GASES THAT OCCUR IN METAL MINES

BY

D. HARRINGTON and E. H. DENNY
CONTENTS

Metal-mine and coal-mine atmospheres
Gases possible in metal mines
Methane or hydrogen in metal mines or tunnels
Gas explosions in tunnel work
High-nitrogen or carbon dioxide and low-oxygen gases
Rico district, Colorado
Cripple Creek district, Colorado
Rock-strata gases
Utah
Nevada
Other localities
Gases in timbered mines
Sulphur gases in metal mines and tunnels
Carbon monoxide in metal mines
Burning materials
Combustible rock minerals
Explosives
Miscellaneous gases in metal mines

Page |
--- |
1 |
1 |
2 |
3 |
4 |
5 |
6 |
7 |
7 |
7 |
7 |
8 |
9 |
9 |
10 |
10 |

Properties of gases
Nitrogen
Carbon dioxide
Oxygen
Methane
Hydrogen sulphide
Sulphur dioxide
Carbon monoxide
Oxides of nitrogen
Precautions against gases found in metal mines
Fire precautions
Recommendations
Ventilation
Recommendations
Temperature and humidity
Detection of gases
Sampling air
Types of detectors
Respiratory protection against gases
Conclusions

Page |
--- |
11 |
11 |
11 |
12 |
12 |
12 |
13 |
13 |
14 |
15 |
15 |
16 |
17 |
18 |
18 |
20 |
21 |
GASES THAT OCCUR IN METAL MINES

By D. Harrington and E. H. Denny

METAL-MINE AND COAL-MINE ATMOSPHERES

When the word "gas" is mentioned in connection with mining almost invariably it is inferred that the explosive gas, methane, is in mind and that the reference is to coal mining. Although methane is likely to occur in any coal mine, the metal mines of the world contain by far a greater variety of gases than do the coal mines. Often the gases in metal mines are as dangerous as the gases likely to be found in coal mines, and sometimes are even more deadly.

A coal mine is more likely to contain methane than a metal mine. In rare instances it may contain high percentages of nitrogen or carbon dioxide or it may be deficient in oxygen where the air is confined in a blind end or in a sealed region. Much more rarely relatively small percentages of ethane or other hydrocarbons with an odor of ether, gasoline, or kerosene, or minute percentages of hydrogen sulphide are found in a coal mine. During a coal-mine fire or explosion carbon monoxide content is likely to be high (4 per cent or more), and if the coal contains much sulphur the fire fumes may contain some sulphur dioxide.

GASES POSSIBLE IN METAL MINES

Methane has been found in a number of metal mines and occurrences have been attended by explosions; its limits of inflammability are 5 to 14 per cent in air. Some metal mines contain appreciable percentages of the deadly explosive hydrogen, whose limits of inflammability are 4 to 74 per cent in air. In some metal-mining regions carbon dioxide flows into the mine, fills the workings, and overflows like water. In other regions high-temperature gases containing a mixture of gases of sulphur (sulphur dioxide, hydrogen sulphide, and possibly sulphur trioxide), carbon dioxide, and nitrogen are found at the working faces; in some high-sulphide metal mines the deadly hydrogen sulphide is found in lethal proportions at blasting time. Carbon monoxide constitutes a decidedly dangerous day-by-day hazard in connection with metal-mine blasting because of the heavy charges of dynamite employed and the use of fuse which in burning gives off much carbon monoxide. The hazard of asphyxial gases is accentuated because of the relatively small open-

1 Work on manuscript completed July 2, 1931.
2 Chief engineer, safety division, U. S. Bureau of Mines.
ings where metal-mine blasting is done and the inefficient ventilation of the ordinary metal mine.

In most metal mines large quantities of dynamite, fuse, and detonators are stored underground; when a fire occurs in an explosives magazine in which dynamite is stored the gases given off, largely carbon monoxide and oxides of nitrogen, are dense and deadly. In addition, the oxygen content is often very low, as the underground metal-mine explosives magazine is usually a dead end, with practically no ventilation. In long-standing metal-mine fires, which are rather widely distributed over the United States, the nature of the gases produced depends upon the ores and other materials involved in the fire region. Gases from metal-mine fires include hydrogen sulphide, sulphur dioxide, carbon monoxide, carbon dioxide, methane, and hydrogen, as well as oxides of arsenic, antimony, etc.; moreover, there is frequently a definite deficiency of oxygen.

In addition to the variety of gases found in metal mines, the effect of gas occurrence is often accentuated by high temperatures due either to the natural heat of surrounding strata, to heated rock from sealed or partly sealed mine fires, or to some form of oxidation or other chemical reaction. Not infrequently the gas condition or the high-temperature condition is complicated by the intrusion of finely divided dusts from drilling, blasting, shoveling, and other operations. Some of these dusts are soluble and some insoluble; both are dangerous, especially if present in the mine air in finely divided form and in large quantities.

**METHANE OR HYDROGEN IN METAL MINES OR TUNNELS**

Notwithstanding the fact that to the metal miner methane is almost invariably associated with coal mines, scarcely a year passes without one or more ignitions of methane in other types of mine workings, including those where gold, silver, copper, iron, zinc, lead, limestone, salt, mercury, potash, and other metallic or nonmetallic substances are produced, and frequently in tunnels or shafts driven in or around cities for water or similar purpose.

In gold-silver properties in Gilpin County, Colo., numerous ignitions of methane have resulted from open lights, especially while long-abandoned shafts were being unwatered. Similar methane ignitions have occurred while long-abandoned timbered shafts in the Butte (Mont.) copper-silver-zinc mining district were being unwatered. In both these districts the strata are distinctly igneous, no shale or other carbonaceous formations being present. The methane undoubtedly was formed by slow decomposition of timber under water, similar to the formation of marsh gas in swamps. Methane ignitions have also occurred in the Michigan copper and iron mines while long-abandoned timbered mines were being unwatered, and as usual the open light has been the igniting agency. In unwatering any kind of mine, coal or metal, long filled with water, precautions should be taken to guard against the occurrence of explosive gas.

In the Grass Valley (Calif.) gold-mining district, where carbonaceous shales are found in conjunction with or close to the gold-bearing measures, some rather extensive and troublesome accumulations of methane have been found.
Several ignitions of methane have occurred in the old Joplin lead-zinc district of Missouri and in the newer Picher (Okla.) district as well; in fact, methane ignitions have occurred in all three States comprising the tri-State lead-zinc district. Methane has been found also in at least one iron ore mine in Alabama and during some quicksilver mining in California. Methane explosions have been started by open lights or matches in salt mines in New York and in Louisiana. Disastrous explosions have been started by ignitions of gas in asphalt mines in Oklahoma and in gilsonite mines in Utah.

In fighting partly sealed metal-mine fires of long standing methane has been found, even when the entire region consisted of igneous rock and no sedimentary strata were present; undoubtedly it comes from some high-temperature reactions between the timber in the fire area and the water introduced to fight the fire. Methane has been found in limestone mines or other similar noncoal-mining operations in sedimentary formations.

Hydrogen has been found in gases coming out of drill holes in South African gold mines and in a potash mine in New Mexico; this gas also has been found, usually in rather small quantities and proportions, in the fumes from very active metal-mine fires, especially when water is introduced into fire areas where some of the strata are heated to incandescence.

Recently, while drilling, a mixture of hydrogen, methane, ethane, and nitrogen in explosive proportions was encountered in New Mexico in a shaft being sunk through formation carrying potash and soda. The gas pressure was high enough to prevent drilling, and it had to be blown off from the drill holes for many hours before work could be resumed.

Methane occurrence in metal mines is by no means confined to the United States. From time to time the foreign technical press has described methane occurrences, explosions, or ignitions in European, African, and other metal mines, the most recent being in the gold mines of South Africa.

Details connected with the occurrences of methane in metal mines are omitted here; details for some have not been published. The reader is referred to published data available.¹

GAS EXPLOSIONS IN TUNNEL WORK

So many hazardous situations due to the occurrence of methane have arisen during the driving of water or other tunnels in or near our large cities and during the sinking of shallow shafts for bridges and other foundations and so few precautions have been taken against possible disasters in connection with this work that some drastic action should be taken to make tunnel driving and excavating for deep foundations safer, with particular reference to lighting,

Report of the State mine inspector of Kansas, 1928.
use of electricity, and ventilation. A brief outline of a few typical occurrences follows:

1. In Chicago in 1913 several gas explosions occurred while a tunnel was being driven for water; as a result a number of workers were burned and some killed. The gas, which was ignited in one instance by the breaking of an incandescent light globe, may have been leakage from city gas mains.

2. In Milwaukee in 1914, while a water tunnel was being driven several thousand feet under Lake Michigan, a worker ignited a body of methane in lighting a cigarette; 29 men were burned, although, fortunately, none were killed. Samples of air from the tunnel were analyzed and found to contain appreciable percentages of methane.

3. In 1914, while sinking for a foundation for a bridge over the Mississippi River, nine men in a caisson were killed by an ignition of methane, probably caused by an electric arc.

4. In Cleveland in 1916, while driving a water tunnel under Lake Erie, 9 men were killed in an explosion of gas, probably ignited by electrical equipment; an hour later 10 more were killed while trying to reach the first 9 victims. This tunnel was found to contain appreciable amounts of methane, which was seeping into it from the surrounding sedimentary strata. During the remainder of the work on the project strict precautions were taken against gas accumulations as well as against sources of gas ignition.

5. In 1918, while driving a tunnel near San Francisco, five men were killed by an explosion of methane, probably caused by an electric arc from an open-type storage-battery locomotive. Some investigators, however, held that the ignition was due to sparks between the wheels of the storage-battery locomotive and the track rail while an attempt was being made to move a very heavy load.

6. In Kansas City in 1926 an explosion of methane in a tunnel being driven for water resulted in the death of eight men. Ignition of the gas was undoubtedly due to an electric arc, either from an open electric switch or open storage-battery locomotive.

7. In 1927 a number of ignitions of methane occurred in a tunnel being driven at Berkeley, Calif. In one, 11 men were burned rather severely, although none died; the ignition was probably caused by a smoker's match, although smoking was against the rules, and all of the men denied that they had been smoking.

8. In connection with the driving of shafts and tunnels for the Hetchy Hetchy water project near San Francisco several ignitions of methane have occurred in which some men have been killed and others burned; one rather serious fire also resulted from this work.5

As methane and other gases occur so frequently in shallow shafts and tunnel work in and around cities, especially where the work is done in sedimentary formations or adjacent to or under rivers or lakes, every State should have definite and stringent regulations governing such work. Generally, these matters are left to city or State engineers, few of whom know even the rudiments of the hazards of gas in subsurface workings, of effective methods of ventilating such workings in the event of an occurrence of gas, or of proper means of detecting explosive gas or preventing its ignition if it should be encountered.

**HIGH-NITROGEN OR CARBON DIOXIDE AND LOW-OXYGEN GASES**

Gases high in carbon dioxide or nitrogen, or both, and low in oxygen are likely to be found in long unventilated dead ends in any kind of mine. This sort of atmosphere may be expected (though it may not always be present) in long unventilated dead-end workings which are raises or dips, especially vertical dips (winzes), or

---

are level or approximately level. These low-oxygen atmospheres high in carbon dioxide and nitrogen are formed in mines in numerous ways; although they are more likely to be found in metal than in coal mines, they are by no means absent from the latter.

**RICO DISTRICT, COLORADO**

Recently an occurrence of irrespirable gases in a metal mine in the Rico district, southwestern Colorado, was investigated by the United States Bureau of Mines. Irrespirable gases have been found in this district virtually since the beginning of mining there and have frequently impeded work and constituted a hazard to miners' lives; the breathing of such gases in small amounts probably has affected efficiency as well as the general health of the miners.

The ore is valuable chiefly for its silver and gold content. Considerable pyrite occurs in and near the vein; limestones, shales, and sandstones characterize the rock formation of the region. Gases that would extinguish a carbide lamp and have distinctive odors have been found in parts of the mine for years, occurring in greater quantity during the summer months. About 1,700 feet from the portal of the fourth level is a vertical winze said to be 65 feet deep. At the time of this investigation the heat increased noticeably as one approached the winze, and there was a distinct odor of hydrogen sulphide at the top. The light of a carbide lamp and a candle were extinguished at the top, and apparently some of the gases in the winze were flowing out and into the tunnel and through connections to the third level. Air samples were taken with vacuum bottles about 1 foot below the collar of the winze and analyzed by the Pittsburgh laboratory of the United States Bureau of Mines. The analysis showed 49.2 per cent of carbon dioxide, 10.8 per cent of oxygen, and 40 per cent of nitrogen, with no methane. Although hydrogen sulphide gas was evidently present, as indicated by the characteristic odor of spoiled eggs, the amount was too small to be disclosed by chemical analysis.

At the breast of the tunnel some air samples were taken; on analysis these showed about 6.5 per cent of carbon dioxide and 19.55 per cent of oxygen. One experienced difficulty in breathing the air, evidently due to the carbon dioxide, as the oxygen in the air was ample to support life. This property of increasing the rate of breathing with resultant physical discomfort is characteristic of carbon dioxide, especially where the temperature is high. The amount of sulphur dioxide present as determined by odor was too small to be determined analytically. A dry-bulb temperature of 99° and a wet-bulb temperature of 79° were recorded.

The excessive heat in this mine, especially in the sections with the irrespirable gases, makes it fairly certain that chemical action, with heat liberation, is proceeding rapidly in the strata. In places numerous vugs and open fissures occur in the formation; it is believed that in this mine, as in some other mines investigated by the bureau, the gases formed and heat produced are a result of the action of atmospheric air and mine water upon the sulphides and carbonates in the fissured rock. In this particular mine there was no record of any sudden liberation of large amounts of gases, but gases were present in considerable amounts in parts of the mine.
at all times. As in other districts, the mine management had noted that storm conditions and prevailing winds from certain directions increased the trouble from gases. It was stated that a number of years ago inflammable gas had been ignited with an open light at the breast of the third level.

CRIPPLE CREEK DISTRICT, COLORADO

As detailed in published reports of the United States Bureau of Mines, similar gas occurrences were investigated in the Cripple Creek gold-mining district of Colorado. Here the coroner's records show that at least 35 lives have been lost by suffocation in irrespirable gases during some 25 years of mining. Such gases are mainly nitrogen and carbon dioxide, present in varying amounts. As a rule the mixture of gases is much heavier than air, but occasionally gases high in nitrogen and consequently lighter than air are found at the top of raises rather than near the floors of drifts, levels, and winzes.

Much of the mining in this district is done in or adjacent to a porous breccia, and the veins mined are often fissured and open. This probably accounts for the fact that gases are liberated suddenly and in considerable volume from the strata upon a slight lowering of atmospheric barometric pressure and disappear again almost as quickly when the barometer rises and weather conditions clear.

In Cripple Creek natural ventilation is relied upon to a large extent; numerous deep shafts with water-level tunnels driven to the surface at points considerably below the collars of the shafts aid in bringing about a copious but variable natural circulation of air, especially during certain seasons. Some of the smaller mines particularly troubled by gases have for years used a pressure system of holding the gases back in the strata; a slight pressure induced by a blower fan or an injector is usually sufficient. To maintain such pressure the tops of shafts are bulkheaded and fitted with doors which may be opened temporarily as ore and rock are raised. Similar systems have been used in drifts in which gases were encountered; one or more bulkheads with doors were erected at points near the mouth of the drift, and a fan or injector was installed to maintain the pressure within the bulkheaded area. Fan-pipe installations are also used to dilute the gases and carry them out of the mines, but small units of this type have not always proved satisfactory.

In one gas occurrence investigated by the Bureau of Mines, in which two men lost their lives, air samples collected by means of a vacuum bottle in the shaft showed less than 0.3 per cent of oxygen, 18 per cent of carbon dioxide, and 81 per cent of nitrogen, although the air in this same shaft had been entirely free of gas a few hours before. One idle mine of considerable extent was entirely free of gas during good weather, but when a storm arose the mine filled with carbon dioxide and nitrogen so that the light of a carbide lamp was extinguished 20 feet outside the portal. Sulphur dioxide was de-

---

ected only once and then by odor only. Tests of large samples of various rocks from the district sealed in glass carboys with atmospheric air and ordinary tap water or mine water showed that gases similar to those found in the mine could be produced in the carboys. The action of water and air upon the rocks for two or three days produced appreciable percentages of carbon dioxide and decreased the oxygen content of the air. After several months all of the oxygen in the air in carboys containing certain rocks was consumed; the residual gases were carbon dioxide and nitrogen. The rocks of the Cripple Creek district probably do not contain more than the average amount of pyrite and other sulphides found in other metal-mining districts, but the fissured and porous nature of the rock affords an opportunity for rapid chemical action when moist air comes in contact with such sulphides.

ROCK-STRATA GASES

UTAH

The Bureau of Mines investigated the occurrence of rock-strata gases in the East Tintic mining district in Utah. The gases found in these mines occurred mainly with low barometer and changing weather conditions and caused much trouble until mechanical means of ventilation were introduced. Rock and air temperatures in these mines were abnormally high. Some of the gases contained more than 60 per cent of carbon dioxide, whereas other gases were almost pure nitrogen and consequently so light that they accumulated in raises.

NEVADA

In several Nevada mines gases high in nitrogen have been found to issue in quantities from freshly cut fissures. They are found in raises and have caused at least one fatality.

OTHER LOCALITIES

Fatalities have resulted from rock gases in Gilpin County, Colo.; Park City, Utah; Picher, Okla.; and many other metal-mining districts in the United States. Occurrences of irrespirable rock-strata gases in metal mines in England, France, New Zealand, and Australia have also been recorded, some of them of relatively recent date.

GASES IN TIMBERED MINES

In addition to metal-mine gases formed by chemical action on the rock strata and released by changes in pressure, few timbered metal mines are free from gases high in carbon dioxide and nitrogen and low in oxygen in long blind ends or winzes. In sections of metal mines in which there is little or no circulation of air, a condition frequently found in damp, timbered places where no work or travel

is being done, some sort of reaction is likely to take place between the damp timber and the oxygen of the air whereby the oxygen is absorbed and its place taken largely by carbon dioxide. When this reaction has continued until the oxygen contact of the air is below 10 per cent the condition of the atmosphere is decidedly dangerous, and when the oxygen content is below 5 per cent a few inhalations result in unconsciousness and probably death. Damp, timbered winzes that have been long abandoned but have not filled with water are decidedly dangerous, as the oxygen-depleted air usually is high in carbon dioxide, which seeks the lowest available place. Even if the gas does not form in the winze itself, oxidation may take place in a level or other working above the winze and the heavy carbon dioxide flow like water into the winze. Anyone who goes into an abandoned, unventilated blind end, whether raise, winze, or level, takes a chance of losing his life unless he tests the air thoroughly or has adequate respiratory protection. High percentages of carbon dioxide and nitrogen and a low percentage of oxygen are found almost invariably at some time or place in connection with fires in metal mines, including not only quick, hot fires but also long-drawn-out partly sealed or sealed fires. One should always keep in mind the fact that if oxygen is deficient no type of gas mask can be worn safely and that the only available respiratory protection against gases low in oxygen is up-to-date oxygen breathing apparatus or some other device that furnishes oxygen as well as excludes the asphyxial gases.

**SULPHUR GASES IN METAL MINES AND TUNNELS**

In general, sulphur gases occur much more frequently and in much more dangerous concentrations in metal mines and tunnels than in coal mines. There have been a number of occurrences (some relatively recent) of the decidedly dangerous hydrogen sulphide gas in comparatively shallow shafts for foundations for bridges over rivers. In some instances workers have been killed and in many others they have been made decidedly ill because sufficient precautions were not taken against this gas, which is dangerous to life even in very low percentages in the air breathed. Recently hydrogen sulphide caused loss of lives in a shallow shaft in connection with waterworks tunnels at Detroit.

In blasting material relatively high in sulphur* or material in which the sulphur is loosely bound or readily oxidized or altered many workers have been gassed, some fatally, from fumes in which hydrogen sulphide was the most dangerous constituent, although it may have been accompanied in some instances by other noxious gases, such as sulphur dioxide, carbon monoxide, and various oxides of nitrogen. In blasting material whose sulphur content exceeds 30 per cent of the whole explosions of sulphide ore dust (chiefly sulphides of iron and copper) have occurred; the resultant gases are high in hydrogen sulphide and sulphur dioxide, and possibly other sulphur gases. Sometimes sulphur gases are found in explosives fumes in metal-mine blasting, even when there is no sulphur in the material being shot.

---

down. In the fumes from some fires in metal mines, especially fires that have been burning for several years, there are likely to be dangerous percentages of sulphur gases even when the sulphur content of the burning material is low. The gases from these fires usually consist of sulphur dioxide with relatively small amounts of hydrogen sulphide and possibly, under certain conditions, sulphur trioxide. In some iron ore mines with adjacent black-shale strata spontaneous fires give off fumes containing hydrogen sulphide and sulphur dioxide as well as carbon monoxide.

Sometimes sulphur gases are liberated in coal and metal mines directly or indirectly from waters released in mining; as a rule, these gases are hydrogen sulphide and possibly sulphur dioxide in small amounts; other sulphur-gas combinations may also occur. They are rarely dangerous to life, although frequently they affect the eyes of workers, causing temporary blindness from swelling or various kinds of inflammation.

CARBON MONOXIDE IN METAL MINES

Probably more than 90 per cent of the fatalities from fires in the metal mines of the United States (the total lives so lost amounts to several hundred) have been due to carbon monoxide, and the main source of carbon monoxide in more than 70 per cent of these fires, as well as those with property loss only, has been timber, although there are generally numerous other possible sources, such as oil, explosives, and many other combustible materials brought in for various purposes.

BURNING MATERIALS

Scarcely a metal mine in the United States is free from fire hazards, although probably 90 per cent of the operators would vigorously deny such a statement. Some of the heaviest losses of life in metal-mine fires have resulted from the burning of less than a railroad freight car or only a few cords of timber. Also, the burning of a box of explosives or a barrel of oil in the confined places so numerous in metal mines readily gives off enough deadly fumes, largely carbon monoxide, to kill several hundred men if they were trapped in the poorly ventilated places so frequently found in the unventilated mines, which include by far the greater number of the metal mines of the United States, as well as in the relatively well-ventilated metal mines.

COMBUSTIBLE ROCK MINERALS

In addition to the fire hazard due to combustible materials brought into the mine (timber, explosives, fuse, oil, etc.), fires in some metal mines are caused by combustible material in the strata. Occasionally

---

explosive gas such as methane accumulates and is ignited. In some regions carbonaceous shales or slates adjacent to the mineral-bearing strata fire spontaneously or are ignited by an open light or other cause. In other metal mines the sulphur content of the ore or of the walls is so high that fire is spontaneous, especially when the ore is crushed during mining operations. Fires may also be started in the broken sulphide by an open light or other ignition. Whatever the source of a mine fire the fumes almost invariably contain carbon monoxide, which generally is present in dangerous percentages.

EXPLOSIVES

Gases evolved by any of the explosives used in metal-mine blasting probably contain carbon monoxide, although those given off by some types of explosives under certain conditions contain comparatively little. If an explosive has partly deteriorated or partly frozen or if it burns rather than explodes, carbon monoxide as well as other dangerous gases are likely to be given off in dangerous quantities.

The fuse used almost universally in metal-mine blasting evolves material quantities of carbon monoxide in burning. Fuse in so-called “tight” places with small cross-sectional area and little or no ventilation is particularly dangerous. It seems strange that electrical blasting is not employed more widely in metal mines, as it is much safer, more efficient, and decidedly more applicable to the faulty ventilation practice so general in metal mines. In some poorly ventilated metal mines analysis has revealed carbon monoxide in small but readily recognizable percentages in the general atmosphere of the working faces.

In some metal mines, as well as in some nonmetallic underground properties, internal-combustion engines used underground for haulage, hoisting, or pumping give off carbon monoxide. Gasoline or similar drive for pumps or hoists has no place underground and should not be allowed there; gasoline trucks should not be allowed to go into mines to pull out mineral products, and the use of steam locomotives, occasionally found in underground workings, should not be permitted in any underground mining work, even in so-called fresh air.

MISCELLANEOUS GASES IN METAL MINES

In addition to carbon monoxide, the fumes from a metal-mine fire under certain conditions may contain hydrogen sulphide, sulphur dioxide, methane, or hydrogen, as well as other gases. If the ore contains antimony or arsenic the fire fumes will give off oxides of these metals; in a few instances it was believed that certain excessively corroding fumes forced out of a highly heated low-grade sulphide ore deposit were sulphur trioxide. If the fire occurs in a confined region the oxygen content may be much less than 10 per cent and the carbon dioxide or nitrogen content relatively high.

If the fire consumes explosives or the boxes, paper, and sawdust in which explosives are wrapped and shipped, the fumes are likely to contain not only high concentrations of carbon monoxide and very low concentrations of oxygen but also high concentrations of various oxides of nitrogen, the breathing of which is dangerous. There is
good reason to believe that metal-mine fires involving explosives or explosives containers give off fumes in quantities that can not be handled adequately by any type of gas mask; hence, only up-to-date oxygen breathing apparatus should be worn if respiratory protection is sought. Fires involving heavily insulated electric power cables or wires also give off fumes that contain high percentages of poisonous gases, including carbon monoxide.

PROPERTIES OF GASES

NITROGEN

Pure nitrogen gas is a hazard to life; it will suffocate a human being in much the same way that water does. When mixed with oxygen in the approximate percentages of 79 to 21, as in ordinary air, it acts to dilute the oxygen.

CARBON DIOXIDE

Pure carbon dioxide will asphyxiate a person. Its property of stimulating breathing is utilized in certain resuscitation apparatus. Such stimulation in ordinary work tends to impair the efficiency of the worker, as he utilizes energy needlessly. If the air contains considerable carbon dioxide, the physical effect is definitely detrimental, particularly if the worker breathes the contaminated air over a long period. If the air contains 0.5 per cent of carbon dioxide, a man breathes deep and fast; with 2 per cent he breathes approximately 50 per cent more air than he would normally; with 5 per cent he breathes three times as much air as he would normally; and with 10 per cent he can breathe only a short time. Inhaling large amounts of carbon dioxide prevents the blood from giving off the gas as an elimination product. When resting a man can breathe 2 per cent of carbon dioxide in otherwise pure air for several hours without ill effects; 3 to 4 per cent of the gas causes an oppressed feeling and produces shortness of breath or panting; and 5 to 6 per cent soon exhausts him so that he can not continue work effectively. The Bureau of Mines recommends that mine air be considered unfit for men to breathe if it contains more than 1 per cent of carbon dioxide.

OXYGEN

Various parts of a mine may be deficient in oxygen (that is, contain less than the normal amount found in the atmosphere), a condition usually associated with the presence of carbon dioxide. The United States Bureau of Mines recommends that mine air be considered unfit for men to breathe if it contains less than 19 per cent of oxygen. A lighted candle is extinguished when oxygen in the air falls below 17 per cent. Work may be continued in air containing less than 17 per cent, but below 13 per cent the blood is unable to absorb oxygen fully; when the oxygen content of the air drops much below 10 per cent the judgment is impaired and delirium may follow.

Under certain conditions unconsciousness is the result, and when the oxygen content is less than 5 per cent paralysis follows quickly. Generally, when a man goes from good air to an atmosphere very deficient in oxygen, he drops almost instantly, without warning. A lighted carbide lamp is extinguished when the oxygen in the air falls below approximately 13 per cent. It seems evident that a man can not be expected to work efficiently and continue in good health if his body is undergoing slow oxygen starvation.

**METHANE**

In its physiological effects methane closely resembles nitrogen; hence it is not harmful when inhaled, unless, because of its presence, the oxygen content of the air is lowered beyond the safe amount. In normal air mixtures of 5 to 14 per cent of methane and air are explosive if brought in contact with an igniting medium, such as an open light or an electric arc.

**HYDROGEN SULPHIDE**

Hydrogen sulphide is one of the most poisonous gases known; fortunately only traces are ordinarily found in mine operation. In some respects it is more poisonous than hydrogen cyanide. In small proportions its odor of spoiled eggs is noticeable, but in heavy concentrations the organ of smell appears to be paralyzed. When it is detected ventilation should be improved at once. Several instances are on record of hydrogen sulphide filtering through sands and muds in tunneling and shaft-sinking operations, overcoming the workers. Numerous fatalities in atmospheres connected with high-sulphur petroleum production and refining amply testify to the extreme danger of this gas. Hydrogen sulphide inhaled in large amounts results in immediate asphyxiation; in small amounts it results in inflammation of the eyes, signs of inflammation of the respiratory tract, and sometimes in bronchitis and pneumonia. Subacute poisoning can be produced by long exposure to concentrations as low as 0.005 per cent; immediate collapse usually is the result when one is exposed to 0.06 to 0.1 per cent of the gas; and death ensues quickly when one is exposed to more than 0.1 per cent.

**SULPHUR DIOXIDE**

Sulphur dioxide has the characteristic odor of burning sulphur matches. It is irritating to the eyes and respiratory passages, and 1 part in 500 is intolerable to breathe. As previously mentioned, the gas is occasionally found in metal mines as a result of oxidation or burning of sulphides and is also formed as an oxidation product in blasting. Sulphur dioxide is a hazard, chiefly in blasting operations and in mine fires; in such instances it is likely to be present in combination with other irritating gases, the combined effect sometimes resulting in irritation of bronchial passages and lungs, with fatal results a few hours after exposure.

---

CARBON MONOXIDE

Carbon monoxide\(^{14}\) when inhaled replaces the oxygen in the red corpuscles of the blood; consequently, a man may be overcome by a relatively small amount. Therefore 0.02 per cent is the upper limit that should be permitted in any part of a mine atmosphere; 0.1 per cent causes severe symptoms in 30 to 60 minutes; and 0.5 per cent is likely to be fatal if breathed for a short period. The gas is colorless, tasteless, and odorless. Carbon monoxide in dangerous quantities is also formed from metal-mine fires owing to incomplete combustion of timbers or other combustible material. The Bureau of Mines has numerous records of men being killed by carbon monoxide because they returned too soon to unventilated places after blasting.

OXIDES OF NITROGEN

Oxides of nitrogen are formed in dangerous amounts when high explosives burn. Miners generally speak of such gases as having a characteristic “burned-powder” odor. As little as 0.01 per cent of oxides of nitrogen may cause dangerous illness if breathed for a short time, and 0.07 per cent is fatal if breathed for 30 minutes. A Bureau of Mines burning test of gelatin dynamite of 40 per cent strength gave among the various gases evolved 11.3 per cent of nitric oxide and 0.6 per cent of nitrogen peroxide.\(^{15}\) The bureau has the record of a case in which explosives detonated incompletely and in large part burned, giving off brownish yellow fumes; 13 men were affected by the smoke and fumes from the explosive, but all revived upon reaching fresh air. Within a short time, however, symptoms of bronchial and lung irritation developed, and in 3 days 9 of the 13 men had died; the remaining 4 took several months to recover.

PRECAUTIONS AGAINST GASES FOUND IN METAL MINES

It is apparent that numerous gases are found in metal mines and that many are dangerous to health or to life; it is equally apparent that most of the noxious gases that afflict the metal miner are those from fires and from explosives. The gases that flow from the strata or are due to chemical action between the rock and water of air exposed by mining operations are serious hazards in some localities, but mine fires and hazards from explosives fumes involve practically all types of underground mining operations in the world. Hence, if the metal-mining industry would realize that every mine presents a fire hazard and would take common-sense, readily available precautions against it, the greatest danger from gases in and around metal mines would be avoided.

FIRE PRECAUTIONS

Foremost among the precautions that should logically be taken are the elimination of open lights and smoking; the limitation and other-


wise safeguarding of transportation and of storage of explosives in mines; the employment of safer methods of blasting, such as using inert tamping material and up-to-date safeguarded electrical methods of blasting—blasting largely through shot firers when the working shift is out of the mine; and the safeguarding and use of all kinds of electrical installations found in and around mines, with particular reference to prevention of ignitions of timber or other combustible material by electric arcs or short circuits.

RECOMMENDATIONS

Other measures for the prevention of fires in mines and their more ready control include:
1. An adequate supply of water available on the surface and underground, furnished if possible through water lines extending to within 100 feet of the breasts of the various levels and drifts, with hose attachments at frequent intervals and hose stored at appropriate points. In small mines filled water barrels and fire buckets or suitable types and sizes of fire extinguishers distributed at suitable points, including shaft stations, may answer the same purpose.
2. Provision for the ready conversion of air lines into water lines.
3. The placing of containers filled with dry sand or other incombustible dust or fire extinguishers of suitable type at or near underground electrical stations and near fixed motors and transformers.
4. Regular inspection of the mine, including entrances and underground workings, for fire hazards, and written reports on such inspections.
5. Inspection of timbered stopes after each shift.
6. Regular inspection and testing of mine fire-fighting equipment.
7. Organization of mine employees for fire prevention and fire control and a written plan of action to be followed in event of fire. Regular instructions, supplemented by fire drills, of mine officials and selected employees in the duties assigned to them in event of fire.
8. Establishment of a surface and underground fire-alarm system. For informing underground workers of fire a general danger signal may be given by interruptions of the lighting circuit or by telephone, or in mines using compressed air a stench warning system may be used.
9. Use of fireproof structures only within 50 feet of any mine entrances.
10. Fireproofing of all dry-timbered shaft stations by guniting or similar method.
11. Installation of tightly closing fire doors near shafts in levels leading from shafts in every timbered mine to permit the separation of various sections of the mine in case of fire.
12. Prohibiting the storage of oil or other dangerously inflammable material within 100 feet of any mine opening.
13. Prohibiting the dumping of oily waste, papers, old hay, manure, waste carbide, and other inflammable débris into abandoned workings and keeping the mine free from empty boxes, wood chips, paper, and combustible rubbish.
14. Fireproofing of main intake shaft lining.
VENTILATION

Of importance at least equal to the taking of adequate precautions against fire in or around metal mines is the provision for adequate ventilation\(^\text{16}\) of the mines. Efficient ventilation of metal mines consists in supplying at all times such volume of circulating air in working places as will enable the worker to exert himself in comfort at maximum physical capacity without endangering his health. In mining ventilation, fire protection and prevention, health, safety, and efficiency are closely interlocked.

Metal-mine operators rarely if ever provide for ventilation until forced to do so by some untoward condition or occurrence; coal-mine operators, however, universally provide for ventilation—they must, otherwise an explosion would ensue. There is just as much reason for providing adequate ventilation for most metal mines as for providing ventilation for coal mines.

Many metal-mine officials, technically educated as well as those without technical training, are ignorant of the principles of air circulation. Ventilation should be under constant supervision, and the man in charge should report to the highest officials of the company, as many local officials in metal mines are not in sympathy with improvements in ventilation.

Workers in metal mines, including shift and other bosses, must be educated to respect ventilating devices such as doors, regulators, overcasts, brattices, and fans as coal miners do, and to become as familiar with those devices as coal miners are. Many present-day metal miners and bosses consider ventilation a useless fad and obstruct rather than aid improvements in ventilation. Metal-mine operators should provide fan ventilation\(^\text{17}\) from the beginning of operations to avoid dangers from explosives and other fumes and should provide fresh air to workers. Each mine should be ventilated wholly within itself; interventilation of mines is likely to be dangerous, inefficient, and unsatisfactory.

RECOMMENDATIONS

Some of the measures recommended to obtain adequate metal-mine ventilation are as follows:

1. Installation of a mechanically driven fan with fireproof housing and mine connections, the fan to be capable of quickly reversing air currents and of capacity adequate to ventilate the mine properly,

the air capacity to be defined further as not less than 100 cubic feet of air per minute for each person underground on any one shift, with such additional quantity as is needed to dilute adequately and render harmless any mine gases encountered.

2. Proper distribution of air to working places by such means as the driving of connections between levels; use of doors, overcasts, bulkheads, regulators, and canvas; use of auxiliary fans or blowers, electric or compressed-air driven, with canvas or other tubing.

3. Requirement that all working places in which the air temperature is above 80° F. (dry bulb) be supplied with a current of moving air by means of a blower and tubing or equivalent means.

4. Continuous operation of the surface fan while men are in the mine.

5. Maintenance of all airways so that they allow ready unobstructed passage of air.

6. Splitting of air currents systematically so that fire in one section of a mine may not necessarily fill the entire mine with asphyxial fumes.

There are records of naturally or otherwise inadequately ventilated mines filling with carbon dioxide or other gas, overcoming some of the workers, and compelling suspension of work for considerable periods of time. Upon establishment of efficient mechanical ventilation this situation has been readily controlled. During seasons when the temperature of surface air and of underground rock and water are about equal, circulation of air at certain times in mines that rely on natural ventilation is sluggish, ceases utterly, or reverses in direction. During a mine fire naturally ventilated mines are likely to be at a decided disadvantage through inability to control direction of air currents.

**TEMPERATURE AND HUMIDITY**

Although finely divided dust in mines is probably the chief cause of miners' consumption, it is now recognized that there may be other factors of almost equal influence, such as high temperatures and humidities, harmful gases, and lack of air movement, all of which are readily remedied by ventilation. With dry-bulb temperatures below 75° F., mine working places may be comparatively comfortable, irrespective of air movement or relative humidity. However, air heavily depleted of oxygen or impregnated with gases such as carbon dioxide, carbon monoxide, and oxides of nitrogen may be uncomfortable or unsafe; moreover, such places may be both uncomfortable and unhealthful if large quantities of finely divided dust are present. With dry-bulb temperatures above 75° F., comfort and maximum working efficiency can be attained only when the air is moving, particularly when the relative humidity is high. The exact velocity necessary is a variable dependent on the temperature and humidity. Saturated atmospheres up to nearly blood temperature may be made endurable and even to a considerable extent comfortable by providing sufficient velocity. Relative humidity, even up to the saturation point, does not appear to be harmful to health, comfort, or efficiency until this temperature is above 75° F.; if enough move-
ment is supplied, high relative humidity is not particularly harmful until the temperature is well above 90° F.\textsuperscript{18}

Many accidents in metal mines are due to deficient ventilation. Failure to remove smoke and fumes after blasting prevents proper safety inspection of working places; many men have been asphyxiated in fumes from explosives. Moreover, in hot, humid, stagnant air men are likely to become dizzy or are unable to think clearly or quickly or they may faint at an inopportune time and be killed. There are instances of men having dropped dead from heart failure in such hot places. Physiological experimental work in South African mines shows that men working in stagnant air with a relative humidity of 95 per cent and a temperature of 87° F. increased the amount of work performed 46 per cent by the mere expedient of installing a small fan to move or stir the air, showing that high humidity in itself is not particularly harmful (at least until the temperature is well above 90° F.) and that air movement has a vital influence on the productive capacity of workers.

Although ventilation has generally been deemed an integral part of coal mining, metal-mine officials usually pay little or no attention to circulation of air until forced to do so by some untoward condition or accident, yet the need of efficient circulation of air is as great in metal mines as in coal mines. In coal mines the dangerous explosive gas methane, fumes from explosives, and sometimes other gases, such as carbon dioxide or nitrogen, must be removed. In metal mines there is a greater need to remove fumes from explosives, and frequently there is occasion to remove carbon dioxide, nitrogen, and other gases from strata; even the coal miner's explosive gas, methane, is occasionally found. In addition, circulating air currents are urgently needed in metal mines to reduce the excessively high humidity and temperature so frequently found there, although these are rare in coal mines. Immense quantities of minutely fine particles of rock dust floating in the air of metal mines and largely responsible for miners' consumption\textsuperscript{19} and some other diseases prevalent among metal miners could be almost wholly removed by adequate ventilation. The generally accepted conclusion that coal miners have a healthful occupation and live to a ripe old age and that many metal miners contract diseases, such as lead poisoning and miners' consumption, and either die early in life or are incapacitated in middle age is due almost wholly to the superior working conditions in coal mines brought about chiefly by ventilation.\textsuperscript{20}

**DETECTION OF GASES**

The detection\textsuperscript{21} and quantitative determination of mine gases have been described in detail in various publications referred to in footnotes.


The extinguishing of a candle or match flame or the flame of a carbide lamp or flame safety lamp shows that the oxygen in the atmosphere tested is insufficient to support the flame and also indicates the presence of abnormally high percentages of nitrogen or carbon dioxide, or both. If the oxygen-deficient air hangs near the top of a raise or a high point it is probably mainly nitrogen (density 0.971) and if it is in a winze, shaft, or near the floor of a tunnel or drift it contains considerable carbon dioxide (density 1.529). The flame of a candle, match, or flame safety lamp is extinguished when the oxygen content of the air drops to about 16 per cent but the flame of a carbide lamp usually is not extinguished until the oxygen content of the air drops to between 13 and 14 per cent.

**SAMPLING AIR**

Air samples may be collected readily at any accessible point in a mine by the use of a vacuum bottle or by emptying a bottle filled with water in the air to be tested and then tightly sealing the bottle. The samples thus collected can be analyzed quickly with a portable Orsat apparatus for oxygen, carbon dioxide, carbon monoxide, and methane and the nitrogen determined by difference. The Orsat apparatus is accurate to within about 0.2 in the percentage found.

**TYPES OF DETECTORS**

Methane is ordinarily detected in coal mines by elongation of the flame of a flame safety lamp or by actual explosion within the lamp. In drifts and tunnels where the presence of methane is suspected a magnetically locked flame safety lamp or equivalent device should be used for testing. Any source of open flame will ignite methane if present in explosive proportions, and such ignition is likely to result in a severe explosion with injury or death to workers, as well as damage to property. Methane detectors other than the flame safety lamp approved by the Bureau of Mines include the Martienssen, the Burrell, and the Union Carbide Co. The last is accurate to within 0.15 per cent. A continuous methane recorder has also been devised for automatically determining and continuously recording the amount of methane; for example, in a return-air current.

Hydrogen sulphide gas may be detected by its characteristic odor of spoiled eggs. If air suspected to contain hydrogen sulphide is passed through a solution of cadmium sulphate or chloride there will be a typical yellow precipitate. Even slight traces of hydrogen sulphide will tarnish a silver coin.

Sulphur dioxide is readily detected by its odor of burning sulphur matches.

Carbon monoxide gas can be detected in a number of ways. A canary or mouse usually will be overcome in quantities of carbon monoxide gas immediately harmful to man much quicker than will

---

a person. The “holmite” or activated iodine pentoxide detector detects the presence of carbon monoxide in percentages as low as 0.07. Air to be tested is aspirated through a metal barrel filled with activated charcoal to remove interfering gases and is then discharged through a small glass tube containing the activated iodine pentoxide. The aspirator bulb, when squeezed, forces an approximately definite volume of air through the glass tube. Carbon monoxide in contact with activated iodine pentoxide liberates free iodine with consequent change in color of the material in the tube from white to green or, if the percentage of carbon monoxide is high, from white to brown. The coloration produced from 10 aspirations of the bulb is compared with a color scale and the percentage of carbon monoxide estimated. If 10 squeezes of the aspirator bulb produce greenish coloration in the material in the tube the atmosphere tested is definitely dangerous to man.

The pyrotannic acid method of carbon monoxide detection depends upon the fact that when normal blood diluted with water is treated with a solution of pyrogallic and tannic acid, a light brownish-gray suspension is formed in a few minutes, whereas when a blood solution having carbon monoxide in combination with the haemoglobin is so treated a carmine suspension is formed. The color of the treated blood solution is compared with color standards and the percentage of blood saturation by carbon monoxide estimated. For quantitative results a known volume of the air to be tested is thoroughly mixed with a blood solution, and from the percentage of blood saturation thus determined the percentage of carbon monoxide in the air is determined by interpolation on a prepared chart or is calculated from formulas. A quick test of the blood of a person supposed to be suffering from carbon monoxide asphyxia can also be made by this method and the presence or absence of carbon monoxide and the percentage of blood saturation determined. The pyrotannic acid method is the most accurate known for determination of carbon monoxide in percentages of 0.1 to 0.2 per cent.

Recently another colorimetric method for the detection of carbon monoxide has been placed on the market. It depends on the deposition of metallic palladium from palladium chloride solution by interaction with carbon monoxide. The palladium chloride is put up in ampoule form; the ampoule is broken and hung by a thread or wire in the air to be tested for 10 minutes; a change in color from yellow to black shows carbon monoxide. The detection of as low as 0.03 per cent of carbon monoxide is claimed. Low temperatures slow up the reaction.

There is also a continuous carbon monoxide recorder for accurately and continuously recording on a chart the amount of carbon monoxide in the air tested. This device is accurate for very low percentages of carbon monoxide (less than 1 part in 10,000). It is extremely

---

reliable for continuous sampling and analysis of air in motor vehicular tunnels.

Oxides of nitrogen may be present if brownish yellow fumes or a strong "burned-powder" odor are detected after blasting. These oxides are so dangerous to man upon inhalation that they should be avoided; good ventilation is therefore necessary, and adequate time should be allowed after blasting before the miners return to work.

RESPIRATORY PROTECTION AGAINST GASES

If an emergency develops so that men have to enter metal mines or portions thereof containing dangerous quantities of any of the harmful gases discussed in this paper means of respiratory protection must be used. The self-contained oxygen breathing apparatus of types approved by the United States Bureau of Mines furnishes such protection. The bureau has published numerous papers regarding the safe and proper use of oxygen breathing apparatus in mines. A few of the important recommendations are as follows:

1. Five trained men in good physical condition should comprise a rescue crew;
2. For all trips except short ones a reserve crew of five men should be stationed at the fresh-air base equipped with rescue apparatus;
3. 2,000 feet (round trip) should be the maximum distance traveled by a crew on a level unobstructed course;
4. And when steep pitches are to be climbed under other unfavorable conditions, smoke obscures the vision, the traveling height is low, the distance of travel away from fresh air should be limited even further.

The type N gas mask furnishes respiratory protection against limited concentrations of all dangerous gases encountered in mines, provided that there is enough oxygen in the air to support life. The United States Bureau of Mines has limited its approval of the type N gas mask in underground work to atmospheres in which a flame safety lamp or a candle will burn; however, neither the flame safety lamp nor the candle gives warning of the presence of poisonous gases in greater concentrations than the gas mask can handle safely. A candle should be used in testing for oxygen only when the metalmine atmosphere is known to contain no explosive gases. The type N gas mask protects against air containing acid gases, organic vapors, or carbon monoxides not exceeding 2 per cent by volume; against smoke, dusts, and mists; against not more than 3 per cent of ammonia; and against atmospheres not exceeding 2 per cent of total poisonous gases when more than one gas is present. Under certain conditions higher percentages of some of these gases are found in mines. It must be remembered that a gas mask is of no help, but rather a distinct hazard to life, in atmosphere deficient in oxygen or in atmospheres with higher percentages of poisonous gases than those just specified.

---

CONCLUSIONS

Many gases harmful to man are widely prevalent in metal mines. They influence the safety, health, and efficiency of miners; workers and officials should therefore become much more familiar with their occurrence, detection, and handling.

The principal means of combating these gases are proper ventilation of all parts of a mine and the adoption of measures to minimize fire hazards and to control a mine fire promptly should it occur. Proper ventilation of metal mines can be provided by the installation of main fans, placed on the surface if at all possible, and auxiliary underground fans, together with measures to direct the air into working places. Such mechanically controlled ventilation is also likely to result in increased efficiency of the miners. Protection against fires can be best obtained by minimizing or avoiding natural fire hazards in and about a mine, by adequate fire-fighting equipment, by a trained fire-fighting organization, and by having full control of the direction and amount of air flow through the agency of an efficient mechanically operated ventilation system.

Metal-mine gases are detected readily by simple tests and equipment; safe means of respiratory protection are also available should emergency work in dangerous gases be necessary. These have been described and illustrated in various publications cited in the footnotes.