

MINE GASES

A. INTRODUCTION

Air is the transparent medium surrounding the earth in which plants, animals, and human beings live and breathe. Air is a mixture of several gases which, though ordinarily invisible, can be weighed, compressed to a liquid, or frozen to a solid.

Pure dry air at sea level contains by volume the following gases: oxygen (O₂), 20.94 percent; nitrogen (N₂), 78.09 percent; argon (AR),

0.94 percent and carbon dioxide (CO₂), 0.03 percent. Traces of other gases such as hydrogen, helium, etc., are also present.

Mine air may be contaminated by the presence of other gases such as carbon monoxide, sulfur dioxide, hydrogen sulfide, methane, oxides of nitrogen and excess carbon dioxide. Mixtures of gases found in mine environments are called damp.

Black Damp Carbon dioxide and nitrogen in an oxygen deficient atmosphere which will cause suffocation.

White Damp Carbon monoxide (CO). Very poisonous.

Stink Damp Hydrogen Sulfide (H₂S). It is colorless, has a sweetish taste, and a very distinctive odor of rotten eggs. As little as .01% in air being capable of detection by this means. The gas is even more poisonous than Carbon Monoxide.

Fire Damp Methane (CH₄).

After Damp Gaseous products and smoke produced by a fire or explosion which includes the following gases: Carbon monoxide, carbon dioxide, water vapor, nitrogen, oxygen, hydrocarbons and hydrogen.

The presence of these gases may be due to any of the following:

- After effects of blasting or other explosions.
- After effects of mine fires.
- Liberation from ore or country rock, as with methane.
- Decay of timbers in poorly ventilated areas.
- Absorption of oxygen by water or oxidation of timber or ore.
- Use of diesel and gasoline motors in enclosed areas.
- Gas carried with thermal water or carbon dioxide.

- Gas carried chemically by various chemicals and reagents.

Except in cases of fire, positive ventilating currents of sufficient quantity will prevent any dangerous accumulation of these gases. Gases may affect people either by their combustible, explosive, or toxic qualities, or, if inert, by the displacement of oxygen.

1. DIFFUSION

A gas diffuses into air and the rate of diffusion is proportional to the square root of its specific gravity (known as Graham's Law)

I.E., diffusion $\sqrt{\frac{1}{\text{sp. gr. of gas}}}$

In other words, the smaller the specific gravity, the faster the rate of diffusion. Thus a gas lighter than air will diffuse faster than the one heavier than air. In absence of diffusion, in stagnant air gases may stratify in layers. Methane layers are found near the roof whenever there is insufficient amount of air or insufficient turbulence in the flowing air.

2. THRESHOLD LIMIT VALUES (TLV)

The degree of effect of both gaseous and particulate contaminants depends largely upon the airborne concentration and the amount of exposure.

A list of threshold limit values (TLV's) is published yearly by the American Conference of Governmental Industrial Hygienists (ACGIH). These TLV's serve as guides for exposure concentrations which, it is believed, a healthy individual normally can tolerate for 8 hours a day, 5 days a week, without harmful effects.

Airborne particulate concentrations are generally listed as milligrams per cubic meter of air (mg/m^3) while gaseous concentrations are listed as parts per million or percent by volume.

3. PARTS PER MILLION (ppm)

All chemicals used in industry which have a toxic effect on workers have maximum allowable concentrations to which the employee can be exposed for an 8-hour day. These concentrations are expressed as parts per million (ppm).

For many of us, 1 part per million is about as hard to visualize as the national debt. The following helps indicate what 1 part per million really represents under various conditions:

1 ounce of sand in 31 tons

1 inch in 16 miles

The relationship between PPM and percent (%) is shown as follows:

<u>PERCENT</u>	<u>PPM</u>
1.0	10,000

0.1	1,000
0.01	100
0.001	10
0.0001	1

B. NITROGEN (N₂)

Nitrogen is a colorless, odorless, inert gas. It is not combustible and will not support combustion. Nitrogen is the main component of pure air (78.09) percent. It is slightly lighter than air.

Nitrogen has no physiological effect upon workers. It is only dangerous if present in concentrations high enough to dilute the oxygen content of air below safe limits. Dilution can result from the oxidation of various substances or from fire which consumes the oxygen in mine atmosphere. Oxygen can, therefore, be reduced to a low level and residual nitrogen can mix with products of combustion including carbon dioxide, carbon monoxide, sulfur dioxide, etc.

Nitrogen may be detected using the flame safety lamp, however, the flame safety lamp is of slight use in detecting concentrations of nitrogen because nitrogen has no effect upon the flame when accompanied by sufficient oxygen at normal atmospheres.

Nitrogen accumulations may be added to others, such as carbon dioxide in blackdamp. This can produce an oxygen deficient atmosphere which is indicated by the decrease in size of the flame or its extinction. The specific gravity of nitrogen is .967 and the weight of nitrogen per cubic foot at 60°F and 30.00 inches of mercury pressure is 0.0740. Nitrogen is approximately 4/5 of the atmosphere.

Threshold limit value (TLV) of nitrogen is 81 percent.

C. OXYGEN (O₂)

The most important gas in our world, oxygen, is nonflammable, yet nothing can burn without it. Oxygen is the element in air that supports normal combustion. In its pure state, however, when combined with fuel gases (acetylene, MAPP, hydrogen, propane) and combustible substances, oxygen causes them to burn fiercely at great speed.

Oxygen is colorless, odorless, and tasteless. It is the most important constituent of air (20.94 percent).

Oxygen is necessary to support life. By breathing, oxygen is absorbed by the blood and carried to the cells of the body. Workers breathe most easily and work best in air which contains approximately 21 percent oxygen. When the oxygen content is about 17 percent, miners at work will breathe a little faster and more deeply. The effect is about the same as going from sea level

to an altitude of 5,000 feet. Workers breathing air containing as little as 15 percent oxygen usually become dizzy, notice a buzzing in their ears, have a rapid heartbeat, and often suffer headaches. Very few workers are free from these symptoms when the oxygen in air falls to 10 percent. The flame of a safety lamp is extinguished when the oxygen level falls to about 16 percent (16.25%).

Since oxygen is more soluble in water than nitrogen, air in a confined area when exposed to water will probably have a lowered oxygen content. For example: the oxygen content of the air from a hydraulic compressed air plant is lowered to about 17.7 percent oxygen--a consequent rise in nitrogen content occurs.

An oxygen percentage higher than 20 to 21 percent apparently has no negative effect on persons. This is found to be the case in using self-contained oxygen breathing apparatus. There is no noticeable effect after successive periods of wear. Oxygen in high percentages, as used with the oxygen breathing apparatus, helps people to work with less fatigue. However, it is dangerous to breathe pure oxygen at a pressure much higher than 15 pounds per square inch for a very long time. Irritating effects of oxygen are only found in humans after they have been exposed for 48 hours or more in an atmosphere containing 80 percent oxygen. Also, people who are medically diagnosed with Chronic Obstructive Pulmonary Disease (COPD) i.e. , pneumoconiosis (black lung), silicosis, emphysema, chronic bronchitis, etc., should not be administered, or exposed to high concentrations of oxygen as such high concentrations can result in oxygen toxicity, or affect the COPD person 's ability to breathe.

At approximately 7 percent oxygen, the face becomes leaden in color, the mind becomes confused and the senses dulled. When there is no oxygen in the atmosphere, loss of consciousness occurs in a few seconds without any warning symptoms. Oxygen previously in the lungs is rapidly removed and used up--loss of consciousness is quickly followed by convulsions and respiratory failure.

Some causes of oxygen deficiency include:

- Absorption by water or certain types of rock, ore, or fill
- Breathing of workers in confined space
- Displacement by carbon dioxide, carbon monoxide, or other gases
- Heating and combustion

Oxygen Deficiency

Oxygen Present (percent)	Effect
21	Breathing easiest.
17	Breathing faster and deeper.
15	Dizziness, buzzing noise,

	rapid pulse, headache, blurred vision.
9	May faint or become unconscious.
6	Movement convulsive, breathing stops, shortly after heart stops.

Mine air should not contain less than 19.5 percent Oxygen.

D. CARBON DIOXIDE (CO₂)

Carbon dioxide, an inert gas, is a product of the decomposition and/or combustion of organic compounds in the presence of oxygen. Carbon dioxide is also produced by respiration of people and animals. It is a colorless, odorless gas which, when breathed in large quantities, may cause a distinctly acid taste. It will not burn or support combustion. Carbon dioxide, being heavier than air, is often found in low places and abandoned mine workings and is a normal constituent of mine air. Carbon dioxide in mine air is increased by breathing, burning of flame lamps, fires, explosions, blasting or by escaping with thermal water. Carbon dioxide is also liberated from some coal beds. The specific gravity of carbon dioxide is 1.529.

Clinical investigations indicate that carbon dioxide influences the respiratory rate. This rate increases rapidly with increasing amounts of carbon dioxide.

The following table shows the effect upon humans of increased amounts of CO₂ in the air breathed:

Concentration of Carbon Dioxide (percent)	Increase in Respiration
0.05	Slight.
0.5	Maximum allowable for an 8-hour day.
2.0	50 percent.
3.0	100 percent.
5.0	300 percent and laborious.
10.0	Cannot be endured for more than a few minutes.
18.0	Rapid death.

Carbon dioxide in air has these effects when the oxygen content remains approximately normal and the individual is at rest. Moving around or working increases symptoms and danger is greater than when the individual is resting. Concentrations of over 5 percent carbon dioxide in air are usually accompanied by an appreciable lowering of the oxygen content.

Carbon dioxide in mine air should not be more than 0.50 percent.

E. METHANE (CH₄)

Methane is encountered in practically all coal mines. Flow of the gas is variable and is present in the pores of coal. Methane is formed by decomposition of organic matter in the presence of water and the absence of air or oxygen.

In a coal mine, methane may be emitted from the cleats or cracks of the coal, from "blowers" or "feeders", or from overlying or underlying strata. It is often released in large amounts from the coal when irregularities, such as clay veins, "horsebacks," or faults occur.

Once liberated from the strata, methane tends to accumulate near the mine roof or in high places where it mixes progressively with air currents and eventually may be found uniformly distributed across a cross section of airflow. Once mixed with fresh air, it will no longer separate into layers or form pockets of still gas. The specific gravity of methane is 0.555. The ignition temperature of methane is 1100-1380°F.

Methane is a colorless, odorless and tasteless gas. An odor caused by the presence of other gases such as hydrogen sulfide often accompanies it. Methane will burn with a pale blue nonluminous flame. Still air that contains 5 to 15 percent methane and 12 percent or more of oxygen will explode--this is its chief danger. The inflammable and explosive range of methane is variable. Occurrences of methane, if suspected or known, should be diluted with the help of adequate ventilation.

Methane is considerably lighter than air and when found at mines it is usually in high places near the roof. Accumulations of the gas may be encountered in poorly ventilated mine workings. Methane is most often detected by a methane detector.

Methane has no direct effect upon workers but it may displace the oxygen content of air to such an extent as to cause oxygen deficiency. An open flame or a spark may cause an explosion. Federal law requires electrical circuits to be isolated in any work area when the methane content in the general body of air in that area reaches 1.0 percent. Federal law also requires that all miners be withdrawn from any work area when the methane content of the general body of air in that area reaches 1.5 percent. No blasting or shot-firing is to be done when methane content exceeds 1.0 percent. Explosiveness of coal dust increases in the presence of methane and coal dust in turn decreases the lower explosive limit of methane.

Law Regarding Measurement of Methane

When requested by the mine inspector in the district, the mine foreman or the superintendent shall once each week direct and see that the methane content of the ventilating current or currents is determined by analyses, or by an instrument capable of accuracy to one-tenth of one percent. The samples or the determinations shall be taken on the return end of the

air circuit or circuits just beyond the last working place, unless otherwise directed by the mine inspector in the district, and a correct report of these determinations shall be promptly furnished to the mine inspector in the district. Said determinations, or samples, shall be taken on days when the men are at work and recorded in a book provided for that purpose.

F. CARBON MONOXIDE (CO)

Carbon monoxide gas constitutes one of the greatest hazards to life in mining. Carbon monoxide is one of the products of combustion in normal blasting operations and in the use of diesel motors and is dangerous unless adequate ventilation is provided.

Carbon monoxide will burn and air that contains 12.5 to 74 percent of carbon monoxide will explode if ignited. It is only slightly soluble in water and is not removed from the air to any extent by water sprays. It is slightly lighter than air having a specific gravity of 0.967. The ignition temperature of carbon monoxide is 1100°F.

Carbon monoxide in excess of 0.01 percent, if breathed indefinitely, may eventually produce symptoms of poisoning; 0.02 percent will produce slight symptoms after several hours' exposure. When 400 parts per million (0.04 percent) is present and the exposure is from 2-to-3 hours, headache and discomfort usually occur. With moderate exercise, when 0.12 percent is present, slight palpitation of the heart will occur in 30 minutes, tendency to stagger in 1.5 hours, and confusion of mind, headache and nausea in 2 hours. In concentrations of 1.20 to 0.25 percent, unconsciousness usually occurs in about 30 minutes. The effect of high concentrations may be so sudden that one has little or no warning before collapsing. The carbon monoxide content of the air in which workers are employed for a period of 8 hours should not exceed 0.005 percent or 50 parts per million.

1. HOW CARBON MONOXIDE ACTS

Oxygen absorbed from air in the lungs is normally taken up by the blood in the form of a loose chemical combination with the red coloring matter (hemoglobin) of the corpuscles. Oxygen is carried in this form to the tissues where it is used. Hemoglobin forms a much more stable compound with carbon monoxide than with oxygen. Hemoglobin cannot take up oxygen when saturated with carbon monoxide.

Hemoglobin's affinity to carbon monoxide is about 300 times its affinity for oxygen. Therefore, even when a small percentage of carbon monoxide is present in inhaled air, hemoglobin will absorb the carbon monoxide in preference to the oxygen. Carbon monoxide, when absorbed by hemoglobin, reduces the capacity of hemoglobin for carrying oxygen to the tissues to a proportionate extent. This interference with the oxygen supply to the tissues produces the symptoms of carbon monoxide poisoning.

The symptoms of carbon monoxide poisoning more or less parallel the extent of blood saturation. The first definite symptoms, during rest, make their appearance when 20 to 30 percent of the hemoglobin is combined with carbon monoxide. Unconsciousness takes place at about 50 percent saturation and death occurs at about 80 percent.

According to experiments conducted by the United States Bureau of Mines, the symptoms produced by various percentages to carbon monoxide in the blood .are as follows:

<u>Percentage of Blood Saturation</u>	<u>Symptoms</u>
0-10	None
10-20	Tightness across forehead, possible headache
20-30	Headache, throbbing in temples
30-40	Severe headache, weakness, dizziness, dimness of vision, nausea, vomiting, and collapse
40-50	Same as 30-40, with more possibility of fainting and collapse, increased pulse and respiration
50-60	Fainting, increased pulse and respiration, coma with intermittent convulsions
60-70	Coma with intermittent convulsions, depressed heart action and respiration, possible death.
70-80	Weak pulse and slowed respiration, respiratory failure, and death

Symptoms decrease in number as the rate of saturation increases. If exposed to high concentrations the victim may experience but few symptoms. The rate at which a person is overcome and the sequence in which symptoms appear depends upon the concentration of gas, extent to which the person is exercising, the victim 's health, individual susceptibility, temperature, humidity and air movement. Exercise, high temperature, and humidity, with little or no air movement, tend to increase respiration and heart rate and consequently result in more rapid absorption of carbon monoxide.

2. TREATMENT FOR CARBON MONOXIDE POISONING

Carbon monoxide poisoning may occur suddenly or gradually depending upon concentration and period of exposure. The most important concerns in treatment are to rest and avoid further exposure to the gas.

The most important thing in treatment of acute carbon monoxide poisoning is to remove gas from the victim's blood as rapidly as possible.

Prompt action will decrease the possibility of serious after-effects or even loss of life from cardiac arrest and respiratory failure. The natural elimination of carbon monoxide will start as soon as the patient begins to breathe air free of carbon monoxide. This normal elimination is slow and often has serious effects. It requires possibly 8 to 15 hours to reduce the carbon monoxide hemoglobin to 10 percent of the total hemoglobin. Inhalation of pure oxygen will remove the carbon monoxide from the blood four or five times faster.

The use of oxygen alone in an oxygen therapy unit is a common practice because oxygen is usually readily available owing to its general use in industry.

Inhalation treatments are preferably given with oxygen therapy units, but oxygen may be administered by improvised apparatus or directly sprayed over the patient's face from a cylinder. Caution should be used to control oxygen flow when using gas directly from the cylinder. The cylinder should be opened and flow regulated before the gas is directed toward the patient. No improvised mask or device should be used in which pressure can build up and injure the victim.

In cases of severe carbon monoxide poisoning, the patient should be transported on a stretcher case for medical aid.

The steps for effective treatment of carbon monoxide poisoning are as follows:

1. Move the victim to fresh air as soon as possible.
2. If respiration has stopped, is weak and intermittent, or present only in occasional gasps, give artificial respiration until normal breathing is resumed, or until it is definitely established that the patient is dead.
3. Administer pure oxygen as soon as possible and continue as long as necessary (at least 20 minutes in mild cases and as long as 1 or 2 hour in severe cases). Immediate inhalation of oxygen for 20 to 30 minutes will significantly lessen the severe effects of carbon monoxide poisoning and lessen the chance of serious after-effects.
4. Aid circulation by rubbing the patient's limbs (toward the heart). Keep the victim warm with blankets, hot water bottles, etc.
5. Keep the victim lying down to avoid strain on the heart and allow plenty of time to rest and recuperate.

Physiological Effects of Carbon Monoxide

PPM	Concentration of Carbon Monoxide (Percent)	Allowable Length of Exposure
50	0.005	Allowable for exposure of several hours.
400-500	0.04-0.05	Can be inhaled for 1 hour without appreciable effect.
600-700	0.06-0.07	Just noticeable effects after 1-hour exposure.
1000-1200	0.10-0.12	Unpleasant, but probably not dangerous after 1-hour exposure.
1500-2000	0.15-0.20	Dangerous for exposure of 1 hour.
4000 or more	0.4 or more	Death in less than 1 hour.

G. OXIDES OF NITROGEN (NO, NO₂, N₂O₄, N₂O₂, N₂O, N₂O₃, N₂O₅)

Oxides of nitrogen are formed in mines by burning of explosives and, to a lesser extent, by their detonation. Oxides of nitrogen can usually be detected by the burnt powder odor familiar to blasters and by the reddish color of nitrogen peroxide (NO₂) fumes, which are formed when nitric oxide (NO) produced by an explosion comes in contact with air. Gases collected from the burning of 40 percent gelatin dynamite contain 11.9 percent oxides of nitrogen. When explosives having properly proportioned components are completely detonated, they usually produce small percentages of oxides of nitrogen which are considered harmless. Explosives from which the wrapper has been removed may produce harmful percentages of oxides of nitrogen--even when detonated. Diesel engines also produce oxides of nitrogen.

Physiological Effects of Oxides of Nitrogen Concentration of Oxides of Nitrogen

PPM	Percent	Effect
5	0.0005	Maximum allowance for 8-hour day.
60	0.006	Minimum causing immediate throat irritation.
100	0.01	Minimum causing coughing.
100-150	0.01-0.015	Dangerous for even short exposure.
200-700	0.02-0.07	Rapidly fatal for short exposure.

A person exposed to dangerous concentrations of nitrogen dioxide may feel no discomfort for several hours after the end of exposure. As much as eight hours after exposure the victim's lungs may become filled with fluid resulting in asphyxia.

When air samples are analyzed for oxides of nitrogen, the results usually are reported in terms of nitrogen dioxide (NO₂), since this designation gives proper evaluation of the toxic properties of the atmosphere.

The threshold limit value (TLV) of oxides of nitrogen is 5 ppm.

H. SULFUR DIOXIDE (SO₂)

Sulfur dioxide gas is produced by burning sulfide ores (pyrites) or by blasting in sulfide ores or explosions of sulfide ore dust. Some diesel fuels produce sulfur dioxide. Sulfur dioxide is not combustible.

This gas has a strong sulfur smell which is suffocating and very irritating to breathe. Sulfur dioxide cannot be tolerated for any length of time in dangerous concentration. The specific gravity of sulfur dioxide is 2.264.

The gas affects the lungs in much the same manner as oxides of nitrogen and hydrogen sulfide. Irritation of the respiratory tract and lungs will cause edema.

Effects of Sulfur Dioxide Concentration of Sulfur Dioxide

PPM	Percent	Effect
5	0.0005	Maximum allowable for an 8-hour day.
20	0.002	Coughing and irritation to eyes, nose, and throat.
150	0.015	May be endured for several minutes.
400	0.04	Impossible to breathe.

Sulfur dioxide is highly soluble in water--in fact it is one of the most soluble gases found in mines. It is a very heavy gas and has a specific gravity of 2.264. It can, therefore, be expected to accumulate in low places. Sulfur dioxide is colorless with a distinctly acid taste.

The threshold limit value (TLV) of sulfur dioxide is 5 ppm.

I. HYDROGEN SULFIDE (H₂S)

Hydrogen sulfide is one of the most poisonous known gases. Only traces of it are ordinarily found in mine operations. In low concentration its distinctive rotten egg odor is noticeable. In high concentrations the sense of smell is quickly paralyzed by the action of the gas on the respiratory center. It is colorless and poisonous even in small concentrations. The gas has a specific gravity (SG) of 1.191 and may collect at low points in mines. The ignition temperature of Hydrogen sulfide is 700°F.

Hydrogen sulfide inhaled in a sufficiently high concentration produces immediate asphyxiation; in low concentrations it produces inflammation of the eyes and respiratory tract and sometimes leads to bronchitis, pneumonia, and edema of the lungs. The immediate effect of hydrogen sulfide is extreme irritation to the eyes.

Sub acute poisoning may be produced by long exposure to concentrations as low as 0.005 percent. Immediate collapse usually results from exposure to concentrations of 0.06 to 0.1 percent, and death quickly follows. The 8-hour daily exposure should not exceed 0.001 percent or 10 parts per million.

Hydrogen sulfide can be detected by hydrogen sulfide detectors. It can also be detected chemically by exposing a paper dipped in acetate which turns black immediately in presence of hydrogen sulfide.

When explosions of dust occur in blasting operations in sulfide ore bodies, the resulting gases may contain varying amounts of hydrogen sulfide, along with sulfur dioxide, and possibly other sulfur gases.

Hydrogen sulfide is highly explosive with an explosive range of 4.3 to 46 percent.

Physiological Effects of Hydrogen Sulfide Concentration of Hydrogen Sulfide

PPM	Percent	Time	Effect
10	0.001	----	Maximum allowable for 8-hour day.
50-100	0.005-0.010	1 hour	Subacute poisoning- 1. Mild eye irritation 2. mild respiratory irritation
200-300	0.02-0.03	1 hour	Subacute poisoning 1. marked eye irritation 2. marked respiratory irritation
500-700	0.05-0.07	5-1 hour	Subacute to acute poisoning--unconsciousness
1000-2000	0.10-0.20	Minutes	Acute poisoning- 1. unconsciousness 2. death

J. HYDROGEN (H₂)

Hydrogen is a colorless, odorless, and tasteless gas. It is very much lighter than air with a specific gravity of 0.0695 and is highly flammable. Hydrogen is explosive over a broad range of concentrations (4.1 to 74 percent). It will explode with as little as 5 percent oxygen in the air and is most violently explosive at concentrations of 7 to 8 percent.

Hydrogen is not a toxic gas and the only danger from inhaling it is when concentrations are such that the oxygen content of the air is reduced.

Hydrogen is normally found in mine air in only very small quantities. It can, however, be produced when mine fires heat rock to incandescence and also as a result of incomplete combustion.

The most common source of hydrogen gas under normal circumstances is in the battery charging area. The electrolytic action which takes place during battery charging releases hydrogen gas. Charging stations must, therefore, be well ventilated and smoking, electric arcs, etc., must be avoided in them.

From a trace to as much as 9 percent can be found in crevices of a coal face after blasting. It is formed here as a result of incomplete combustion of explosives and by distillation of the coal caused by the explosion.

Hydrogen gas is usually present in amounts up to 2 percent in gas from ordinary mine fires and is always present after coal dust explosions.

Keep flames and sparks away from hydrogen, as with other fuel gases. Do not crack the valve of a hydrogen cylinder to blow out dirt, etc., it could be dangerous.

Hydrogen is detected only by chemical analysis.