EU DEFENCE AGENCY
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STUDY: BREATHING AGENT POLLUTION

(VERSION: APRIL 2020)

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ResQU2

This document was financially supported from EU project № #C005 entitled: "*Enhancing the durability of learning experiences gained in ChemSAR, HAZARD, DiveSmart Baltic and Mirg-Ex projects on guidelines, operational plans and procedures and exercises related to incidents at sea and in ports*" under the program *Interreg–Baltic Sea Region* and project ID 458611 of the program entitled: "*International Co-financed Projects*", sponsored by Polish Ministry of Science and Higher Education

Context

Introduction

An unexpected air hyperbaric exposition can occur as a result of submarine damage or during the presence of people in air traps following sinking of a surface vessel.

As for submarines, their crews are trained in damage control (survival) procedures, have access to rescue equipment and submarine have resources designed to cope with some damage scenarios. An increase in pressure in one of the compartments may not affect a whole vessel. The vessel can retain some power supplies and its crew can seal the vessel, and then using compressors can put decompression under control. When the damage is extensive the crew can use special equipment to escape to the surface, preventing, in this way, their organisms from becoming saturated.

There do not exist any dedicated elements of the rescue system which people who have got stuck in a sunken surface vessel could use to counter the effects of air saturation hampering the rescue operation. So far chances for survival of victims under such conditions have been viewed with scepticism. However the case of $Harrison\ Okene$ who survived for more than 62 hrs in a sunken tugboat $Jascon$-4, which had sunk in the Atlantic on 26 May, 2013 at the depth of 30 mH_2O about 30 km off the Nigerian coast requires a change in approach to this issue.

Breathing agent pollution

Pollution of a breathing agent by toxic components which affect human organism is always undesirable. Generally, it can be assumed that the response of an organism to a toxic component in the form of vapor or gas is dependent on its partial pressure: $p_i \equiv p \cdot x_i$, where: p_i is partial pressure of the i^{th} component $[Pa]$, p represents total pressure of gas mixture $[Pa]$, and x_i is mole fraction of the i^{th} component $[mol \cdot mol^{-1}]$. If for the atmospheric pressure p_0 the acceptable content of toxic component is equal to $x_i^{max} = x_i$, for the pressure equivalent to the depth of 10 mH_2O the acceptable content of this component is half lower: $x_i^{max} = 0{,}5 \cdot x_i$. If in the breathing agent there occur more than one type of pollutants, the law of cumulative pollution action is applied (1): $\sum_i \frac{x_i}{x_i^{max}} \leq 1{,}3$. Some authors recommend adopting magnitude 1,0 instead of 1,5. The maximum acceptable concentration C_i^{max} of the toxic substances is usually calculated in relation to the atmospheric pressure p_0. Using the definition of partial pressure the maximum pressure p_i^{max} can be calculated for toxic substances: $p_i^{max} = p_0 \cdot \frac{C_i^{max}}{100\%}$. Using the definition of percentage concentration $C_i \stackrel{\text{def}}{=} x_i \cdot 100\%$, the following can be written:

$$\sum_i \frac{C_i}{C_i^{max}} = \sum_i \frac{x_i}{x_i^{max}} = \sum_i \frac{p_i}{p_i^{max}} \leq 1{,}5 \quad (1)$$

where: C_i –concentration of the i- th polluting component $[\%_{v.}]$; C_i^{max} –maximum acceptable concentration of the i- th polluting component $[\%_v]$; x_i –mole fraction of the i th polluting component $[mol \cdot mol^{-1}]$; x_i^{max} –maximum acceptable mole fraction the i th polluting component $[mol \cdot mol^{-1}]$; p_i –partial pressure of the i- th polluting component $[Pa]$; p_i^{max} –maximum acceptable partial pressure of the i th polluting component $[Pa]$.

As the partial pressure of the toxic substance i is $p_i = p_0 \cdot \frac{C_i}{100\%}$, the dependence can be written for hyperbaric conditions (1):

$$\frac{p}{p_0} \sum_i \frac{C_i}{C_i^{max}} \leq 1{,}5 \quad (2)$$

where: p –total pressure at the depth of diving $[Pa]$; p_0 –atmospheric pressure $[Pa]$.

Air pollution in an ecologically closed atmosphere can be divided into three groups:

- pollutants caused by air[1]
- pollutants caused by technical elements being in contact with a breathing agent[2]
- pollutants caused by human organism.

Pollutants caused by breathing air

Typical pollutants caused by breathing air are: carbon dioxide $< 0{,}05\%_{obj.}$, nitrogen oxides $< 0{,}7\ mg \cdot m^{-3}$, hydrocarbons $< 5{,}0\ mg \cdot m^{-3}$, carbon oxide $< 3{,}0\ mg \cdot m^{-3}$,water vapor $[0{,}01 - 0{,}1]\ g \cdot m^{-3}$ etc. The composition of dry air is shown in **Table 1**.

[1]or other components of breathing gas mixture

[2]e.g. volatile components of paints, volatile components of thermal insulation, maintenance preparations, etc.

Tab. 1.

Composition of dry air in volume and mass percentage

Gas	N_2	O_2	Ar	CO_2	H_2	Ne	He	Kr	Xe
$C\ [\%_v]$	78,03	20,99	0,93	0,030	0,01	0,018	0,0005	0,001	0,00001
$C\ [\%_v]$	75,47	23,20	28	0,046	0,001	0,0012	0,0001	0,0003	0,0004

Pollutants caused by technical equipment

Classification societies provide the most common types of pollutants caused by technical equipment and their maximum acceptable concentration magnitudes. The review of the selected pollutants coming from technical equipment is illustrated in **Table 2** (2; 3). Data on safe concentration of pollutants can be found in some instruction manuals dealing with the issue of survival in special conditions, e.g. (3).

Table 3 contains the maximum acceptable concentration of some toxic vapors and gases used in struggle for survival. These magnitudes are used in the formula for cumulative action of pollutants. **Table 4** contains the maximum acceptable concentration confirmed with modern research methods and legally approved limits for concentration of selected toxic compounds in the environment, which in everyday time-limited exposition do not cause, in a longer period, pathological changes or diseases in present and future generations.

Table 2 and **Table 3** present examples of acceptable equivalent content magnitudes x_{SEV} for some selected pollutants for various exposition periods. The measurement results of concentration of polluting substances x can be applied to calculate the maximum safe depth for using breathing agent p_H with regard to equivalent content SEV [3] of toxic substance x_{SEV}:

$$p_H = \frac{x_{SEV}}{x} \cdot p_0 \tag{3}$$

where: x_{SEV} −equivalent content of pollutant $[ppm_v^{SEV}]$; x −content of pollutant in sample $[ppm]$; p_H −total hyperbaric pressure $[Pa]$; p_0 −normal pressure $[Pa]$.

[3] Surface Equivalent Value.

Tab. 2.
Maximum acceptable concentration of some toxic substances in submersible objects[4] (1)

Chemical compound		Source of pollution	Maximum acceptable concentration for the moment of exposition		
			1 *hrs*	24 *hrs*	90 *days*
acetylene	C_2H_2	fried dishes	6000 *ppm*	6000 *ppm*	6000 *ppm*
acrolein	CH_2CHCHO	fried dishes	—	0,1 *ppm*	—
isopryl alcohol	C_3H_7OH	paint diluent	—	—	1 *ppm*
ammoniac	NH_3	metabolism	400 *ppm*	50 *ppm*	25 *ppm*
stibine	SbH_3	battery gassing	—	0,05 *ppm*	0,01 *ppm*
arsine	AsH_3	battery gassing	—	0,1 *ppm*	0,1 *ppm*
benzene	C_6H_6	diluent	—	100 *ppm*	0 *ppm*
methyl chloride	CH_3Cl	diluent	—	—	25 *ppm*
chloroform	$CHCl_3$	diluent	—	—	1 *ppm*
hydrogen chloride	HCl	freon decomposition	10 *ppm*	4,0 *ppm*	0 *ppm*
nitrogen dioxide	NO_2	generators	10 *ppm*	0 *ppm*	0,5 *ppm*
sulphur dioxide	SO_2	sanitation	10 *ppm*	5,0 *ppm*	0 *ppm*
carbon dioxide	CO_2	metabolism	2,5%	0%	0,5%
ethanol	C_2H_5OH	diluent	—	—	100 *ppm*
hydrogen fluoride	HF	freon decomposition	8 *ppm*	1,0 *ppm*	0,1 *ppm*
formaldehyde	$HCHO$	ready-made dishes	5 *ppm*	5 *ppm*	5 *ppm*
phosgene	$COCl_2$	freon decomposition	0 *ppm*	0,1 *ppm*	0,05 *ppm*
freon 113	$CClF_2CCl_2F$	cooling installations	—	—	100 *ppm*
freon 11	CCl_3F	cooling installations	—	—	100 *ppm*
freon 12	CCl_2F_2	cooling installations	—	—	100 *ppm*
freon 114	$CClF_2CClF_2$	cooling installations	—	—	100 *ppm*
methyl-ethyl ketone	$CH_3COC_2H_5$	diluent	—	—	20 *ppm*
methyl-isobutyl ketone	$CH_3COC_3H_7$	diluent	—	—	20 *ppm*
xylene	$C_6H_4(CH_3)_2$	paint diluents	—	—	50 *ppm*
methane	CH_4	sanitation	3%	3%	3%
methanol	CH_3OH	diluent	-	-	10 *ppm*
ozone	O_3	commutated motors	0 *ppm*	0,1 *ppm*	0,02 *ppm*
nitrogen oxide	NO	generators	10 *ppm*	0 *ppm*	0,5 *ppm*
toluene	$C_6H_5CH_3$	diluents	—	—	20 *ppm*
trimethylobenzenes	$C_6H_3\ (CH_3)_3$	diluents	—	—	3 *ppm*
aromatic hydrocarbons except benzene		paint diluents	—	—	10 $mg{\cdot}m^{-3}$
aliphatic hydrocarbons except methane		paint diluents	—	—	10 $mg{\cdot}m^{-3}$
hydrogen	H_2	battery gassing	1000 *ppm*	1000 *ppm*	1000 *ppm*

[4] Normal conditions.

Tab. 3.

Maximum acceptable concentration of some toxic vapours and gases used in struggle for survival (3)

Time	Carbon oxide	Nitrogen oxides	Benzene	Toluene	Xylene	Formaldehyde	Acetaldehyde
$[min]$	$[mg{\cdot}m^{-3}]$						
5	700	60	—	—	—	—	—
10	600	45	90	—	—	—	—
15	400	35	70	270	—	—	—
20	360	30	60	—	—	—	—
30	300	25	50	170	130	8	100
40	240	20	45	—	—	—	—
60	200	15	37	165	123	—	—
120	150	—	25	115	110	—	—
240	100	—	15	80	90	—	—
480	60	10	—	—	79	—	—
1440	40	—	—	—	60	—	—

Tab. 4.

Maximum acceptable concentration of selected toxic compounds for work environment (3)

Chemical compound		Maximum acceptable concentration for the time of exposition $[mg{\cdot}m^{-3}]$			
		4 hrs	8 hrs	24 hrs	$[2000; 3000] hrs$
stibine	SbH_3	0,5	0,3	0,15	—
arsine	AsH_3	—	0,1	—	0,003
benzene	C_6H_6	—	5	—	2
phosgene	$COCl_2$	—	0,5	—	—
freon 12	CCl_2F_2	6000	3000	—	150
freon 114	$CClF_2CClF_2$	—	1000	—	100
xylene	$C_6H_4(CH_3)_2$	—	50	—	12
mercury	Hg	—	0,01	—	0,003
nitrogen oxide	NO	5	5	—	0,5
carbon oxide	CO	30	20	18	5
toluene	$C_6H_5CH_3$	—	50	—	8
hydrocarbons	C_xH_y	—	300	—	35

Pollutant whose source is human organism
In order to analyze survival a model was developed of pollution emitted by a 'standard human being', engaged only to very light work, is presented in **Table 5** (2).
Use of oxygen and emission of carbon dioxide can be substantially reduced by being in the totally non-active state – **Table 6.** The investigations show that in the condition of non-activity use of oxygen can be at the level of 18,7 $dm^3 \cdot hour^{-1} \cdot person^{-1} STP$ [5], and carbon dioxide emission at the level of 17,0 $dm^3 \cdot hour^{-1} \cdot person^{-1} STP$ (5). There can occur higher magnitudes of oxygen use at the level of 30,0 $dm^3 \cdot hour^{-1} \cdot person^{-1} STP$ and carbon dioxide emission at the level of 25,0 $dm^3 \cdot hour^{-1} \cdot person^{-1} STP$. Survival is possible as long as partial pressure of oxide can be maintained above $p_{O_2} \gtrsim 16\ kPa$, and partial pressure of carbon dioxide up to the level of $p_{CO_2} < 2{,}5\ kPa$.
Short-term conditions under which survival is possible are regarded as those where partial pressure of oxygen is at the level of $p_{O_2} \geq 14\ kPa$, and of carbon dioxide has not exceeded $p_{CO_2} \leq 5\ kPa$. At present it is claimed that action of small concentration of volatile hydrocarbon pollutants of a breathing agent on a human organism usually has narcotic character[6]. It is high concentration magnitudes that produce toxicity (6).

Tab. 5.
Pollutants emitted by a "standard human being" under the condition of little effort (2)

Pollutant		Emission of pollutant over 24 hrs period
carbon dioxide	CO_2	550 dm^3
methane	CH_4	3 dm^3
carbon oxide	CO	0,7 dm^3
acetone	$(CH_3)_2CO$	0,0005 dm^3
water vapour	H_2O	2000 dm^3
Heat emission: - latent heat - the other heat		 5600 kJ 6300 kJ

[5] ***S**tandard **T**emperature and **P**ressure — STP.*
[6] anesthetic.

Tab. 6.
Streams of used oxygen and lung ventilation depending on physical effort (4)

Physical effort		Stream of used oxygen	Number of breathes per minute	Lung ventilation	Border stream of used oxygen
Intensity	Example	$[dm^3 \cdot min^{-1}]$	$[min^{-1}]$	$[dm^3 \cdot min^{-1}]$	
very light	lying on bed	0,25	do 20	8–10	do 0,5
	sitting still	0,30			
	standing still	0,40			
light	walk 3,5 $km \cdot h^{-1}$	0,7	20–25	10–20	0,5–0
moderate	march 6,5 $km \cdot h^{-1}$	2	25–30	20–30	0–5
hard	swimming at speed of 3,0 $km \cdot h^{-1}$	8	30–35	30–50	5–2,0
very hard	running at speed of 13 $km \cdot h^{-1}$	2,0	35–40	50–65	2,0–2,5
extremely hard	running uphill	4,0	>40	>65	>2,5

Conclusions

Possibilities for survival in hyperbaric facilities generate a multithreaded problem situation. One of the issues discussed briefly in this study is assessment of the danger generated by toxic pollutants that can occur in a breathing agent. It carries out an initial analysis of breathing agent pollutants which can occur and their possible action on a human body. Many of them are dependent on time and they are connected with each other in an interactive manner. These issues are not dealt with in here as they will be the subject of further analyses dedicated to toxicity of the main components of the breathing agent.

Acknowledgement
This Document was financially supported by project ID 458611 of the program entitled: International Co-financed Projects sponsored by Polish Ministry of Science and Higher Education.

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