Possibility of the use Polish soda lime as the absorbent in the canisters of the oxygen breathing apparatus type Oxy-NG

R. Klos\textsuperscript{1} & A. Majchrzycka\textsuperscript{2}

\textsuperscript{1}The Naval Academy of Gdynia, Department of Diving Gear and Underwater Work Technology, Poland
\textsuperscript{2}The Technical University of Szczecin, The Faculty of Mechanical Engineering, Poland

Abstract

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

1 Methods

Fourteen Polish Navy experimental divers served as the subjects. Each subject had passed a standard oxygen tolerance test prior to the beginning of diving training and became familiar with experimental/scientific hyperbaric exposition. Each of them was experienced in the use of closed -circuit oxygen rebreathing apparatus type Oxy-NG (oxygen set produced by La Spirotechnique – Nice). Their main physiological data are shown in Figure 1. Twenty-seven experimental exposures in the hyperbaric complex were performed. The results of 6 exposures were turned down for the following reasons: choice of wrong load, wrong assembled diving set, the diver felt himself badly, wrong breathing – the diver breathed by nose. The divers’ condition was determined on the base of their oxygen uptake and other physiological data. Standard spirometric measurements, including: FVC – forced vital capacity, FEV\textsubscript{1} – forced expiratory volume at 1 s, MEF25–maximal expiratory flow at 25% forced expiratory vital capacity, MEF50- maximal expiratory flow at 50% forced expiratory vital capacity, MEF75- maximal expiratory flow at 75% forced expiratory vital capacity, were obtained before and immediately after the longest oxygen
exposure. The results were obtained by means of a spirometer abc PNEUMO 2000.

Figure 1: Age, weight, height and diving experience of the divers who served as the subjects

All diving expositions were performed in dry diving chamber. The divers where pressurised to simulated depth of dive. The divers exercised by means of Bicycle Ergometer Model 824E. The divers 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, diving apparatus was placed inside the chamber atmosphere. The divers breathed by means of oxygen diving apparatus type Oxy-NG. Soda Lime (Polish Standard ZN-9712CHO-26) and medical oxygen (Polish Standard PN-70/C-84910) were used in experiments. Average mass of soda lime contained in the absorber was \((1.94 \pm 0.03)\) kg. Before exposition, the diving apparatus was flushed three times by means of pure oxygen. The following procedure was used:

- the diver sucked gas through the mouthpiece, as much as possible, from breathing loop and exhale by nose,
- the breathing loop was filled with fresh oxygen by means of purge valve.
- the diver repeated this operation for three times.
During flushing, diver has to keep all time the mouthpiece in his mouth or he could close the mouthpiece valve before charging of the breathing loop. It should be noted that content stabilisation of the breathing relies on the dynamic equilibrium between fresh and exhaled mixture. Flushing process with the fresh breathing gas doesn’t guarantee that equilibrium will be reached immediately, however, it will cause that oxygen percentage in the inspired bag will be more closed to the value occurred while the diver rests. Molar balance of oxygen and breathing gas as the whole is presented in Table 1. According to the balance it may be expressed as:

\[ x(i+1) = \frac{p}{p_0} \left[ V_z x(i) + (V_c - V_z) x_w \right] = \frac{p}{p_0} V_c \left[ x(i) - x_w \right] + x_w \]  

(1)

Table 1. Molar balance of oxygen and the breathing gas in the flushing process of the breathing loop

<table>
<thead>
<tr>
<th></th>
<th>Emptying</th>
<th>Filling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oxygen</strong></td>
<td>Increase</td>
<td>( \frac{p}{p_0} (V_e - V_s) x_e )</td>
</tr>
<tr>
<td></td>
<td>Decrease</td>
<td>( \frac{p}{p_0} V_s x(i) )</td>
</tr>
<tr>
<td></td>
<td>Remain</td>
<td>( \frac{p}{p_0} V_e x(i) + (V_e - V_s) x_e )</td>
</tr>
<tr>
<td><strong>Breathing gas</strong></td>
<td>Increase</td>
<td>( \frac{p}{p_0} (V_e - V_s) )</td>
</tr>
<tr>
<td></td>
<td>Decrease</td>
<td>( \frac{p}{p_0} V_s )</td>
</tr>
<tr>
<td></td>
<td>Remain</td>
<td>( \frac{p}{p_0} V_e )</td>
</tr>
</tbody>
</table>

Oxygen content after \((i+2)\) flushing of the breathing loop can be written using eqn (1) as follows:

\[ x(i+2) = \frac{V_z}{V_c} \left[ x(i) - x_w \right] + x_w \]  

(2)

Comparing eqn (1) and (2) gives:

\[ x(i+j) = \frac{V_z}{V_c} \left[ x(i) - x_w \right] + x_w \]  

(3)

On the assumption that for \(i=0 \Rightarrow x(0)=x_{oa}\), eqn (3) can be written as:
Eqn (4) enables to draw an important conclusion that $x(j) \neq f(H)$. It means that flushing of the breathing space is of the same effectiveness for each depth. Theoretical results of oxygen content calculations in the breathing bag as the function of the breathing loop flushing multiplication factor of the oxygen diving apparatus type Oxy-NGT are presented in Table 2. Compatibility of theoretical and experimental results has been checked repeatedly. During 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.

Table 2. Theoretical oxygen content in the breathing bag as the function of the breathing loop flushing multiplication factor of the oxygen diving apparatus type Oxy-NG

<table>
<thead>
<tr>
<th>j</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x(j)$ [mol/mol]</td>
<td>0.74</td>
<td>0.90</td>
<td>0.96</td>
<td>0.97</td>
</tr>
</tbody>
</table>

where: $V_c = 2.5 \text{ dm}^3$, $V_e = 8.0 \text{ dm}^3$.

During experimental diving two methods of gas sampling were for analytical reasons. In majority of cases the continuous method of sampling was used. The stream flow was maintained at the level $40 \pm 5 \text{ dm}^3 \text{ h}^{-1}$. Periodical methods of gas sampling were used as well. The continuous gas sampling resulted in the increase of oxygen percentage in the inspired breathing gas due to automatic supplement of the gas decrement from the breathing loop by the use of the fresh oxygen supplied from the cylinder. Experimental dives were divided into two parts. The first part consists of carbon dioxide absorbent canister duration studies and the second one consists of analysis of the breathing atmosphere composition at graded diver's exercise. During carbon dioxide absorbent canister duration studies, subjects pedalled the ergometer at 50 W. If the absorbent canister breakthrough didn’t occur during permissible exposition of the subject at the given depth, the diving apparatus was blanked. After replacement of the hoses and the 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, in this case approximately 100kPa) didn’t exceed 1% by volume. The breakdown point (end-point) of carbon dioxide is defined as duration after which carbon dioxide partial pressure in the inspired gas was constantly maintained at the level 0.5kPa. Studies of the inspired gas composition at graded exercises consisted of seven 10min cycles. All experiments were performed after treble flushing of the diving breathing apparatus space and stabilisation of the gas composition. One cycle consisted of 6min 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 80 W. As it was already mentioned before, duration studies were performed in temperature 20°C (the hyperbaric complex temperature) and in 0°C (immersion in ice-water mixture. Before each diving, the divers were briefed about the signs and symptoms of oxygen toxicity. The air-supplied diver and medical officer (outside the chamber) accompanied the subjects during all dives. Each subject was medically examined before and after each diving. Breathing rate, systolic and diastolic pressure and heart rate were examined. The subjects were examined in wet hyperbaric chamber by an attendant diver. Gas sampling point was located on supply hose before the direction valve. In order to gas sampling, the special pipe connection was manufactured. Gas samples were analysed with the respect to oxygen and carbon dioxide content. Percentage of oxygen was monitored with gas analyser SERVOMEX 262A. Carbon dioxide content was monitored with ANALOX 5000 analyser. Gas analysers were calibrated by means of the pure gases or their mixture manufactured with the use of the analytical pomp, type SA-27/3-F. Packed absorbent was sampled before and after each diving. Carbon dioxide absorber of the diving apparatus Oxy-NG contained soda lime of the properties covered by the standard ZN-97/ZChO-26. Hyperbaric complex was pressurised with air. In order to control air quality, the gas analysis was performed before each exposition. Quality of air used for the diving purposes is covered by the standard BN-79/3746-12. Mean oxygen consumption was computed from oxygen-supply cylinder pressure drop, the known water volume of the cylinder, and suitable corrections for gas sample rate and temperature. Eqn (5) enables to calculate mean oxygen consumption:

\[
\bar{V}(O_2) = \frac{T_0}{I + T_0} \frac{\Delta p}{\Delta t} \frac{1}{P_o} V_B - V_o x(O_2)
\]

2 The results

Twenty seven exposures at the depth [(0.5+9.0)±0.4] m H2 were obtained in 14 divers. Table 3 summarises the results of the Oxy-NG diving apparatus canister-duration studies. The results are presented in Figure-2, Figure-3 and Figure 4. The breakthrough of carbon dioxide canister is defined as the point where partial pressure of carbon dioxide in the inspired gas will stabile exceed 0.5kPa. However, canister-duration study should be performed until partial pressure of carbon dioxide in the inspired breathing gas will be 1kPa. For example, the permissible partial pressure in the inspired breathing gas is maintained at the level 2kPa, [1]. There were no symptoms of oxygen toxicity during the whole study. Only the one exposure was discontinued because the diver's respiration rate decreased to 4 breathes/min with further declining tendency. Earlier measured respiration rate at the similar work rate was compared with the observed one. Earlier respiration rate was twice greater than while discontinued exposure. Possibility of oxygen toxicity was the reason of the exposure completion. There were also the other technical reasons of the exposure
discontinuity. The other authors reported symptoms that occurred in the similar exposures; for example tinnitus [2]. 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. Observed changes were within the range of measuring error. Exposures performed in cold water have shown decrease in canister –duration, approximately 60 min. It is 20% that of exposures in warm water, Table 3.

Table 3. The results of the canister- duration study (the diving apparatus of the type Oxy-NG).

<table>
<thead>
<tr>
<th>No of exposure</th>
<th>Depth [mH2O] ±0.4 mH2O</th>
<th>Duration [min] ±10 min</th>
<th>Ambient temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>7,5</td>
<td>250</td>
<td>21,8±0,2</td>
</tr>
<tr>
<td>13</td>
<td>0,5</td>
<td>260</td>
<td>21,6±0,2</td>
</tr>
<tr>
<td>18</td>
<td>7,5</td>
<td>200</td>
<td>0,0±0,0</td>
</tr>
<tr>
<td>27</td>
<td>1,0</td>
<td>190</td>
<td>0,0±0,0</td>
</tr>
</tbody>
</table>

Figure 2: Partial pressure of carbon dioxide in the inspired breathing gas vs time of respiration from the diving apparatus Oxy-NG during oxygen exposures of work rate 50 W.
Besides, the process was more intensive (rapid increase of carbon dioxide partial pressure). The results are presented in Figure 3. Figure-2 presents the partial pressure of carbon dioxide in the inspired breathing gas vs time of respiration from the diving apparatus Oxy-NG during oxygen exposures of work rate 50 W. Figure 4: presents comparison of the diving apparatuses LAR V [Technical Manual-Underwater Breathing Apparatus LAR V: NAVSEA SS600-AJ-MMO-01062326] and Oxy-NG.

Figure 3: Summary of oxygen exposures: maximal partial pressure of carbon dioxide reached in exposures which were not aimed at reaching carbon dioxide canister breakthrough, (mean value is marked), mean oxygen percentage in each exposure (mean value is marked), the mean temperature of exposure.
Conclusions

1. In order to determine carbon dioxide-canister breakthrough of the diving apparatus Oxy-NG 27 exposures were performed. The relationship between carbon dioxide-absorber-duration and the temperature was determined. The obtained results were compared with absorber-duration of the diving apparatus type LARV. Carbon dioxide-absorber-duration is shorter in cold water than in warm water. Due to the rapid increase of carbon dioxide, the canister breakthrough will be reached in short time. It occurs after normal work of absorber in cold water. The results of exposures have shown (exposure duration up to 1.5 h) that there was no possibility of carbon dioxide toxicity, if the diving apparatus was suitably prepared and not damaged.

2. As it follows from comparison of carbon dioxide absorber efficiency of the diving apparatuses Oxy-NG and LARV, the Oxy-NG absorber is more efficient. Despite of the fact, that LARV absorber may contain 20% more of mass. The diving apparatus Oxy-NG carbon dioxide absorber efficiency is less dependent upon the temperature. It is due to the different construction, ensuring better thermal protection.
3. Carbon dioxide-absorber-duration enables pure-oxygen diving without disturbances. The Oxy-NG carbon dioxide-absorber-duration is 2.5 hour at temperature 0°C

4. Polish soda lime may be used as the absorbent of the diving apparatus canister. The Oxy-NG apparatus equipped with canisters containing soda lime may be used in diving up to the depth 12m of sea water.

5. The results of the gas analysis have shown that oxygen content in the inspired gas is maintained at the level (94±1)%vol. It seems that values obtained are typical for the majority of the diving apparatuses. No cumulative contaminants leading to decrease oxygen content in the inspired gas were observed. Oxygen percentages obtained during exposures can be increased due to the gas analysis technique.

6. The use of medical oxygen in the diving apparatus Oxy-NG is acceptable. Oxygen of the better quality is recommended (content of pure-oxygen not less than 99.9%). Pure-oxygen treble flushing of the breathing space is needed. During diving, the diving apparatus should be flushed every 30 min.

Nomenclature

- \( j \) - multiplication factor of the breathing loop flushing
- \( p, p_0 \) - the total pressure, barometric pressure, MPa.
- \( t, T_0 \) - temperature of the gas cylinder, normal temperature °C, K,
- \( \nu(O_2) \) - the oxygen consumption [dm³ min⁻¹, related to NTP conditions],
- \( V_B, V_c \) - volume of cylinder, total volume of the breathing loop dm³,
- \( V_x \) - dead space [dm³],
- \( \frac{A_p}{A_t} \) - the supply cylinder pressure drop \( A_p \) in time \( A_t \) [MPa min⁻¹],
- \( V_o \) - gas sample stream flow at NTP conditions.
- \( x(i), x_w \) - molar fraction of oxygen in the breathing loop after \( i \)-th flushing, in inspired breathing gas
- \( x(O_2) \) - the oxygen molar fraction in the gas sample

References


