

Mine Gases

The gases most commonly found in mines are [oxygen](#), nitrogen, carbon dioxide, and methane. In connection with gob fires, blasting operations, and explosions, carbon monoxide is very common, while in these and cases hydrogen sulphide, hydrogen, ethylene, nitrous oxide, etc., sometimes occur.

The chief noxious gases that are very poisonous are

[Carbon-monoxide](#) ... is slightly lighter than air and is colourless, odourless, and tasteless.

[Carbon-dioxide](#) ... is a heavy, colourless, and odourless gas with an acid taste when in large quantities.

[Hydrogen-sulphide](#) ... is exceedingly poisonous and is five times as deadly as carbon monoxide, but it is seldom found in quantities dangerous to life

The Chief Inflammable Gas is methane, which constitutes 97 to 100 % of the inflammable constituent of firedamp.

The Damps

The word " Damp " originally meant " Mist " or " Vapour," but is now used as meaning " Gas," and prefixes are attached to indicate the various gases according to their peculiarities

[Fire-damp](#) ... is inflammable and consists chiefly of methane (marsh gas).

[Black-damp](#) ... extinguishes flame and causes death by suffocation It is composed of carbon dioxide and nitrogen. It is also known as stythe or choke-damp.

[White-damp](#) ... is a subtle and extremely poisonous gas, also known as carbon monoxide.

[After-damp](#) ... is the gas resulting from an explosion; it nearly always contains dangerous amounts of carbon monoxide.

[Stink-damp](#) ... or sulphuretted hydrogen, is hydrogen sulphide and is a very poisonous gas with a pungent smell of rotten eggs, but it is seldom found in dangerous quantities.

Oxygen

The breathing of oxygen is absolutely necessary to human life and for ordinary combustion. The effects of a decrease in oxygen percentage are as follows:-

Oxygen %	Nitrogen %	Effects
20.97	79.03	Breathing and combustion normal
19	81	Breathing almost normal, lamp or candle flame loses 30% luminosity
17	83	Breathing almost normal, combustion is difficult
15	85	Breathing nearly normal, flame extinguished between 17 & 15% Oxygen
12	88	Breathing deepens, flame extinguished between 17 & 15% Oxygen
10	90	Abnormal shortness of breath, face flushed and darkened
5	95	Panting, unconsciousness and death
0	100	Convulsions and death in a very short time

It will be readily understood from the above figures why the Coal Mines Act, 1911, requires that at least 19 per cent. of oxygen shall be present in the atmosphere of all roads and workings that are in use.

Exemption is made where ventilation is accidentally interrupted, but no person is to work in less than 19 per cent. of oxygen unless engaged in restoring the ventilation. Another exemption is granted in the case of mines liable to spontaneous combustion, but only by order of and subject to conditions laid down by the Mines Department.

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Carbon Monoxide

Carbon monoxide or white damp is the most dangerous of all gases which occur in mines. It is nearly always contained in the after-damp, following an explosion of coal dust or fire-damp, and also results from gob fires and shot-firing with certain explosives. It has been suggested that this gas is a normal constituent (in small amounts) of the return air of coal mines over 500 yards deep.

Properties

Carbon monoxide is slightly lighter than air and is colourless, odourless, and tasteless. The gas is inflammable and burns in air with a non-luminous flickering blue flame, but it does not support combustion. The flame of the safety lamp burns more brightly in air containing certain percentages of the gas, but no reliable test can be made with a lamp under about 12 %. Moreover, the gas is so deadly poisonous that death would ensue in a few seconds in much smaller percentages than could be discovered with a safety lamp. The blood very readily absorbs the gas, which is very slow to part with it even under the best conditions. It therefore accumulates in the blood at a speed depending upon the percentage of the gas present and the rate and extent of breathing. It has been found that if a person continues to breathe air containing more than 0.2 %, death is only a matter of time. The limbs are affected very quickly, and then the more a man exerts himself to get out of it the sooner he is overcome. This is due to the fact that with increased exertion breathing is quicker and deeper, whilst the pulse is more rapid; consequently the carbon monoxide is absorbed more quickly under such conditions than at the normal rate of exertion. It is probable that if a man once unwittingly enters an atmosphere containing 0.2 % of the gas he will be overcome before he can escape. Blood absorbs carbon monoxide much more readily than it does oxygen and converts the oxyhaemoglobin (red blood corpuscles) into carboxyhaemoglobin, a stable pink compound. Consequently a person suffering from carbon-monoxide poisoning has a pink skin and a healthy appearance. When all the blood has absorbed as much of the gas as it is capable, it is said to be saturated, but death occurs at 80 % saturation. Under 0.2 % the absorption of the gas by the blood stops at certain percentages of saturation, and the smaller the percentage of the gas the smaller is the maximum absorption. For 0.2 % the maximum absorption is about 80 % saturation. At 0.2 %, therefore, death occurs in about two hours, and the greater the exertion or the greater the percentage of gas present, the sooner death occurs. The effect of the gas varies with the person breathing it, some being overcome more quickly than others; but anything over 0.1 % should be regarded as very dangerous, and as low as 0.01 % is indicative of danger.

PHYSIOLOGICAL EFFECTS OF CARBON MONOXIDE

% Carbon Monoxide in Air	Max. Absorption % saturation of blood	Effect on Man after prolonged breathing
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Below 0.02%	-	No appreciably poisonous symptoms.
0.02%	20	slight giddiness, headache and breathlessness
0.08%	50	
0.08 to 0.02%	50 to 80	The above symptoms still more severe, partial loss of consciousness, especially in exertion, and later collapse and unconsciousness.
0.2%	80	The above symptoms followed by death in one to two hours.
Over 0.2%	-	The greater the percentage the sooner death occurs, especially in exertion.

Treatment of Carbon Monoxide Poisoning

In all cases of carbon monoxide poisoning, oxygen should be breathed or caused to be breathed into the lungs as soon as possible. If oxygen is not immediately available, fresh air should be applied at once. If neither fresh air nor oxygen is immediately available, the patient should be removed as quickly as possible to fresh air and oxygen must be obtained at the earliest possible moment. If the patient is unconscious, artificial respiration must be applied the moment fresh air or oxygen is available. He should be then wrapped up warm and a stimulant should be given as soon as possible. The patient should be kept under close observation, as there is a danger of relapse into unconsciousness in this particular case of poisoning.

Detection of Carbon Monoxide in the Mine

The best practical method of detection is by means of warm-blooded animals such as linnets, canaries, and mice. These are affected more quickly than a man and therefore give warning early enough to allow of withdrawal from the affected atmosphere. These effects, however, vary even with two similar birds, though birds are affected rather more quickly than mice and mice more quickly than men. An important point to observe, however, is that a man working vigorously may be affected before a bird at rest. Therefore tests should be carried out very cautiously and with two or more birds.

The General Regulations require that at every mine there shall be provided and maintained two small birds or mice for testing for carbon monoxide.

The Estimation of Carbon Monoxide

The use of warm-blooded animals are a good method of testing for carbon monoxide in the hands of a colliery official.

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Carbon Dioxide or Carbonic Acid Gas (not Carbonic Acid)

Occurrence

Carbon dioxide occurs in mine air and also in black-damp and after-damp. It is produced by the breathing of men and animals, burning of lamps and candles, oxidation of coal and carbonaceous shale, decay of timber, blasting operations, explosions of fire-damp and coal dust, and the action of some pit waters on certain rocks. Since the gas is $r \sim$ times as heavy as air it is found in dip workings and in disused wells. Where ventilation is insufficient it tends to accumulate near the floor and is usually found in old workings. As in the case of fire-damp, accumulations are only possible when the gas is being given off at a greater rate than it can diffuse, and therefore it must creep or gravitate downwards because of its weight.

Properties

Carbon dioxide is a heavy, colourless, and odourless gas with an acid taste when in large quantities. (The sharpness of mineral waters is due to this gas.) It does not burn and does not support combustion. The gas is a narcotic poison over 15%, and extinguishes flame when present in air to the extent of 15% or more.

Effects of Carbon Dioxide

% of Carbon Dioxide	% of Atmospheric Air	Effect on Man	Effect on Flame
1	99	No appreciable effect	No appreciable effect
3	97	Breathing slightly more difficult	Slightly dim
5 to 6	95 to 94	Decided panting and headache	Flame dim
10	90	Severe distress	Flame very dull
15	85	Partial loss of consciousness with narcotic poison effects	Flame extinguished
18	82	Suffocation and death	-
25	75	Death in short time	-

Effects of Carbon Dioxide with Corresponding Shortage of Oxygen

% of Carbon Dioxide	% of Oxygen	% of Nitrogen	Effect on Man	Effect on Flame
0.6	20.4	79	Deeper breathing	No appreciable effect
1.0	20	79	Panting on exertion	Flame rather dull
2.0	19	79	Decided panting headache	Flame dull and smoky
3.0	18	79	Severe panting, headache, face very flushed	Flame extinguished
5	16	79	Severe distress	-
9	12	79	Unconsciousness and death	-
10	11	79	Death in a few seconds	-

The last table has been included to show that the combined effects of carbon dioxide and a shortage of oxygen are much more intense than either of the two conditions alone, and further, this is the kind of air which is breathed out from the lungs and is given off from the burning of lamps and oxidation of coal; in fact, with the inclusion of fire-damp it is the kind of atmosphere which would be produced in mines if they were not efficiently ventilated (see "Black-damp "). Unless actual death has taken place, a man rendered unconscious by carbon dioxide or a shortage of oxygen or both can be rapidly restored to consciousness by artificial respiration in fresh air or oxygen.

The Coal Mines Act limits the percentage of carbon dioxide to 1.25% except in mines that have been exempted by the Mines Department on the ground of liability to spontaneous combustion, provided that certain conditions are complied with.

Detection of Carbon Dioxide

The gas may be detected by its action on the flame of the safety lamp; a dull and smoky flame would indicate at least 2%, and men must be withdrawn where the amount exceeds 1 %.

A reliable test for carbon dioxide is obtained when the gas is passed through lime-water. The liquid becomes milky and chalk is precipitated (deposited). This effect can be obtained by breathing exhaled air from the lungs into lime-water, due to the presence of carbon dioxide in exhaled air.

The Estimation of Carbon Dioxide in air is more accurately done by chemical analysis; the gas is absorbed by caustic potash or caustic soda, and the reduction in volume measured in a given sample.

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Hydrogen Sulphide

Hydrogen sulphide is exceedingly poisonous; according to Dr. J. S. Haldane it is five times as deadly as carbon monoxide, but it is seldom found in quantities dangerous to life, whilst its characteristic pungent odour gives warning of smaller quantities than would prove to be poisonous. Traces of the gas are associated with gob fires, but it seldom does any harm beyond causing discomfort to the eyes, nose, and throat. Hydrogen sulphide is somewhat heavier than air, its specific gravity being 1.18. Small warm-blooded animals like birds or mice may be used to estimate small quantities, but its smell serves to indicate its presence even in traces.

Physiological Effects of Hydrogen Sulphide

0.07 % in air, if breathed for a long period, may prove fatal.

1.0% will cause death in a very short time.

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Fire Damp

Fire-damp is composed chiefly of methane with varying percentages of other gases. The fire-damp actually given off by coal or other strata has a composition lying between the following approximate limits

Methane	from 70 to 98 %	Inflammable gas
Ethane, propane, etc	From 0 to 2 %	
Ethylene, acetylene, hydrogen sulphide	From 0 to a trace	
Carbon Dioxide	From 0 to 4%	Uninflammable gas
Nitrogen	From 0 to 15%	
Oxygen	From 0 to a trace	

Occurrence of Fire-Damp

Fire-damp is the natural gas given off by coal and carbonaceous strata in coal mines, or it may occur under great pressure in porous rocks adjacent to a coal seam, where it has been imprisoned by an overlying bed of non-porous rock. In such cases the gas may be stored under enormous pressure both in the coal and the adjacent strata. Seepage, blowers, feeders, and outbursts release this pressure. Seepage is the steady oozing out of gas from coal and other strata through pores or tiny fissures. Blowers or feeders are issues of gas through fissures or holes which often have a hissing sound and frequently cause great accumulations. Explosions or out bursts often occur when coal is being worked containing gas under enormous pressure. As soon as the face is cut or broken great blocks of coal are projected violently from the face, with fatal results to the men working on the face. The gas is also associated with petroleum in oil districts under great pressure.

Fire-damp being a very light gas tends to rise when the rate at which it is being given off is greater than the rate at which it can diffuse into the airway. Consequently, when ventilation is weak, it accumulates in rise workings, especially near the roof, where it fills cavities, breaks fissures, etc., and occurs at the face of ripping, cauches, or brushings.

Properties of Fire-Damp

Fire-damp is not poisonous, but it does not support life. It has no colour, but may have a taste or smell according to the traces of gas associated with the odourless and tasteless methane. The practical tests applied underground for the detection and estimation of "fire-damp" really give the percentage of inflammable gas present and neglect the uninflammable constituent. Now methane constitutes from 97 to 100 % of the inflammable portion of fire-damp, and from 70 to 98 % of the whole.

Methane is very inflammable, and when mixed with air in certain proportions forms an easily ignited explosive mixture. Now an inflammable mixture is one that, when once ignited, will continue to burn of itself independent of the source of ignition.

Any mixture of methane and air containing between 5 and 14.8% of methane is inflammable under the conditions which normally prevail in mines. These figures compose what is called the explosive range of methane and air.

The lower limit of inflammation of methane in still air is about 5.25 %.; below this proportion of methane the mixture does not explode, but burns round the flame or source of ignition, forming a second flame or cap over the other.

The upper limit of inflammation of methane in still air is about 14.8%., and above this proportion the mixture does not explode, but continues to burn around the source of heat.

The most violently explosive mixture of methane and air is that which contains 9.4 %, methane. With decreasing or increasing amounts of methane the explosion is less violent. The inflammability of Methane is affected by various factors, some of which can be made to depress the lower limit below the normal figure. Our present knowledge regarding the limits of inflammability of methane can be summarised from the point of view of its application to coal-mining problems as follows:-

- 1 The effect of the Direction of Flame Propagation. The widest range of inflammability occurs during upward propagation of flame and the narrowest during downward propagation.
- 2 The Effect of the Manner of Confinement of the Inflammable Mixture. In general this makes no appreciable difference except that in upward propagation the confinement of the mixture gives the least lower limit of inflammability, other things being equal.
- 3 The Initial Temperature and Pressure do not vary sufficiently in practice to appreciably affect the limits of inflammability.
- 4 The Composition of the Atmosphere. The normal variations in the humidity of the atmosphere have no appreciable effect. The reduction of the oxygen content narrows the limits. At 13% of oxygen only a 6 % methane mixture can be ignited. The specific heat and thermal conductivity of the in-combustible gases have a marked effect. The presence of carbon dioxide tends to raise the lower limit since it has a higher specific heat than nitrogen.

- 5 The Movement of the Gas Mixture has an important effect on the limits of inflammability. For
- (a) Still mixtures the limits are 52.% (lower) and 14.8.% (upper).
 - (b) Turbulent mixtures the lower limit is 5.0%
 - (c) Mixtures travelling as currents between 69 and 128 feet per minute the lower limit is 5.05%
- 6 The Presence of other Inflammable Gases has a marked effect, since those which occur in association with methane have lower limits of inflammability and tend to reduce the lower limit of inflammability of methane to an appreciable extent.

Under the conditions that prevail in coalmines the lower limit of inflammability of methane may be taken as 5% and the upper limit as 14.8 %. The figure for inflammable gas will probably be lower according to the nature and amount of gases present other than methane. In practice, however, only small amounts occur of these other inflammable gases, and have therefore relatively little effect on the inflammability of fire-damp.

Ethane and Propane are very similar in general properties to methane since they are members of the same series (paraffins). They are heavier and are more inflammable than methane. They are also ignited at a lower temperature and have a lower limit of inflammability than methane. Though they only occur in small amounts they tend to make fire-damp more easily ignited and consequently more dangerous.

Ethylene or Olefiant Gas also occurs in small quantities in some fire-damps. It has no colour, but has a smell resembling ether. It is slightly lighter than air, and when mixed with air is very inflammable. It is not poisonous, but does not support either life or combustion. Since it is more inflammable than methane, its presence in fire-damp makes the latter more explosive and easier to ignite.

Gas Caps

If a flame be introduced into a mixture of methane and air having less than about 5.3% of methane, a secondary flame or "cap" - coloured pale blue, is formed above the other flame. If the flame is lowered until it has lost nearly all its luminosity, the cap will be more easily seen. The size and intensity of the cap are governed by the following conditions:

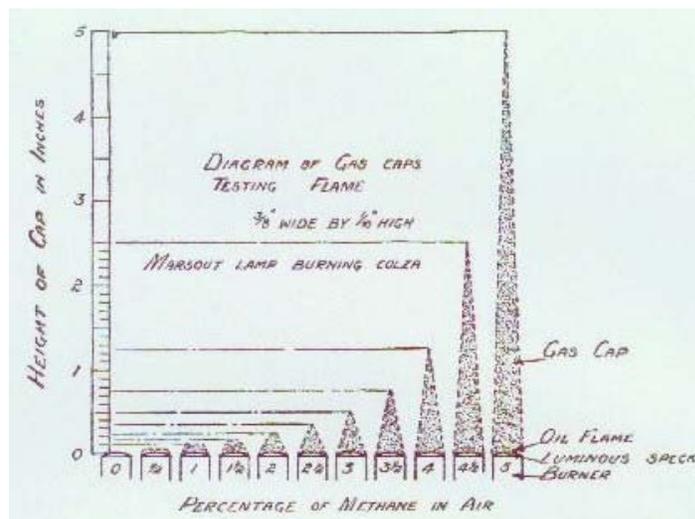
- 1 The percentage of inflammable gas present.
- 2 The size of the testing flame.
- 3 The kind of fuel burnt.

- 4 The construction, shape, etc., of the lamp.
- 5 The temperature, pressure, and humidity of the atmosphere.

The last two conditions do not appreciably affect the size of the cap under practical conditions, but advantage is taken of the effect of different fuels in certain special fire-damp detectors such as alcohol and hydrogen flame detectors.

With a standard-sized testing flame and a "known" oil the percentage of inflammable gas can be estimated to the nearest % between 4 and 5% by an ordinary miner, whilst a more experienced man can detect as low as 1% with even greater accuracy. Moreover, if a spirit safety-lamp be used, a recognisable cap can be obtained for as low as 1/2 to % of methane.

Detection and Estimation of Inflammable Gas by the Ordinary Flame Safety-Lamp



Before going underground the observer must see that the safety-lamp is in order, glass and shield intact gauzes in position, and bottom securely locked to the top. He should blow around the top and bottom of the glass, and if the flame is not disturbed the lamp is ready for use. A superficial examination of the lamp should be made before each test, as the safety of those underground depends upon the intactness of the safety lamp in the presence of an explosive mixture. If an ordinary flame safety - lamp be

introduced into an explosive mixture the flame is extinguished and does not pass through the gauze. If the observer becomes accustomed to a certain height of flame for lighting purposes he can detect the presence of a small percentage of gas without lowering the flame; with increasing amounts of gas the flame becomes longer and longer and is said to climb. This test is very useful in the hands of an experienced man, but the use of the standard testing flame gives more accurate results. The standard testing flame is one-tenth of an inch high by three-eighths of an inch wide, and should be almost non-luminous. It should be observed whether the particular oil in use gives a fuel cap on the testing flame. If so, it appears as a small indistinct cap along the upper edge of the testing flame; but with a little practice it can be distinguished from the ordinary gas cap.

In all gas tests the lamp must be introduced very carefully and cautiously and should be entirely withdrawn as soon as the cap reaches the top of the glass; but if the gas does fire in the lamp it should not be snatched away but deliberately smothered out with some textile material or extinguished in water. Now the size of the cap varies according to the

different kinds of oil in use, but when a person becomes accustomed to a certain oil the height of the testing flame will indicate with fair accuracy the percentage of gas present.

Details of Caps Formed on a Testing Flame 0.375 inches wide by 0.1 inches High, Burning Colza Oil

Methane %	Height of Cap (inches)	Height of Cap in terms of width	Remarks
1.5	0.16	about 0.5	Faint blue and incomplete
2	0.25	equilateral	Pale blue and visible to a person with normal eyesight; top hardly complete
2.5	0.35	about	Caps completely and fairly well defined
3	0.5	about 1.5	Well defined and easily seen
3.5	0.75	2	Caps increase in intensity and the point tends to draw out more and more as percentage increases
4	1.25	3	
4.5	top of glass	top of glass	
5	top of gauze	top of gauze	

Type of Lamp	Kind of Oil	Height of Caps in Inches for the Various Percentages of fire damp							Remarks
		1%	1.5%	2%	2.5%	3%	3.5%	4%	
Marsaut	Colza Oil	0.1	0.2	0.25	0.35	0.5	0.75	1.25	No Fuel Cap if oil is pure
Ackroyd & Best	Ackroyd & Best's Safety Lamp Oil	0.1	0.2	0.25	0.4	0.6	0.9	1.35	Very slight fuel cap
Naylor	Paraffin	0.125	0.25	0.375	0.55	0.75	1.1	1.5v	In testing for low percentages care is necessary
Protector	Colzaline	0.125	0.25	0.375	0.5	0.75	1.1	1.6	
Wolf	Benzine	0.25	0.35	0.5	0.75	1.0	1.6	2.3	

The Coal Mines Acts and General Regulations are very stringent as regards the use of electricity, methods of lighting, types of explosives used, and the introduction and storage of materials in mines where inflammable gas has occurred or is likely to occur in quantities indicative of danger and where an explosion of such gas has already occurred causing personal injury within a certain period preceding the date in question. In such cases electricity should not be used except in the case of approved safety lamps, telephones, and signalling apparatus. For lighting only approved safety lamps should be used, and blasting operations should be performed with "Permitted" explosives only.

It should be carefully noted that the Coal Mines Act uses the term "inflammable gas" and not "fire-damp," since fire-damp may contain nitrogen and carbon dioxide. The former term is well chosen, since it is only inflammable gas that explodes and which can be detected by the "cap in the oil safety lamp. The fireman (examiner or deputy) must report whether he has found any inflammable gas during his inspection.

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Black Damp

Black-damp is also known as choke-damp or stythe, and is a mixture of nitrogen and oxygen in proportion varying from 5 to 20 % of carbon dioxide.

With 5 % carbon dioxide it is about as heavy as air but increases in density according to the percentage of carbon dioxide.

It is not a poisonous gas except in proportions which would cause death by suffocation in a short time.

The properties of the gas vary with its composition, but they are approximately indicated where the combined effects of carbon dioxide and a shortage of oxygen are tabulated; the presence of black-damp would produce a somewhat similar atmosphere and therefore similar effect.

The gas occurs in old workings, badly ventilated dip workings, and in the coal and adjacent strata. As a rule it tends to accumulate on the floor, but this depends upon the percentage of the heavier carbon dioxide.<

Black-damp may be regarded as the residual nitrogen of the air mixed with carbon dioxide which has taken the place of oxygen due to oxidation, decay, etc. Though the whole of the oxygen may have been absorbed, only part of it is, as a rule, replaced by carbon dioxide, since some of the oxygen remains occluded in the coal. Therefore black-damp will normally contain more nitrogen than ordinary air.

The following is a representative sample of return air

Oxygen	20.34%
Nitrogen	78.768%
Methane	0.5%
Carbon dioxide	0.392%
	100.000%

This corresponds to 97% pure air, 0.5 %, methane, and 2.5 % black-damp, as indicated below

Oxygen	20.34%	97.0% air
Nitrogen	76.63%	

Carbon dioxide	0.03%	
Methane	0.5%	0.5% methane
Nitrogen	2.0138%	2.5% black-damp
Carbon dioxide	0.362%	

In this sample black-damp contains 14.5 % carbon dioxide, but we may regard 13 % as the average carbon dioxide content of black-damp. About 15 to 19 %, of the gas will extinguish lights.

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After Damp

After-damp is the mixture of gases resulting from an explosion of fire-damp or coal dust, and its composition varies according to the nature of the gases and the amount of oxygen taking part in the explosion. The complete combustion of methane produces carbon dioxide and steam, whilst the nitrogen remains unchanged. In that case the after-damp would really be a black-damp whose properties would be those due to the presence of carbon dioxide and a shortage of oxygen.

If there is insufficient oxygen available, carbon monoxide and hydrogen are formed as well as carbon dioxide and water. The greater the proportion of methane or the smaller the proportions of oxygen taking part in the explosion, the greater the percentage of carbon monoxide which is present in after-damp. It may be mentioned that if air be readmitted to such a mixture a new explosive mixture could be formed, and such explosions have been known to occur.

The after-damp just mentioned will consist of carbon monoxide, carbon dioxide, nitrogen, and hydrogen. The extremely poisonous effects of carbon monoxide combined with the effects of carbon dioxide and a shortage of oxygen make such an after-damp very deadly indeed. In fact, over 75 % of the deaths caused by explosions in the coal mines of Great Britain have been directly due to the after-damp alone. Carbon monoxide is the chief agent causing death after mine explosions. No doubt traces of other gases are found in after damp, since there are a number of substances which could be ignited and burnt during an explosion. Among these may be mentioned hydrogen sulphide, sulphur dioxide, nitrous oxide, nitric oxide, ammonia, and other nitrogen compounds and distillation products of coal and timber in general.

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Stink Damp

Stink-damp or sulphuretted hydrogen is chemically known as hydrogen sulphide. It is produced in mines by the decomposition of sulphides of iron (pyrites) which are often present in coal and adjacent strata. The gas is colourless, but has a disagreeable taste and a strong pungent odour very much like that of rotten eggs. It is very flammable, but does not support combustion. It is very explosive when mixed with air in certain proportions and ignited.

By Haydn Ansell (Simple Exploration Group 2007)

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