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GASES FOUND IN COAL MINES

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By George A. Burrell and Frank M. Seibert.

INTRODUCTION.

It should be the aim of every miner to learn all he can about the dangers that surround him in his daily work. Knowing these dangers he has a better chance to protect his own life and the lives of his fellow men. Among the dangers that threaten the coal miner are those due to the presence of gases that escape from the coal, or are produced by mine fires and explosions, or by the reaction between mine air and the coal.

The Bureau of Mines, believing that in the past many disasters have occurred through a lack of knowledge concerning these unseen dangers, offers this publication for the benefit of the miner in the hope that its statements may lead to a clearer understanding of the nature of the gases found in coal mines.

THE GASES OF THE AIR.

Perhaps the easiest way to begin the study of mine gases is to remember what are the important gases in ordinary outside air. Pure dry air is chiefly a mixture of oxygen, nitrogen, and carbon dioxide, containing nearly four volumes or parts of nitrogen to one part of oxygen. These figures are easily remembered but are not exact enough for use in calculating the amount of oxygen in a given volume of air. For most purposes air may be considered to consist of 21 per cent oxygen and 79 per cent nitrogen. The chemist, however, frequently uses figures that are still more exact, as follows:

Composition of pure dry air.

	Per cent.
Carbon dioxide (CO_2)	0.03
Oxygen (O_2)	20.93
Nitrogen (N_2)	79.04
Total	100.00

These percentages are those commonly used and refer to parts by volume, that is, 100 cubic feet of air contains 0.03 cubic foot of carbon dioxide, 20.93 cubic feet of oxygen, and 79.04 cubic feet of nitrogen. By weight, the percentages of oxygen and nitrogen are different, for in 100 pounds of dry air there are approximately 23 pounds of oxygen and 77 pounds of nitrogen. Ordinary air is not perfectly dry but contains some water vapor.

Besides oxygen, nitrogen, and carbon dioxide air contains five so-called rare gases which constitute about 1 per cent of the total volume. These gases act about the same as nitrogen, are considered as nitrogen in most calculations, and in the table on page 5 are included in the nitrogen.

All of the gases found in pure air are without color, smell, or taste. Pure dry air contains oxygen and nitrogen in the same proportions by volume all over the globe, at either sea level or high altitudes.

By mixing the gases of the atmosphere in correct proportions man can make air that can not be told from natural air. Gases do not combine chemically to form air, but simply mix with each other. In other words, air is not a chemical combination, but is simply a mixture of gases.

OXYGEN AND NITROGEN.

Oxygen, which is the gas upon which all animal life depends, has a strong attraction for many substances and enters into combination with them. With most metals, such as copper and iron, the action at ordinary temperatures is slow. In the case of iron the result of the action is the substance known as rust. The union of oxygen with a metal is called oxidation. With some substances, such as coal, the action of the oxygen may be rapid and even violent and may be accompanied by much heat and by flame. The substance is then said to burn. Burning is often called combustion by the chemist or engineer.

When oxygen combines very rapidly, or violently, with a substance, as with certain mine gases, there is an explosion. When oxidation, combustion, or explosion takes place in air, it must be remembered that it is the oxygen of the air that is active and not the nitrogen. The same is true in breathing. In the lungs the blood extracts the oxygen from the air breathed in and carries it by circulation to the tissues. The nitrogen, which forms four-fifths of the air, is breathed out unchanged.

Thus the nitrogen of the air in burning and in breathing simply dilutes the oxygen and reduces its activity. Pure oxygen can not be continuously breathed for a long time without injury.

The nitrogen of the air is mainly useful in aiding the growth of plants. Very small organisms, known as bacteria, that live in the soil can take nitrogen from the air and form substances that serve as plant food.

CARBON DIOXIDE.

The complete burning of carbon forms the gas known as carbon dioxide (CO_2), which consists of one part of carbon and two parts of oxygen. Carbon dioxide is also produced in the lungs by the carbon in the body uniting with the oxygen in the air inhaled, so that a man's breath contains about 4 per cent of carbon dioxide.

The total amount of carbon dioxide yearly produced on the earth by burning fuel in stoves and furnaces, by fires, and by the decay, or slow oxidation, of plants is hundreds of millions of tons, but in spite of this the proportion of carbon dioxide in the atmosphere (0.03 per cent) remains about the same. Practically all of the carbon of the living world, in all plants and animals, comes from this 0.03 per cent of carbon dioxide in the atmosphere. Growing plants take up carbon dioxide, extract from it the carbon they need for their growth, and give off oxygen. But even if plants did not use the carbon dioxide, the proportion in the atmosphere would increase so slowly that the yearly gain could not be determined by the most exact methods.

CHANGES IN AIR AFTER IT ENTERS A COAL MINE.

The pure outside air that enters a coal mine contains oxygen, nitrogen, and carbon dioxide in the proportions stated in the table on page 5, but the mine air that leaves the upcast shaft is somewhat different from the air that enters the intake. The most important changes that occur in the air of well-ventilated coal mines are stated below.

CHANGES IN THE PROPORTIONS OF OXYGEN AND CARBON DIOXIDE.

Some oxygen is taken from the air and some carbon dioxide is added to it by the breathing of men and animals, by the burning of lamps, and by the burning of blasting powder, but the total changes caused in these ways in the proportions of oxygen and carbon dioxide in the mine air are so small as to be insignificant. There are very few mines in which, through these causes, the proportion of either gas in the return air differs 0.01 per cent from that in the intake air. Some oxygen is taken from the air by the oxidation of fine particles of "sulphur" (iron pyrites), such as occur in many coal seams, and more is taken up by the coal. Most of the carbon dioxide found in the return air of well-ventilated coal mines comes from the coal, escaping continuously from the pores of the coal as entries and rooms are driven and coal is broken down. Some carbon dioxide is formed by the action of the oxygen of the air on the carbon of the coal and timber, the volume of carbon dioxide produced in this way being equal to the volume of oxygen taken from the air to form the carbon dioxide. Oxygen also combines with the coal or is absorbed by it without the formation of carbon dioxide. The exact nature of the change is not clearly understood. The decrease of oxygen in the air of coal mines is caused chiefly by this change.

CHANGES IN THE PERCENTAGE OF WATER VAPOR.

The air of all mines carries some moisture or water that can not be seen because it is in the form of vapor, and the proportion of moisture in the air varies with temperature and pressure. Cold air can not carry as much moisture as warm air, and for this reason mines are naturally drier in winter than in summer. In winter the outside air, which is colder than the mine, holds little water. When this cold air enters the mine it is heated by the mine walls. As it gets warmer it can hold more water, and it takes this water from the floor, roof, and ribs and thus dries the mine. Under such conditions, in order to keep the coal dust from getting so dry that, if it is raised in the air in the presence of a flame, a dust explosion may start, the practice at many mines is to put water in the intake air by means of exhaust steam or water sprays, so that the air will not dry the mine.

At any given pressure and temperature a given quantity of air will hold a certain amount of invisible moisture, and no more. Air containing this maximum amount of moisture is said to be saturated. If the pressure does not change, the capacity of air to hold moisture increases and decreases with the temperature, although not in direct ratio. Hence the quantity of moisture required to saturate an air current varies with the temperature.

Air seldom remains fully saturated for a long time. Usually it is only partly saturated, and is said to have a certain relative humidity. Thus air at a given temperature containing half the quantity of moisture that it can carry is said to have a relative humidity of 50, or to contain 50 per cent of the quantity required to saturate it at that temperature. A relative humidity of 85 indicates 85 per cent of the quantity necessary to saturate, and similarly for any other figure. Air fully saturated has a humidity of 100 per cent.

If 100,000 cubic feet of air per minute enters a mine on a winter day, at a temperature of 32° F. and with a humidity of 70 per cent, then about 2½ gallons of water per minute are being carried into the mine with the air. If the temperature of the return air is 60° F. and its relative humidity is 90 per cent, an air current of 100,000 cubic feet per minute carries about 9 gallons of moisture per minute out of the mine. As the same volume of air takes in 2½ gallons and takes out 9 gallons of moisture in a minute, the air current must take from the mine about 6½ gallons of water in a minute, or over 9,000 gallons, almost 40 tons, in a day.

The subject of humidity in mine air is extensively discussed in Bureau of Mines Bulletin 20, "The explosibility of coal dust."

ADDITION OF "GAS" (METHANE) TO MINE AIR.

In most coal mines some "gas" (methane) is added to the air. The proportion added for a given air current depends chiefly on the rate at which the gas is given off by the coal seam or the rocks above or below the coal, the depth of the seeam below the surface, and the rate at which workings are advanced.

Methane or marsh gas, commonly known as "gas," forms explosive mixtures with air; consequently a knowledge of its properties is very important to the coal miner. Because of the danger of such mixtures forming, the detection of methane is essential to safety in coal mining. More than 1.5 or 2 per cent of methane in mine air can be readily detected with an ordinary safety lamp by means of the cap on the flame, but less than this proportion may be of great consequence. If the main return of a mine is passing each minute 150,000 cubic feet of air containing only 0.5 per cent of methane, a not uncommon proportion, then 450,000 cubic feet of methane is being discharged from that mine in 10 hours. Great care on the part of the mine officials and miners is necessary to insure safety under such conditions. If the ventilation is not kept good, methane may accumulate; and if the accumulation is ignited, an explosion may result.

In the normal everyday working of a mine the most important changes that air undergoes after it enters a mine are those that have been mentioned. If a mine is not well ventilated, the air in the rooms will contain less oxygen and more carbon dioxide than it should, explosive mixtures of methane and air may gather, and powder smoke, lamp smoke, and warm and stagnant air may not be quickly removed from working places.

In the return air of well-ventilated coal mines the total addition of carbon dioxide and methane is seldom more than 0.50 or 0.60 per cent, and the loss of oxygen is seldom greater than 0.80 per cent. In the different splits or entries and especially at the working faces or in old workings there is, of course, more difficulty in maintaining good ventilation.

THE DANGEROUS MINE GASES OR "DAMPS."

The dangerous gases or mixtures of gases commonly found in coal mines are relatively few, and miners have given them the general name of "damps." The different "damps" are known as choke damp, black damp, fire damp, stink damp, and afterdamp. The term "aftergases" is also applied to the gases produced by explosions or mine fires. The ventilating current is commonly called "air," and fire damp is termed "gas." Many miners and mining men frequently use these names, but the chemical names are more often used in scientific and technical books, because the popular names are not given by all miners to the same gases.

FIRE DAMP.

Fire damp is the name that miners usually give to methane. It is often more familiarly known as "gas." Different meanings have been given the term "fire damp" by different persons and in different countries. However, nearly all chemists now agree that the inflammable gas issuing directly from the coal consists chiefly of methane, also known as marsh gas or light carbureted hydrogen (CH_4). Methane can be prepared artificially by heating coal away from the air. Artificial lighting gas, which is made by heating coal in retorts, contains methane and also hydrogen, carbon monoxide, and other gases.

Methane is colorless, tasteless, and odorless. It forms when organic substances, such as remains of plants, decompose in the absence of air and in the presence of water. Hence it appears in large quantities in many coal seams, because these represent the remains of plants that grew in past ages. Some idea of the enormous quantity of methane that may be carried from a mine by the ventilating current is shown by the following statement: The main airway of a certain mine sampled by the Bureau of Mines passed 150,000 cubic feet of air per minute; this air contained 1 per cent of methane; hence the total amount of methane expelled from the mine in 10 hours, or 600 minutes, was $150{,}000 \times 0.01 \times 600 = 900{,}000$ cubic feet.

An explosive mixture of methane and air ignites if heated to a temperature of about 700° C., or 1,300° F. If the flame of burning methane is cooled below this temperature it goes out. When a safety lamp is put into fire damp the gas passes into the lamp through the gauze and takes fire at the lamp flame. But the flame of the burning gas can not pass back through the gauze to ignite the fire damp outside the lamp because contact with the gauze cools the flame and puts it out. However, if the gas continues to burn inside the lamp, the wires of the gauze may become so hot that they will not cool the flame enough to put it out. Then the flame will pass through the gauze and cause an explosion of fire damp outside. Such an accident, however, rarely happens with a modern safety lamp.

The Bureau of Mines has analyzed many samples of gas collected in different mines. The results show that under normal working conditions the inflammable gas coming from the coal in a mine may be considered pure methane. It is very rare that the proportion of other inflammable gases is more than one or two hundredths of 1 per cent.

DIFFUSION OF METHANE.

Methane is about one-half (0.53 times) as heavy as air. On account of its lightness methane has a tendency to accumulate in the high parts of workings and to gather in the cavities in the roof. However, it will diffuse or mix uniformly in air in spite of being lighter, and when once mixed with air will not again separate. The rate at which methane and air mix depends to some extent on how the gas enters the air.

If the gas is given off in the upper part of a coal seam or from the roof, it will usually take a longer time to mix with the air than if given off in the lower part or the bottom of the seam. In a steady air current with a few obstructions the gas may move in a layer along the airway for a considerable distance. If in the roof of a mine there is a cavity that the air current can not reach, methane may accumulate there. The bottom layers of the gas in the cavity will be in contact with fresh air, which will mix with and dilute them so that they will contain more air than the upper layers. The mine or fire boss remembers this when testing for gas in such a cavity. He raises the lamp slowly into the cavity, watching for the cap on the flame, instead of pushing it up quickly, for if the lamp is pushed up quickly it may be put out by entering an atmosphere containing much methane and too little oxygen. The extent of a dangerous accumulation of methane, a very important thing to know, can be found in open workings by carefully testing with a safety lamp.

EXPLOSIBILITY OF MIXTURES OF METHANE AND AIR.

Combustible gases form explosive mixtures with air, but the mixtures must contain gas and air in certain proportions to be explosive. If one starts with a small nonexplosive proportion of methane and increases the proportion of the gas a mixture is obtained that is explosive; by increasing the proportion of methane beyond a certain limit another mixture is obtained that is not explosive. The first-mentioned explosive mixture is called the "lower limit" of explosion, the second is called the "upper limit" of explosion, and both are termed the "explosive limits" for methane and air. As determined by the chemists of the Bureau of Mines the lower explosive limit is 5.5 per cent of methane, and the upper explosive limit about 13 per cent of methane, respectively. Others have made the same observation, although some different results have been published.

When a mixture of air and methane containing 5.5 to 13 per cent of methane is ignited the flame spreads to all parts of the mixture. With 5.5 per cent of methane the explosion is not violent and can easily be followed by the eye. With larger percentages of methane the explosion becomes more violent. In mixtures of methane and air containing less or more methane than the limits stated the methane is not completely burned. If a mixture of air and methane containing 4.5 per cent of methane is lighted there is, under some conditions, an incomplete burning of the gas, which is noticeable, of course, in the safety lamp. When a safety lamp is placed in a mixture containing about 1.5 or 2 per cent of gas, a small "cap" can usually be seen on the flame when low. Careful and experienced men may detect as little as 1 per cent of gas with a modern safety lamp. As the percentage of methane increases, the height of the "cap" increases. Also, in a mixture of air and methane containing more than 13 per cent methane, there is some burning of the gas. The Bureau of Mines found that with even 20 per cent of methane present an electric flash about one-half inch long, produced by breaking a 220-volt circuit, caused a slight burning, the flame extending about 3 inches above the electric flash.

In a part of a mine where methane has accumulated, the mixture of methane, black damp, and air does not have the same composition throughout and the composition is continually changing. Methane may continue to escape from the coal for a long time. The oxygen of the air continues to combine with the coal and increasing proportions of carbon dioxide form. In addition, in high parts of the workings more methane accumulates where it has been given off and before it has mixed with the other mine gases in the area. In a sealed area of a mine the atmosphere is at first nonexplosive, then explosive, if fresh air does not reach it, and finally nonexplosive again from lack of oxygen and the presence of too much methane.

It has been proved by experiments that the presenct of methane in small quantities greatly increases the chances of a dust explosion. Less than explosive proportions of the gas may, when added to mixtures of dust and air, make those mixtures explosive.

ODOR OF FIRE DAMP.

In old workings, in the goave, and other places where the air is stagnant and methane may have accumulated, a person may notice an odor that he thinks is the odor of fire damp. However, pure methane has no odor. It has happened that natural gas from an old oil or gas well has escaped into a mine. Natural gas may contain gases other than methane, and some of these give it an odor resembling that of crude oil. As a result of its examination of many samples of mine gases, the Bureau of Mines can state positively that no gas has been found in fire damp that would give fire damp a characteristic odor.

EFFECT OF BREATHING METHANE.

Methane has no effect on the human system. Sometimes, however, the atmosphere in a hole in the roof or some closed place in a mine contains so much methane and so little oxygen that a person may be suffocated by breathing it.

BLACK DAMP.

Carbon dioxide is generally called black damp by mining men. Strictly speaking, however, black damp, as Haldane, an English chemist, first pointed out, is a mixture of nitrogen and carbon dioxide. As stated before, when outside air enters a coal mine it undergoes certain changes. Among others, some oxygen is absorbed and some carbon dioxide is given off by the coal. When oxygen is taken away from the air of a room the " air " left in the room, of course, contains a smaller percentage of oxygen and more nitrogen than ordinary air. A mixture of this excess of nitrogen with the carbon dioxide that comes from the coal constitutes black damp. Although sometimes carbon dioxide may be largely responsible for the effects produced by black-damp mixtures, yet, as regards the effect of black damp on lights, it is the lack of oxygen, not the presence of carbon dioxide, that makes a light go out. Average black damp contains 10 to 15 per cent carbon dioxide and 85 to 95 per cent nitrogen; the proportion of carbon dioxide is seldom more than 20 per cent or less than 5 per cent.

Old abandoned workings often contain large quantities of black damp, because the atmosphere is motionless and the oxygen has been removed by long contact with coal. Black damp is always produced by underground fires, is present in the afterdamp of an explosion, and is always found in small proportions in the return air of coal mines, especially of those wherein the coal is liable to take fire spontaneously. The Bureau of Mines has analyzed many samples of air from coal mines and made calculations to show the proportions of black damp in different parts of a mine. Some of these analyses will be published by the bureau in a report on mine air that will describe black damp and give fuller reasons for not applying the term to carbon dioxide alone, but to a mixture of carbon dioxide and nitrogen.

EFFECTS PRODUCED ON MEN AND LIGHTS BY BLACK DAMP.

As a rule, an atmosphere that contains black damp dims or puts out a lamp flame because the proportion of oxygen is less than that in ordinary air, not because the proportion of carbon dioxide is greater. The Bureau of Mines has found that the proportion of carbon dioxide in a mine atmosphere in which lamps go out is seldom large enough to affect the flame. On the other hand, discomfort produced in men by atmospheres in which lamps do not burn may be due to carbon dioxide. A person may, however, suddenly enter an atmosphere that causes distress because it contains either little oxygen or little oxygen and much carbon dioxide.

EFFECT OF BLACK DAMP ON ATMOSPHERES CONTAINING FIRE DAMP.

It has been found by experiment that atmospheres containing only 13 per cent of oxygen may be explosive when enough methane is also present. Consequently the atmosphere in one part of a mine may contain black damp enough to put out an oil flame and yet be nonexplosive, but farther on in the mine, where more methane is present, an electric spark or a flicker of the flame in an attempt to relight the lamp may cause an explosion.

LACK OF OXYGEN IN MINE AIR.

EFFECT ON THE FLAME OF ORDINARY LIGHTS.

An ordinary miner's lamp, a safety lamp, or an open torch goes out in an atmosphere containing less than about 17 per cent of oxygen. Experiments by several men, including engineers and chemists of the Bureau of Mines, have shown this. The light burns better, of course, in an atmosphere containing the same proportion of oxygen, 21 per cent, as ordinary air. As the oxygen in air diminishes the flame grows dimmer and is more easily put out by a jar or a sudden movement of the lamp. Experiments in England have shown that even in air containing 19 per cent of oxygen a safety lamp gives only about one-third as much light as in pure air.

EFFECT ON THE FLAME OF THE ACETYLENE LAMP.

An acetylene lamp will burn in air that contains only 12 to 13 per cent of oxygen, a proportion which is much too low to support the flame of an ordinary lamp. For this reason objection has been made to the use of acetylene lamps in mines, because they may not warn the miner that an atmosphere is so low in oxygen as to cause him immediate harm. If a man exerts himself in such an atmosphere, his labored breathing warns him that the air is not fit to breathe.

EFFECT OF BREATHING MINE AIR LOW IN OXYGEN.

Many authors have stated that air containing less oxygen and more carbon dioxide than ordinary outside air is in itself without effect on man. As regards oxygen, this is proved by the fact that in 1 pound of the air at a place 5,000 feet above sea level, like Denver, there is the same weight of oxygen as in 1 pound of air at sea level containing by volume 17.5 per cent oxygen. Men live and work 5,000 feet and even 10,000 feet above sea level. Of course, Denver air contains by volume 20.93 per cent oxygen, like all atmospheric air.

Haldane, the English chemist, in a report on "The Causes of Death in Colliery Explosions and Underground Fires," makes the following comment:

A diminution from 20.93 to 15 per cent oxygen by volume is practically without effect on man, although, of course, a candle or wick-fed flame is instantly extinguished. As the decrease of oxygen proceeds further certain effects begin to be noticed, but a person not exerting himself will, as a rule, not notice anything unusual until the oxygen percentage has fallen to about 10 per cent. The breathing then becomes deeper and more frequent, the pulse more frequent, and the face somewhat dusky. From this to lower percentages the symptoms are more pronounced, and a person's life becomes in grave peril.

Haldane's experiments refer to fresh air. Experiments by the Bureau of Mines support Haldane's statements.

ACETYLENE.

Acetylene, described below, is not a gas naturally found in mines, but it is described because it is used for lighting and miners may wish to know its properties.

Calcium carbide, called "carbon" by many miners, is composed of carbon and calcium, and when touched by water turns into acetylene (C_2H_2), a gas composed of carbon and hydrogen, and slaked lime. One pound of absolutely pure carbide produces 5½ cubic feet of the gas, and in practice, 1 pound of good carbide may be expected to produce about $4\frac{8}{10}$ cubic feet as an average yield.

All hydrocarbons (substances made of carbon and hydrogen) burn, and they form carbon dioxide and water when completely burned. Acetylene is colorless and tasteless but has a peculiar smell. When burning properly at the jet of a burner it gives no odor, and if there is any smell of it about a lamp in use, then pipes are not tight, a cock is open, or the gas is leaking in some other way. Acetylene is about nine-tenths as light as air. In properly designed burners it yields a very brilliant light without smoke.

EXPLOSIBILITY OF ACETYLENE.

All gases that burn in air will explode when they are mixed with air in the proper proportions and are ignited. Common illuminating gas, methane, and natural gas will do this, and acetylene is no exception. A mixture of acetylene and air containing less than 3 per cent of acetylene does not explode if it is heated to the temperature at which it burns, about 900° F. This temperature is lower than the temperature at which coal gas or natural gas takes fire. Acetylene can be lighted by allowing it to come in contact with the glowing end of a cigar. Common illuminating gas can not be lighted in this way. Experiments made by the Bureau of Mines show that a mixture of acetylene and air containing about 65 per cent of acetylene does not explode when heated. Mixtures of acetylene and air containing less than 3 per cent or more than 65 per cent of acetylene are not explosive.

POISONOUS PROPERTIES OF ACETYLENE.

Acetylene is slightly poisonous, though very much less so than coal gas or water gas. Investigations made by the chemists of the Bureau of Mines and by others with acetylene generated from carbide such as is used in a miner's lamp, indicate that there is little, if any, chance of men being poisoned because of the use of acetylene in mines. Acetylene, of course, is suffocating, as are carbon dioxide, nitrogen, and hydrogen.

PROPERTIES OF CALCIUM CARBIDE.

If sealed from air and moisture, calcium carbide or "carbon," as miners term it, can be kept for any length of time, but if it is exposed to air the moisture in the air gradually slakes it, producing acetylene. For this reason carbide should be kept tightly sealed until used. Calcium carbide has a peculiar disagreeable smell, which, however, is not due to the carbide itself, but to very small quantities of impurities in the acetylene that is produced by the moisture in the air touching the carbide.

CARBON DIOXIDE AND ITS EFFECT ON MAN.

Haldane, the English chemist, says that carbon dioxide in air produces no very noticeable effect on man until the proportion of carbon dioxide reaches about 3 per cent. When the proportion is increased to 5 or 6 per cent there is distinct panting, throbbing, and flushing of the face.

In exploring a certain mine after an explosion engineers of the Bureau of Mines suddenly entered a mine atmosphere containing 13 per cent of oxygen and 4 per cent of carbon dioxide. They experienced no distress, but they were in the atmosphere only a few minutes.

The effects of carbon dioxide on men will be described more fully in another report of the Bureau of Mines.

IMPURITIES IN MINE AIR.

Although experiments have shown that a relatively large proportion of carbon dioxide, or low proportion of oxygen, is without harm, in mines these proportions usually indicate that not enough air is passing to keep fire damp from accumulating, if the mine is gaseous, and to remove powder smoke, lamp smoke, and warm stagnant air.

It is also true that heated and still air can have bad effects, even though it is what is termed chemically pure. Mine air that contains only 0.2 or 0.3 per cent of carbon dioxide, a common enough proportion, may cause discomfort if hot, still, and saturated with moisture.

EFFECTS OF WARM, MOIST, AND STILL AIR ON MAN.

In a part of a mine where the air is still and very warm, the air next to the body is warmed to the temperature of the body, and the body, bathed in sweat that does not evaporate, becomes heated and uncomfortable. Less distress is felt in a hot, moist atmosphere if the air is kept moving. Air that may be warmed to the temperature of the body is thus removed from next the skin. The occurrence of hot air in coal mines, however, is not nearly so common as in metal mines, in many of which strong air currents are not used.

CHOKE DAMP.

Choke damp is a name sometimes given in England to carbon dioxide. A mine atmosphere that causes choking may contain so little oxygen as to suffocate a man almost instantly. Distress produced by atmospheres containing less oxygen than ordinary may be increased by the presence of much carbon dioxide. More than 3 per cent of the latter, as mentioned elsewhere, causes distress. Smoke, carbon monoxide, hydrogen sulphide, and sulphurous acid (all constituents of afterdamp) produce choking, irritation, panting, dizziness, or other unpleasant effects, depending upon the proportions present. Thus the term "choke damp," as applied to "air" that causes choking, does not mean any single gas or combination of gases.

AFTERDAMP.

Afterdamp is the term commonly applied to the gases produced by explosions or mine fires. Oxygen, carbon dioxide, methane, carbon monoxide, nitrogen, hydrogen, hydrogen sulphide, sulphurous acid, water vapor, and smoke may be found in afterdamp. Oxygen, carbon dioxide, nitrogen, water vapor, and usually some methane are present before an explosion or mine fire. The heat of the explosion or fire causes a considerable increase in the carbon dioxide, an increase in the methane, a decrease in oxygen, and the formation of smoke, carbon monoxide, hydrogen, hydrogen sulphide, and sulphurous acid. Small amounts of creosote and benzol (products also obtained by heating coal in retorts) are also formed and are in part responsible for the characteristic smell that remains in a mine after a fire has been extinguished. If the fan is injured or the air courses damaged by an explosion, the methane that would normally be carried away accumulates, and more oxygen is removed from the air by the coal than under ordinary conditions. A small part of the increase of carbon dioxide is also due to the action of the oxygen on the coal at ordinary temperatures.

WHITE DAMP, OR CARBON MONOXIDE.

Carbon monoxide, carbonic oxide gas (CO), also called white damp, is responsible for many of the deaths caused by mine explosions. It is a colorless, odorless, and tasteless gas, and is formed, with other gases, in mines when not enough air is present for the complete burning of materials that contain carbon, such as methane, coal dust, and timber. It is produced by mine fires and explosions, and also by the explosion of powder in blasting. Producer gas, water gas, and illuminating gas contain much carbon monoxide. Natural gas contains none.

EXPLOSIVE PROPERTIES.

Carbon monoxide mixed with air is explosive, but explosions of mixtures of carbon monoxide and air in mines are very rare, not nearly as frequent as those of methane and air, both because carbon monoxide is not as common as methane, and because a much larger proportion of carbon monoxide than of methane must be mixed with air to make an explosive mixture. A mixture of methane and air must contain at least 5.5 per cent of methane to be explosive, whereas if the conditions are the same, a mixture of carbon monoxide and air must contain about 15.5 per cent of carbon monoxide to be explosive. Such a large percentage of carbon monoxide has not been found in the gases from any of the mine fires investigated by the bureau, although only in one case were the gases collected directly at the fire. It is possible, however, that in a fire area in a mine conditions may be somewhat like those in a large retort, such as is used in making illuminating gas for towns, and at times large quantities of carbon monoxide, hydrogen, and methane are given off by the heated coal. A mixture of carbon monoxide and air containing too little carbon monoxide to be explosive may become explosive by the addition of enough methane, even if the proportion of methane in the mixture be below the low explosive limit of methane.

Men have been killed while fighting a mine fire by an explosion of gas from the fire. The Bureau of Mines recently investigated an accident in which four men had been burned by such an explosion. After the men had been ordered from the mine the air current was reversed, the four men entered, and were burned by an explosion close to the fire. When the air was reversed the gases from the burning coal were forced back on the fire where they mixed with the proper quantity of air and exploded. This part of the mine was considered quite free from gas, hence the explosion may have been due more to the gaseous products of the fire than to accumulations of methane from the coal. This accident and others of a similar nature show that to admit air to a fire area may be very dangerous to men fighting the fire.

POISONOUS EFFECTS OF CARBON MONOXIDE.

Carbon monoxide is poisonous because it combines with the red coloring matter of the blood more readily than oxygen does, and blood that is saturated with carbon monoxide can not take up oxygen. After an explosion or mine fire, carbon monoxide may linger in the mine atmosphhere for some time and kill members of rescue parties.

Some mining men still think that the flame of a safety lamp by lengthening or brightening indicates the presence of carbon monoxide in proportions that are too small to be harmful. This idea is wrong, for a safety lamp will not detect a proportion that will kill a man. A miner would find it difficult to detect the presence of 1.5 per cent carbon monoxide with a safety lamp, although this proportion would overpower a man almost at once.

USE OF BIRDS AND MICE.

Birds and mice may be used to detect carbon monoxide, because they are much more sensitive to the poisonous action of the gas than are men. Experiments by the Bureau of Mines show that canaries should be used in preference to mice, sparrows, or pigeons, because canaries are more sensitive to the gas. Rabbits, chickens, guinea pigs, or dogs, although useful for exploration work in mines, should be used only when birds or mice are unobtainable, and then cautiously, because of their greater resistance to carbon-monoxide poisoning.

Many experiments have shown that if a canary is quickly removed to good air after its collapse from breathing carbon monoxide it always recovers and can be used again and again for exploration work without danger of its becoming less sensitive. Breathing apparatus must be used where birds show signs of distress, and for this reason birds are of great value in enabling rescue parties to use breathing apparatus to best advantage.

EFFECT ON MAN OF SMALL PROPORTIONS OF CARBON MONOXIDE.

Haldane states that it seems probable that exposure to an atmosphere containing more than 0.20 per cent of carbon monoxide would be very dangerous to man, and exposure to an atmosphere containing more than 0.02 per cent might cause headache and disablement. Breathing an atmosphere containing 0.20 per cent carbon monoxide would probably cause a man at rest to collapse in an hour.

Different men are differently affected. The proportion of oxygen in the atmosphere and a man's activity, whether he is working or resting, have much to do with the effect of the gas. One of the authors of this circular was very sick for 8 hours after exposure for 20 minutes to an atmosphere containing 0.25 per cent of this gas.

OTHER GASES IN MINE AIR.

Hydrogen sulphide or sulphureted hydrogen (H_2S), sometimes called "stink damp," is rarely found in mines. It is a poisonous gas, but its bad odor—like that of rotten eggs—is usually ample warning of its presence, even in very small quantities. However, when dangerous proportions of hydrogen sulphide are present the sense of smell is no longer a reliable guide. One of the authors of this circular, when approaching a shaft from which the gas was issuing, smelled the gas at a distance of 200 feet, but did not find the smell strong at the shaft. Small animals collapse suddenly in atmospheres containing small proportions of the gas; as little as 0.10 per cent causes immediate distress to mice. Water takes up this gas readily, and if the gas is thought to be escaping from a pool of water, care should be used in stirring the pool, or so much of the gas will be suddenly given off that anybody near by may be overcome.

GASES PRODUCED BY BLASTING.

Carbon monoxide, carbon dioxide, hydrogen sulphide, and methane are gases that may be produced in blasting. Hydrogen, an explosive gas, that is also produced in blasting, is colorless, odorless, tasteless, and very light, being about one-fourteenth as light as air. It burns with an almost colorless flame. This property was made use of by Clowes in constructing his hydrogen-gas testing lamp. The flame of the hydrogen lamp has so little color that a cap produced by methane burning around it becomes more distinct by contrast. The low explosive limit of hydrogen is about 9 per cent. Hydrogen is not a poisonous gas.

Some of the gases given out from the cracks made in the coal bed by blasting are both poisonous and inflammable, and for this reason a miner should not return at once to the working face after firing a shot. These gases collect in open spaces and crevices near or at the face, and a miner may be burned if he carelessly puts his lamp to a crevice or into an open space to examine the effect of a blast.

SUMMARY.

The more important statements made in this paper are summarized as follows:

Pure, dry, outside air contains about 21 per cent oxygen and 79 per cent nitrogen all over the globe.

All mine air contains water vapor, the proportion depending chiefly upon the temperature of the air and the amount of water present along the passageways.

A mixture of methane and air is explosive when it contains 5.5 per cent to 13 per cent of methane, but some burning will occur in a mixture that contains considerably less or more methane than these proportions.

Methane, or any other gas, once thoroughly mixed with air will not separate from the mixture.

Ordinary fire damp has no smell.

Black damp is not carbon dioxide alone, but a mixture of carbon dioxide and nitrogen.

Lights grow dim or go out in atmospheres containing black damp because of the low proportion of oxygen in the atmospheres and not because of the presence of carbon dioxide.

The effects on man of the black damp in atmospheres in which lamps do not burn are sometimes due to the carbon dioxide present, sometimes to the lack of oxygen, and sometimes to both of these causes.

An ordinary wick-fed flame goes out when the proportion of oxygen in mine air is reduced to about 17 per cent.

An acetylene flame goes out when the proportion of oxygen is reduced to about 12 or 13 per cent.

All flames become dimmer when the proportion of oxygen becomes less than that in outside air.

Air may be what is termed chemically pure and yet cause distress if its temperature is high and much moisture is present. This distress is heightened if the air is motionless.

The most dangerous gas in afterdamp is carbon monoxide.

An atmosphere must not be assumed to be nonexplosive because it does not contain enough oxygen to support the combustion of an oil-fed flame.

A lamp flame may burn fairly well in an atmosphere that contains a fatal proportion of carbon monoxide. The presence of fatal proportions of this gas is not indicated by the appearance of the flame.

Mice or birds, preferably canaries, should be used by parties not wearing breathing apparatus when exploring mines after explosions or fires.

PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF MINING.

Limited editions of the following Bureau of Mines publications are available for free distribution. Applicants should remember that requests for all copies can not be granted, and should select those publications that interest them most. Requests for publications should be addressed to the Director, Bureau of Mines, Washington, D. C.

BULLETIN 10. The use of permissible explosives, by J. J. Rutledge and Clarence Hall. 1912. 34 pp., 5 pls., 4 figs.

BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs. Reprint of United States Geological Survey Bulletin 425.

BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 116 pp., 2 pls., 23 figs.

BULLETIN 46. An investigation of explosive-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls., 14 figs.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1913. 50 pp., 3 pls., 7 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

BULLETIN 56. First series of coal-dust explosion tests in the experimental mine, by G. S. Rice, L. M. Jones, J. K. Clement, and W. L. Egy. 1913. 115 pp., 12 pls., 28 figs.

BULLETIN 62. National mine-rescue and first-aid conference, Pittsburgh, Pa., September 23–26, 1912, by H. M. Wilson. 1913. 74 pp.

TECHNICAL PAPER 4. The electrical section of the Bureau of Mines, its purpose and equipment, by H. H. Clark. 1911. 12 pp.

TECHNICAL PAPER 6. The rate of burning of fuse as influenced by temperature and pressure, by W. O. Snelling and W. C. Cope. 1912. 28 pp.

TECHNICAL PAPER 7. Investigations of fuse and miners' squibs, by Clarence Hall and S. P. Howell. 1912. 19 pp.

TECHNICAL PAPER 11. The use of mice and birds for detecting carbon monoxide after mine fires and explosions, by G. A. Burrell. 1912. 15 pp.

TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 17. The effect of stemming on the efficiency of explosives, by W. O. Snelling and Clarence Hall. 1912. 20 pp., 11 figs.

TECHNICAL PAPER 18. Magazines and thaw houses for explosives, by Clarence Hall and S. P. Howell. 1912. 34 pp., 1 pl., 5 figs.

TECHNICAL PAPER 19. The factor of safety in mine electrical installations, by H. H. Clark. 1912. 14 pp.

TECHNICAL PAPER 21. The prevention of mine explosions, report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 12 pp. Reprint of United States Geological Survey Bulletin 369.

TECHNICAL PAPER 22. Electrical symbols for mine maps, by H. H. Clark. 1912. 11 pp., 8 figs.

TECHNICAL PAPER 23. Ignition of mine gas by miniature electric lamps with tungsten filaments, by H. H. Clark. 1912. 5 pp.

TECHNICAL PAPER 24. Mine fires, a preliminary study, by G. S. Rice. 1912. 51 pp., 1 fig.

TECHNICAL PAPER 28. The ignition of mine gas by standard incandescent lamps, by H. H. Clark. 1912. 6 pp.

TECHNICAL PAPER 30. Mine-accident prevention at Lake Superior iron mines, by D. E. Woodbridge. 1913. 38 pp., 8 figs.

TECHNICAL PAPER 39. The inflammable gases in mine air, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 2 figs.

TECHNICAL PAPER 40. Metal-mine accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 54 pp.

TECHNICAL PAPER 41. Mining and treatment of lead and zinc ores in the Joplin district, Missouri, by C. A. Wright. 1913. 43 pp., 5 figs.

TECHNICAL PAPER 43. The influence of inert gases on inflammable gaseous mixtures, by J. K. Clement. 1913. 24 pp., 1 pl., 8 figs.

TECHNICAL PAPER 44. Safety electric switches for mines, by H. H. Clark. 1913. 8 pp.

TECHNICAL PAPER 46. Quarry accidents in the United States during the calendar year 1911, compiled by A. H. Fay. 1913. 32 pp.

TECHNICAL PAPER 47. Portable electric mine lamps, by H. H. Clark. 1913. 13 pp

TECHNICAL PAPER 48. Coal-mine accidents in the United States, 1896–1912, with monthly statistics for 1912, compiled by F. W. Horton. 1913. 74 pp. 10 figs.

TECHNICAL PAPER 58. The action of acid mine water on the insulation of electrical conductors; a preliminary report, by H. H. Clark and L. C. Ilsley. 1913. 26 pp., 1 fig.

TECHNICAL PAPER 59. Fires in Lake Superior iron mines, by Edwin Higgins. 1914. 34 pp., 2 pls.

TECHNICAL PAPER 61. Metal-mine accidents in the United States during the calendar year 1912, compiled by A. H. Fay. 1913. 78 pp., 1 fig.

TECHNICAL PAPER 67. Mine signboards, by Edwin Higgins and Edward Steidle. 1913. 15 pp., 1 pl., 4 figs.

TECHNICAL PAPER 71. Permissible explosives tested prior to January 1, 1914, by Clarence Hall. 1914. 12 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp., 5 figs.

MINERS' CIRCULAR 5. Electrical accidents in mines, their causes and prevention, by H. H. Clark, W. D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp., 3 pls.

MINERS' CIRCULAR 6. Permissible explosives tested prior to January 1, 1912, and precautions to be taken in their use, by Clarence Hall. 1912. 20 pp.

MINERS' CIRCULAR 7. The use and misuse of explosives in coal mining, by J. J. Rutledge. 1913. 52 pp., 8 figs.

MINERS' CIRCULAR 8. First aid instructions for miners, by M. W. Glasgow, W. A. Raudenbush, and C. O. Roberts. 1913. 66 pp., 46 figs.

MINERS' CIRCULAR 9. Accidents from falls of roof and coal, by G. S. Rice. 1912. 16 pp.

MINERS' CIRCULAR 10. Mine fires and how to fight them, by J. W. Paul. 1912. 14 pp.

MINERS' CIRCULAR 11. Accidents from mine cars and locomotives, by L. M. Jones. 1912. 16 pp.

MINERS' CIRCULAR 12. The use and care of miners' safety lamps, by J. W. Paul. 1913. 16 pp., 4 figs.

MINERS' CIRCULAR 13. Safety in tunneling, by D. W. Brunton and J. R. Davis. 1913. 19 pp.

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