Environmental Technology in Mining

Chapter I. Mine Gases

3. The air in the mine. Firedamp

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The Ideal Gas Law Equation

$$P \cdot V = n \cdot R \cdot T$$

P = Pressure in atm.
V = Volume in litres.
n = moles (mass (g) / Molecular Weight (MW).
R = Gas constant (0.082 L · atm / (K · mol))
T = Temperature in K.

Density of a Gas

$$\rho = \frac{P \cdot Mw}{R \cdot T}$$

Units to express concentration of gases

% = Percentage in terms of volume
ppm = parts per million (in terms of volumen).
mg/m^3 = mass / volume

Air composition

O_2 = 20.9% (21%).
N_2 = 78.1% (79%).
Ar = 0.9%.
CO_2 = 0.04% 400 ppm.
H2 = 0.01% (100 ppm).
Ne = 0.0018% (18 ppm).
He, Kr, Xe.

The volumetric composition of air does not significatively change with altitude (< 80 km).

Local emanations (sulfur gases, methane, other gases) can alter this composition (punctual episodies).

Air composition

Human activities can modify this composition by producing (releasing) gases and toxic compounds.

When these alterations take place in confined and relative small spaces (like underground mining or works) it is necessary and air exchange between this space and the exterior to get and air atmosphere similar to that in the exterior.

Keeping toxic compounds beneath dangeorus levels.

Threshold Limit Values (TLVs)

The threshold limit value (TLV) of a chemical substance is believed to be a level to which a worker can be exposed day after day for a working lifetime **without adverse effects**.

The TLV is an estimation based on the known toxicity in humans or animals of a given chemical substance, and the reliability and accuracy of the latest sampling and analytical methods. **It is not a static definition** since new research can often modify the risk assessment of substances and new laboratory or instrumental analysis methods can improve analytical detection limits.

Toxicity indexes

OSHA: Occupational Safety and Health Administration (USA):
PEL: Permissible Exposure Limits
Threshold value (maximum concentration) for a chemical agent 8 hours/days exposure.

NIOSH: National Institute for Occupational Safety and Health (USA):
REL: Recommended Exposure Limits.
TWA: Time-Weighted Average.
STEL: Short Term Exposure Limit.

MAC: Maximum Allowable Concentration (EU).
Time-Weighted Average.

ACGIH: American Conference of Governmental Industrial Hygienists (USA and Canada).
TLV- Threshold Limit value

VLA: Valor límite ambiental del INSHT (Spain).
Similar to TLV.

Threshold Limit Values (TLVs)

The TLV for chemical substances is defined as a concentration in air, typically for inhalation or skin exposure. Its units are in parts per million (ppm) for gases and in milligrams per cubic meter (mg/m³) for particulates such as dust, smoke and mist. The basic formula for converting between ppm and mg/m³ for gases is ppm = (mg/m³) * 24.45 / molecular weight. This formula is not applicable to airborne particles.

$$C_{(ppm)} = C_{\left(mg/_{m^3}\right)} \cdot \frac{24.45}{MW}$$

Three types of TLVs for chemical substances are defined:

Threshold limit value − **time-weighted average** (**TLV-TWA**): average exposure on the basis of a 8h/day, 40h/week work schedule

Threshold limit value − **short-term exposure** (**TLV-STEL**): spot exposure for a duration of 15 minutes, that cannot be repeated more than 4 times per day with at least 60 minutes between exposure periods

Threshold limit value − **ceiling** (**TLV-C**): absolute exposure limit that should not be exceeded at any time.

Air condition in a mine

- Quantity → Flow of air, Ventilation system
- ⇕
- Quality → Chemical composition of the air

Design of a mine ventilation system → Control of Air quality

MAJOR TASK

Industrial environment

Impurities sources are well identified and located

Ventilation system is designed to isolate the contaminant source

Underground mine environment

All the underground mine working place contain the potential for release of air contaminants: strata gas, blasting gases, engines and human breath.

Types of contaminants

The same passageways in which the contaminants are generated or released are used to transport the air for underground workers

Non-particulate: gases and vapours.

Particulated: liquids and solids (mists and fogs; dust, smoke)

The most common contaminants in underground mining

Gases and dust.

Before the problem of maintaining the quality of the air it is essential to be familiar with the properties of the impurities that can be found

Mine gases

All the underground mine working place contain the potential for releasing air contaminants:

- **Strata gases**: The gases in the strata are those that exist within the rock structures of the mine: CH_4, CO_2, CO, H_2S. These can be released spontaneously and during mining activities.
- **Blasting gases**: toxic gases coming from chemical reactions of explosions: CO_2, CO, dust.
- **Internal combustion engines exhaust gases**: Combustion of hydrocarbons: CO_2, CO, NOx.
- **Human breath**: O_2 decayment, CO_2 generation

Mine gases

- Oxygen (O_2).
- Carbon Dioxide (CO_2).
- Methane (CH_4).
- Carbon Monoxide (CO).
- Hydrogen Sulphide (H_2S).
- Sulfur Dioxide (SO_2).
- Nitrogen Dioxide (NO_2).
- Hydrogen (H_2).
- Dust (not a gas).

Risks:

- Explosivity.
- Flamability.
- Toxicity.
- Irritant.
- Suffocation.
- Narcotic.

Oxygen (O_2)

The most important gas

The quantity of oxygen required by humans is a function of their physical activity:

Respiratory requirements

Type of activity	Respiratory rate (breaths/min)	Air inhaled / breath (ml)	Air inhaled rate (ml/sec)	O_2 consumed (ml/sec)	O2 used (%)	Respiratory quotient (CO_2/O_2)
At rest	12-18	377-705	75-218	4.7	10-27	0.75
Moderate	30	1476-1968	764-983	33	16-21	0.9
Very vigorous	40	2460	1640	47	14	1

Oxygen

Properties: odorless, colourless, tasteless.

Normal level in air: 21% (in volume).

Deficiency levels: Respiration problems.

Alarm level: 19.5% (Minimum required).

Causes of oxygen depletion:

- Workers breath.
- Oxidation and combustion processes.
- Dilution by other gases.

% O_2 in air	Effect
17	Faster, deep breathing
15	Dizziness, buzzing in ears, rapid heartbeat
13	Loss of consciousness (prolonged exposure)
9	Fainting, unconsciousness
7	Life endargenment
6	Convulsive movements, death

Mine gases

Carbon dioxide (CO_2)

Properties: odorless, colourless, non combustible, acid taste at high concentrations (10%).

Suffocating gas

Normal level in mine air: 0.03% (in volume).

Higher levels: Increasing lung ventilation.

Alarm level: 0.5% (Maximum allowed).

Causes of carbon dioxide augmentation:

- Workers breath.
- Oxidation and combustion processes.
- Blasting operations.
- Strata gases.

% CO_2 in air	Effect
0.03	Normal levels
0.3 - 0.5	Deeper and faster breath Headache
0.5	Lung ventilation increased
1-3	Heat sensation, lack of attention, fatigue, anxiety, energy failure, weakness in the knees
5-10	Extreme wheezing and fatigue to the point of exhaustion. Acute headache
18	Death in short time

Mine gases

Carbon dioxide

TLV-TWA = 0.5% (5000 ppm)

TLV-STEL = 3.0% (30,000 ppm)

1 % = 10,000 ppm

CO_2 density >>> air density

Tendency to get accumulated in the lower parts of closed spaces.

It is easy to detect at very high concentrations (10%) because it causes irritation in the nose and the eyes.

Mine gases

Carbon dioxide

Origins:

- Combustion of substances containing coal: fossil fuels, wood, plastic, oil…
- Explossions of firedamp and dust.
- Slow oxidation of wood and coal.
- Blasting operations.
- Human breath.

Mine gases

Carbon monoxide (CO)

Properties: odorless, colourless, tasteless, very toxic and flammable gas.

Very toxic gas: It combines with hemoglobin to produce carboxyhemoglobin, which usurps the space in hemoglobin that normally carries oxygen, but is ineffective for delivering oxygen to bodily tissues.

Alarm level: 25 ppm

Formation of carbon monoxide:

- Fires and explosions.
- Blasting operations.
- Internal combustion engines.
- Slow oxidation of wood and coal (strata).

Mine gases

Carbon monoxide (CO)

CO density < air density

Slightly lighter than air. It spreads easily through the air and gets accumulated in the roofline of the closed spaces.

It is flammable and explosive at concentrations between 12.5-74%.

It is very dangerous because of its high toxicity.

It is not irritant, so it is not detectable when inhaled.

Mine gases

Carbon monoxide

TLV-TWA = 0.0025% (25 ppm)

PEL (OSHA) = 50 ppm

TLV-STEL = 0.04% (400 ppm)

1 % = 10,000 ppm

Explosive range: 12.5-74%.

CO in air (ppm)	Effect
< 25	TLV-TWA, no effects
200	Low headache and sickness in 2-3 hours
400	Headache and sickness in 1-2 hours
800	Headache and sickness in 45 min. Possible death in 2 hours.
1600	Headache, dizziness, sickness in 20 min. Possible death in 1 hour.
3200	Headache, dizziness, sickness in 5-10 min. Possible death in 30 min.
6400	Headache, dizziness, sickness, Loss of consciousness. Death in 10-15 minutes
12,800	Immediate effects, death in 1-3 minutes.

Mine gases

Carbon monoxide

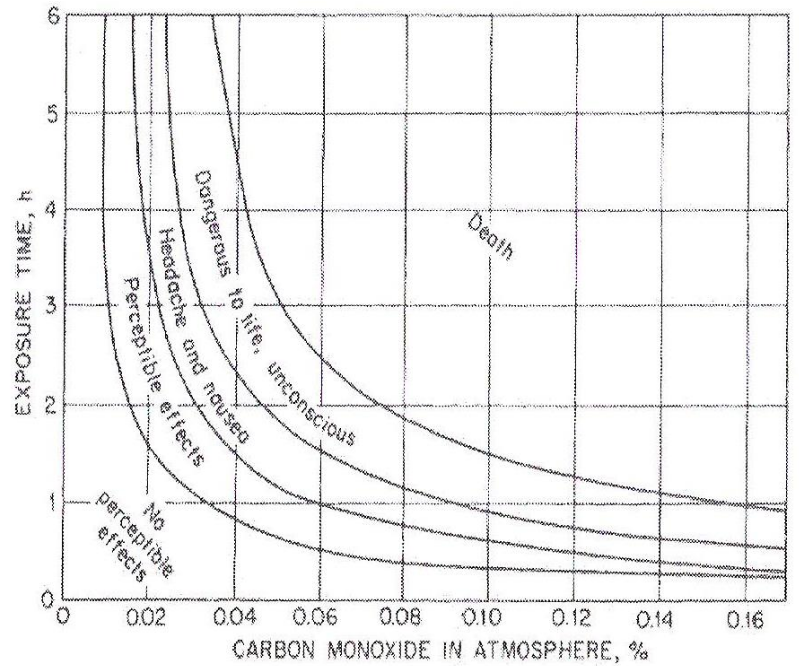


FIGURE 3.4 Toxicity of carbon monoxide as a function of concentration and time. (After Bryom, 1957. By permission of *Engineering and Mining Journal*, Chicago, IL.)

Methane (firedamp)

Methane (firedamp) CH_4.

The most common gas found in coal mines.

It can also be found in non-coal mines.

Properties: odorless, colourless, tasteless, highly flammable and lighter than air.

Suffocant gas, explosive.

Due to the low density of methane, accumulations of this gas will be located along rooflines, in the upper part of closed spaces.

Explosive range: 5-15%.

Lower explosive limit: 5%

Upper explosive limit: 15%

Within these limits and ignition source is required for the deflagration.

Methane (firedamp)

Origin:

Final product from anaerobic decomposition of organic biomass.

Tendency to get accumulated in the strata of organic origin, in gas bags or scattered among the rock material.

Firedamp is a very dangerous gas because within the explosive limits, a simple spark can lead to a big explosion.

After a firedamp explosion, oxygen will disapear and the air will be mainly composed of N_2 and CO_2.

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$

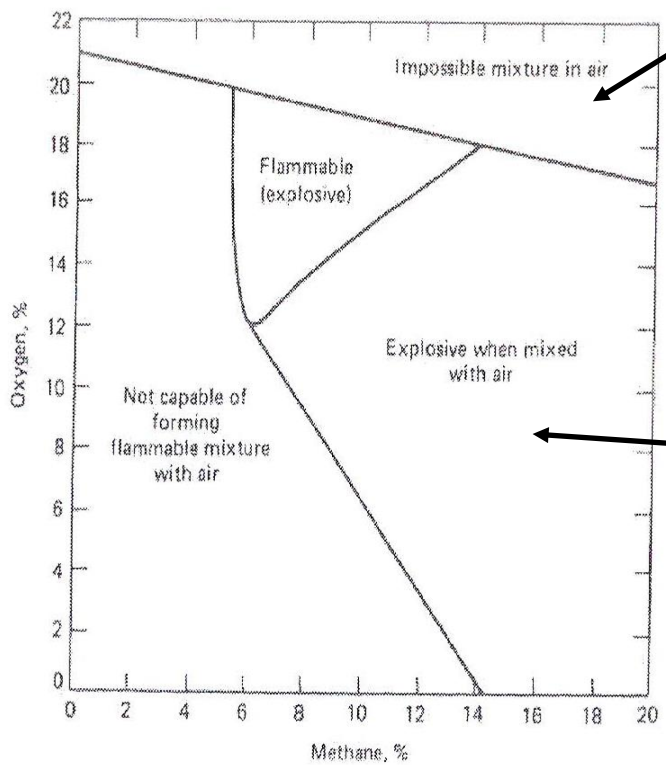
https://www.youtube.com/watch?v=rhavaxv3a40

Mine gases

Methane (CH_4)

Explosibility diagram for methane

Only possible with supplementation of oxygen



Able to produce explosive mixtures if diluted with air.

Mine gases

Methane

Calculate the % of O_2, N_2 and CH_4 if 1 m3 of air (21% O_2 – 79% N_2) is mixed with the following volumes of CH_4:

a) 1 m^3 air and 1 m^3 CH_4.
b) 1 m^3 air and 0.1 m^3 CH_4.
c) 1 m^3 air and 0.22 m^3 CH_4.
d) 1 m^3 air and 0.03 m^3 CH_4.

Which mixture will be explosive?

Mine gases

Sulfur dioxide (SO_2)

Properties: colourless, non flammable, irritant, toxic.

Suffocant gas

SO_2 in air (ppm)	Effect
0.3-1	Detectable by taste (acidic)
3 - 5	Detectable by odor (sulfur)
6-20	Irritation of eyes, nose, throat
50	Pronounced irritation of eyes, nose, throat and lungs. Possible to breath for some minutes.
100	Inmediatly dangerous to life 30 minutes
400	Letal concentration 1 minute

Causes of sulfur dioxide generation:

- Fires in involving sulfur compounds (pyrites).
- Blasting of sulfur ores.
- Internal combustion engines.

Mine gases

Sulfur dioxide

TLV-TWA = 2 ppm

TLV-STEL = 5 ppm

1 % = 10,000 ppm

Mine gases

Hydrogen Sulphide (stink damp) H_2S.

Properties: colourless, toxic, smells like rotten eggs, explosive gas.

Formation and source of hydrogen sulphide:

- Decomposition of sulfur compounds (pyrite).
- Decomposition of organic matter.
- Strata gases.

H_2S in air (ppm)	Effect
0.13	Threshold of odor
1	Slight symptoms. Eyes irritation.
50-100	Cough; eye irritation; loss of sense of smell after 2-5 min
200-700	Increased eye irritation, headache, dizziness, nausea, pain in the nose. Loss of counsciousness. Danger of death in about an hour
1000-2000	Death in minutes.
>2000	Death.

Mine gases

Hydrogen Sulphide

TLV-TWA = 0.0005% (5 ppm)

TLV-STEL = 0.001% (10 ppm)

1 % = 10,000 ppm

Explosive range: 4-44%.

Mine gases

Nitrogen oxides (NOx)

NOx is a generic term that includes NO, NO_2 and NO_3. (NO and NO_2 the most important)

The most dangerous is NO_2.

Properties: Colourless (NO_2 reddish-brown), non flammable, irritant odour, toxic, bitter taste.

Causes of Nitrogen dioxides generation:

- Blasting operations.
- Internal combustion engines.

Mine gases

Nitrogen dioxide

TLV-TWA = 3 ppm

TLV-STEL = 5 ppm

1 % = 10,000 ppm

NO_2 in air (ppm)	Effect
3	Current TLV
5-10	Nose and throat irritation
20	Irritation of eyes
50	Very dangerous at exposures longer than 30 minutes
100-200	Chest tightness, acute bronchitis, and death from prolonged exposure
>200	Rapidly letal

NO in air (ppm)	Effect
25	Light nose and throat irritation.
0-50	Easy to detect (smell)
60-150	Higher irritation, cough.
200-700	Can be letal, even at short exposure

Other gases

Hydrogen (H_2)

Gas flammable, colorless, odorless.

Much lighter tan air (gets accumulated in the top parts of closed spaces).

It can be produced in small amounts in coal fires, incomplete combustion processes and decomposition of organic matter.

It is not toxic but suffocant.

Explosivity range: 4-75%.

Other gases

Aldehydes and aromatic hydrocarbons

These compounds are originated in internal combustion engines.

These compounds can be irritant, toxic, narcotic and/or carcinogenyc.

Toxic compound

Concentration

Time of exposure

} **Dose** → **Health effect:**
- **Chronic.**
- **Acute.**

Other gases

Health effect:
- **Chronic.**
- **Acute.**

Distractions: work accident.

Acute intoxications.

Long term illness.