ is } 79.04, \text{ O}_2 = 20.93$$

$$\text{When } \text{N}_2 \text{ is } 78.49, \text{ O}_2 = \frac{20.93}{79.04} \times 78.74 = 20.78\%$$

$$\text{Amount of O}_2 \text{ absorbed from the air} = 20.78 - 19.92 = 0.86\%$$

Ratio $\frac{\text{CO formed}}{\text{O}_2 \text{ absorbed}}$ is $\frac{0.02}{0.86} = 0.023$ or 23% and this is high which

indicates that coal oxidation is in the advanced stage. Normal figures are 0.05 to 4%.

The ratio $\frac{\text{CO}_2 \text{ formed}}{\text{O}_2 \text{ absorbed}}$ is $\frac{0.4 - 0.03}{0.86} = 0.43$ or 43% which is above normal and confirms the above statement. Finally, the figures given in the question are very closely related to those obtained during goaf-fire experiments carried out at the Buxton Research station.

From a mine where regular air samples are taken and analysed the following figures are available :

No. of Sample.	Percentage O_2	Percentage N_2	Percentage CH_4	Percentage CO_2	Percentage CO	Percentage Location.
1	20.93	79.04	—	0.03	—	Intake air.
2	19.89	79.01	0.69	0.40	.008	Return air.
3	19.95	79.04	0.59	0.41	.030	Return air.
4	29.10	78.74	0.70	0.42	.020	Return air.

Intake sample No. 1 shows percentage of O₂, CO₂ in the air. Firedamp present in the return shows that the seam is gassy. If the seam is not gassy, the presence of CH₄ would indicate that spontaneous heating has already been started. Due to dry distillation of coal, CH₄ has been formed.

CO...The most important aspect for CO is the norm for the mine. CO in minute percentages is not detectable by normal methods. The presence of CO above 0.005 to 0.007 will indicate definite symptom of heating.

<u>Sample</u>	<u>CO produced O₂ absorbed</u>	<u>%</u>	<u>CO₂ produced O₂ absorbed</u>	<u>%</u>
Air sample No.2	0.8%		36%	
Air sample No.3	1.2%		37%	
Air sample No.4	2.7%		53%	

CO/O₂Ratios

Sample No. 2 showing 0.8% indicates that precaution must be taken against spontaneous heating which is in fairly advanced stage.

Sample No. 3 showing 1.2% indicates a sure signal to take precautionary measures against fire.

Sample No.4 showing 2.7% indicates that active fire has already started.

3.10 Graham's Ratio and its Importance

It is the ratio of CO produced to O₂ consumed in the mine atmosphere. The ratio indicates the spontaneous heating and its stage.

$$\begin{aligned} \text{Graham's ratio (GR)} &= \frac{\text{CO produced}}{\text{Oxygen consumed}} * 100 = \frac{\text{CO}_f - \text{CO}_i}{\text{O}_2_i - \text{O}_2_f} * 100 \\ &= \frac{\text{CO}_i - \text{CO}_f}{\frac{20.95}{79.02} * \text{N}_2_f - \text{O}_2_f} * 100 = \frac{\text{CO}_i - \text{CO}_f}{0.265 * \text{N}_2_f - \text{O}_2_f} * 100 \end{aligned}$$

Where, O_{2i} = initial oxygen concentration (%)

N_{2f} = final nitrogen concentration (%)

O_{2f} = final oxygen concentration (%)

CO_i = initial CO concentration (%)

CO_f = final CO concentration (%)

GR → 0.1 – 0.5 % is normal to coal mine

GR → 1 % indicates existence of spontaneous heating

GR → 2 % indicates heating in advanced stage approaching active fire

GR → 3 % or more indicates active fire

- Like other indices, a normal range of Graham's Ratio should be established for any given mine. This will usually be less than 0.5%. Any consistently rising values in excess of 0.5% is indicative of a heating.

Typical values of the carbon CO/ O₂ deficiency ratio for underground coal mines are given below:

- 0.4% or less – normal value
- 0.5% – necessary for thorough check-up
- 1.0% – heating is almost certain
- 2.0% – heating is serious with or without the presence of active fire
- 3.0% – active fire surely exists

Drawbacks of Graham's Ratio

- Its accuracy becomes suspect if very little O₂ has been consumed, i.e. Graham's Ratio is unreliable if the oxygen deficiency, ΔO₂, is < 0.3 %.
- This is a weakness shared by the other indices that involve O₂ deficiency.
- It is affected by sources of CO other than the fire, e.g.
 - use of diesel equipment, or
 - if the air supplied to the fire is not fresh: it occurs if the fire is fed by air that has migrated through old workings and contains blackdamp (de-oxygenated air).

Young's Ratio

- CO₂ is the most prolific of the gases produced in mine fires. Hence, the values of CO₂ /ΔO₂ will be much higher than CO/ ΔO₂.
- As a fire progresses from smouldering to open flame, the burning of CO will produce an increase in CO₂.
- Hence a simultaneous rise in CO₂ / ΔO₂ and fall in CO/ ΔO₂ indicates further development of the fire.
- However, as both ratios have the same denominator, the straightforward plots of CO and CO₂ show the same trends.
- Young's Ratio is nearly independent of dilution by fresh air.
- It suffers from similar limitations to Graham's Ratio. Additionally, the conc. of CO₂ may have been influenced by adsorption, its solubility in water, strata emissions of the gas and other chemical reactions.
- Thus, the extraneous origin of CO₂ as well as its solubility in water make the interpretation anomalous at times.

Willett's Ratio

- This ratio was introduced by Dr. H.L. Willett in 1951 with specific reference to situations where there is a higher than usual evolution of CO by ongoing low temp. oxidation.
- In these cases, gradual extinction of a fire in a sealed area may not be reflected well by the CO trend alone but as a percentage of the air-free content of the sample.
- In these cases, Willet suggested to use the ratio

$$\frac{\text{CO produced}}{\text{Black damp + Combustible gas}} \quad \%$$

besides the analysis of CO, to understand the magnitude and extent of fire.

- This ratio can be used only as a supplementary index along with other fire indices.

Jones and Tricket Ratio (JTR)

- Jones-Tricket Ratio is used as a measure of reliability of sample analysis and also as an indicator of the type of fuel involved.
- It can be used for the gaseous products of both fires and explosions.
- Jones and Tricket Ratio (JTR), giving the relationship between the products of combustion with O₂ deficiency is defined as below:

$$(CO_2 + 0.75 CO - 0.25 H_2) / \Delta O_2$$

- Dilution by fresh air has no effect on the Jones-Tricket Ratio. However, it is subjected to the limitations of O₂ deficiency.
- This ratio helps in distinguishing coal dust explosions from methane explosion-from examination of post-explosion gases.
 - JTR values ≤ 0.5 indicates methane explosion,
 - values around 0.85 ± 0.18 indicates coal dust explosion.
 - Values in between are indicative of both methane and coal dust explosion.

Oxides of Carbon Ratio

- The Oxides of Carbon Ratio, CO/CO₂ or the ratio of P.O.C (Products of Combustion) is a useful pointer to the progression of fire, rising during the early stages and tending to remain constant during flaming combustion.
- However, the CO/CO₂ rises rapidly again as a fire becomes fuel-rich and is an excellent indicator of this condition.
- This ratio may also be favoured because it is unaffected by inflows of air, methane or injected nitrogen (Mitchell, 1990).
- It is, however, subject to variations in CO and CO₂ that are not caused by the fire.

C/H Ratio

- C/H ratio of the mine gases was introduced by Ghosh and Banerjee (1967) for assessing the intensity of fire, along with O₂ consumption values that indicate extensivity character of it.
- They argued that in case of burning of fuel (mainly compound of C and H₂ in varied proportion) the temp. determines the extent to which the C and H₂ part of it would burn.
- At low temp, the H₂ part may burn completely but there would be a lot of unburned C deposited as soot.
- In case of rapid burning of CH₄, the C/H ratio calculated from the product gases is always less than 3, which is the maximum value for complete combustion of CH₄.
- Likewise, the maximum attainable C/H value for complete burning of bituminous coal lies between 16-20, depending on the type of coal.
- Higher C/H values indicate burning of the cellulose bodies (i.e. timber etc. having higher C/H values) while lower values indicate partial burning of coal.
- Thus, the degree or intensity of burning of coal may be adjudged from the value of C/H ratio of the product gases obtained.

C) Estimating sealed off area condition:

Sampling & analysis at regular intervals is necessary to know the condition of the heating in the sealed off area. Trends are imp. than real values.

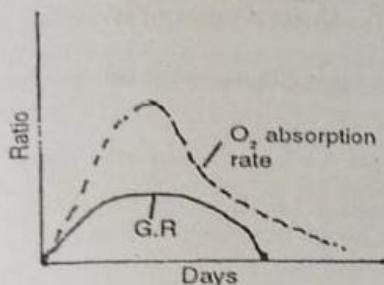


Fig 2-1 O₂ absorption rate and G.R.,

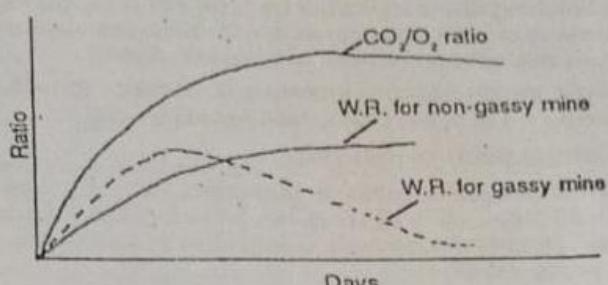


Fig 2-2 Behaviour of CO₂/O₂ ratio, W.R.,

- a) CO%, CO/O₂ ratio (Graham's ratio, GR): pl refer to Topic 3 (B)
- b) O₂ %: It is an important parameter to know whether a fire is extinct or not.
 - (i) O₂ below 12%: combustion with emission of flames stops but incandescence may continue
 - (ii) With 5%: a dying fire may be maintained.
 - (iii) With 1-2%, an assessment can be made whether fire is extinct or not by considering other parameters.
 - (iv) Rate of consumption of O₂ below 0.007 % per day would indicate extinction of heating. (Fig. 2-1)
- c) CO₂/O₂ ratio: The problem with this ratio is CO₂, in some mines, comes from strata. Immediately after sealing, CO₂/O₂ ratio would rise and would be steady or slightly drop in case the fire is getting extinct. (Fig. 2-2)
- d) Willet's ratio (WR) = CO₂ produced ÷ (Blackdamp + combustible gases)
 - (In one course conducted by CMRI (998) WR is given as
 - CO produced ÷ (Blackdamp + combustible gases) } .

This is useful where GR can not be applied due to non-disappearance of CO. It is also useful to estimate the condition of fire in a sealed off area when CO₂ comes out along with CH₄ from strata.

The absolute values vary from seam to seam and even from dt. to dt., so it is only the trends that can be applied. In gassy mines WR falls sharply as the fire dies down. In non-gassy mines the values become steady (Fig. 2-2).
- e) Oxides of Carbon ratio (CO/CO₂): It rises rapidly as the fire becomes fuel rich. If the value of the ratio is more than 2%, it indicates active fire in the adjacent zone. Its main advantage is that its value is unaffected by methane or injected N₂. Therefore, where N₂ is injected, CO/CO₂ ratio has to be used.
- f) Hydrogen : It is a product of distillation, indicates that fire is in an advanced stage. H₂ is not usually present at the onset or termination of heating.
- g) C/H ratio : Fluctuations in percentages of gases indicate that leakage is taking place and action is needed to prevent leakage.

tire.

3. SYMPTOMS OF HEATING, INTERPRETATION OF SAMPLING RESULTS.

Q. Describe the symptoms indicating outbreak of the fire due to spontaneous heating. How does analysis of air samples help in early detection of heating. The analysis results of a samples taken from inside a sealed off fire area are:

$N_2 = 79\%$ $CO_2 = 9\%$ $CH_4 = 4\%$ $O_2 = 5\%$ $CO = 2\%$ $H_2 = 1\%$
Calculate CO/O_2 and CO_2/O_2 ratios and indicate the conclusions you would draw. (1984)

Ans:

(A) Symptoms of self-heating and outbreak of fire:

Best mine lay out is no substitute for constant attention and inspection for early detection of fire. Considerable damage and loss can be avoided if spon. combustion is detected at an early stage.

Self-heating is accompanied progressively by the following:

- a Haze - Due to moisture released during oxidation.
- b Condensation of moisture on cooler surfaces
- c Gob Stink - It has characteristic smell .
- d Slight discomfort : - a sensation of tickling in nose
- e Pronounced petrol like odour indicating beginning of distillation
- f Tarry odour.
- g Smoke:- observed beyond ignition temperature.
- h- It may so happen that the various symptoms may overlap

B) how does analysis of air samples help in early detection of heating:

Analysis enables CO/O₂ and CO₂/O₂ ratios to be found out. These ratios are useful indicators of heating.

CO/O₂ Ratio: (Graham's ratio, GR)

Oxidation of coal takes place all the time and some CO is produced, which varies with the temp. of coal. GR, can be used as an index of oxidation in a mine.

Generally, 0.1 - 0.5 % may be normal to a seam.

1% indicates existence of heating.

2% indicates serious heating approaching active fire.

3 % indicates fire with certainty.

(Any figure above 10 may be due to production of water gas.)

Merit of GR ratio: CO is given off before any other gas and rate of increase of GR ratio far exceeds that of other parameters.

Another advantage: The ratio is independent of dilution by leakage of air. The ratio is not to be completely relied upon as (i) absence of CO means active combustion has stopped and does not mean that fire has been extinguished (ii) CO may be lost due to dilution, oxidation by wet coal (iii) In some cases CO produced in goaves may not disappear even after the heating has become extinct. (iv) It is effected if the fire is fed partially by air migrated through old workings.

CO₂/O₂ Ratio (Young's ratio): This should have been the most direct guide of heating, but for the fact CO₂ may be produced by other sources. CO₂/O₂ ratio above 50% and a steady rising trend above 40 % indicate worsening situation.

Trend of the ratios is more important than absolute values. Indication of heating is best given by rising trend of CO/O₂ ratio. Change from heating to actual fire is shown by higher values of CO₂/O₂ ratio.

C) GRs of the sample analysed: O₂ equivalent to 79% of N₂ may be taken as 21% .

$$\text{O}_2 \text{ absorbed} = 21 - 5 = 16\%$$

$$\text{CO}/\text{O}_2 \text{ ration} = (2/16) \times 100 = 12.5\%$$

$$\text{Ignoring small \% (0.03), CO}_2 \text{ produced}/\text{O}_2 \text{ absorbed ratio} = (9/16) \times 100 = 56.25\%$$

CONCLUSION:

CO/O₂ and CO₂/O₂ ratios are very high indicating an active fire.

Since the oxygen is below 12 %, active combustion must have stopped which contradicts high GRs. A contradictory picture is emerging from high Graham's ratios and high % of methane and H₂, but low % of O₂.

One can not conclude on single result. Interpretations are made based on trends and not on single sample analysis result –basis

6. Interpretation of sampling results.

Q. A sample of air has been taken from the pipe leading through the stopping of a dt. which has been sealed off in consequence of recent spontaneous heating. Give approximately the figures of an analysis of such a sample, and state in what way further samples and analysis would indicate an increase or diminution of the heating.(1988)

Ans: Analysis result of a sample taken 5 days after sealing of a fire in a degree one gassy seam is given below:

CO ₂	O ₂	CH ₄	CO	H ₂	N ₂	CO ₂ /O ₂	CO/O ₂
4.50	11.60	Nil	0.55	Nil	83.35	43.0	5.30

Diminishing fire is indicated by : (a) Fall of O₂ (b) Fall of CO and CO₂/O₂ ratios, eventually becoming zero (In some cases due to seam characteristic CO does not disappear) (c) CO₂, CO₂/O₂ ratio:-The values rise and become steady.

Results which indicate increase of heating: (I) High CO₂ & High CO₂/O₂ ratios (ii) O₂ % would be + 4 to 5. (iii) CO/O₂ ratio would be + 0.5

7. Composition of mine air.

Q. What are the ingredient of normal air? An analysis of mine air is : O₂ =19.5%, N₂ = 78.5%; CO₂= 0.5%, CH₄= 1.5% Express the composition in terms of Air and Black Damp. Mention the sources of formation of Carbon Dioxide in mines and likely places of its occurrence. (1982)

Ans: A) Ingredients of normal air (% by volume)

$$O_2 = 20.93, N_2 = 79.04, CO_2 = 0.03$$

N₂ equivalent of the O₂ present :

$$= (O_2 \text{ in the sample} \times N_2 \text{ in air} / O_2 \text{ in air}) = (19.5 \times 79.04) / 20.93 = 73.64$$

CO₂ = Its value can be taken as 0.03%

$$\text{Normal air in the sample} = 19.50 + 73.64 + 0.03 = 93.17$$

$$\text{Excess } N_2 = 78.5 - 73.64 = 4.86, \text{ Excess } CO_2 = 0.50 - 0.03 = 0.47$$

$$\text{Blackdamp} = 4.86 + 0.47 = 5.33$$

The sample contains: Ordinary Air=93.17, Blackdamp=5.33, CH4=1.5

Sources of formation of CO₂:

- (1) Respiration by human beings
- (2) Oxidation and Combustion of coal
- (3) Mine fires & explosions
- (4) Burning of lamps
- (5) Decay of timber
- (6) Blasting
- (7) from strata
- (8) CO₂ flushing done to control fire

Places where CO₂ found: - In the return air of mines in small percentages, Dip Areas of Depillaring districts

FACTORS AFFECTING SPONTANEOUS HEATING OF COAL:

The magnitude of sp. combustion depends on a complex relationship of a range of internal (intrinsic) and external (extrinsic) factors:

<p>Intrinsic Factors</p> <p>(Nature of Coal)</p> <p>Coal characteristics/Seam factors</p>	<p>Extrinsic Factors</p> <p>(Atmospheric, Geological and Mining Conditions)</p>
---	---

Intrinsic Factors (Coal characteristics/Seam factors)

- Composition, rank and petrographic constituents of coal.
- Friability, particle size and surface area of coal
- Moisture content
- Presence of iron pyrites
- Bacteria
- Other minerals

Extrinsic Factors (Atmospheric, Geological and Mining Conditions)

Climatic conditions:

- Temperature
- Moisture/relative humidity
- Barometric pressure
- O₂ conc.

Geological factors

- Coal seam and surrounding strata condition
- Seam thickness
- Seam gradient
- Caving characteristics
- Faulting and other geological disturbances
- Coal outbursts
- Friability
- Depth of cover

Mining factors

- Mining methods
- Rate of advance
- Pillar conditions
- Roof condition
- Crushing
- Packing
- Presence of timber or other organic waste material in abandoned areas or dumps
- Leakage
- Multi-seam working
- Coal losses
- Worked out areas
- Heat from machines
- Stowing
- Ventilation system and airflow rate
- Ventilation pressure
- Method of stockpiling and stockpile compaction

Apart from the natural affinity of coal to self-heating, a number of factors are significant when determining the risk of spontaneous combustion. The important factors that affect spontaneous heating of coal are rank, petrographic composition, methane (CH_4) content, type and amounts of mineral present, moisture, particle size and surface area. A number of physical properties such as porosity, permeability, hardness, thermal conductivity and specific heat can influence the rate of oxidation and thus result in spontaneous combustion. Hardness affects the friability, hence the surface area. The rate of heat transportation from the coal depends on its thermal conductivity. Coals with low thermal conductivity tend more frequently to spontaneous combustion. Mining method, rate of advance, leakage and ventilation also play a dominant role in the spontaneous heating of coal.

- **Surface area of coal:** The rate of oxidation of coal and hence, the amount of heat liberated depends on the total surface area of the coal including the internal surface area due to its pore structure.

Area of exposed coal surface:

- ✓ Exposed surface area as well as internal surface area (pore spaces) of coal is a significant factor influencing its self-heating.
- ✓ The entire pore surfaces in coal may be above $80 \text{ m}^2/\text{g}$.
- ✓ The smaller the coal particle, the greater the exposed surface area in contact with the air and the greater will be the rate of oxidation and tendency towards sp. combustion.
- ✓ The rate of oxidation increases with increasing fineness of coal.
- ✓ The rate of heating has been found to be proportional to the cube root of the specific internal surface area of coal (Schmidt, 1945).
- ✓ In case of an average bituminous coal, it is generally considered that the danger of sp. combustion is slight for sizes larger than 38mm.

Freshness of exposed coal surface:

- ✓ For any given set of constant conditions, the rate of oxidation of exposed fresh surface of coal decreases continuously during the progress of oxidation, that is, with time.
- ✓ In case of weathered coal, the exposed surface of coal reaches the stage of saturation and no further interaction with O₂ at ambient temperature occurs.
- **Coal Rank:**
 - i. Coals of different ranks have different capacities to absorb O₂.
 - ii. The rate of oxidation decreases with increase in rank of coal.
 - iii. Lower rank coals containing higher moisture, O₂ and volatile content are more easily oxidized and hence, the risk of sp. combustion is higher in lower rank coals.
 - iv. The lower rank coals which are generally higher in moisture, oxygen, and volatile contents are more reactive and hence, more susceptible to spontaneous heating than higher rank coals.
- **Volatile content:** Medium- to high-volatile coals (VM greater than about 18%) oxidize faster than low-volatile coals and those high-volatile coals are more susceptible to spontaneous heating than are medium-volatile coals.
 - ✓ Increase in volatile content of coal increases the rate of oxidation.
 - ✓ Schmidt-Elder found that coal with 38% VM oxidizes 3 times as fast as coal with 18% VM.

- ✓ The research institute of Ostrava-Radvanice (Czechoslovakia) considers coals having a volatile content of 28% and more are liable to sp. heating.
- **Petrographic composition of coal:** The ease of oxidation of coal decreases with the macro-constituents in the order: vitrain, clarain, durain, and fusain.
 - ✓ Coal constituents like vitrain, clarain, durain and fusain influence the liability of coal to spontaneous heating.
 - ✓ Liability of spontaneous combustion decreases in the order: vitrain-clarain-durain-fusain content.
- **Oxygen content:** The increased reactivity of low-rank coals is attributed to their higher inherent oxygen content, and hence, the oxidation rate decreases with decreasing oxygen content, although the heating tendency is not in all cases proportional to the oxygen content.
 - ✓ The liability of coal to sp. heating is directly related to its O₂ content.
 - ✓ With coals having O₂ content less than 2%, the oxidation rate is not large enough to cause any appreciable increase in temperature.
- **Moisture content:** The oxidation of coal in air at ambient temperatures takes place practically always in presence of moisture in the surrounding oxidizing atmosphere, moisture inherent in the coal itself, or formed through oxidation. As the ability of coal to sorb moisture is considerably higher than that for oxygen or nitrogen, the H₂O formed due to the oxidation reaction is mostly absorbed in the coal affecting its ability to absorb oxygen by hindering its diffusion and hence its oxidation rate. But a high inherent moisture and oxygen content as found in low-rank coals and humidity in the surrounding atmosphere have been reported to be indicative of a tendency to spontaneous heating. It has been reported that the coal piles of Raniganj Coals (India) are more liable to spontaneous heating when the moisture content lies between 5 and 7 per cent.

It is apparent that the presence of moisture would tend to reduce the tendency to spontaneous heating because of the latent heat of vaporization and high specific heat of water.

Studies conducted by the US Bureau of Mine on North Dakota lignite have shown that the rates of oxidation were found to be maximum at 20% content and lower at either above or below this value.

- ✓ Moisture inherent in coal, present in the surrounding oxidizing atmosphere, or produced from oxidation of coal in the early stages of oxidation influences the oxidation process. It acts as a catalytic agent.
 - ✓ The high moisture coals have higher tendency of spontaneous heating.
 - ✓ Nandy et al. (1967) had shown that there is an optimum moisture level of around 5% in coal showing maximum spontaneous heating tendency.
- **Presence of pyrite:** Iron pyrite (FeS_2), which frequently occurs in coal seams as discrete particles in a wide variety of shapes and sizes, is distributed through the coal matrix. It oxidizes easily at ordinary temperatures in moist air through a combination of reactions leading to the formations of ferrous sulphate and sulphuric acid besides other products. During these formations, it liberates heat, which in turn leading to accelerated oxidation and self-heating of coal. It has been reported that the heat change caused by oxidation is the same for coal and pyrite in dry state and the reactivity of coal is only doubled when wet, whilst the reactivity of finely-dispersed pyrite (below 0.06 mm size) is raised 10-fold. The oxidation of pyrite in the presence of free moisture has only a promoting effect on auto-oxidation of coal when present in concentration higher than 3%.
- ✓ **Presence of iron pyrite (FeS_2) increases the potential of coal for sp. combustion, particularly when the pyrite concentration exceeds 2% and when it is in very finely divided state.**
- ✓ **Pyrite accelerates sp. combustion by swelling and causing disintegration of coal mass, thereby increases the surface area available for oxidation.**
- ✓ **It easily oxidizes by its own in presence of O_2 of the air and moisture at ordinary atmospheric temp. according to the following equation:**
 - $$2\text{FeS}_2 + 7\text{O}_2 + 16 \text{H}_2\text{O} = 2\text{H}_2\text{SO}_4 + 2\text{FeSO}_4 \cdot 7\text{H}_2\text{O} + 316 \times 2 \text{ kcal}$$
- ✓ **The oxidation of pyrites has only a promoting effect on auto-oxidation of coal.**
- **Ash content:**
- ✓ Ash present in coal generally decreases the oxidation rate which is also influenced by the mineral composition of the ash.
- ✓ Ash in coal generally decreases the oxidation rate but may be influenced to some extent by mineral composition of the ash, which is reported to have both accelerating and inhibiting effects on oxidation.
- **Temperature:** Temperature exercises a great influence on the oxidation rate. Below 70°C, the relationship between them is described by the Arrhenius equation. The rate of oxidation increases about two times for every 10°C rise in temperature. At a constant

temperature, the oxidation rate will decrease with time and the oxidized products will be accumulated on the coal. Lower temperatures favor accumulation of oxygen on the coal, whereas at higher temperatures $> 70^\circ\text{C}$, gaseous oxidation products are released.

- Freshness of exposed coal surface: Freshly exposed surfaces of coal, which is first mined, consume oxygen at a relatively high rate and then falls continuously with time during the progress of oxidation for a given set of constant conditions.
- Concentration of oxygen in contact: At any point on a coal surface, the oxidation rate is directly proportional to the oxygen concentration i.e. partial pressure of oxygen surrounding the particles. For an atmosphere devoid of oxygen, the oxidation rate is zero regardless of all other factors. Coal may be stored in water indefinitely as there is no oxidation without air. From laboratory studies conducted, the minimum oxygen concentration to develop spontaneous combustion has been found to be 7%.
- Methane content of coal: The desorption of methane from coal creates an inert atmosphere in the macropores and micropores and may retard low-temperature oxidation, particularly in highly gassy coals. However, as the desorption of methane falls sharply with time, more and more of coal surface becomes exposed to oxidation by air. The residual methane content of coal is reported to be the best indicator for predicting the hazard in a mine due to spontaneous combustion. Coals containing less than 5 m^3 of CH_4/ton of coal show high oxidation rate and are, hence, more liable to spontaneous combustion, while coals containing above 8 m^3 of CH_4/ton of coal are not oxidized.

Thermal conductivity of coal:

- ✓ The thermal conductivity of coal determines the rate of heat dissipation.
- ✓ Coals with low thermal conductivity are more liable to spontaneous heating.

2. GEOLOGICAL FACTORS

a. Seam thickness

- Thick coal seams are more prone to sp. combustion because the working of these seams is invariably accompanied by high losses of coal in the goaf area.
- The unmined part which is left in the goaf is more prone to sp. combustion since it is exposed to sluggish ventilation flow.
- In some coal seams, coal is left in the roof or floor. Some of the roof coals drop in the gob, which will eventually be sealed off. This coal can get access to air either by waste “breathing” or by leakage.
- Coal in the floor breaks when the floor heaves, which exposes the coal to airflow.
- Also in thick coal seams, certain bands within the seam can be more liable to sp. combustion than other bands.

b. Dip of the seam

- ✓ In inclined seams control of sp. combustion becomes complicated as temperature difference causes convection air currents in the gob.
- ✓ Within the gob, flow may be due to buoyancy as a result of differing densities
- ✓ of CH₄, CO₂, and N₂.
- ✓ The induced airflow in the gob increases the possibility of sp. combustion of coal in the gob or old workings.

c. Depth of cover

- ✓ When a coal seam under a shallow overburden is mined, the goaf areas get connected to the surface by cracks and fissures. Air and water from the surface can gain access to the coal and increase the potential for sp. combustion.
- ✓ Also at depths, the in situ coal temperature tends to be higher making deeper seams more vulnerable to sp. combustion.
- ✓ At greater depth, the excessive rock pressure acting on coal pillars results in their crushing and thereby increases the surface area of coal exposed to oxidation, which help in increasing sp. heating.

d. Presence of multi seams

- ✓ When multi-seams in close proximity are worked, the cracks and fissures developed in the intervening strata increase the potential for sp. combustion of the surrounding unmined seams, particularly the undermined seams.

e. Caving characteristics

- **Caving characteristics of the strata above the mining sections of the seam may considerably influence the likelihood of sp. combustion.**

f. Faulting

- ✓ Presence of faults in coal seams allow air and water to migrate into the coal seams and helps in development of heating in coal mines.
- ✓ Any grinding of coal along the fault plane may lead to self-heating.

g. Coal friability

- ✓ Friable coals tend to produce coal fines which, due to larger surface area, have a greater tendency to sp. combustion.

3. Mining Factors

a. Mining methods

- ✓ Longwall advancing leaves extracted areas lying between the entries serving the working places.
- ✓ The ventilating pressure differences will encourage airflow across these areas with the accompanying problem of incomplete combustion.
- ✓ In high-risk situations, a retreat system of working is preferable.

b. Multi seam workings

- ✓ In case of multi seam workings, where a seam has been mined with another virgin seam laying below, leakage paths are created from the upper seam into the lower seam with a consequent risk of heating.

c. Rate of advance

- The rate of mining and advance rate of the face determine the time in which the broken coal in the gob is exposed to ventilation air.
- If the rate of advance is slow, and time taken in entering and leaving a panel is excessive, the oxidation may occur to an unacceptable degree and a gob fire could result.

d. Pillar size

- ✓ Pillar size should be sufficient to prevent crushing.
- ✓ Pillars that have been standing for a long time are prone to heating, particularly when they are liable to crushing.
- ✓ Pillar crushing can create air leakage paths leading to the flow of air through the coal. Loose coal is usually produced by pillar spalling or crushing. When associated with sluggish ventilation, these areas are hazardous.

e. Regulators, doors, stoppings and air crossings

- ✓ These are the points of high air leakage. Unless they are well sealed, will tend to leak air through the fractures in the solid coal around them.
- ✓ The greater the air pressure difference across them, the more the air leakage.
- ✓ Doors between the main intake and return airway are the most vulnerable.
- ✓ Problem is more significant in air crossings as the pressure difference is high.
- ✓ Air leakage through a stopping depends on the permeability of the stopping and the pressure difference across the stopping.

f. Obstruction in roads

- All roads in thick coal seams have breaks/fractures associated with them. Any obstruction in the road, viz. a stockpile of materials, mine cars, etc. can force air into the fractures, causing heating.

g. Ventilation/air flow rates

- For sp. combustion to develop, the rate of heat generation should be more than the rate of heat dissipation.
- In case of a strong ventilating current or at very high airflow rates, almost unlimited O₂ for the oxidation of coal is available, but the dissipation of the heat generated by oxidation is very efficient.
- The strong ventilating current conducts away the heat produced from oxidation without materially rising the temperature of coal.
- On the other hand, a weak ventilating current or a low flow rate might supply air just sufficient for oxidation but not sufficient to keep down the temperature.
- **A critical flow rate** is one that provides sufficient O₂ for widespread oxidation but does not dissipate the heat generated.
- A good rule to be observed by mining men would be "**No ventilation at all is better than a deficient ventilation**".

Table: Set elements of mining conditions influencing sp. Combustion

Sl. No.	Mining parameter conditions	Set elements	Probability of spontaneous fire risk	
			High	Low
1.	Category of coal (Chemical nature)	a) Highly susceptible b) Poorly susceptible	High - -	- Low
2.	Friability of coal	a) Highly friable b) Poor friability	High - -	- Low
3.	Method of working	a) Bord and Pillar b) Longwall	High - -	- Low
4.	State of stowing	a) Extraction with caving b) With complete stowing	High - -	- Low
5.	Seam thickness	a) High (>5m) b) Low (<4m)	High - -	- Low
6.	State of extraction	a) Partial extraction b) Complete extraction	High - -	- Low
7.	Nature of extraction	a) Extraction with more than one slice b) In one slice	High - -	- Low

8.	Geological disturbances	a) Present b) Absent	High - Low	- Low
9.	Rock bumps	a) Present b) Absent	High - Low	- Low
10.	Dykes	a) Present	High	-
		b) Absent	-	Low
11.	Overburden	a) Greater than 300m b) Less than 300m	High - Low	- Low
12.	Parting	a) Shale structure b) Rocky and consolidated	High - Low	- Low
13.	State of consolidation of barrier	a) Fractured and crushed b) Well consolidated	High - Low	- Low
14.	Scope of accumulation of fines	a) Fine accumulation sustained b) Fines avoided	High - Low	- Low
15.	Method of ventilation	a) Advancing type b) Retreating type	High - Low	- Low

16.	Quantity of ventilation	a) Intensity of pressure difference high b) Low pressure difference	High - Low	- Low
17.	Humidity	a) Wet mines b) Dry	High - Low	- Low
18.	Source of hot spots	a) Present b) Absent	High - Low	- Low
19.	Gas emission rate	a) Low b) High	High - Low	- Low
20.	Size of panel of the face	a) Large b) Small	High - Low	- Low
21.	Rate of face advance	a) Slow b) Fast	High - Low	- Low
22.	Chances for blockage of face advance	a) Present b) Absent	High - Low	- Low

Detection and control of spontaneous heating and fires

Detecting spontaneous heating in early stages

1. Return air of every depillaring distt. and goaf area not isolated—
 - (a) shall be tested for **% of CO** once in **7 days** with an approved automatic detector, and
 - (b) completely analysed once in **30 days** to determine Graham's ratio **CO formed/ O₂ absorbed.**

Results shall be recorded.

If successive tests show **steady increase** of CO formed/ O₂ absorbed, the site of heating shall be searched out to deal with it.
2. In seams liable to spontaneous heating, telemonitoring system may be installed for continuous watch on CO%.
3. Every **depillaring distt.** shall be inspected on **idle day**.
 - **Unused workings** : at least once in **7 days**,
 - **Isolation stoppings** around goaved out areas and unused workings : atleast once in **7 days**.
4. **Subsidence** areas over depillaring distts. shall be inspected once in **7 days** for any indications of spon. heating.

Sensory indications of spontaneous heating u.g.

Sensory indications (in order of progression) in the incipient or initial stage are :

- (a) *Faint haze*, produced by moisture driven off from coal coming in contact with cooler air some distance away from the heating and getting condensed.
- (b) *Sweating* of roof, sides, timbers and metal surfaces—due to moisture coming in contact with these cooler surfaces, getting condensed and depositing on them in the form of droplets. Sweating occurs at advanced stage after formation of haze.
- (c) *Typical faint odour*, known as 'gob stink'—slightly oily, sometimes sweet, sometimes like the smell of decaying timber—due to evolution of some hydrocarbons. Smell is recognised when coal temperature increases to over 120°C .
- (d) *Slight discomfort and uneasiness to men* near the site of heating because of increased temperature and humidity. The discomfort is exhibited by tickling in nose, increased secretion of saliva in mouth and 'dry throat'.

As heating develops, the above symptoms become stronger and petrally smell is given off. As heating approaches ignition, petrally smell changes to tarry odour, and later smoke may also be seen.

4. Early detection and control of fire.

Q. a) What precautions shall be taken for an early *detection of fire* in a mine working a coal seam liable to spontaneous heating and (b) the measures you would be taking to *control the fire* after it has been detected? (2000)

Ans:

Best design of mine, covering all aspects is, no substitute for constant attention and inspection for early detection of fire. Considerable damage and loss can be avoided if spontaneous combustion is detected at the early stage. Industry is not fully aware of the indirect cost of a fire and hence tends to be conservative on direct costs.

a) The following steps would help in *early detection*:

- 1) All *unused workings/workings* that are not sealed off shall be *inspected every day* with particular reference to fallen coal.

- (In one highly fire prone mine of Singareni, this measure initiated by the author has helped in prevention of heatings. It is not necessary that such daily inspections should be made only by statutory certificate holders. Any sincere and smart worker can make the examination. In a large mine 3-4 persons may make the examination so that entire mine is covered every day. They may carry iron or copper rod to insert in debris and to feel temp. rise.)
- 2) *Systematic reading of d & w bulb temps.* Increase, in wet bulb temp. may indicate spontaneous heating.
 - 3) *Sampling of return airways to get CO, CO₂, CO/O₂ and CO₂/O₂ values*
Increase of CO and CO/O₂ ratio indicates heating. For Indian coals CO/O₂ ratio is almost zero. Increase of this ratio upto 0.5% is considered to be serious heating approaching fire. CO₂/O₂ ratio is useful when there is change from heating to actual fire. Fire is indicated by higher values.
 - 4) *Periodicity of monitoring CO:*
In this regard, statutory provisions Reg.118 (A)(3) are totally inadequate. CO can be tested every shift. Samples can be collected once a week and even in lesser intervals and get them analysed within 24 hours.
 - 5) *Continuous monitoring system* should be installed. It gives the state of real time environment. It is not costly too.

(b) **Fire control measures:**

- (i) Cooling by water (ii) Water slurry injection. (iii) Inert gas infusion (iv) Foam – Inert gas infusion (v) Sealing off the fire (vi) Surface blanketing of sufficient thickness followed by repeated compaction (vii) Pressure balancing (viii) Flooding the mine – rarely done (ix) Reversal of vent.

Fire control measures are site - , situation - specific. They depend on the fire location, extent, nature, accessibility, progress rate, presence of gas and vent. current direction.

- I. *Water Jet:* Arrangements have to be made in the mine to supply water at high pr. to deal with any open fire at the initial stage itself. Water has high potential of heat removal. Steam formed restricts air access to the burning objects.
Dangers with this method: (a) formation of water gas (ii) likelihood of roof falls. (iii) cracks may develop in coal favouring self-heating.
- II. *Water slurry infusion:*
It is nothing but hydraulic stowing. In this water and solids are sent in the ratio of 10:1. Solids used are: mud, fly-ash, bentonite, limestone dust etc. It can be used only as a supplementary method along with other fire combat operations.
- III. *Inert gas infusion:* N₂, CO₂ or both in gaseous or liquid form. This is being commonly practiced in BG panels.
- IV. *Foam inert gas infusion:* It was used in Jhanjra fire
- V. *Sealing of the fire:* It works on the principle of cutting off oxygen supply. Stoppings should be as close to fire as possible and they should be leak proof. In case of gassy mines (where methane evolves) the seals should not be too close to fire but 100-300 m away so that an explosive mixture is not formed.
In gassy mine, vent. has to be maintained during construction of seals, leaving openings in the intake and return seals. They are to be closed simultaneously. Sealing of fire from remote location was done at GDK 9 Incline, Chirimiri and new Kenda.
- VI. *Reversal of vent:* It may be considered when there is a growing fire in the main intake airway or near d.c shaft bottom. A clear knowledge of conditions ug is essential before taking a decision to reverse. An alternative to reversal is to slow down the fan or short circuit the air at surface or ug through separation doors.

DEALING WITH MINE FIRES- DIRECT AND INDIRECT METHODS

DEALING WITH HEATINGS AND FIRES

The procedure to be adopted when a heating occurs depends upon the site of the heating, its extent, the nature of fire, the stage it has reached, whether gas is present or not, and other local factors.

If a heating is discovered in its early stage, steps should be taken at once to locate the site, and cause of the trouble and to prevent it from developing further. The area must be kept under constant observation until it is certain that the heating has died down. On the appearance in any part of a mine of smoke or other signs indicating that a fire or spontaneous heating has or may have broken out, all persons other than those whose presence in the mine is deemed necessary with it, shall be immediately withdrawn from the mine. No such persons shall be re-admitted in the mine, until the fire or heating has been extinguished or effectively sealed off, and the mine is declared safe after proper examination.

The methods of dealing with a heating or fire may be enumerated as follows—

1. Direct attack by water, sand, stonedust, or portable fire-extinguishers.
2. Digging out and extinguishing.

3. Blanketing or local sealing including cement injection or grouting.

4. Foam-plug method.
5. Sealing off.
6. Flooding.

Choice of the method depends upon careful consideration of the following factors—

- (a) Cause of the fire—whether it is accidental or due to spontaneous heating.
- (b) Material involved-coal, belt, oil, etc.
- (c) Extent of fire—incipient or flaming.
- (d) Accessibility—whether fire is in pillar, in goaf, or in coal stock.
- (e) Presence of gas—whether there is any risk of explosion.
- (f) Time factor—whether fire is deep seated due to delayed action.
- (g) Resources—availability of resources is the most important factor.

1. Direct Attack : The best method to extinguish a fire is the direct application of some extinguishing agent on it that will cool down the hot masses, or will seal the surface. Accidental fires having exposed surface e.g. electrical fires, conveyor fires, diesel loco fires involving oily materials, etc. can be put out most easily by application of dust, sand, or by portable fire-extinguishers. The fire should be attacked from fresh-air side.

Spontaneous heating, if detected in early stages, and deep seated, can be extinguished by direct application of water. From a series it has been found that water is the most effective of the twelve different extinguishing agents tested. But the use of water quench a blazing fire is associated with the following disadvantages—

- (a) Dense volumes of steam are formed, visibility is impaired, and conditions are rendered very uncomfortable for the men.
- (b) It has an adverse effect on the roof.
- (c) Water gas may be formed which may cause an explosion.
- (d) There is also the danger of carbon monoxide poisoning.

2. Digging Out & Extinguishing : The method consists of digging out the hot material and simultaneously cooling it by covering the area with sand or stone-dust, or by the application of water or fire-extinguishers. This is preferred in some districts, where practicable, because it is a more certain cure for the fire trouble. but it is only possible—

- (i) If the heating or fire is accessible.
- (ii) If it has not attained appreciable dimensions.
- (iii) If there is no danger from firedamp.
- (iv) If the roof condition is good.

If the heating has occurred in the goaf—

In case of fire inside a stowed goaf, it would necessary to drive one or more entries through the sand packs to reach the site of the fire. The ventilation should be a minimum but sufficient to dilute and carry away the noxious gas given off. The

air current may be short-circuted out by the fire, and in extreme cases the main fan may be slowed down. The possible danger of the atmosphere becoming explosive should always receive a careful consideration.

The heated material should be dug out and simultaneously cooled down by covering with sand or stone-dust or by fire extinguishers. The cooled down mass should then be removed away from the site by filling into steel tubs. Glowing or burning material should be treated with fire-extinguishers. When the material has all been removed, the dug out fire area should be packed with sand and stone-dust.

During the operations, a flame safety lamp and a carbon monoxide detector or suitable birds should be kept constantly at the site. Two smoke helmets and a hygrometer should also be available at hand. Hygrometer readings should be taken frequently to guard against conditions leading to heat-stroke. A rescue team should be available in case of emergency. First-aid equipment and a telephone arrangement should also be kept nearby.

The method is associated with the following dangers which must be guarded against-

1. Danger of heat-stroke : High temperature and humidity may cause heat-stroke to the persons at work.

2. Danger of CO poisoning : If birds are used for detection of carbon monoxide, these may not give an indication of any carbon monoxide below 10 parts per million and fire-fighters may be affected on prolonged exposure in such atmosphere.

3. Danger of outbreak of fire : Dug out materials if not fully quenched and cooled down may burst out into flames again on exposure to air.

3. **Blanketing or Local Sealing** : In case where a small fire is detected in its early stage, it can be extinguished by blanketing the fire zone with some substances and thus preventing access of air to the heated material. Simple expedient of piling up loose sand all around the perimeter of the affected area has been found sufficient to reduce oxidation and allow the heating to cool down. The sites of fire area may be blanketed or sealed by

(a) Piling up loose sand.

(b) Building wall of sand bags or stone-dust bags.

(c) Erecting barricade of corrugated iron sheets with sand or stonedust

behind them.

(d) **Wax Walling**—plastering the area with thick mud or clay to which 10–15% of calcium chloride or sodium chloride or sodium chlorate added to keep it moist and to prevent it from cracking. Wax Walling has been found most effective for fires in solid coal pillars.

(e) **Guinating**—spraying the area with liquid cement-sand mixture in the ratio of 1 : 3, to form a thin coating impervious to air.

- (f) Letex lining to form a film impervious to passage of air. The liquid Latex sealant is applied to the desired surface by a compressed-air operated gun, the coating fully dries out within 24 hours to form an impervious coating.
- (g) Brick Walling the whole perimeter of the roadway or a part of it in a settled ground to reduce air leakage.
- (h) Cement-injection impregnating the strata through drill holes commonly applied to fires in solid coal pillars or coal barriers to seal air passages (breaks and fissures).

4. Foam-plug method : This consists of erecting a net across the roadway on the intake side of the fire and spraying the net with water containing a wetting agent and foam stabiliser. The air passing through the wetted net produces bubbles which form a mass of foam known as "foam-plug" filling the airway. The foam-plug cools and subdues the fire rapidly by absorbing heat of evaporation of water, reducing oxygen concentration of the air by producing steam and blanketing the area to prevent air circulation.

5. Sealing off : When a mine fire can not be controlled by direct attack with fire extinguishers or water due to the extent of the fire or inaccessibility of heating, with the result that the fire becomes unmanageable, or when there is risk of any explosion, then the fire must be smothered by erecting stoppings to seal off all possible supplies of the air which is required to support combustion.

Temporary Stopping can be erected when there is no danger from gas explosions and when the function of the stopping is solely to prevent inflow of oxygen to the fire.

Explosion-proof stoppings must be constructed if inflammable gas is present and there is possibility of the occurrence of a firedamp explosion. Such stoppings are built of sufficient strength to withstand force of an explosion and being of such a nature as to prevent air penetrating into the fire area.

The essential factors for selection of sites for stoppings are—

- The safety of the personnel building the stoppings.
- The complete stopping of air-flow into the sealed area.
- The time required to build the seals.
- Accessibility of the selected sites with respect to transport facilities.
- The operation of rescue teams. Any stoppings built in an irrespirable atmosphere would have to be built by men wearing breathing apparatus.

Whilst for economic reasons it may be desirable to seal off the least possible area, it is more expedient and safer to seal off a large area, utilising the least possible number of seals. Stoppings are made in firm well supported ground both in intake and return airways through which air can gain access to the fire.

FIRE STOPPINGS

Q. 15. Draw a sketch of fire stopping for a gallery 4m high in deg.II gassy seam. Describe its fittings.

Fire stopping for deg.II seam

Construction of fire stopping is shown in the sketch. Normally thickness of fire stopping in deg.II seam is 1m, but since the height of gallery is 4m, an off-set of 15cm has been provided for the lower 2m portion. Foundation cutting would be 1m in coal or 30cm in shale or 15cm in sandstone.

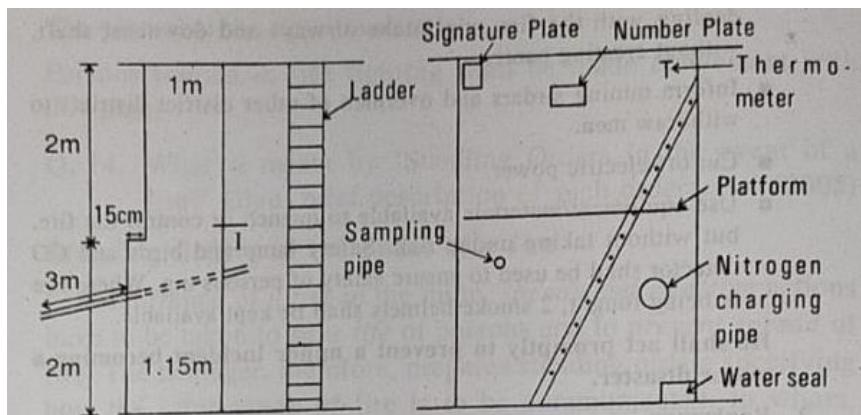


Fig : Fire stopping

Fittings

1. **Water seal** : Required if water is likely to accumulate behind the stopping. Water seal would consist of a pipe 75 to 125mm dia (depending on expected make of water) provided at the outbye end with a U-bend, which would be always kept immersed in water in a small reservoir built near the floor so that water may come out but air may not enter the sealed area.
2. **Air-sampling pipe** : Air sampling pipe 25mm or 50mm in dia fitted with suitable sluice valve/cap would be provided in a few strategically located stoppings, including at least one on rise side. Sampling pipe would be extended at least 3 m inbye of the stopping. Some of the sampling pipes would be placed within 30cm of the roof.
3. **Platform** : Since it is a high gallery, a platform is to be provided to facilitate inspection and maintenance.
4. **Ladder** : Although not a fitting of stopping, a bamboo ladder is essential for providing access to the platform and the sides etc. for inspection and maintenance.
5. **Tar trap** : This is provided only when water coming out from the sealed off area has a tarry smell creating false symptoms of heating. The tar trap is a perforated drum containing hard coke and sand. The sand and hard coke are replaced at regular intervals depending upon the rate of flow of water. Some mines in Jharia coalfield use tar trap.
6. **Nitrogen charging pipe** : These days in some of the fire

stoppings a pipe is provided for charging nitrogen to control the heating.

7. **Thermometer** : A thermometer encased in brass casing would be embedded in a narrow slit made of cement mortar, near the top of the stopping where rise of temperature is likely to take place earlier . It will show relative temperature only and not temperature inside the sealed off area.
8. **Signature plate** : It is made of cement mortar divided in the middle by vertical line. Overman inspecting the stopping would sign starting on the left half. When the whole plate is filled up, he will wipe off the left half leaving right half signatures intact. This would enable asstt/UM/ manager to see whether the inspections have been done.
9. **Number plate** : All stoppings are numbered serially for identification.

Note :

1. In deg. I seam also a similar stopping would be provided.
2. Roof and sides upto 10m on either side of the stopping shall be dressed, cleaned and supported.
3. Roof/sides upto 3m on either side of the stopping shall be cement plastered.
4. Stopping shall be kept approachable throughout the life of the stopping.
5. Samples of atmosphere in the sealed off area shall be drawn at 30 days' intervals. If inflammable gas behind the stopping exceeds 2%, a similar stopping shall be built 4.5m outbye the first one and the intervening space filled up with incombustible material to convert the stopping into an explosion proof isolation/fire stopping (as is required in case of a deg.3 gassy mine).

Q. 16. Write a short-note on explosion proof stopping.

(1990, 1995, 2002, 2003)

Explosion proof stopping

- In deg.III seam, to seal off a heating/fire, to enclose a depillaring panel or to isolate disused workings the stoppings have to be explosion-proof because of danger of explosion of inflammable gas by fire.
- In deg.I & II seams also, if on drawing sample from a sealed off area inflammable gas is found to exceed 2%, the

stopping is converted into an explosion proof stopping.

- Explosion-proof stopping consists of two 1m thick stoppings built 4.5m apart and the intervening space is filled with sand or incombustible material.
- The two stoppings are built after cutting foundation in roof, floor and sides to a depth of 1m in coal, 30cm in shale or 15cm in sandstone.
- Face of the stoppings and roof, floor and sides of the gallery (at least) upto 1m outbye are plastered with lime or cement mortar and kept white washed.
- It is fitted with air sampling pipe and water seal (if water is likely to accumulate behind it).
- The stopping is numbered and a signature plate provided.
- These days some such stoppings are provided with nitrogen charging pipe also.
- Roof on either side the stopping is kept well supported and the approach well ventilated, free from accumulation of water and free from obstructions to facilitate inspection and maintenance.

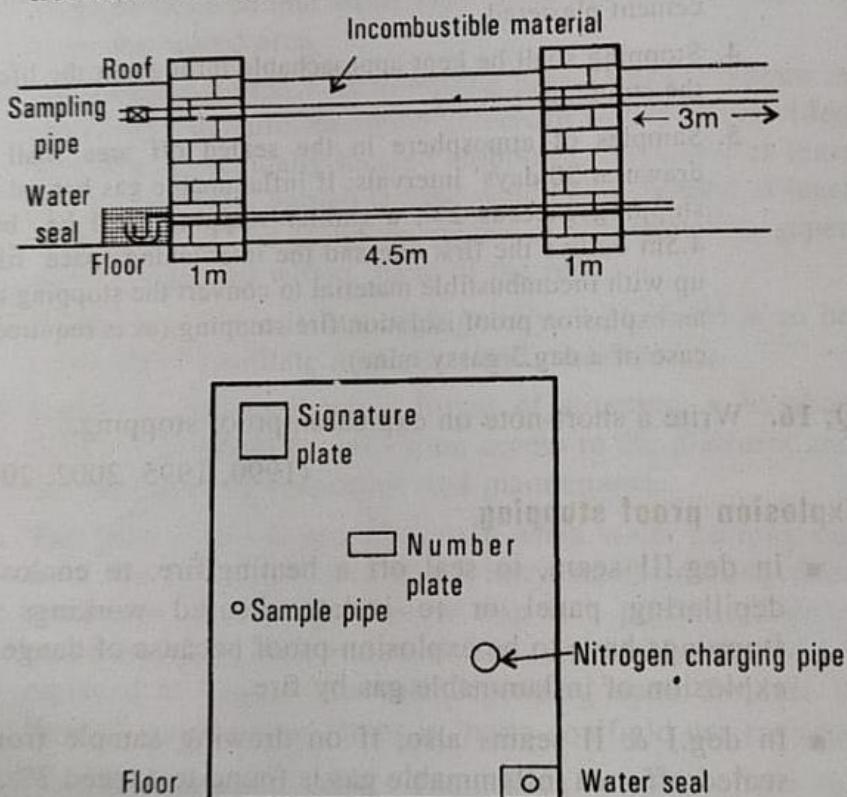


Fig : Explosion proof isolation stopping

RE-OPENING OF SEALED-OFF FIRE AREAS

RE - OPENING A SEALED AREA

The re-opening of an area which has been sealed-off in consequence of a fire due to spontaneous combustion or one resulting from an explosion or from any other cause is necessarily an operation attended with considerable risk. The difficulties are—

1. Active combustion may have ceased, materials may still be hot. If the ventilation in the area is restored, the hot materials may again into flame.
2. How long the area should remain closed to make certain that the material has properly cooled down can not be predicted.
3. The atmosphere behind the stoppings may be extinctive and non inflammable, and yet be capable of forming an explosive when diluted with fresh air.

A sealed-off area may be opened when the analysis of the atmosphere behind the stopping, indicates that the fire has been extinguished and when sufficient time has been allowed for the fire area to cool. The time allowed for cooling down the area may be as short as one week. When a fire is caused by freely burning materials, or may be several years in the case where a large area of coal is involved. It must be understood that, If the pressure on the stoppings is balanced so that leakage is negligible, the only cooling action within the sealed will be by diffusion and conduction to the starta.

The time of re-opening a fire is governed by the following factors—

1. Extent and intensity of fire the time of sealing.
2. Nature of burning material and adjacent strata.
3. Air-tightness of stoppings and the enclosed area.
4. Composition of atmosphere behind the stopping.

A Correct decision regarding re-opening depends mainly on correct interpretation of the analysis results of samples drawn from behind the stoppings. the area should be opened only when—

1. The Graham's Ratio CO- produced /O₂- absorbed has come down to a value normal to the seam or section in mines or section, where the Graham's index does not apply, Willet's Ratio may be used as a guide. CO₂- produced/ (Black damp+combustible gases) expressed as a percentage which rises fairly sharply after a fire, but after the fire is extinct at a diminishing rate of increase until becomes stable or else begins to fall.
2. The oxygen content in the sealed in the sealed-off area is very low (1% or less).
3. The temperature has come down to the normal strata temperature. For this purpose temperature behind stoppings should be regularly recorded. Where the stoppings are unapproachable, boreholes may be drilled for temperature recording. Comical thermometres (15.5°–37.8°C, 32.2°–54.4°C and 43.3°–65.5°C) encased in cylindrical brass casings tied to a cord and for temperatures higher than 65°C and

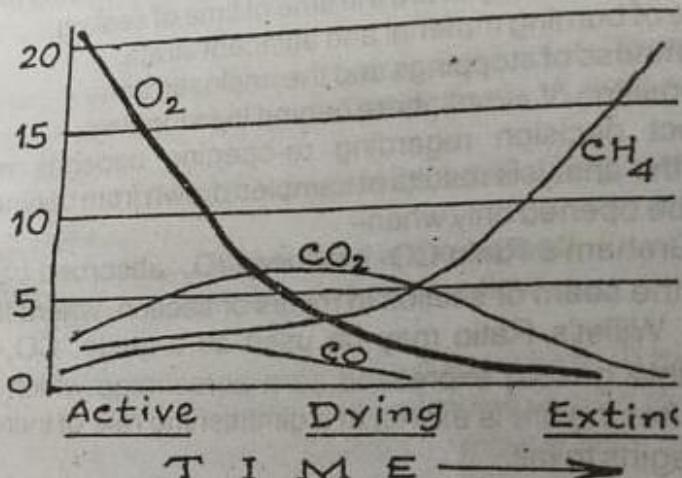
up to 150°C, thermistors (resistance thermometers) fitted in brass casing were lowered into boreholes in Kurasia Colliery.

The samples of the gases from behind the stoppings must be taken at regular intervals and analysed. Such samples should be taken, if possible, when the pressure behind the stopping is positive because then "breathing" is in an outward direction and the samples are more likely to be representative of the atmosphere behind the stoppings.

Early samples collected shortly after sealing will show a relatively large percentages of oxygen and carbon dioxide, a small percentages of carbon monoxide (fraction of 1%) and methane (quantity depending on the gassiness of the seam) the remainder being nitrogen. The Graham's Ratio in such cases will be respectively high.

Continuance of fire will be indicated when percentage of oxygen decreases with gradual increase in the percentage of carbon dioxide (upto 5 to 6%) maintaining a high CO/O₂ ratio.

Active flame ceases when percentage of oxygen falls below 12 per cent and the percentages of carbon dioxide and carbon monoxide begin to fall with rise in the methane percentage.



Behaviour of Gases in a Sealed off Area

Extinction of fire may be interpreted when the oxygen percentage is negligible, CO/O₂ ratio has returned to normal and the percentage of methane has increased much forming the most of the atmosphere behind the seals.

Preparatory Measures
For the successful recovery of any sealed-off area certain preparatory measures and precautions should be undertaken. These are—

1. Rescue and recovery teams should be assembled.
2. All men except those employed in re-opening work, should be withdrawn from the mine.
3. A responsible fan attendant should be stationed to that the main fan continues to run efficiently.
4. Electric power from the section which a fire is sealed off should be disconnected.
5. The roadways leading to and from the area should be heavily stone-dusted outbye the stoppings for several hundred metres.
6. The return airway should be fenced off.
7. A fresh air base should be established in telephonic communication with the surface at which rescue teams are stationed.
8. Water mains for fire-fighting purposes should be inspected and renewed.
9. Height of evase'e chimney should be raised and steps taken to prohibit open lights or sparking at the surface near the upcast shaft fan evast'e whilst the area is being reventilated.

Selection of the Method of Re-Opening

The following factors should be considered before selecting a suitable method—

1. The type and extent of fire.
2. The size of the sealed off area.
3. The period that has been allowed for the cooling off.
4. The volume of firedamp enclosed.
5. The inclination and accessibility of roadways.
6. The temperature and humidity in the sealed area, add risk of heat collapse.

Method of Re-opening

The methods of re-opening can classified four main groups, namely —

1. **The Direct circulation Method :** Rescue Brigades, wearing self-contained breathing apparatus remove the plug from a return stopping or make a hole in the stopping, while the other workmen remove the plug from an intake stopping. A regulated amount of air is then allowed to circulate through the fire area. Rescue men take air samples from the return airway until such time as it is considered safe to enter and inspect the district. The direct circulation of air without prior inspection of the area by the rescue teams is not generally desirable.
2. **The Prior-Inspection Method :** An air-lock is built in front of one stopping, and rescue men with breathing apparatus remove the plug from that stopping or make a in hole the stopping. An inspection is of made of the sealed off area, noting

the condition of the roadways, the wet and dry bulb temperature, the presence or absence of hot materials, of hot materials, and air collected from the fire area. The doors of the air-lock are kept shut during breaching of the stopping, during the inspection and until the air samples are analysed and conditions are considered safe for the air circulation. In this method the whole is inspected first by rescue teams before being ventilated.

The method may not be suitable, if the heat and humidity in the area is high or the stoppings are a long way from the face or travelling conditions for the rescue teams difficult.

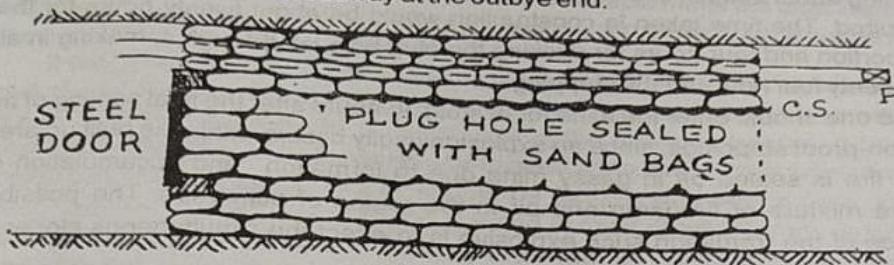
3. **The Stage Method :** Recovery of a sealed-off area may have to be undertaken in stages where the area is very large and includes more than one section, where large quantities of inflammable gas have to be cleared out, where falls of ground or hot, humid atmosphere prevents the circulation of air. Under the circumstances, rescue brigades are engaged to build temporary stoppings at selected sites in the intake and return airways and the area is re-opened as far as the temporary stoppings. A second set of temporary stoppings is then erected and the second stage is re-opened, progress is made in this way, working through air locks at each temporary stopping, and gradually extending the fresh air into the affected area.

4. **The Partial Recovery Method :** In this method a part of the sealed-off area is re-opened, the rest being sealed off by stopping built by rescue brigades. This is the most difficult method and can be adopted only when it is necessary to open a part of the district which can not be opened fully due to possible of fire inside.

PLUG HOLE FIRE STOPPING WITH STEEL DOOR

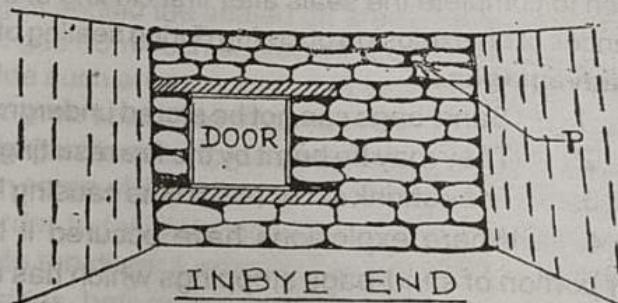
The function of this type of stopping is to arrest air-flow in the least possible time after the decision to seal off has been made.

The main body of the stopping not less than 4 metres in length is built of sandbags, interlocked in successive layers as headers and stretchers, is well tamped together and the intervening spaces filled with loose sand to effect air tightness. The sandbag structure may be re-inforced with vertical steel rails or girders needled into the roof and floor at the inbye and corrugated steel sheets with horizontal girders set from side to side across the roadway at the outbye end.



SECTION THROUGH PASSAGE

While building work is in progress, the ventilation of fire area should be maintained at as near the normal quantity as possible to prevent any increase in the firedamp content of the air. This is accomplished by leaving a passageway, or plug hole in the stopping as shown in the figure. The floor and sides of the plug hole are made of sand-bags, but the roof is of corrugated sheeting to provide the necessary foundation on which to built further sandbags. When the passageway is finally plugged with sand-bags, it is almost impossible to interlace the bags into the sandbags which form the main part of the stopping. A tapered passageway of larger sectional area at the inbye end is desirable. Should an explosion occur in the sealed-off area, the force of the explosion will tend to tighten the bags in passageway, and the filling of the plug hole will not be a weak point in the construction. An air sampling pipe 'P' is incorporated in the stopping so that the air sample can sample can be collected at a later date for analysis to assess the condition behind the stoppings.



Plug hole fire stopping with Steel door (Explosion-proof)

When both intake and return stoppings are complete except for the plug hole left through, simultaneous closure can be readily effected by the synchronised closing of the inbye steel doors. The plug holes are then packed up with sand-bags as quickly as possible. The final closing in the plug holes should be carried out after all men except those indispensable have left the mine.

Immediately the plug hole has been sealed and the roadway on the outbye side has been given a liberal dose of stone dust, all men return to the surface. On a road measuring 3m wide and 2.4m high about 5000 sandbags containing about 25kg of fine angular sand having the open end folded over would be required. The time taken in construction would be about twenty hours for the major portion and four hours for packing the plug hole left through it, making in all about twenty four hours for the stopping.

No one should enter the mine for at least 36 hours after the final sealing of an explosion-proof stoppings, since an explosion usually occurs within the built up area when a fire is sealed off in gassy mine due to formation and accumulation of explosive mixture of firedamp and air in the region of active fire. The possible avoidance of the formation such explosive is to effect the simultaneous closer of intake and return stoppings.

Advantages :

1. Speed is essential when constructing explosion-proof stoppings, this can be attained by keeping the structures simple and by using sand and sand-bags as building materials.
2. It may be additionally re-inforced by interlaced steel channels set between roof and floor or from side to side.
3. A brickwall may be built later in front of the stopping to reduce air leakage.
4. The main advantage of this method is to reduce to the least possible time taken to complete the seals after first closing of the roads, and thereby reduce the chances of an explosion occurring during sealing of plug holes.

Disadvantages :

1. Sand-bags can not be stored underground.
2. They may be burnt by the fire resulting on the running off of the sand.
3. They shrink in course of time causing leakage of air along the roof.
4. Where explosions have occurred it has been observed that it is the upper portion of sand-bags stoppings which has been displaced, or blown out. This is due to the fact that the resistance to movement of purely granular material stopping is very small at the roof level. It also indicates the need for tight packing, particularly near the roof level.
5. A large number of bags will be required.