Submarine atmosphere regeneration

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ABSTRACT

In the paper was presented introduction of Polish soda lime (produced by the Chemical Company Dwory SA) successfully used for filling the carbon dioxide scrubber of a regeneration system built in KOBBEN class submarines for eliminating carbon dioxide from its atmosphere without any additional construction changes. Research on the atmosphere regeneration was carried out on a KOBBEN class submarine. The initial CO_2 concentration was achieved by releasing content of two cylinders filled with CO_2/N_2 gas mixture. Further CO_2 emission adequate to its maximum production by the ship's crew during breathing, was simulated by means of a constant emission simulator.The time of the preventive operation amounted to about 2 hours. The dynamic absorbing capacity of carbon dioxide was validated experimentally.

Key words : submarine, live support systems (LSS), soda lime

INTRODUCTION

Regeneration procedure

Air regeneration of disabled/distress submarine (DISSUB) is necessary due to tactical or emergency reasons when the vessel is not able to emerge on the surface and to ventilate its atmosphere. Regeneration of DISSUB's atmosphere consists in oxygen enriching and excessive carbon dioxide amount removing. In most situations carbon dioxide elimination is provided by means of soda lime which is a chemical compound used for removing carbon dioxide from gas mixtures. Soda lime consists of calcium hydroxide $Ca(OH)_2$, sodium hydroxide NaOH and/or potassium hydroxide KOH. An approximate content of NaOH and/or KOH is 2÷5%$_m$ of the solid phase. On submarines soda lime is placed in a separate absorber connected to an appropriate ventilation system. A suitable reserve of soda lime is also saved on board.

Procedures of using soda lime on the DISSUBs can be different, but it is usually accepted that if carbon dioxide content reaches 1%$_{vol.}$, the absorption of carbon dioxide has to be started. At 2%$_{vol.}$$CO_2$ content the DISSUB must be ventilated or prepared for abandonment.

Mean oxygen consumption by one human is assumed to be ca 25 $dm^3 \cdot hour^{-1}$, and it is generally accepted that the ratio of CO_2 emission and oxygen consumption, per person, (respiratory quotient) amounts to $\xi = 0.8$ [2]. It means that CO_2 emission produced by one person during the respiration process, amounting to ca 20 $dm^3 \cdot hour^{-1}$, is assumed. These values are used to calculate the reserve of soda lime for the DISSUB.

Soda lime qualities

Soda lime porosity and bulk density are most important at designing the carbon dioxide scrubber but these qualities are not available from producers. Therefore, it has been necessary to determine soda lime porosity and bulk density.

Bulk density was measured by weighing in air (1000± ±100) cm^3 of the bed. The soda lime bed mass was (801±20) g being equivalent to the soda lime bulk density d = (0.80±0.02) $kg \cdot m^{-3}$ as the buoyancy correction could be neglected due to its low value of 1g only, i.e.less than the mass measuring error [1].

Tab. 1. *Basic qualities of granulated soda lime*

Item	Value
Properties covered by the Polish industrial standard : № *ZN-2001/"DWORY"S.A.-70*	
Appearance	White or white-grey pellets of the diameter 2.8÷3.5 mm
Absorbing capacity with the respect to carbon dioxide	Not less than 26% (by mass)
Absorbing capacity with the respect to moisture	Not exceeding 7.5% (by mass)
Negative mesh, square mesh dimension 2.0 mm	Not exceeding 5% (by mass)
Moisture content	10÷18% (by mass)
Drum strength according to the standard PN-81/c-04533	Not less than 92% (by mass)
Additional properties necessary for fore-designing of the soda lime bed	
Bulk density	(0.80±0.02) $kg \cdot m^{-3}$
Porosity	0.55±0.02
Hydraulic diameter	$(3.470 \pm 0.003) \cdot 10^{-3}$m

Soda lime bed porosity, defined as the total free inter-molecular volume to the total volume occupied by a granulated material, was determined by water flooding the bed of the height l = (75±2) mm and diameter D = (90±2) mm, and the volume equal to V = (500±5) cm^3, consisting 10236 granules. The volume of the water necessary for flooding the bed was V_W = (276±2) cm^3 which gave the porosity ε = (0.55±0.02), typical for granulates.

Such determination of the mean soda-lime hydraulic diameter was approximate as the soda-lime granules are additionally twisted (thus measurement results may differ even by 10÷20%). According to Sauter [1], the mean hydraulic diameter of soda lime determined from an earlier experiment has been equal to $(3.470\pm0.003)\cdot10^{-3}$m.

Scrubber foredesign

The example calculations of the carbon dioxide scrubber are presented in Tab.2 on the assumption that :

- the air, being in laminar flow, passes through the fully filled scrubber
- the resistance (consisted of that imposed by scrubber construction, the sorbent bed resistance and the scrubber body resistance) is relatively small in comparison with the sorbent bed resistance
- the resistance coefficient for granulates (for one granulate fraction) can be defined according to Blake-Kozena's definition [1]
- the particle diameter of the granular bed is determined according to the Sauter's definition
- air viscosity is not dependent on temperature and pressure [3]
- 1 dm^3 of soda lime approximately bonds 90 dm^3 of CO_2 , [3].

Tab. 2. *Calculation of the sorbent bed dimensions [3]*

Data :	
Flow rate of the breathing gas	$\mathring{V}$ = 1320 $dm^3\cdot min^{-1}$
Porosity of the bed	ε = 0,55
The granule diameter according to Sauter	$d_S = 3.470 \cdot 10^{-3}$ m
Shape factor	a = 730
The breathing gas viscosity (air)	$\eta = 1.85 \cdot 10^{-5}$ Pa·s
Flow resistance	100 Pa
Maximum volume of the absorbed CO_2	V=2100 dm^3
Calculations :	

$$\begin{cases} l = \dfrac{\varepsilon}{1-\varepsilon} \cdot d_s \cdot \sqrt{\dfrac{\varepsilon}{a \cdot \eta}} \cdot \sqrt{\dfrac{\Delta p}{\mathring{V}} \cdot \dfrac{V(CO_2)}{90}} \cong 0{,}278\ \text{m} \\ d_h = \dfrac{2}{\sqrt{\pi}} \sqrt{\dfrac{V(CO_2)}{90 \cdot 1}} \cong 0{,}327\ \text{m} \\ \dfrac{l}{d_h} \cong 0{,}852 \end{cases}$$

l – height of the bed
d_h – hydraulic diameter
Δp – bed resistance

OBJECT

The submarine soda-lime scrubber of the internal dimensions of ca 299 x 278 mm and 276 mm height, was filled with (18.73±0.02)kg of the soda lime (Tab.1.) The calculated bulk density was d = 0.82 kg · dm^{-3} which corresponded to the density earlier determined in the laboratory. An overall view and technical drawing of the canister is given in Fig.1.

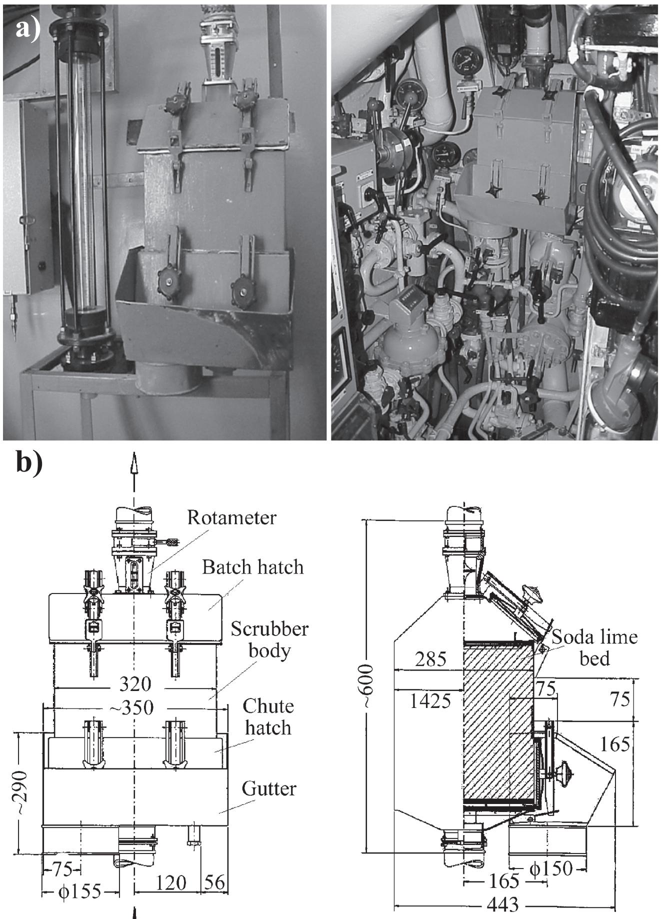

Fig.1. *Soda-lime scrubber for KOBBEN class submarine:*
a) *experimental stand and built in submarine*
b) *engineering drawing*

The total flow resistance (the channel flow resistance and bed flow resistance) in the carbon dioxide scrubber is measured with the aid of a differential manometer. For the air flow rate (1320±10) $dm^3\cdot min^{-1}$ the bed resistance was Δ_p = (100± ±2) Pa. The shape factor of soda-lime particles, necessary for scrubber foredesign, was determined from the measurement results and soda-lime qualities (Tab.1), as shown in (Tab.2).

METHOD

Carbon dioxide emission

Research on the atmosphere regeneration was carried out on a submarine of KOBBEN class. Gas cylinders filled with (3.50±0.0) kg of CO_2 and (0.25±0.0) kg of N_2 were prepared for simulating the initial CO_2 concentration in the DISSUB atmosphere.

The initial CO_2 concentration was realized by releasing content of the two cylinders into DISSUB's atmosphere (Fig.2). After stabilization of CO_2 concentration (ca 10 min - Fig.3), the stable CO_2 content amounts to (1.16±0.05)$\%_{vol.}CO_2$ (Fig.3). Further CO_2 emission, adequate to its maximum production by the ship's crew during breathing, was simulated by means of a special simulator [1]. Its emission amounted to (10.8±0.05) dm^3 of CO_2 per min.

Monitoring system

The submarine was equipped with a portable atmosphere monitoring system. The monitoring system consisted of four POLYTRON IR CO_2 gas analyzers produced by Drägerwerk

AG Lübeck, placed at bow, midship, stern and a hydro-cabin. The analyzers were connected through a typical personal computer and Advantech data acquisition modules into a RS 485 measuring network (Fig.2). Readouts was recorded every 5 s. The PC unit connected to the RS485 measuring network was capable of monitoring the submarine's atmosphere by means of a special computer program.

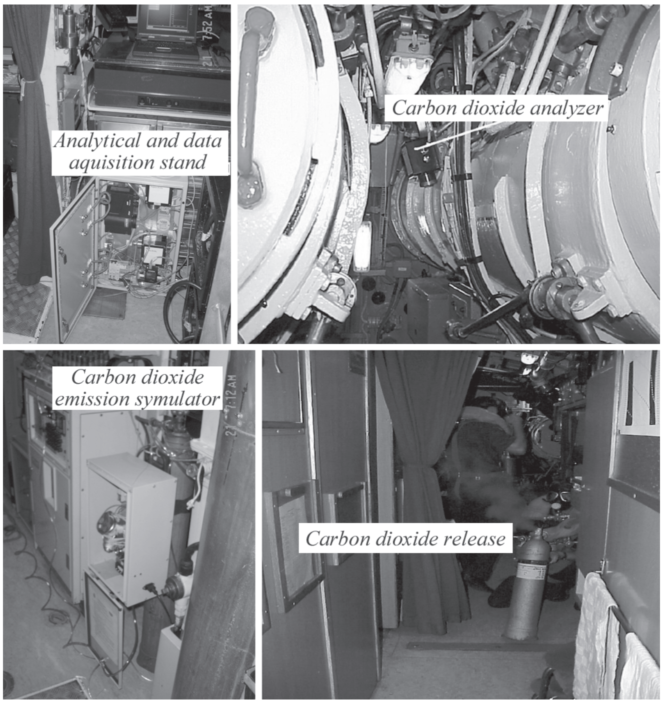

Fig.2. The system of measuring, CO_2 releasing and dosing it into DISSUB atmosphere

Regeneration of the DISSUB's atmosphere

The scrubber of the regeneration system (Fig.2) was filled with 13,2 kg of soda lime (Tab.1). Regeneration of the DISSUB's atmosphere was initiated with start of carbon dioxide simulator emission. The regeneration was carried out as long as one of the analyzers did not show stable CO_2 content of the same value as that before starting a regeneration system. The time of the preventive operation amounted to about 2 hours.

If the dynamic absorbing power of 90 dm^3 of CO_2 per 1 dm^3 of soda lime, is assumed, the soda lime amount placed into the canister (13.2 kg corresponds to 16.1dm^3 of soda lime) should absorb about 1450 dm^3 of CO_2. The CO_2 saturation in the soda lime was measured; the measurement results are shown in Tab.3.

Tab. 3. *Carbon dioxide saturation in the soda lime samples located in different layers of canister*

Sample location	Moisture content	Content of absorbed CO_2
	[%]	[$\%_m$]
Upper part of canister	3.2	6.8
Middle part of canister	4.1	14.9
Middle part of bottom canister	3.7	10.6
Lower part of canister	3.6	12.0
Average	3.6	11.1
Fresh soda lime	15.7	28.7

CONCLUSIONS

- The simple and effective foredesign method of a CO_2 removing scrubber was proved experimentally.
- The soda lime complying with the Polish industrial standard : ZN-2001/"DWORY" S.A.-70 was successfully used for filling the CO_2 removing scrubber of the atmosphere regeneration system installed in a KOBBEN class submarine.
- The dynamic absorbing capacity of carbon dioxide was 90 dm^3 of CO_2 per 1dm^3 of soda lime, due to which the effective absorbing capacity of the system in question was guaranteed.

Acknowledgement

This research was financially supported by Polish Ministry of Defence.

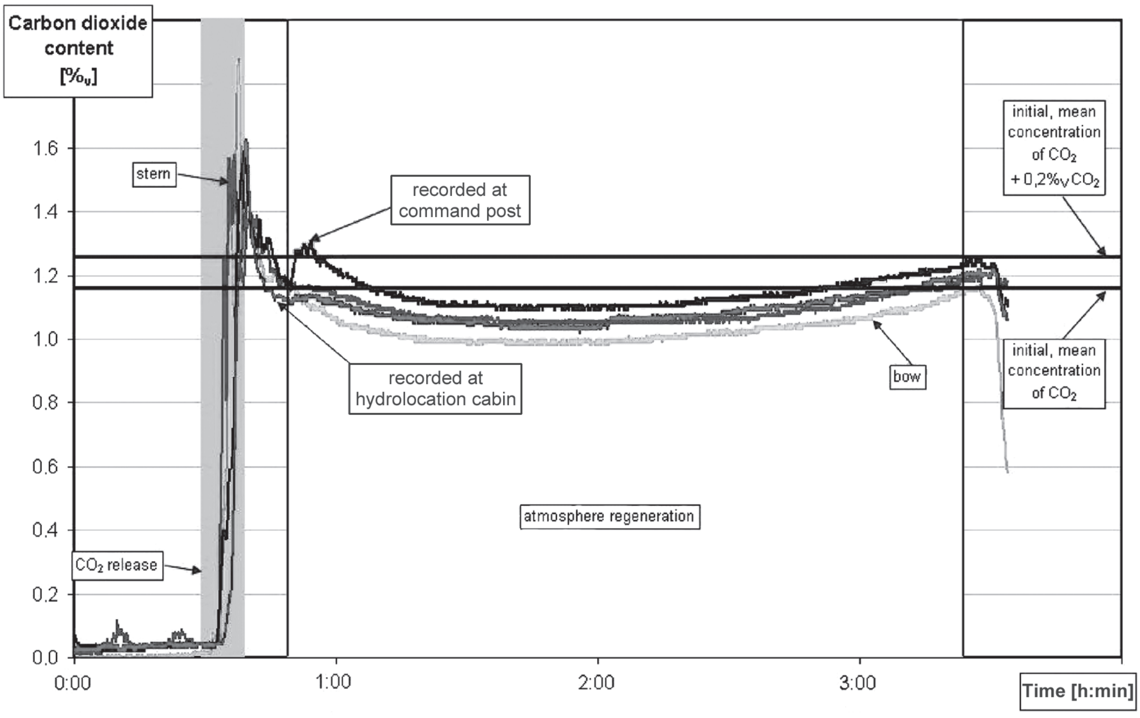

Fig.3. Rate of carbon dioxide elimination by built in KOBBEN class submarine regeneration system

BIBLIOGRAPHY

1. Kłos R.: *Diving apparatuses with regeneration of breathing mixtures* (in Polish). KOOPgraf. Poznań, 2000
2. Kłos R.: *Metabolic simulator supports diving apparatus researches*. Sea Technology, Vol.12, 2002
3. Pasternack A.: *Design principles for soda lime cartridges in respiratory protection apparatus*. Dräger Review, No 61, 1988

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Conference

SILWOJ 2003

On 22-24 October 2003
6th Scientific Technical Symposium on :

Combustion Engines in Military Applications

was held at Jurata on Hel Peninsula. It was organized by Polish Naval University, Gdynia and Military Engineering Academy, Warsaw.

During the Symposium 57 papers were presented : 14 of which - at 4 plenary sessions and the remaining - during 5 topical sessions on :

- Fuels and oils (6 papers)
- Construction and engineering processes (13 papers)
- Drives and controls (7 papers)
- Operation and Diagnostics (13 papers)
- Technology and construction (4 papers)

The papers dealt with applications of combustion engines in army, airforce and navy, and most of them concerned construction and engineering processes as well as operation and diagnostics of the engines. Scientific workers of Military Engineering Academy, Warsaw, most contributed in preparation of the symposium materials (22 papers), 11 papers were prepared by authors from Polish Naval University, and 5 by those of Rzeszów University of Technology. The remaining papers were elaborated by authors from 12 other universities, institutes and research centres.

Conference

SemEco 2003

Under this acronym 2nd series of seminars devoted to ecological problems of operation of combustion engines and organized by Naval University, Gdynia, was held in the last year. The seminars have been one of the activities of Maritime Technology Unit, Section of Transport Means, Transport Committee, Polish Academy of Sciences; and their main organizer was Cmdr., Prof. L. Piaseczny.

The following papers directly concerned ecological problems :

- *Problems of application of biofuels in the light of the present development state of piston combustion engines* – by J. Merkisz (Technical University of Poznań)
- *Working and ecological features of the engines supplied with rape oil, rape-oil methyl esters and their mixtures with fuel oil* – by Z. Szlachta (Technical University of Kraków)
- *Inventory problems of contaminations emitted by combustion engines* – by Z. Chłopek (Warsaw University of Technology)
- *Influence of partition of fuel dosage injected to diesel engine on its cycle parameters and NO_x emission* by I. Kafar (Polish Naval University)
- *Ecological aspects of application of controlled timing gears* – W. Kozaczewski (Industrial Institute of Motorization, Warsaw).

The remaining papers dealt with other interesting topics regarding combustion engines :

- *Steam-gas engines applicable to torpedos – their construction, working parameters and operational features* – by St. Czarnecki (Polish Naval University)
- *Selected problems of modelling supply processes in combustion engines* – by M. Sobieszczański (Academy of Engineering and Humanistics, Bielsko-Biała)
- *Application of connection graphs and state equations to modelling energy systems* – by M. Cichy (Gdańsk University of Technology)
- *Modelling the process of charge inlet into engine's cylinder* – by M. Łutowicz (Polish Naval University)
- *Identification of the compression process in ship engine cylinder on the basis of indication diagram data* by S. Polanowski (Polish Naval University).

Diesel engine test stand equipped with MEXA 9300 Horiba exhaust gas analyzer, at Polish Naval University, Gdynia