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The dynamics of carbon oxide evacuation from closed enclosures

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Abstract. The carrying out of human activities of an industrial nature involves the use, handling or accidental presence of substances of a toxic nature such as carbon oxide. The presence of this gas in closed or semi-closed spaces can seriously affect the human body and when concentrations are high it can lead to death. Knowing how carbon oxide affects the human body and how it disperses into the air is very important for establishing preventive measures. Also, in order to establish the escape routes and the refuge areas, it is necessary to know the dispersion dynamics of carbon oxide both horizontally and vertically. The paper presents the experiment on establishing the dynamics dilution and evacuation of carbon monoxide in a closed enclosure.

1 Introduction

Carbon oxide is an inorganic gas, extremely flammable and toxic [3, 15], is a product of the incomplete combination of carbon-containing solid, liquid or gaseous materials. Carbon oxide is an odorless, colorless and tasteless gas with a molar mass of 28.01 g/mol. It also has a density of 1.2501 kg/m3 at 0 ° C and a relative density of 0.9672 kg/m3, the melting point is -205.1 ° C and the boiling point is -191.5 ° C at 1013 hPa.

Carbon oxide is a combustible gas and has an ignition temperature of 605 ° C. It is also an explosive gas that has explosive limits ranging from 12.5% vol. To 74.2% vol. Carbon oxide arises from the incomplete combustion of combustible gases, liquids and solids, as well as various materials rich in carbon atoms. The most important feature of this gas is its toxic action on humans, even in very low concentrations. This gas is also highly dangerous due to the fact that it cannot be detected by the human senses.

The most important biochemical property of carbon oxide is its combination with hemoglobin in the blood. It enters the respiratory tract and, following the combination with oxyhemoglobin, gives carboxyhemoglobin, a pigment that no longer participates in the transport of oxygen in the body. Toxic phenomena occur as a result of the anoxia that is created. The affinity of hemoglobin for carbon oxide is 220 times higher than for oxygen. A pigment molecule fixes a carbon oxide molecule: $HbO2 + CO \leftrightarrow HbCO + O2$.

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It follows that one volume of CO acts as 220 volumes of oxygen. Saturation of hemoglobin at 50% with oxygen occurs when its pressure reaches 30 mmHg, while at CO it takes place at a partial pressure of 0.12 mmHg. The presence of carboxyhemoglobin (HbCO) does not reduce the partial pressure of oxygen in the arterial blood. HbCO dissociation is 220 times slower. Because of this, a high concentration of HbCO is obtained with relatively small amounts of CO entering the circulation.

Binding of CO to hemoglobin is not the only toxic effect of this gas. It circulates in the blood and in free form and enters the brain, myocardium and other vital organs, where it can be found even if it is absent in the blood. Carbon oxide also dislocates CO2 from the blood, leading to alkalosis. Alkalosis prevents excitation of the respiratory center.

The toxicity of carbon oxide is determined by the following factors: its concentration in the air, the duration of exposure, cardiac output, the concentration of HbO2 and HbCO in the blood and the oxygen needs of the tissues. In all cases, increased metabolism increases the severity of symptoms.

The rate at which blood takes in CO from inhaled air depends on respiratory volume and cardiac output. Pulmonary ventilation must be correlated with the partial pressure of the gas in the inhaled air. If respiratory volume increases as a result of exercise, the rate of CO absorption increases proportionally. Toxicity is aggravated by physical labor, anemia and a pronounced metabolism. The presence of HbCO gives the blood a bright red color.

CO release from HbCO occurs slowly and is eliminated through the lungs (15% per hour). At concentrations below 10% HBCO (by exposure to 0.01% CO), physiological symptoms rarely occur, for example in smokers concentrations of 4-5% HBCO frequently occur. The first toxic symptoms such as headache, cutaneous vasodilation and rapid breathing occur at approximately 15 - 20% HBCO (by exposure to 0.02% CO). At concentrations of 30 - 35% HBCO (by exposure to 0.05% CO) the following symptoms appear: fatigue, dizziness, vomiting, visual disturbances, tendency to collapse. At concentrations of 50 - 55% HBCO (by exposure to 0.1% CO) the following symptoms appear: unconsciousness, collapse and fainting, possibly syncope leading slowly to death. At a concentration of 66% HBCO (by exposure to 0.2% CO) death occurs in about 5 hours, in a coma and convulsions. At 80% HBCO (exposure to 1% CO) death occurs rapidly. When 40% of hemoglobin is blocked by carbon monoxide, significant symptoms of the central nervous system and even death occur. In sensitive individuals, even a carboxyhemoglobinemia below 40% has been shown to be fatal. Death certainly occurs when 2/3 of the blood is saturated with CO, respectively 16-17 cm3 of gas per 100 ml of blood. Regardless of the amount of HbCO, death is the result of insufficient oxygen for hematosis.

Central nervous system cells are very sensitive to lack of oxygen, and as a result: dizziness, agitation, tremors, drowsiness, confusion and loss of consciousness. These disorders are reversible if first aid measures are taken. Prolonged anoxemia leads to central lesions. It can be said that CO invalidates the body by hypoxia and kills by suffocation.

Symptoms occur at a concentration of 15-20% HbCO. They appear progressively as the amount of HbCO increases. The symptoms are closely correlated with the concentration of the toxicant in the air and with the carboxyhemoglobinemia.

Hyperthermia is a very serious symptom, which leads to the installation of cerebral edema with paralysis of the thermoregulatory centers. Weakness is the beginning of central paralysis, when epileptiform seizures occur.

In addition to the symptoms mentioned, skin lesions, profuse sweating, enlarged liver, tendency to bleeding may also occur. Oliguria with albuminuria and glycosuria. Hyperglycemia and azotemia. After the initial alkalosis, acidosis sets in. Skin marks often appear on the body in the form of red spots.

Among the complications of acute asphyxia, we mention: transient speech disorders, lack of locomotor coordination, deafness and blindness. Intermittent CO exposure causes chronic disease as a result of the cumulative effects of repeated tissue damage. Breathing in an atmosphere containing less than 0.01% CO for long periods can lead to acute or subacute accidents. The symptoms that appear make up the symptomatic triad: asthenia, dizziness and headache. From a neurological point of view, it has been found that carbon oxide poisoning is a cause that triggers Parkinson's syndrome. The national mandatory occupational exposure limit value is 20 mg/m3 or 17.5 ppm. for long-term exposure at 8 hours, respectively 30 mg/m3 or 26 ppm for short-term exposure at 15 min.

2 Description of the problem

The issue imposed by the presence of toxins in industrial premises is very important because it directly affects the human body [7]. Workers may be exposed for short or long periods to the action of toxic substances in which acute intoxication or occupational diseases may occur. The topic of gas dispersion has been studied extensively internationally [8, 9, 10, 11, 12, 13, 14]. However, in particular, the dynamics of toxic gas dilution and evacuation indoors has been less studied but can be analyzed using fluid dynamics. The results of the detailed analysis can be used to determine areas of refuge or escape routes in the event of an accidental release of carbon monoxide in an enclosed industrial area [1, 4, 5, 6].

3 Establishing the experimentation conditions

The experimentation regarding the establishment of the dynamics of dilution and evacuation of toxic atmospheres was carried out in the industrial ventilation laboratory within INCD INSEMEX Petroșani [2]. The experimental system used consists of a data acquisition equipment and a monitoring system consisting of 6 pulleys to which are attached 6 multigas gas detectors of ALTAIR type, which can detect concentrations of O2, CO2, CO and CH4. pulleys can configure a variable spatial arrangement in order to determine the rate of gas dispersion as well as the dynamics of the formation of toxic atmospheres. In order to ensure the safety and health conditions at work at the place of experimentation as well as for the study of dilution and discharge dynamics, a complex ventilation system with variable structure is used to study the ventilation capacity of closed enclosures with the risk of forming potentially explosive / toxic / asphyxiating atmospheres. This ventilation system consists of a fan unit - 3 kW centrifugal motor and a network with several branches of rectangular pipes with dimensions of 300/400 mm that control the indoor atmosphere.

The network of rectangular pipes intended for the suction of air consists of short and long branches intended for the ventilation of the enclosures in which gases with low, medium or high specific weight can be found.

4 Laboratory experiments

In the experimental laboratory, the dynamics dilution and evacuation of the toxic atmosphere through the use of carbon oxide, CO were analyzed.

The measuring instruments used are of the MSA - ALTAIR type and have the following series: Apparatus no. 1: 000 6011 454 MSA; Apparatus No. 2: 000 6010 119 MSA; Apparatus No. 3,000 6011 456 MSA; Apparatus No. 4: 000 6011 457 MSA; Apparatus No. 5,000 6010 120 MSA; Apparatus No. 6: 000 6011 455 MSA. The ground section of the

experimental enclosure is 5.8x5.62 m. The height of the enclosure is 3.65 m. Consequently, the total volume of the experimental enclosure is 118.9754 m^3. Considering the fact that other experimental systems are located in the enclosure, the free volume of the enclosure is 116 m^3.
For dilution and gas exhausting from the enclosure of the experimental enclosure was used "complex experimental system with variable structure for the study of the ventilation capacity of closed enclosures with risk of formation of potentially explosive / toxic / asphyxiating atmospheres" which has 18 flow variators and 15 suction mouths. At the level of the experimental enclosure this system has 6 flow variators and 5 suction mouths. The suction openings are arranged as follows: 3 suction openings with horizontal suction respectively 2 suction openings with vertical suction. The centrifugal drive fan is type V20 - 450D - 3kW. The flow rate achieved by this type of fan is 2800m^3/h. The average flow achieved at the level of a suction mouth was 3.11 m^3/min. At the level of the experimental enclosure, the average flow achieved was 15.55 m^3/min. The initial test conditions were as follows: Temperature: T = 23.8 ° C; Atmospheric pressure: B = 9,460 da Pa; Relative humidity: RH = 53.7%; maximum gas flow: q = 35.8 l / min. The system for introducing the gas into the enclosure is shown in fig. 1a.
The system with which the toxic atmosphere was created was formed from a bottle of carbon oxide compressed at a pressure of 200 bar and a concentration of 230 ppm, a pressure reducer and a flow meter with a float.
The detection devices MSA - ALTAIR were positioned on the 6 pulleys at medium level and the height at which the suction and detection area of the devices was positioned was 1.8 m from the floor fig. 1b.

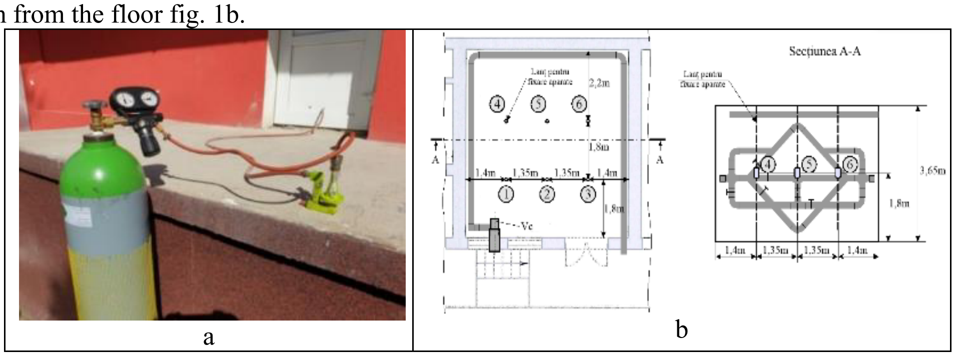

Fig. 1. a. Introduction gas system into the enclosure: b. Location of the detection system.

After the stage of introducing carbon oxide into the enclosure and stopping the discharge system, the ventilation system of the enclosure was started. The ventilation system of the enclosure was structured with the help of flow variators. The ventilation system as well as the flow variators were operated by the SCADA type command and control system. As a result of the experiment, the following results were obtained in tables 1-6:

Table 1. At the level of the MSA ALTAIR device no. 1.

Date **Altair 5X -1**	COMB(1)	O2(2)		CO(3)	H2S(4)	CO2(6)	°C
	Peak	Min	Max	Peak	Peak	Peak	
8/7/2020 2:00:30 PM	0	19.5	19.5	16	0	0.01	28
8/7/2020 2:03:30 PM	0	19.5	19.8	15	0	0.01	28
8/7/2020 2:06:30 PM	0	19.8	20.3	11	0	0.02	28
8/7/2020 2:09:30 PM	0	20.2	20.8	6	0	0.03	28
8/7/2020 2:12:00 PM	0	20.8	20.8	0	0	0.03	29
8/7/2020 2:15:15 PM	0	20.8	20.8	0	0	0.03	29

Table 2. At the level of the MSA ALTAIR device no. 2.

Date **Altair 5X -2**	COMB(1)	O2(2)		CO(3)	H2S(4)	CO2(6)	°C
	Peak	Min	Max	Peak	Peak	Peak	
8/7/2020 1:57:45 PM	0	19.4	19.5	17	0	0.03	30
8/7/2020 2:00:45 PM	0	19.4	19.6	17	0	0.03	31
8/7/2020 2:03:45 PM	0	19.4	19.9	16	0	0.03	31
8/7/2020 2:06:45 PM	0	19.7	20.1	13	0	0.03	31
8/7/2020 2:09:45 PM	0	20	20.3	9	0	0.03	31
8/7/2020 2:12:45 PM	0	20.8	20.8	0	0	0.03	33

Table 3. At the level of the MSA ALTAIR device no. 3.

Date **Altair 5X -3**	COMB(1)	O2(2)		CO(3)	H2S(4)	CO2(6)	°C
	Peak	Min	Max	Peak	Peak	Peak	
8/7/2020 1:58:15 PM	0	19.4	19.5	17	0	0.03	28
8/7/2020 2:01:15 PM	0	19.3	19.5	16	0	0.03	29
8/7/2020 2:04:15 PM	0	19.4	19.8	16	0	0.03	29
8/7/2020 2:07:15 PM	0	19.6	20.1	13	0	0.03	29
8/7/2020 2:10:15 PM	0	20.1	20.4	9	0	0.03	29
8/7/2020 2:13:15 PM	0	20.8	20.8	0	0	0.03	30
8/7/2020 2:16:15 PM	0	20.8	20.8	1	0	0.03	30
8/7/2020 2:19:15 PM	0	20.8	20.8	0	0	0.03	30

Table 4. At the level of the MSA ALTAIR device no. 4.

Date **Altair 5X -4**	COMB(1)	O2(2)		CO(3)	H2S(4)	CO2(6)	°C
	Peak	Min	Max	Peak	Peak	Peak	
8/7/2020 1:55:30 PM	0	19.3	19.6	17	0	0.03	28
8/7/2020 1:58:30 PM	0	19.4	19.6	17	0	0.03	28
8/7/2020 2:01:30 PM	0	19.2	19.6	17	0	0.03	29
8/7/2020 2:04:30 PM	0	19.3	19.9	16	0	0.03	29
8/7/2020 2:07:30 PM	0	19.8	20.3	11	0	0.03	29
8/7/2020 2:10:30 PM	0	20.3	20.4	7	0	0.03	29
8/7/2020 2:13:30 PM	0	20.8	20.8	0	0	0.03	30
8/7/2020 2:16:30 PM	0	20.8	20.8	0	0	0.03	30

Table 5. At the level of the MSA ALTAIR device no. 5.

Date **Altair 5X -5**	COMB(1)	O2(2)		CO(3)	H2S(4)	CO2(6)	°C
	Peak	Min	Max	Peak	Peak	Peak	
8/7/2020 2:01:15 PM	0	19.2	19.6	18	0	0.03	29
8/7/2020 2:04:15 PM	0	19.3	19.9	17	0	0.03	29
8/7/2020 2:07:15 PM	0	19.8	20.2	11	0	0.03	29
8/7/2020 2:10:15 PM	0	20.2	20.4	7	0	0.03	29
8/7/2020 2:13:15 PM	0	20.8	20.8	0	0	0.03	30
8/7/2020 2:16:15 PM	0	20.8	20.8	0	0	0.03	30
8/7/2020 2:19:15 PM	0	20.8	20.8	0	0	0.03	30

Table 6. At the level of the MSA ALTAIR device no. 6.

Date **Altair 5X -6**	COMB(1)	O2(2)		CO(3)	H2S(4)	CO2(6)	°C
	Peak	Min	Max	Peak	Peak	Peak	
8/7/2020 2:01:30 PM	0	19.3	19.6	17	0	0.03	29
8/7/2020 2:04:30 PM	0	19.4	19.9	16	0	0.03	29
8/7/2020 2:07:30 PM	0	19.7	20.3	13	0	0.03	29
8/7/2020 2:10:30 PM	0	20.2	20.4	8	0	0.03	29
8/7/2020 2:13:30 PM	0	20.8	20.8	0	0	0.05	30
8/7/2020 2:15:30 PM	0	20.8	20.8	0	0	0.05	30
8/7/2020 2:18:30 PM	0	20.8	20.8	0	0	0.05	30

The duration of the experiment was 21 min. The volume of carbon oxide introduced into the enclosure was 8,000 liters or 8 m^3. The time allotted for ventilation was 30 min.
The dynamics of the dispersion of carbon oxide at the closed enclosure is shown graphically in fig. 2.

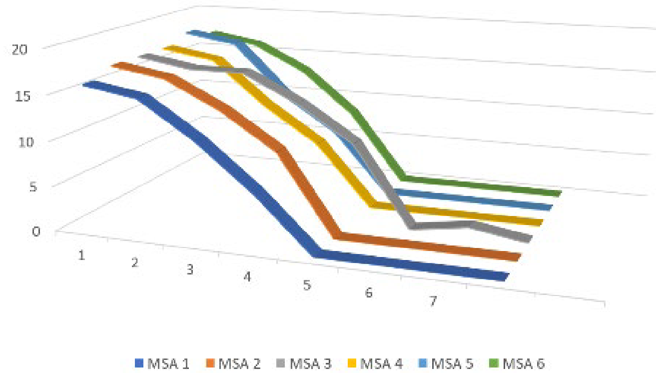

Fig. 2. Dynamics of diluting and discharging Carbon Oxide from closed enclosures.

5 Discussions

The following aspects can be deduced from the experiment on the dilution and evacuation of toxic gases in a closed enclosure using carbon oxide:

- The process of diluting and evacuating carbon oxide indoors comprised the ventilation period in which the gas is discharged by means of the ventilation system with variable structure;
- The dilution and evacuation process is characterized by a relatively homogeneous evolution both horizontally and vertically. This is evidenced by the relatively close values of the gas concentrations at the level of the detectors, in the same time interval;
- The period of ventilation and progressive dilution of the gas showed relatively similar developments depending on the position in the plane of the detection devices as follows:
- The period of ventilation and progressive dilution of the gas was short at the level of the detection devices located in points 1, 5 and 6 being 12 min .;
- The period of aeration and progressive dilution of the gas was average at the level of the detection devices located in points 2 and 3 being 15 min .;
- The period of ventilation and progressive dilution of the gas was relatively long at the level of the detection device located in point 4 being 19 min .;
- The maximum gas concentration showed close evolutions depending on the position in the plane of the detection devices as follows:
- The maximum gas concentration of the gas was relatively low at the level of the detection device located in point 1 being 16 ppm;
- The maximum gas concentration was average at the level of the detection devices located in points 2, 3, 4 and 6 being 17 ppm;
- The maximum gas concentration of the gas was relatively high at the level of the detection device located in point 5 being 18 ppm;
- The gradient of dispersion and progressive dilution of the gas at the level of the closed enclosure, Gd, showed a variable evolution depending on the position in the plane of the detection devices as follows:
- The gradient of dispersion and progressive dilution of the gas at the enclosure level, Gd, showed reduced values at the level of the detection device located in point 4 being 56,66 ppm / h;
- The gradient of dispersion and progressive dilution of the gas at the enclosure level, Gd, presented average values at the level of the detection devices located in points 2 and 3 being of 68,00 ppm / h;
- The gradient of dispersion and progressive dilution of the gas at the enclosure level, Gd, presented high values at the level of the detection devices located in points 2 and 3 being of 4,538 respectively 4,589 ppm / h;
- The gradient of dispersion and progressive dilution of the gas at the enclosure, Gd, showed a very high value at the level of the detection device located in points 1; 5 and 6 being 80.00; 90.00 and 85.00 ppm / h, respectively;;

The toxic gas - carbon oxide, accumulated in the closed enclosure, showed a phenomenon of rapid and relatively uniform dilution and evacuation compared to the geometric shape of the enclosure. The average ventilation time in relation to the indications of the detection devices, respectively with the shape of the enclosure, was less than 15 min. which gives carbon monoxide a high capacity for total evacuation from closed enclosures.

6 Conclusions

For the study of the dynamics of formation of toxic atmospheres, within the experimentation laboratory within INCD INSEMEX Petroșani, the following experiments were performed on the dynamics of dilution and evacuation of toxic atmosphere by using carbon oxide, CO;

The process of diluting and evacuating carbon oxide indoors included the ventilation period;

The process of dilution and evacuation of carbon oxide is characterized by a relatively homogeneous evolution both horizontally and vertically. This aspect is proved by the relatively close values of the gas concentrations at the level of the detection devices, in the same time interval;

The ventilation period showed evolutions between: 12 and 18 minutes;

The maximum concentration of carbon oxide gas showed a variable evolution with values between: 16 and 18 ppm;

The gradient of dispersion and progressive dilution of carbon oxide gas at the closed enclosure, Gd, presented a variable evolution being between: 56.66 - 90.00 ppm / h;

The average ventilation time in relation to the indications of the detection devices, respectively with the shape of the enclosure, was less than 15 min. which gives carbon oxide a high capacity for total evacuation from closed enclosures.

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