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Low Concentration of Oxygen in External Environment - Modeling the Consequences of Accident

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The lack of oxygen (asphyxiation) usually occurs inside the device. However, literature describes several accidents that occurred in an outdoor environment.
According to the information EIGA (European Industrial Gases Association) several tens of cases of asphyxiation per year in average occur in the chemical industry. [1] Although these accidents usually have only local effects, in a few cases the release of large quantities of chemicals to the external environment affects external workers.
This article presents several examples of accidents that can affect the surroundings of technological equipment, discusses the possibility of modeling the accident and determines the extent of the consequences.
This article also summarizes the information needed to calculate the severity of the reduction in oxygen concentration and describes the typical accident scenarios that can lead to a reduction in the concentration of oxygen in the environment. These three scenarios are modeled in ALOHA software. The results show that only one scenario, i.e. biphasic spillage of liquid nitrogen and subsequent evaporation from the reservoirs, can affect the population living in the vicinity of the equipment. Based on these results, preventative measures are proposed.

1. Accidents in history

According to information of EIGA (European Industrial Gases Association) several tens of cases of worker's asphyxiation occur in the chemical industry as an average per year (EIGA, 2009). Although these accidents usually have only local effects, in a few cases a displacement of gas in the external environment by release of large quantities of chemicals affects external workers.
The first group of accidents is caused by violation of integrity of the tank or pipe with stored liquefied inert gas. It should be noted that in case of tank rupture, the consequences caused by spilling of fragments are also essential (e.g. August 28, 1992 in Japan, the surrounding infrastructure was damaged due to fragments being spilled at a distance of 350 m).
The second group of accidents is caused by degassing of inert technology; it affects people near the outfall of degassing. For example, in September 20th, 2012 at the company SKW Stickstoffwerke Piesteritz GmbH three people died. During the shutdown they were maintaining the flare (on platforms at different heights), which was disconnected. However, unexpectedly, nitrogen was released from inerting technology (MDR.DE, 2012). A similar accident occurred in October 27th, 1998 at the Union Carbide's Taft in Hahnville, USA (Chemical Safety Associates, Inc., 1990).
By the U.S. Safety board (Chemical Safety Associates, Inc., 2003), there were 85 nitrogen asphyxiation incidents in the workplace between 1992 and 2002, 80 people were killed and 50 were injured - about 40 percent of these victims were working in the external environment, out of confined space. Of the 85

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incidents reported, 62 percent occurred in chemical plants and refineries, food processing and storage facilities, metal and manufacturing operations, and other industrial, maritime, and manufacturing sites, including nuclear plants.
Another common cause of asphyxiation is displacement of oxygen by carbon dioxide, although in this case it is rather poisoning. These accidents occur most frequently in fermentation productions and dairies within a confined space.

2. Determining the extent of consequences

The normal concentration of oxygen in air is approximately 21 % vol. However, if it falls below this threshold (either due to displacement of oxygen by other gas - such as nitrogen, argon, or due to the absence of oxygen), a person is affected in his/her mental and physiological abilities. Inert substance is not a “poison” in the traditional sense, It presents a hazard when it displaces oxygen, making the atmosphere hazardous to human beings. Breathing atmosphere with deficite of oxygen can have serious effects, including unconsciousness after only one or two breaths. (Safety Bulletin, 2003).
When population is exposed to the effects of reduced oxygen concentration, it is necessary to determine the concentration of oxygen which causes consequences with expected probabilities. It must be based on a predetermined value of the probit function (which indicates the probability of fatal injury) and duration of exposure. The probit for exposure to toxic substances is indicated using the relationship:

$$Pr = a + b\, ln(\int C^n dt) \qquad (1)$$

where

- Pr – probit associated with the probability of dying,
- a, b, n – constants for the toxicity of a substance,
- C – concentration at time t [% vol.]
- t – exposure time [min.]

Probit for the innert substances can be calculated by the following equation (RIVM, 2009):

$$Pr = -65{,}7 + \ln(C^{5{,}2} t) \qquad (2)$$

where:

- Pr – probit value
- C – concentration of inert substances in the area [ppmv]
- t – time [min.]

There is the vulnerability model for various exposure times and different concentrations of inert material in the air in the Figure 1. The model were created on the dataset from (RIVM, 2009).

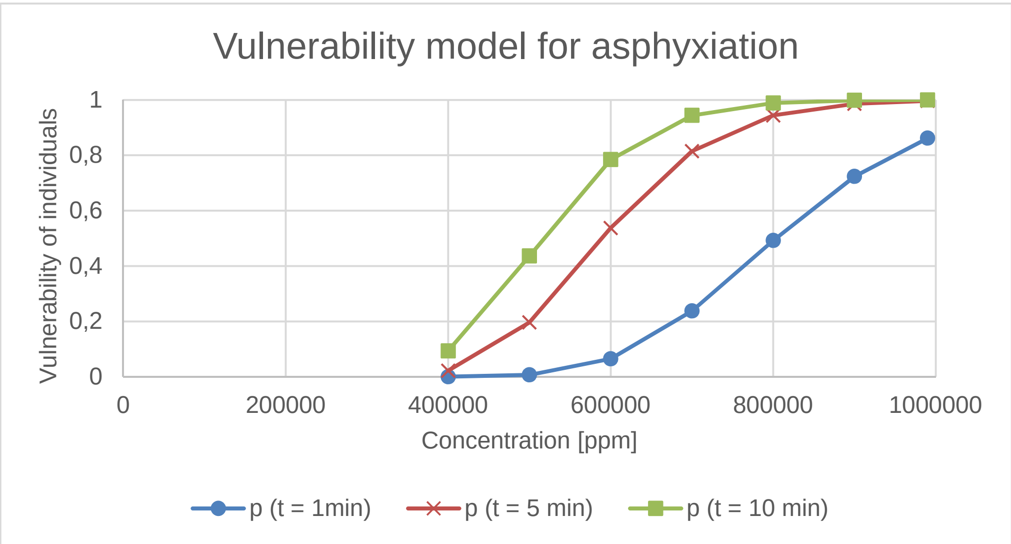

Figure 1: Vulnerability model for asphyxiation for different exposure times

Lack of oxygen significantly affects decision-making and psychomotor skills (Pighin et al., 2012). The phases of effects can be divided by the concentration of oxygen into:

- 11 ÷ 18 % vol. - reduction of mental abilities (the affected person is unable to diagnose the cause)
- 8 ÷ 11 % vol. - possible loss of consciousness within few minutes, the probability of death allows 11 %
- 6 ÷ 8 % vol. - loss of consciousness; the possibility of immediate resuscitation,
- 0 ÷ 6 % vol. - loss of consciousness; after about 6 minutes, brain damage even with rescue attempt. (EIGA, 2009).

A special case is the effect of carbon dioxide. The extent of consequences connected with carbon dioxide is greater than with an inert gas.

Probit can be calculated by the following equation (Energy Institute, 2013.):

$$Pr = -89{,}8 + ln(C^8 t) \tag{3}$$

where:

- Pr – probit value;
- C – concentration of carbon dioxide in the area ppmv];
- t – time [min.]

There is the vulnerability model for various exposure times and different concentrations of carbon dioxide in the air in the Figure 2. The model were created on the dataset from (RIVM, 2009).

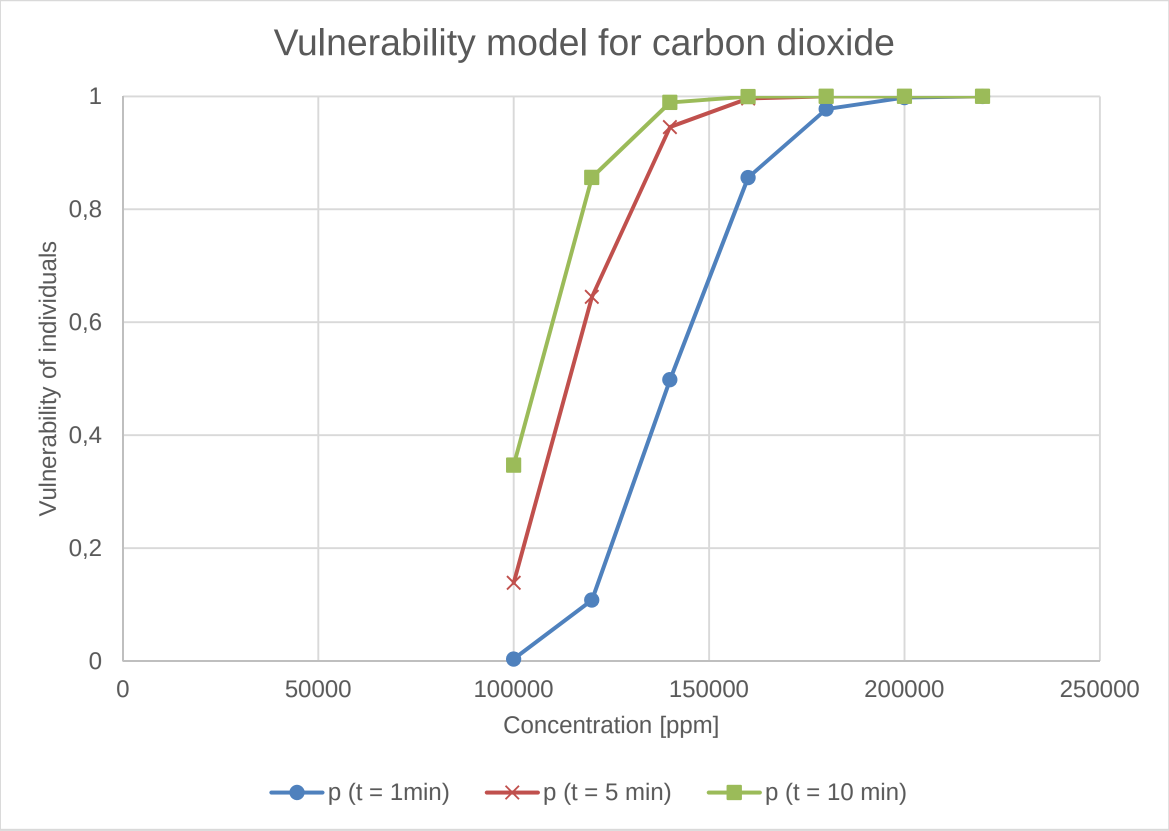

Figure 2: Vulnerability model for carbon dioxide for different exposure times

The phases of effects can be divided by the concentration of carbon dioxide into:

- 10 % vol. - loss of consciousness within 30 min,
- 12 % vol. - loss of consciousness within 5 min,
- 20 % vol. - loss of consciousness within 1 min. (HEALTH AND SAFETY EXECUTIVE, 2012).

The fundamental problems of work in areas with potential reduction of oxygen concentration are the speed of exposure and the impossibility of identification. Especially, falls can occur due to the loss of consciousness when working at height or above free space.

3. Selection of typical accident scenarios for modeling

On the basis of the study of accidents and near misses, which are described in the literature and in the Internet, we have determined typical accident scenarios with reduction of oxygen concentration in the outdoor environment. For further modeling, following typical accident scenarios will be considered:

- Scenario 1: the spillage of liquefied nitrogen from the bottom of the storage tank (storage temperature -196 °C, volume 6 m^3) – violation of integrity of tank or inlet pipe, the hole has a diameter of 10 cm, 80 % loading,
- Scenario 2: release of gaseous nitrogen during the inertization of equipment by exhaust pipe DN64, (volume 200 m^3, pressure 200 kPa),
- Scenario 3: release of carbon dioxide from fermentation equipment, pipeline DN300, (flow rate 0.2 m^3/min).

4. Accidents modeling

This article presents classes of consequences and estimates the potentially affected areas through modeling. In the modeling only one meteorological scenario was taken into account (it was the worst scenario with very stable weather conditions). This conservative approach was adopted because the fact that ALOHA does not account for terrain variations and 3D meteorological data. Moreover, obstacles and terrain geometries are often not available in a suitable format (Pontiggia et al., 2012).

The consequences of unexpected events were modeled in the software ALOHA 5.4.3 with conservative estimates for spillage and dispersion. Adverse atmospheric conditions were considered in the modeling - air temperature 20 °C, wind speed 2 m / s, stability class F.

Table 1: Length of the affected area for each spillage scenario

Length of the affected area [m]	Loss of consciousness within 30 min	Loss of consciousness within 5 min	Immediate loss of consciousness
Scenario 1	132 m	122 m	111 m
Scenario 2	less than 10 m	not found	not found
Scenario 3	not found	not found	not found

From the result of modeling it is clear that only one scenario, i.e. biphasic spillage of liquid nitrogen and subsequent evaporation from the reservoirs, has important consequences, including the object outside, i.e. it can affect the population living in the vicinity of the equipment. An extent of the affected area for this scenario is shown in the following figure.

Scenario 2 may have local effects (as also confirmed by the accident which occurred near the pipe outlet that led from inerting equipment).

In terms of scenarios effects, scenario 3 is insignificant due to the low pressure and flow rate of carbon dioxide.

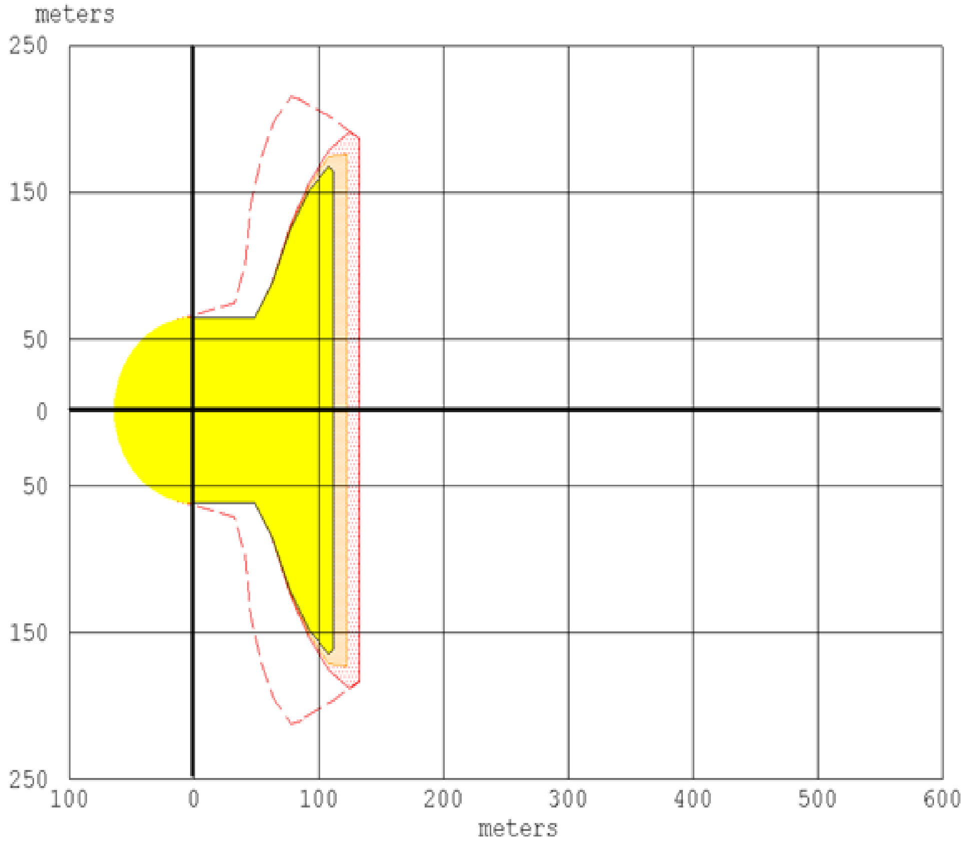

Figure 3: The range of consequences of scenario 1

5. Preventative measures

The presented study shows that even in outdoor areas with a potential spillage of the unbreathable atmosphere from the equipment, it is necessary to take measures to minimize the risks. The unbreathable atmosphere constitutes a danger which arises without warning (e.g. odour), so it is especially necessary to inform the workers (staff training and personal monitoring for the control of atmosphere quality). Other measures are detailed work instructions and sufficient coordination of work near the equipment with a potential spillage of the unbreathable atmosphere.

When working in the environment with increased risk of asphyxiation, it is also necessary to use adequate respiratory devices (respirators). It is important to point out that the breathing mask in this case is not the adequate equipment.

Finally, it is necessary to prepare emergency procedures in case of workers who are in contact with unbreathable atmosphere.

6. Conclusions

This article summarizes the information needed to calculate the extent of consequences due to reduction of oxygen concentration. The article also describes the typical accident scenarios that can lead to the reduction of oxygen concentration in the outdoor environment. These scenarios were modeled in ALOHA software. The results show that only immediate release of large quantities of inert gas is significant in terms of the effects on the surrounding population.

In addition the article deals with the accumulation of inert gases inside enclosed spaces (as supported by relatively frequent accidents of this type). In these spaces, warning related to decrease in oxygen concentration in the atmosphere is particularly important (e.g. use of portable detectors).

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