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RISK OF CARBON MONOXIDE INTOXICATION IN EXPLOSIONS

Absztrakt/Abstract

A foglalkozási mérgezések között az egyik leggyakoribb a szén-monoxid mérgezés, ennek egyik oka a robbantási munkafolyamatok során keletkező mérges gázok belélegzése is lehet. Ez a veszély főleg zárt terekben, barlangokban, bányákban, épületekben lezajlott robbanás után lép fel, de előfordult már kőbányászati omlasztás után is. Ilyenkor nemcsak a munkavállalók, hanem a lakosság védelmére is gondolni kell, a kőzetréseken, talajon keresztül a pincékbe, házakba is bejuthat a mérgező gáz. Kiemelt fontosságú mind nyílt, mind zárt térben a szellőztetési, a füstrevárási idő betartása, melyet befolyásolnak a klímaviszonyok, domborzat és természetesen zárt térben az elszívás minősége.

Carbone monoxide poisoning most frequently occur among occupational intoxications due to inhalation of poisonous gas during explosions. This hazard takes place after explosions: confined spaces, caves, mines, buildings and even undercut caving of quarry. At such a time we have to take into consideration not only the safety of employees but the population since the poisonous gas can migrate into the cellars and houses through the joints of rock or soil. It is highly important to respect the rules of ventilation and smoke waiting time which is influenced by climate, terrain and of course the quality of extraction of gas in enclosed space.

***Kulcsszavak/Keywords**: explosion, carbone monoxide, waiting time, respiratory protection ~ robbantás, szén-monoxid, szellőztetési idő, légzésvédő*

1. INTRODUCTION

Explosions may occur in mining, demolition of buildings, military operations and even in caving. Vast volume of gas is produced in explosions which expands in milliseconds and therefore induces shock waves resulting work. This gas contains poisonous and less poisonous compounds. We have to examine and analyse this gas, because during operations the employees approach and check the location of the explosion and do labour there, hence safety regulations should be introduced to avoid intoxications and protect their health.

1. figure. Attention! Explosion!

2. OXYGEN BALANCE OF EXPLOSIVES

During explosions the composition of substance changes rapidly, it develops heat and gas. Due to the enormous rate of reaction, combustion cannot be supported externally; therefore explosives contain all elements of combustions including oxygen. [1]

Detonation of condensed explosives results in high pressure, characteristic of compressed products significantly differs from the feature the ideal gas. During the process chemical balance is not always developed, intermediate compounds remain in explosive products. Composition of explosive products depends on not only the thermodynamic balance, but kinetics of the chemical reaction and expansion kinetics of compressed gases on high pressure.

Organic explosives mainly consist of carbon, hydrogen, oxygen and nitrogen, but may contain sulphur, chlorine and metals also. Therefore in the explosive products many various gaseous and solid compounds occur. The ratio of the above-mentioned components depends on the oxygen balance of the explosive substance.

- CO_2, H_2O, CO, O_2, H_2, CH_4, C;
- N_2, NH_3, C_2N_2, HCN, NO, N_2O, NO_x;
- SO_2, H_2S, HCl, Cl_2;
- metal-oxide, -carbonate, -bicarbonate, -cyanide, -sulphate, -sulphite, -sulphide, -chloride.[2]

The ratio of the combustible compounds and oxygen contents in explosive compound determines the oxygen balance, referring to 100 grams explosives, and the subtraction of essential oxygen quantity for current and total oxidation. Appearance of end-products, thus the quantity of poisonous gases depends on the values of this index number.

In the most ideal scenario the oxygen balance (OB) is 0, for example nitro-glycerine (OB: +3,5), ammonium nitrate (OB: +20), in this case mainly carbon dioxide, water vapour and nitrogen are produced; during detonation the fume is light grey or white.

In case of positive oxygen balance during detonation nitrous gases are produced, the fume is ferruginous or yellow. Oxygen balance is negative, thus there is oxygen shortage of most explosives. This index number is negative in military explosives, such as trinitrituluol, hexogen and nitropenta. At detonation deep grey fume is produced, detonated material becomes sooty. Oxygen balance can be ameliorated by the use of oxygen carrier compounds, for example sodium nitrate or sodium perchlorate. [1,3]

Explosives	Oxygen balance
Ammonium nitrate	+20,0
Hexagen	-21,6
Fulminating mercury	-11,3
Nitro-glycerine	+3,5
Nitrocellulose	-38,7
Octogen	-21,6
Picric acid	-45,4
Tetril	-47,4
TNT	-74,0
Nitropenta	-10,1

1. table. Oxygen balance of explosives [1]

Apart from oxygen balance, composition of explosive fumes are influenced by its physical characteristics, circumstance of utilization (incomplete detonation, inadequate tamping), method of initiation, adverse weather conditions (stillness of air, descending air current). [1]

During detonation high volume gas (several thousand cubic metres) is produced in very short time, due to high pressure gaseous particles are pressed into the soil or joints of rock, there accumulate and subsequently migrate outwards. Due to intoxications in quarry operations, measurements were taken; carbon monoxide was detected even 8 days after the detonation. Carbon monoxide accumulated in the cellars close to quarry leading to CO intoxication. [4,5]

In enclosed spaces carbon monoxide may be transformed into carbon dioxide by the use of atmospheric oxygen, resulting in oxygen-deficient environment and increase of the level of poisonous carbon dioxide.

3. CHARACTERISTICS OF CARBON MONOXIDE POISONING

We have to take into consideration adverse health effects and environmental pollution caused by poisonous gases. The most significant gas is carbon monoxide due to its health effects and its high volume produced during detonation.

Carbon monoxide is a chemical asphyxiating gas, colorless, odorless with lower density than air. It results from incomplete combustion of organic matter. Carbon monoxide is oxidized to form carbon dioxide. Carbon monoxide and chlorine produce phosgene (COCl2) by exposure of sunlight.

Health effects: Absorption of carbon monoxide is accomplished exclusively by lungs. The affinity of hemoglobin for carbon monoxide is 300 times greater than its affinity for oxygen, therefore in the presence of small amount of carbon monoxide a part of hemoglobin converts into carboxyhemoglobin, which inhibits oxygen uptake toward tissues. Earliest symptoms develop in central nervous system due to reduced oxygen supply, although it has specific poisoning effects such as injuries of the high iron-containing parts of central nervous system. Excretion of carbon monoxide is done by lungs. Biological half-life of carbon monoxide is 5 hours, which can be reduced by inhalation of air rich in oxygen. Toxicity depends on the sensivity for carbon monoxide which is individual, the age (young people are more prone to toxicity), duration of exposition, carbon monoxide content of inhaled air, metabolic state (for example physical exertion), hemoglobin content of blood (anemia) and smokers are more susceptible due to high carboxyhemoglobin concentration in the blood.

Symptoms:

1. Acute intoxication: dizziness, headache, faintness, initially symptoms similar to drunkenness, terminally unconsciousness and death. It's impossible to escape because of muscle weakness. Face is cherry-red. Late symptoms: vertigo, memory loss, hearing and vision disorders, frequently myocardial infarct (ECG abnormalities occur if carboxyhemoglobin is 2%).

Carboxyhemoglobin concentration in the blood (%)	Symptoms
5-10	Few complaints, vision disorders
10-20	Headache, vertigo
20-30	Strong headache, dizziness, palpitation
30-40	Vision disorders, nausea, vomiting, tendency to collapse
40-50	Unconsciousness, tachycardia (high heart rate) and tachypnoe (breathing in higher frequency)
50-60	Deep coma, convulsions
>60	Death

2. table. Symptoms of carbon monoxide intoxication according to carboxyhemoglobin concentration in the blood

Phases of intoxication	Symptoms
Phase of dizziness	Headache, tinnitus, vertigo, nausea, vomiting, dizziness, but could be agitation
Phase of convulsions	Incontinence, dysphagia (Difficulty in swallowing), unconsciousness, convulsions
Phase of respiratory arrest (cessation of breathing)	Death
Phase of convalescence	In case of survival persistent symptoms develop: parkinsonism, physical impairment, balance disorder, psychic illnesses

3. table. Phases of carbon monoxide intoxication

2. Symptoms of chronic intoxication: vertigo, headache, insomnia, epigastrial and cardiac pain, cardiovascular disorders, low intellectual ability, memory loss, sleeping disorder, decreased work performance, irritability, emotional lability. In many cases high levels of cholesterol, lipoprotein and glucose in the blood was observed.

If intoxication develops it is important to rescue the poisoned person and give symptomatic treatment and inhalation of oxygen. Hospitalization is inevitable to prevent late complications. It's crucial to wear protective gear for rescuers to avoid.[6]

17 proved and 39 suspected cases were registered in USA and Canada since 1988, employees became intoxicated from carbon monoxide when explosive blasting was conducted in deep or surface mine blasting and construction operations, one person died. [7] Carbon monoxide intoxication is the 7th most frequent occupational disease in the army of USA resulting from dealing with fuel or explosives. [8]

4. DETECTION OF CO CONCENTRATION DURING BLASTING OPERATIONS

Earlier was mentioned that chemical reactions sometimes deviate from the rule, chemical balance doesn't develop, and we have to take into consideration combustion products formed from other ingredients. We took measurement to detect carbon monoxide during blasting.

Method: blasting was conducted in a barrel with capacity of 0,2 cubic metre. LASCAR Electronics EL USB-CO datalogger was used for the measures. This instrument operates with accuracy of 1 ppm and logging rate of 10 seconds. The data can be downloaded on PC and can then be graphed.

2. figure. LASCAR EL USB CO datalogger

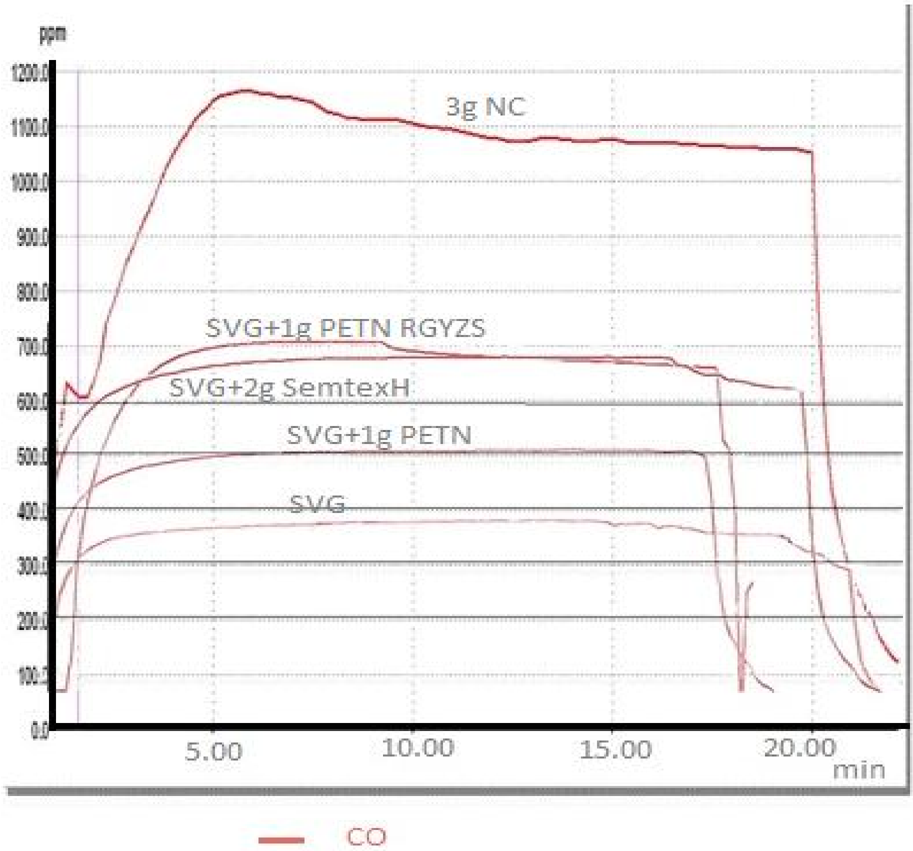
3. figure. Measuring

Following explosives were examined:

– - SVG detonator, which contains 0,64 g PETN, 0,36 g lead styphnate + lead azide (brizant explosives are initiated with SVG detonator).
– - 1g nitropenta with SVG detonator in aluminium case
– - 1g nitropenta containing explosive detonating fuse (16,6 cm) with SVG detonator
– - 2g SEMTEX H (PETN+RDX+Al+PIB) SVG detonator
– - 3g smoke-free (REX) gunpowder (nitrocellulose)

Explosives	Maximal CO level in a 0,2 m^3 barrel
SVG detonator	375 ppm
1g nitropenta with SVG detonator in aluminium case	511 ppm
1g nitropenta containing explosive detonating fuse (16,6 cm) with SVG detonator	711 ppm
2g SEMTEX H (PETN+RDX+Al+PIB) SVG detonator	679 ppm
3g smoke-free (REX) gunpowder (nitrocellulose)	1164 ppm

4. table. Measurement data



4. figure. Measurement data plotted against time

From the measurement data we can determine the CO level dispersed in unit volume originated from explosives in unit quantity, produced gases at the detonator and explosive detonating fuse can be derived from other compounds of the blasting agents such as a plastic cover.

Explosives	Volume	Maximal CO level in 1 m^3
SVG detonator	1 piece	75 ppm
Nitropenta	1 g	27,2 ppm
explosive detonating fuse	1 m	404,8 ppm
SEMTEX H	1 g	30,4 ppm
Nitrocellulose gunpowder	1 g	77,6 ppm

5. table. Maximal CO level referred to unit explosive

It is easy to calculate the dilution of carbon monoxide based on the estimated volume of the cave. This is an example of the calculation:

100 gram SEMTEX H and 4 SVG detonator is used for detonation in a 20 cubic metre cave:

(4x75+100x30,4)/20= 1535 ppm

In the following table health effects depending on CO concentration are shown:

Effects of various CO concentrations	
0-35 ppm	Average apartment (in 1 hour).
<100 ppm	Safe, mild headache.
200 ppm	Mild headache, fatigue, vertigo, nausea in 2-3 hours.
400 ppm	Frontal headache in 1-2 hours, life threatening in 3 hours.
800 ppm	Nausea, vertigo, fainting in 2 hours, death in 2-3 hours.
1600 ppm	Headache, vertigo, nausea in 20 minutes, death in 1 hour.
3200 ppm	Headache, vertigo, nausea in 5-10 minutes, death in 15-20 minutes.
6400 ppm	Headache, vertigo, nausea in 1-2 minutes, death in 10-15 minutes.
12800 ppm	Death in 1-3 minutes.

6. table. Health effects depending on CO concentration [9]

Monitoring in workplace	**Concentration (mg/m^3)**
allowable average concentration	33 (30 ppm)
allowable peak concentration	66 (60 ppm)
Stages of prevention	**Concentration (mg/m^3)**
Stage of readiness	20-40
Stage of defence	40-450
Stage of evacuation	> 450

7. table. Allowable limit values and stages of preventions of carbon monoxide in airspace [6]

It is visible from the tables above that CO concentration, which was produced at detonation, exceeds limit value; consequently nature of work defines Peak concentration. Therefore it is required to wait for complete ventilation of the cave in order to prevent CO intoxication.

5. REGULATIONS OF LABOUR SAFETY AND HYGIENE

In case of military operations and surface mining safety time is not determinated, after the dispersing of blasting gascloud control of the blast hole can be executed. Explosion related health effects didn't occur in national military operations, based on practical observations this safety time is sufficient outdoors. Relief and weather conditions (temperature, wind and precipitation) should be considered. On the other hand fume waiting time is 30 minutes with artificial ventilation in case of blasting in deep mines.

Indoors installed CO detectors indicate noxious CO concentration. In that case application of respiratory protective equipment may prevent intoxication.

In fire-protection and mining disposable, filtered, self-rescuer protective respiratory equipment with hood may be applied to escape from fume, CO and other noxious gas containing room and are not suitable to be used in oxygen deficiency. Filtered respirator is designed to protect against CO produced mainly in fire and underground explosions. Mouthpiece is composed of kit and filters. Respirators are serviceable for a short period of time; in case of oxygen deficiency isolated respirators are recommended. [6]

1. figure. Smoke hood [10]

2. figure. Isolated respirator [10]

Safety distance should be respected from the view of safety technology and hygiene. It is advisable to consider relief and wind.

Substitute for hazardous materials is a principle of chemical safety and safety hygiene. When the oxygen balance of explosives is negative eg. trinitrotoluene or hexogene, they should be substituted by ammonic nitrate or mixed with it. Applying the electric or NONEL system instead of explosive detonating fuse is better, because the quantity of poisonous gases decreases.

In addition the education of employments is very important too, because they have to be able recognising the poisoning symptoms, rescuing and giving first aid for the casualty.

6. SUMMARY

In our publication we summarize the composition of blasting gases. The most volume quantity of poisonous gases is the carbon-monoxide, we particularize the health damage effects of it and the possibility of prevention. In the last years the manufacturers take account of the work safety and the environmental rules. They improve and perfect the explosive materials, that the generating of the toxic gases be much less. The most volume quantity of poisonous gases is the carbon-monoxide, it is colorless, odorless, it can kill the employments without any special signs. The keeping the safety rules, the protection of employers and the prevention of health damage are the most important tasks in the industrial and military blasting operations. In buildings and confined spaces we have to think the gas, in most of cases wainting the ventilation time or wearing the personal protection devices are enough to prevention of poisoning.

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