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On possible use of a Polish soda lime and oxygen in the oxygen breathing diving apparatus

SUMMARY

The paper presents research aimed at implementation of Polish soda lime (produced by Chemical Company Oświęcim) as the absorbent in carbon dioxide canisters of Oxy-NG diving apparatus.

Results of this work were presented during Annual Meeting of Underwater Diving Working Group, NATO Standardization Agency, held at US Navy Experimental Diving Unit, Panama City, USA

METHODS

Fourteen Polish Navy experimental divers from Army and Navy served as the research subjects. They were recruited from Military Diving School, the diving naval vessel ORP „LECH", Military Sporting Centre „Flota" and Diving Gear and Underwater Work Technology Department, Polish Naval Academy in Gdynia.

Each subject passed a standard oxygen tolerance test prior to beginning diving and became familiar with experimental scientific hyperbaric exposure. Each of them was trained in the use of closed - - circuit oxygen rebreathing apparatus of Oxy-NG type (produced by La Spirotechnique, Nice, France).

Their main physiological data are shown in Fig.1. Their diving experience was different. None of them had an earlier experience in diving with an oxygen breathing apparatus. 27 experimental exposures in the hyperbaric complex were performed. The divers were medium conditioned and not physical exercised prior to the experimental series. The divers were examined by Department of Physiology, Sport Academy, Gdańsk. The divers' condition was determined on the basis of their oxygen uptake, standard spirometric measurements and other physiological data.

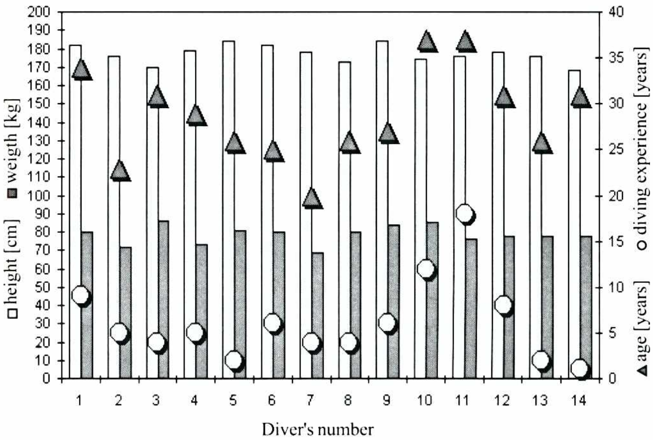

Fig.1. *Height, weight, age and diving experience of the divers who served as the subjects*

All diving exposures were performed in a dry diving chamber. The divers were subject to pressure to simulate diving depth. The divers exercised by means of 824E Bicycle Ergometer (produced by MONARK EXERCISE AB, Verberg, Sweden). They were not loaded with the diving apparatus. Two types of temperature tests were performed. In the first series the diving apparatus was immersed in ice--water mixture. During second type of tests the diving apparatus was placed in the chamber atmosphere.

The divers breathed by means of the mentioned Oxy-NG oxygen diving apparatus. Polish soda lime made by DWORY Co, Oświęcim, Poland – acc. to a Polish standard and medical oxygen made by Gdańsk Technical Gases Works, Gdańsk, – acc. to a Polish standard were used in experiments. Average mass of the soda lime contained in the absorber was 1.94 (±0.03) kg [3]. Before exposure the diving apparatus was flushed three times by means of pure oxygen. The following procedure was used :

- the diver sucked gas, as much as possible, from breathing loop through the mouthpiece and exhaled it by nose
- the breathing loop was filled with fresh oxygen through the purge valve
- the diver repeated this operation three times.

During flushing the diver had to keep the mouthpiece all time in his mouth or he could close the mouthpiece valve before charging of the breathing loop. It should be noted that stabilisation of the breathing content relies on the dynamic equilibrium between fresh and exhaled mixture. Flushing process with the fresh breathing gas does not guarantee that the equilibrium is reached immediately, however, it can cause that oxygen percentage in the inspired bag would be closer to that which occurs during the diver rest. The percentage content of oxygen in the medical oxygen is 98% by volume. Theoretically flushing of the breathing space is of the same effectiveness for each depth. Theoretical results of oxygen content calculations in the breathing bag is a function of the breathing loop flushing multiplication factor for the Oxy-NG oxygen diving apparatus ; compatibility of theoretical and experimental results were repeatedly checked. During the experiments an effort was made to maintain oxygen percentage in the inspired breathing gas at the level higher than 90% after the flushing process was finished [3].

During experimental diving two methods of gas sampling were applied for analytical reasons. In majority of cases the continuous method of sampling was used. The continuous flow was maintained at the level of 40 (±5) $dm^3 \cdot h^{-1}$. Periodical methods of gas sampling were also used. Some used methods of periodical gas sampling are presented in Tab.1. The delay time due to the measurement pipe (of 3 mm diameter and about 5 m length) was approximately 1min 20 s.

Tab.1. *Periodical gas sampling methods used for analysis of oxygen and carbon dioxide content in the inspired breathing gas*

Number of exposure	Methods of gas sampling for analytical purposes
21	every 10 min : opening for 3 min, readout in 3 min
22	every 10 min : opening for 2 min, readout in 2 min
23	every 10 min : opening for 5 min, readout in 5 min

The experimental dives were divided into two parts. The first part consisted of carbon dioxide absorbent canister duration studies and the second one consisted of analysis of the breathing atmosphere composition at diver's graded exercise. During carbon dioxide absorbent canister duration studies the subjects pedalled the ergometer at 50 W. If the absorbent canister breakthrough did not occur during permissible exposure of the subject at a given depth, the diving apparatus was blanked. After replacement of the hoses and mouthpiece the diving apparatus was prepared to the next use of the next diver. The same procedure was used when oxygen was used up from the supply cylinder. Such procedure was continued as long as carbon dioxide percentage, at normal pressure (i.e. approximately at 100 kPa), did not exceed 1% by volume. The breakdown point (end-point) of carbon dioxide supply is defined as a duration after which carbon dioxide partial pressure in the inspired gas maintains at the level of 0.5 kPa.

The studies of the inspired gas composition at the graded exercises consisted of seven 10 min cycles. All experiments were performed after treble flushing of the diving breathing apparatus space and stabilisation of the gas composition. One cycle consisted of 6 min exercising and 4 min of rest. The work rates were 30, 50, 80, 80, 100, 120, 150 W. In order to prolong oxygen exposure two cycles were performed at work rate of 80 W. The duration studies were performed at about 21°C temperature (the hyperbaric complex temperature) and 0°C (immersion in ice-water mixture).

Before each diving the divers were briefed about the signs and symptoms of oxygen toxicity. An air-breathing diver inside and medical officer outside the chamber accompanied the subjects all the time. Medical examination of each subject was performed before and after each diving. Breathing rate, systolic and diastolic pressure and heart rate were examined. The attendant diver examined the subjects in wet hyperbaric chamber. Gas sampling point was located on the supply hose in front of the control valve (Fig.2).

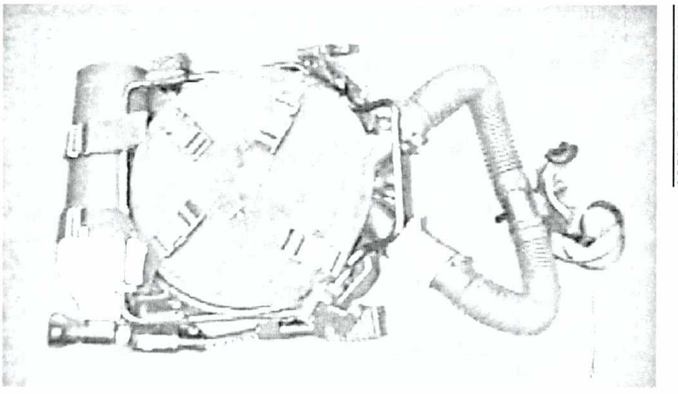

Fig.2. Location of the gas sampling pipe connection in the Oxy-NG diving apparatus

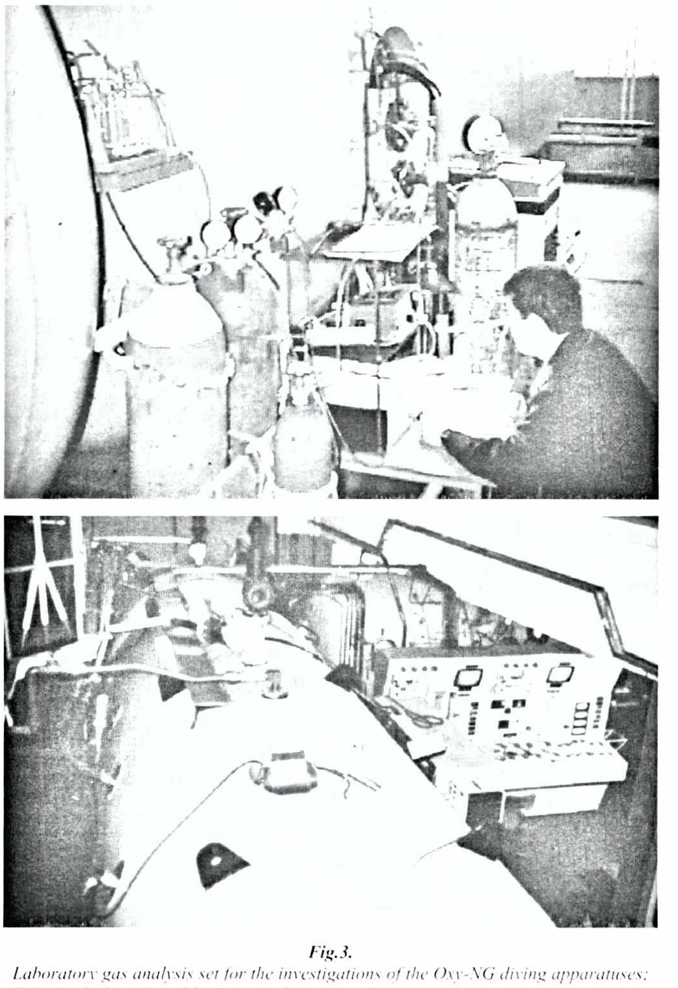

Fig.3.
Laboratory gas analysis set for the investigations of the Oxy-NG diving apparatuses; DGKN-120 land-based hyperbaric diving complex of Polish Naval Academy, Gdynia

***Tab.2.** The relationship between partial pressure of carbon dioxide in the inspired gas and respiration time from the Oxy-NG diving apparatus*

	Number of exposure																							
	2	3	4	7	8	10	11	12	14	15	16	17	19	5	9	13	18	21	22	23	24	25	26	27
	Water depth [m]																							
	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	0.5	7.5	7.5	7.5	7.5	7.5	9	7.5	1
	Temperature [°C]																							
	19.6	18.8	18.6	21.2		26.4	25.7	20.6	22.3	21.9	22	22.5	18.5	19.7	21.8	21.6	0	17.8	22.6	19.9	0	20	0	0
Time	Programmed work rate													Constant work rate of 50 W										
[min]	Partial pressure of CO_2 [kPa]																							
10	0.002	0.002	0.000	-	0.002	0.005	0.007	0.000	0.000	0.002	0.000	0.002	0.007	0.002	-	0.001	0.000	0.002	0.000	0.028	0.023	0.028	-	0.000
20	0.002	0.002	0.000	0.002	0.014	0.002	0.018	0.002	0.000	0.004	0.004	0.002	0.046	0.000	0.016	0.000	0.000	0.000	0.000	0.024	0.026	0.044	0.028	0.000
30	0.002	0.002	0.000	0.000	0.014	0.000	0.018	0.000	0.000	0.002	0.004	0.002	0.070	0.002	0.038	0.000	0.000	0.000	0.000	0.023	0.032	0.057	0.000	0.000
40	0.004	0.002	0.002	0.000		0.002	0.028	0.002	0.000	0.005	0.005	0.002	0.074	0.002	0.038	0.000	0.000	0.052	0.000	0.024	0.067	0.106	0.000	0.001
50	0.009	0.007	0.005	0.000		0.002	0.056	0.002	0.000	0.021	-	0.004	0.088	0.004	0.058	0.000	0.000	0.014	0.002	0.033	0.070	0.137	0.000	0.000
60	0.016	0.014	0.016	0.007		0.002	0.079	0.005	0.010	0.054	0.009	0.007	0.142	0.012	0.077	0.001	0.002	0.028	0.002	0.033			0.000	0.001
70	0.028	0.023	0.042	0.021		0.004	0.096	0.016	0.030	0.084	0.032	0.016	0.198	0.024	0.100	0.001	0.005	0.037	0.007	0.042			0.000	0.001
80	0.040	0.037	0.075	0.046		0.010	0.135	0.052	0.060		0.066	0.042	0.282	0.035	0.110	0.002	0.010	0.051	0.012	0.049			0.004	0.001
90				0.018										0.047	0.122	0.005	0.018	0.040	0.015	0.040				0.002
100														0.028	0.119	0.005	0.005							0.001
110															0.032	0.007	0.023							0.037
120															0.117	0.002	0.035							0.050
130															0.161	0.005	0.052							0.076
140															0.156	0.016	0.066							0.098
150															0.191	0.019	0.102							0.117
160															0.217	0.032	0.112							0.170
170															0.233	0.042	0.144							0.201
180															0.254	0.051	0.126							0.312
190															0.282	0.059	0.038							0.345
200															0.046	0.082	0.150							0.579
210															0.346	0.102	0.506							0.502
220															0.339	0.116	0.602							
230															0.413	0.169								
240															0.429	0.123								
250															0.486	0.301								
260															0.516	0.353								
270															0.624	0.565								
280																0.646								

***Note :** Results of exposures no. 1, 6 and 20 were not taken into account because of some technical troubles experienced during measurements*

Gas samples were analysed with the respect to oxygen and carbon dioxide content. Percentage of oxygen was monitored with the use of SERVOMEX 262A gas analyser manufactured by SERVOMEX, UK. Carbon dioxide content was monitored by using ANALOX 5000 analyser manufactured by SCOTTISH ANGLO, UK. Gas analysers were calibrated by means of the pure gases or their mixture prepared with the use of SA-27/3-F analytical pump of ±0.25% relative accuracy, manufactured by H.WÖSTHOFF oHG, Bochum, Germany. The same procedure was used only to control the gas analyser's indications after the exposures had been completed. During experiments the gas analyser indications were from time to time checked up by means of a rapid air method or pure gases and their mixtures. No deviations exceeding the permissible error resulting from the instrument accuracy were observed.

Packed absorbent was sampled before and after each diving. Carbon dioxide absorber of the Oxy-NG diving apparatus contained soda lime of the properties in accordance with the Polish standard. The results of its chemical analysis complied with that standard [3].

The hyperbaric complex was pressurized with air. In order to control air quality the gas analysis was performed before each exposure. Quality of air used for the diving purposes was covered by the Polish standard.

Results and discussion of experimental diving

27 exposures were conducted by 14 divers at the water depth of 0.5 to 9.0 (±0.4) m and the exposure time from 30 to 360 min. The results of the Oxy-NG diving apparatus canister duration studies are summarized in Tab.3 (compare also Tab.2). The breakthrough of carbon dioxide canister is defined as the instant when partial pressure of carbon dioxide in the inspired gas is stable and exceeds 0.5 kPa. However, a canister duration study should be performed until partial pressure of carbon dioxide in the inspired breathing gas is 1 kPa. For example, according to the US Navy standards the instantaneous partial pressure in the inspired breathing gas is maintained at the level of 2 kPa [2,6].

Tab.3. *The results of the canister duration study (for Oxy-NG diving apparatus)*

No of exposure	Water depth	Duration	Ambient temperature
	[m]	[min]	[°C]
	±0.4 m	±10 min	
9	7.5	250	21.8±0.2
13	0.5	260	21.6±0.2
18	7.5	200	0.0±0.0
27	1.0	190	0.0±0.0

No symptoms of oxygen toxicity occurred during the whole study. Only exposure No 8 was discontinued because the diver's respiration rate decreased to 4 breathes/min with further declining tendency. During the exposure the diver felt well, but looked tired. The earlier measured respiration rate, at the similar work rate, was compared with the observed one. The earlier respiration rate was twice greater than that during the discontinued exposure. Possible occurrence of oxygen toxicity (and also some technical reasons) led to the exposure completion.

The reasons for exposure ending the other authors reported and symptoms that occurred in the similar exposures, was e.g. tinnitus [4]. There were also certain mild symptoms of oxygen pulmonary toxicity during exposures i.e. retrosternal burning associated with small changes in forced vital capacity. No important spirometric changes after oxygen exposures were observed. The observed changes were contained within the measuring error range.

Exposures performed in cold water showed decrease in canister duration by about 60 min. It was 20% of that for exposures in warm water (Tab.3). Besides, the process was more intensive (rapid increase of carbon dioxide partial pressure). Tab.2 presents the relationship between carbon dioxide partial pressure in the inspired breathing gas and exposure duration, at different work rates and temperatures. Cycloergometer work performed by the diver was determined with the use of the following equation [1] :

$$W = 0.06 \cdot P \cdot t + 2 \cdot t$$

where :

W - performed work [kcal]
P - work rate on cycloergometer [W]
t - work time [min].

In Fig.4 the canister duration of the LAR V diving apparatus [7] and Oxy-NG apparatus are compared.

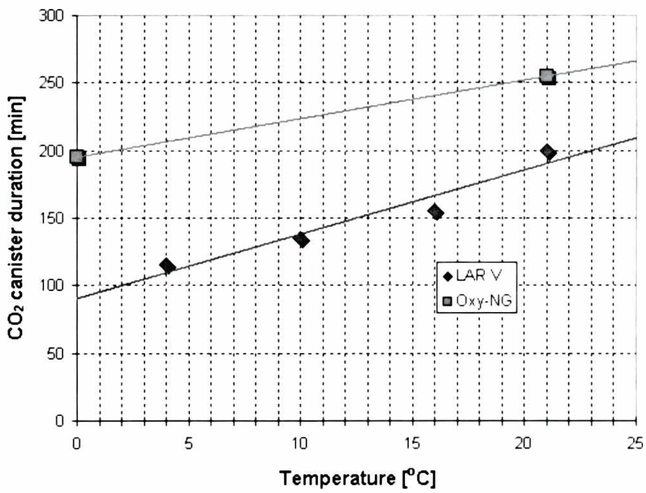

Fig.4. *Comparison of canister duration of the diving apparatuses : LAR V (mass of absorbent : 2.4 kg, assumed oxygen consumption : 1.3 dm³min⁻¹) and Oxy-NG (mean mass of absorbent-soda lime : 1.94 (±0.03) kg of the properties covered by the Polish standard)*

CONCLUSIONS

❑ As far as the carbon dioxide absorber of the properties covered by the Polish standard, used for the Oxy-NG diving apparatus, is concerned :

* Carbon dioxide absorber duration in cold water is shorter than that in warm water and mechanism of carbon dioxide increase is different in each case. Due to the rapid increase of carbon dioxide content the canister breakthrough is reached in a short time. It occurs after normal work of absorber in cold water. The results of exposures of duration up to 1.5 h have shown that carbon dioxide poisoning will be not possible if only the diving apparatus is suitably prepared and not damaged (for example flooded).

* The carbon dioxide absorber efficiency of Oxy-NG diving apparatus is slightly dependent on temperature. It is due to its different construction which ensures better thermal protection.

* The following conclusions were drawn from the experiments :

- the carbon dioxide absorber duration enables pure oxygen diving without disturbances. The diver is supplied from the gas cylinder of 1.5 dm^3 volume and 20 MPa pressure
- the duration of the considered carbon dioxide absorber applied to Oxy-NG diving apparatus, amounts to 2.5 hour at 0°C temperature (i.e in the worst conditions)
- the soda lime of the properties covered by the Polish standard may be safely used as an absorbent for the Oxy-NG diving apparatuses. The Oxy-NG apparatus equipped with canisters containing soda lime may be used in diving up to the seawater depth of 12 m, according to the permissible diving duration provided in the Polish diving regulations [5].

❑ As far as the quality of oxygen used in diving is concerned :

- ✶ The gas analysis results have shown that oxygen content in the inspired gas is maintained at the level of 94 (±1) $\%_{vol.}$. The obtained values seem to be typical for the majority of the diving apparatuses. No cumulative contaminants leading to a decrease of oxygen content in the inspired gas were observed. Oxygen percentages obtained during the exposures can be increased due to the gas analysis technique. However results obtained by means of the different gas analysis technique have not shown any significant statistical discrepancies according to the Q-Dixon Test [8]
- ✶ The use of medical oxygen (of the properties covered by the Polish standard) in the Oxy-NG diving apparatus is acceptable. An oxygen of a better quality is recommended (of pure oxygen content not less than 99.9%)
- ✶ The applied pure-oxygen treble flushing of the breathing space is necessary. During diving, the diving apparatus should be flushed every 30 min.

Appraised by Romuald Olszański, D.Sc.med.

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where : NEDU - Navy Experimental Diving Unit
UBA - Underwater Breathing Apparatus

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Conference

Drives and Control Systems 2002

On 12÷14 February 2002, already for the eighth time, the „Fair for Producers, Subcontractors and Sellers of Drives & Control Systems was held in Gdańsk. The event has been willingly visited by exhibitors and guests. On the one hand it gives an opportunity of presenting many interesting design solutions and achievements in the field of production processes for various driving and control units, often of wide application. On the other hand the fair makes direct contacts of producers with potential purchasers, and usually with users of such products, possible. It is also a convenient place for signing commercial contracts.

For several years an integral part of the fair - due to efforts Gdańsk University of Technology - is a special seminar during which scientific workers of the University transfer their knowledge being in the area of interest of the Seminar's participants, and in comparison with the fair exhibits.

This year the Seminar was also carried out in two sessions :

- ❖ Mechanical, hydraulic and pneumatic drives
- ❖ Automation of electric drives and electronic control

During the **first session** the following topics were considered :

- ★ Application of magnetoreological and electroreological liquids to hydrokinetic gear control
- ★ Assessment of energy and ecological parameters of hydraulic systems with combustion engine drive – at spectral form of loading
- ★ Predictive control for driving systems
- ★ Diagnostic control of machine bearing units
- ★ Dilemmas of water jet propulsion for ships
- ★ Technology of hydraulic valves
- ★ Ceramic materials applicable to sliding bearings
- ★ Testing of lapping quality of flat ceramic elements.

Moreover, research ability was presented of the tribology laboratory of the Department of Construction and Exploitation of Machines, Mechanical Faculty, Gdańsk University of Technology.

The **second session** was devoted to :

- ✶ Practical realization of asynchronic motor control
- ✶ A novel system of MRAS velocity estimator
- ✶ Direct control of asynchronic motor torque, based on multiscalar model
- ✶ Inverters of central resonance circuit, applicable to electric drives – a comparative analysis
- ✶ Dynamic characteristics of asynchronic motor gauge-free drive
- ✶ Evolutionary design of control systems
- ✶ Numerical conditions for synthesis tasks of time-discrete control systems

Arrangement of education – training workshops is especially worthmentioning, namely :

- ❋ Oil servicing and monitoring during exploitation of machines and devices
- ❋ Diagnosing and identification of sound sources by means of modern energy methods with application of sounder and acoustic holography
- ❋ Energy-electronic active filtration systems : up-to-date technique of electric energy conditioning and supply quality improving
- ❋ Asynchronic motor control method : theory and practice.

All participants of the workshops were granted with occasional participation certificates.

The Seminar in question was organized under the auspices of Gdańsk University of Technology and the Section on Hydraulic Drive & Control, Society of Polish Mechanical Engineers, Gdańsk.