Defence Science Journal, Vol 46, No 3, July 1996, pp 155-160

Underwater Breathing Apparatus

B.V.S. Setty, G.S.N. Murthy, K. Thammaiah & Lazar Mathew
Defence Bio-Engineering & Electromedical Laboratory, Bangalore-560 093.

ABSTRACT

An independent closed circuit regenerative type of breathing apparatus has been developed for isolating the respiratory tract from the ambient medium for use during breathing by personnel working in underwater or polluted atmosphere. An oxygen reducer is used in the design of this apparatus for catering to the required flows of oxygen for breathing during use of the apparatus and thus avoiding oxygen poisoning. The paper describes some of the salient aspects of the breathing apparatus to be deployed for submariners and other diving personnel of the Indian Navy and its potential usefulness as a life saving equipment.

1. INTRODUCTION

Any descent into the sea is known to increase the pressure around the human body significantly. In the case of personnel descending into water, it becomes necessary to supply air under pressure to prevent the exposure of blood in the lungs to extremely high alveolar gas pressures and thus to keep the lungs from collapsing[1]. Normally, nitrogen, oxygen and carbondioxide are the three gases to which a sea diver is exposed, although helium also sometimes can be used as a substitute for nitrogen in the breathing mixture[2].

It is however well known that nitrogen which approximately constitutes four-fifth of the air and which at sea level pressure is not observed to cause any adverse effect on the body physiology, can be expected to produce varying degrees of narcosis at pressures beyond 8.5 atm[3]. Sometimes, the diver becomes ineffective as a result of nitrogen narcosis. To overcome these environmental stresses, the diving underwater personnel needs an underwater breathing apparatus. During ascent, the diver faces yet another problem in which gases in the breathing bag expand because of reduction in pressure leading to increase in buoyancy, thereby causing rapid and uncontrolled ascent to the surface. This leads to decompression sickness[4]. To vent out the excess gases, a pressure release safety valve has been provided in the design of the breathing apparatus. The paper describes the breathing apparatus which has been indigenously developed and its usefulness for the Indian Navy.

2. MATERIALS & METHODS

The indigenously developed underwater breathing apparatus (Fig. 1) is an independent close circuit, regenerative type system that can be conveniently used up to depths of 120 m. Its main function is to isolate the respiratory tract from the ambient medium and use the same for breathing when working in underwater or in a poisonous atmosphere. The regenerative system produces additional oxygen for enhancing the endurance limit of the apparatus besides enabling absorption of carbon dioxide. The requirement of oxygen for breathing during use of the apparatus is taken care of by an oxygen reducer which gives appropriate flows to avoid oxygen poisoning.

The underwater breathing apparatus consists of the following components :

2.1 Annular Breathing Bag

It is made out of rubberised nylon cloth with good wear resistance, flexibility, and light weight. It endures foldings without getting damaged at the crease.

Received 16 May 1995, revised 16 February 1996

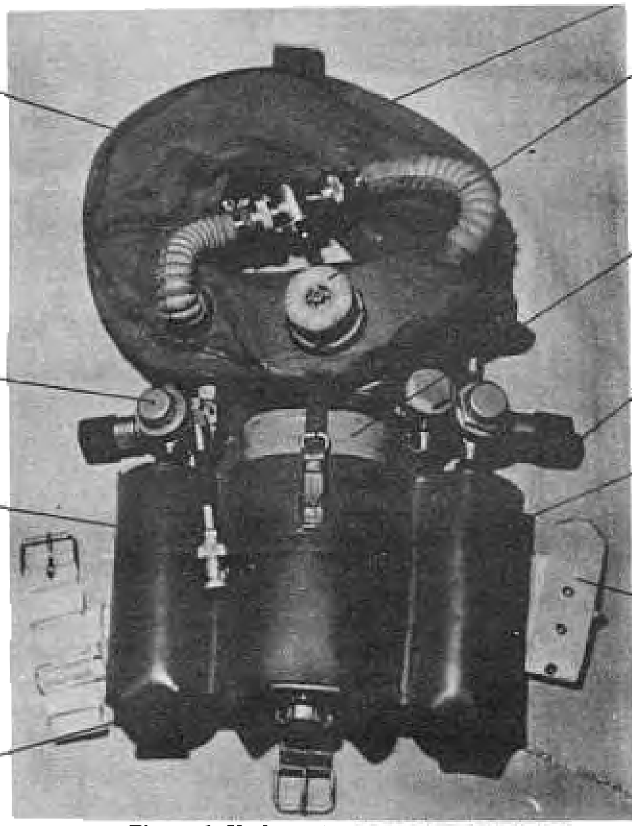

Figure 1. Underwater Breathing Apparatus.

2.2 Pressure Release Safety Valve

It is provided with two mushroom type diaphragms and is fixed on the lower front side of the breathing bag. This valve has a dual function: it works as a safety valve by releasing excess gas from the bag to ambient during ascent and as a relief valve when pressure in the breathing bag exceeds 400 mm of water.

2.3 Automatic Demand Valve

It allows gas mixture to the breathing bag at depths below 55 m on demand. This valve is located at the rear side of the breathing bag and is directly connected to the gas mixture reducer. This valve opens at rarefactions ranging between 100 to 160 mm of water.

2.4 Valve Box

It is connected between inspiratory and expiratory tracts of the apparatus through corrugated hoses. A control cock is provided on the valve box which facilitates changeover of breathing, i.e., from apparatus to the atmosphere and vice versa. Inlet and outlet valves of the valve box are provided with spring controlled diaphragms. For effective breathing cycle, outlet and inlet valves are closed during inhalation and exhalation, respectively.

2.5 Oxygen & Gas Mixture Reducers

These reducers are designed to give LP pressure from 200 kg/sq cm to 5.5 kg/sq cm. Gas mixture reducer is connected directly to demand valve (Fig. 1) and supplies gas mixture to the breathing bag on demand through the automatic demand valve. During ascent, this reducer works up to 55 m depth beyond which the oxygen reducer takes over automatically. The oxygen reducer, apart from reducing pressure, also controls the flow of oxygen at different depths ranging from 0.5 to 4.4 l/min to prevent oxygen poisoning.

2.6 Canister

It is provided with two shells. The outer shell is provided with two unions for connecting the inhale and exhale tubes of the breathing bag. The inner shell is filled with regenerative chemical which absorbs carbon dioxide from exhaled gas and produces additional oxygen which helps to enhance the endurance of the apparatus.

2.7 Oxygen & Gas Mixture Cylinders

These are made out of seamless steel tube and charged with medical oxygen and gas mixture of nitrogen, helium and oxygen at 200 kg/sq cm pressure.

All these apart, there exist (i) inlet and outlet hoses, made of leak-proof corrugated rubber hose with fabric braiding, (ii) securing belts, made of heavy duty nylon material and have strong buckles, and (iii) non-return valve of oxygen connection, which is a one-way valve.

3. DESIGN CONSIDERATIONS

All the metal components of this apparatus have been manufactured out of Naval brass which is known for its corrosion resistance in the marine atmosphere. The length of the cylinder used in the apparatus has been limited to 250 mm to prevent obstruction during escape while crawling through the torpedo tube. The volume of the breathing bag of the apparatus has been limited to 7 l which is equivalent to lung capacity. Any change in the capacity of the bag has been found to adversely affect the buoyancy of the apparatus.

The other salient features of the breathing apparatus are :

(a) The annular type breathing bag is made out of neoprene rubber coated on nylon fabric which has a capacity of 7 l and consists of automatic demand valve, pressure release safety valve, valve box/chest, and cylinder bib with waist belt, lower brace and snap hook.

(b) The canister is filled with a carbon dioxide absorbent such as potassium superoxide.

(c) Oxygen and mixture gas cylinders fitted with reducers are also provided in the breathing apparatus.

4. OPERATION OF UNDERWATER BREATHING APPARATUS

At predetermined depths, the user dons the breathing apparatus, opens both the reducers and starts ascending towards surface. Up to 55 m depth, the gas mixture of nitrogen, helium and oxygen is used by the user. During ascent, the exhaled gas enters the canister; carbon dioxide and moisture in the exhaled gas get absorbed by the absorbent in the canister. In addition, the absorbent releases oxygen, which re-enters the breathing circuit of the apparatus along with purified gas mixture through the outlet of the canister. The breathing bag is always full with breathing gas.

During inhalation cycle, pressure in the breathing bag falls. When pressure difference between ambient and bag falls between 100 to 160 mm of water, the automatic demand valve opens and the gas mixture from the gas mixture cylinder through mixture reducer enters the breathing bag till the pressure equalises. This process continues up to 55 m depth. At this depth, the supply of oxygen to breathing bag is taken over by the oxygen reducer. In addition, the oxygen reducer also supplies appropriate flows depending upon the ambient pressure which varies from 0.5 to 4.4 l/min. These flows are regulated automatically by the changeover valve of the oxygen reducer. After reaching the surface, the user puts the control cock of the valve box to 'atmosphere' to allow atmospheric air for breathing and at the same time cuts off the supply of breathing gas from the apparatus.

5. FUNCTIONAL EVALUATION

Name of component	Test mode	Result required
Breathing bag	Leak test at 400 mm of water	No leak shall appear
Opening pressure of pressure release safety value	When cover closed	250 to 400 mm of water
	When cover opened	Not to exceed 150 mm of water
Automatic demand valve	At rarefaction of 100 to 160 mm of water inside the breathing bag	Valve has to open
Valve box assembly	Leak test for inhale/inlet valve at 400 mm of water inside the breathing bag	Not to exceed 0.5 l/min

Contd on next page

Name of component	Test mode	Result required
	Leak test for exhale/outlet valve at 400 mm of water inside the breathing bag	Not to exceed 0.5 l/min
Canister	Leak test at 100 mm of water	Nil leakage
Oxygen reducer with high pressure of 180 to 200 kg/sq cm and low pressure of 5.5 to 6.5 kg/sq cm)	Flows in (l/min) during	
	Descent	
	Surface	3.6 - 4.4
	2.4 kg/sq cm	3.0 - 4.4
	3.0 kg/sq cm	0.5 - 1.1
	6.8 kg/sq cm	Nil
	Ascent	
	6.8 kg/sq cm	Nil
	4.5 kg/sq cm	1.1 - 0.5
	3.0 kg/sq cm	3.0 - 4.4
	Surface	3.2 - 4.4
	Safety valve operating pressure (kg/sq	11 - 15
Mixture reducer with High pressure—180 to 200 kg/sq cm, low pressure 5.5 to 6.5 kg/sq cm	Safety valve operating pressure (kg/sq cm)	14 - 17

6. DISCUSSION

The breathing of oxygen at very high alveolar oxygen pressure due to extremely high tissue partial pressure of oxygen can be detrimental to many of the body's tissues. In fact, an exposure to 3 atm pressure oxygen will cause convulsions followed by coma in most persons after one to several hours[5]. The convulsions often occur without any warning and, for obvious reasons, are likely to be lethal to the divers submerged beneath the sea.

If the diving gear is properly designed and also functions properly, the divers have no problem from carbon dioxide toxicity, for the depth alone does not increase the rate of carbon dioxide partial pressure in alveoli. However, in certain types of diving gears, such as diving helmet and different types of rebreathing apparatus, carbon dioxide can frequently build up in the dead space of the apparatus and be rebreathed by the diver. Up to 80 mm *Hg* level, the situation is flexible, but beyond that the situation becomes intolerable[6].

In very deep dives, helium is used in place of nitrogen because it has only one-fifth of the narcotic effect of nitrogen. No ill-effects of helium are observed until a person descends below 180 m. Beyond this depth, the divers begin to experience a so called 'high pressure nervous syndrome' which is characterised by a tremor at about 230 m and drowsiness beyond that.

To enhance the endurance of the apparatus, the exhaled gas is passed through the canister for absorption of carbon dioxide and regeneration of oxygen by the carbondioxide absorbent. The flow of oxygen into the breathing bag is controlled by providing automatic sensors in the form of nozzles as it increases the depth of operation by controlling partial pressure of oxygen[7].

7. CONCLUSION

The breathing apparatus developed indigenously at this laboratory can be used in conjunction with the submarine escape suit to enable the submariners to escape from a depth of 120 m, safely.

ACKNOWLEDGEMENTS

The assistance given by the Evaluation Team at INS Veerbahu, Submarine HQrs, Visakhapatnam, during the development, trials and testing is gratefully acknowledged. The help given by Dr C.A. Verghese, Ex-Director, DEBEL, for the project at the initial stages is also acknowledged.

REFERENCES

1. Behnke, A.R. (Jr.) & Lanphier, E.H. Underwater physiology. *In* Fenn, W.O. and Rahn H. (eds). Handbook of Physiology, Sec 3, Vol 2, Baltimore, Williams & Wilkins, 1965. p 1159.

2. Guyton, C.A. Physiology of deep sea diving and other hyperbaric condition. *In* Igaku-Shoin/Saunders International Edition Medical Physiology, 1986, Sec 45. pp. 537-43.

3. Halsey, M.J. Effects of high pressure on the central nervous system. *Physiol. Review*, 1982, **62**, 1341.

4. Straus, R.H. Diving medicine. *In* Grunne and Stratton inc (Publisher) Barotrauma, 1976, Sec 5, 49-60.

5. Fischer, A.B. Oxygen toxicity of the lung. *In* Fishman, A.P. and Renkin, E.M. (Eds) Pulmonary Edema, Baltimore, Waverly Press, 1979. p 207.

6. Vail, E.G. Hyperbaric respiratory mechanics. *Aerospace Med.* 1971, **42**, 536.

7. Strauss, R.H. Diving medicine. *In* Grunne and Stratto inc (Publisher) Diving Equipment 1976, Sec 3. pp. 23-33.

Contributors

Mr BV Srinivasaiah Setty obtained his BE degree in Mechanical Engineering from Mysore University. Presently, he is a Scientist at the Defence Bio-engineering & Electromedical Laboratory (DEBEL), Bangalore. He has 20 years of experience in the design and development of life support systems for the Air Force and Navy.

Mr GSN Murthy, an MSc (Tech) in Instrumentation, is a Scientist at DEBEL. He is currently engaged in the design and development of life support systems for the Services.

Mr K Thammaiah, a BE in Mechanical Engineering and ME in M/c Design, is a Scientist at DEBEL. He is a member of the Institute of Engineering & Aeronautical Society of India.

Dr T Lazar Mathew, a PhD in Medical Physiology, is currently Director, DEBEL. He is also the Programme Executive for the Society for Biomedical Technology. He is a Fellow of the Association of Biomedical Scientists and also of the International Medical Sciences Academy. He has more than 31 years of experience in the field of applied physiology. He has published 147 research papers and technical reports in national and international journals, and has four technical books to his credit. He has obtained several research awards and gold medals for his outstanding research contributions. He was the President of the Physiology Section in the Indian Science Congress (1991-92), Vice-President of the Indian Association of Biomedical Scientists and member of a number of science associations. He is also a member of the editorial board of five science journals and also a member of various committees of DST, TIFAC, UGC and DRDO. He is a post-graduate teacher and examiner for MSc, MD, MTech and PhD; and member in some international committees including the Committee on International Union of Physiological Sciences. He has been a member of Indian delegation in the Commonwealth Defence Conference, on two occasions. Recently, he has been awarded the Scientist of the Year Award for 1994 by DRDO.

ANNEXURE 1

Table 1. Results of user evaluation of underwater breathing apparatus

Component	Test mode	Required value	Actual value	Remarks
	Leak test			
	Valve open pressure in (mm of water)			
	Valve closed (pressure in mm of water)	Not to exceed 400	380	Satisfactory
Automatic demand valve	Operating vacuum pressure (mm of water)	110 - 160	145	Satisfactory
NRV for oxygen connection of BB	Leak test	No leak	No leak	Satisfactory
Valve box assembly	Leak test	No leak	No leak	Satisfactory
Corrugated tubes	Leak test	No leak	No leak	Satisfactory
Inlet valve	Leak test (l/min)	Not to exceed 0.5	0.1	Satisfactory
Outlet valve	Leak test (l/min)	Not to exceed 0.5	0.2	Satisfactory
Canister				
Outer shell	Canister pressure test by PKY at 100 mm water	No leak	No leak	Satisfactory
Inner shell	Canister pressure test by PKY at 100 mm water	No leak	No leak	Satisfactory
Oxygen reducer	HP (kg/sq cm)	180 - 200	80 - 200	Satisfactory
	LP (kg/sq cm)	5.5 - 6.5	6	Satisfactory
	Flow rate (in l/min) at			
	Surface	3.6 - 4.4	3.4	Satisfactory
	2.4 kg/sq cm	3:0 - 4.4	1.8	Slight lower side
	3.0 kg/sq cm	0.5 - 1.1	1.2	Slightly higher side
	6.8 kg/sq cm	0	0	Satisfactory
	10.0 kg/sq cm	0	0	Satisfactory
	13 kg/sq cm	0	0	Satisfactory
	6 kg/sq cm	0	0	Satisfactory
	6.8 kg/sq cm	0	0	Satisfactory
	4.5 kg/sq cm	0	0	Satisfactory
	2.0 kg/sq cm	3.0 - 4.4 l/min	2.2 l/min	Slightly lower side
	Surface	3.2 - 4.4 l/min	2.2 l/min	Slightly lower side
	Residual pressure (kg/sq cm)	160 - 170	100 - 150	Satisfactory
Mixure reducer	Leak test	No leak	No leak	Satisfactory
	LP kg/sq cm	5.5 - 6.5	6	Satisfactory
	Safety valve operating pressure (kg/sq cm)	14 - 17	15	Satisfactory