The Rebreather Invasion

by

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(*Shadow diver*)

In the sixty's aerospace technology revolution was on. The race to the moon and the technology supported it. While man was focusing outward toward the stars there were a few aerospace engineers looking inward, "innerspace". The technology being developed to support Astronauts was also compatible for marine exploration. Gas tight zippers, high-density waterproof materials, electronics, plastics, high and low pressure regulated pneumatic plumbing, efficient CO2 scrubber breathing systems and small galvanic oxygen sensors made advanced diving systems possible. As in the aerospace industry, another race was on to develop innerspace life-support systems that would support a diver at any depth for a great length of time. Driven by Uncle Sam for military application and offshore oil companies, systems were developed to support those types of mission driven applications. One system in the latter sixty's rose above the rest. With the current technology at that time the system capability was impressive, six hour duration at any depth rated for a maximum depth of 1000 fsw.(2000 fsw for saturation using passive and active thermal heating systems.) The US Navy Experimental Diving Unit tested the system. They found the breathing qualities and system integrity was second to none at the time. The failure analysis on the research & development program exceeded most fighter aircraft of that period, and has been the U.S. Navy's mainstay for almost two decades. With an accumulation of over a million manned diving hours. The system was a modified Bio-Marine CCR-1000 Called the Innerspace Porpoise Pack one, a highly efficient and robust system that had no equal, and at this current time systems as old as 20 years are still in operation.

The design criteria for the system was:

- Complete autonomous diver operations without umbilical or surface support.
- Depth advantageous of mixed gas, such as minimal inert gas narcosis.
- No tell tail bubbles.
- Acoustically invisible.
- Maximize gas conservation.
- Increased overall safety.
- Capable of inert gas switches and oxygen Partial Pressure manipulation to reduce decompression.

The commercial dive industry was interested in maximum gas conservation and maximum diver productivity. Gas consumption at 1000 fsw ran about $3,756.30 per hour, not including paying the diver and support equipment.

Rebreathers closed the loop for the subsea industry.

To understand Rebreathers, the principles of operation must be understood:

- Recirculate breathing gas for reuse.
- Remove carbon dioxide produced by the metabolic action of the body.
- Add oxygen to the breathing loop to replace oxygen consumed.

Rebreathers operate on a closed exhaust principle unlike open exhaust where the gas is regulated down to the diver on inhalation and exhausted into the environment where it cannot be reused.

The above principal operation is the basis for all rebreathing systems. Systems are broken down into full closed circuit, semi-closed circuit, and variable volume mixed gas closed circuit.

Full closed circuit utilizes 100% oxygen in the breathing loop system, primarily used by military for clandestine operations, or for scientific research in shallow water. It is a truly bubble-less system (i.e. Full Closed Circuit). The oxygen is metabolized by the body and the CO2 by-product is absorbed by the CO2 absorbent material, thus no bubbles are produced. Oxygen systems are utilized at shallow depths (20 fsw) with one deep excursion allowed for a limited period of time. Normal gas duration for an O2 closed loop system using a ten cubic foot cylinder is 240 minutes depending on temperature of the water and the individual divers gas consumption. Current systems being used. Bio-Marine BMR-25 and the Drager LAR-V.

Semi-closed systems use pre-mixed gases to achieve multi-depth profiles, however they work off ether an active continuous gas flow system or a passive counter mass ratio system.. The continuous flow system, the breathing gas is continuously injected through a pre-adjusted orifice that allows for a calculated gas flow to support the diver at a pre selected depth and work rate. If the diver over breathes the system or miscalculates consumption ratios, hypoxia or hypercapnia is possible. The continuous gas flow that is being injected into the system that is not metabolized or absorbed is continuously purged via a variable volume exhaust valve so inert gas build up is reduced to tolerable levels. The Passive counter mass ratio system will only add oxygen enriched gas when required, tied in to the divers RMV (work rate or effort of breathing) thus increasing gas duration and decreasing gas wastage compared to active continuous flow systems. Further calculation for semi-closed is for the fraction of oxygen in the counter lung (bag level). This is required so decompression planning is possible. Semi-closed is not electronically dependent and the bases of operation is simple and systems are relatively inexpensive, however to fully exploit the system, gas mixing and mixed gas physiology must be understood.

Variable Volume Mixed Gas Rebreathers (VVMGR) such as the Bio-Marine series systems and the Bio-Marine Hybrid Innerspace Porpoise Pack 1A and other advanced systems, are electronically controlled. Oxygen is injected into a counter lung and mixed at a pre selected level (setpoint control) with a diluent gas using air, heliox or a trimix. The diluent is determined depending on depth and duration of the dive. Diluent gas is automatically or manually added during the descent to compensate for hydrostatic pressure on the counterlung. Inversely, inert gases must be exhausted from the system during ascent to prevent the over-expansion of the counter lung. Part of this gas is absorbed into the tissues according to dive physiology theories. The setpoint control is of two types, a fixed setpoint that is calibrated and adjusted prior to a diving operation or a scheduled maintenance plan by the end user. And an adjustable (on the fly) setpoint control which is adjusted by the diver during the course of the dive at strategic pre planned points to minimize decompression obligation.. A fixed or adjustable setpoint will deliver what is called the "best mix" at any depth. The oxygen set point with proper dive planning and manipulation with gas switches can minimize inert gas absorption thus maximize accelerated decompression.

To understand VVMGR's we must further understand what is called set point theory. On the surface we are exposed to air at one atmosphere of pressure, and 21% of the air we breath is oxygen, therefore, the partial pressure of O2 is .21 Ata. We can see that on the surface the partial pressure is numerically equivalent to percentage of a gas. This is not so under pressure. Diving with a premix (constant percentage) i.e. 79% N2/21% O2 air or enriched air NOAA Nitrox -1, 68% N2/32% O2 the PPO2 (partial pressure of oxygen) will fluctuate with depth. Since the human body is sensitive to oxygen partial pressure rather than oxygen percentage, it is apparent that a system such as a variable volume mixed gas rebreather which provides constant PPO2, regardless of depth, is supplying oxygen to the diver with greater precision than a pre-mix diving mode using a fixed percentage of oxygen. When diving with a VVMGR such as the Bio-Marine/Innerspace systems, benefits are realized. As the total atmospheric pressure decreases on the ascent the percentage of oxygen will increase in order to maintain the system oxygen setpoint (see Table 1.1).

Table 1.1

Open Circuit Pre-mix (79/21 Air)			**Closed Circuit Setpoint (1.4 Ata)**		**Equivalent Air Depth (EAD)**
Depth	**FO2**	**PPO2**	**FO2**	**PPO2**	**(Feet sea water)**
40 fsw	21%	.46 Ata	63%	1.4 Ata	N/A
60 fsw	21%	.58 Ata	50%	1.4 Ata	26.24 fsw
100fsw	21%	.84 Ata	35%	1.4 Ata	76.87 fsw
130 fsw	21%	1.02 Ata	28%	1.4Ata	114 fsw

This has the effect of allowing the inert gas pressure to reduce which accelerates decompression. The setpoint safety factor is a direct benefit to the users of VVMGR system. Precise constant PPO2 control, regardless of depth, results in:

- Avoids most problems concerning in-water oxygen toxicity at depth
- Increases O2 percentage during in-water decompression (All dives are decompression dives).
- Equivalent air depth calculations and tables can be used

Dive duration is primarily determined by two factors, one being temperature of the water the diver is diving in. The scrubber material is sensitive to temperature. At 40 degrees F using commonly used absorbent material in , the scrubber can last up to 300 minutes. At 70 degrees F the scrubber can last up to 400 minutes. Time can be increased by using the more expensive CO2 absorbent material or a passive/active heating system on the breathing loop. however that will require more from your pocket book. The other factor is the divers personnel metabolism and CO2 production. A man generally consumes between 0.4 to 3.0 liters per minute, depending on his activity level. Tests have shown that over an extended period of time, a hard working diver will consume an average of about 432 liters (15) cubic feet of oxygen to meet the respiratory needs of the diver. The Bio-Marine/Innerspace 1000 ft. systems provides storage of approximately 21 cubic feet of O2 at a pressure of 3000 psi, therefore providing an abundant reserve for the diver. Gas consumption is independent of depth.

System designs are oriented around safety for the diver. When designing an underwater breathing system the designer must remember that such a system is providing an artificial atmosphere, an electro-mechanical extension of the divers body. A rebreathing system has a counter lung to provide a flexible breathing space for gases to be mixed and circulated by the breathing action of the lungs, a high and low pressure pneumatic system to inject life-giving gas to the needs to the body, a scrubber system to absorb the natural byproduct CO_2 that is produced by our body metabolism, and an exoskeleton to house and protect the system. Design criteria is most critical. Failure is not an option but it is a possibility as said in Apollo 13 when a catastrophic loss of gas reduced the life duration for the Astronauts to a minute scale. Redundancy, reliability, and robustness is the critical foundation built into the best closed circuit systems. If an electrical failure appeared in a VVMGR the diver can manually maintain the partial pressure of O_2 at any setpoint. The flooding of the system can easily be detected by breathing resistance and a gurgling sound. The detection of a "flood out" is easy and counter measures are just as easily employed to drain the system and safely return to the surface. The Bio-Marine BMR-155 and the Porpoise Pack 1A by InnerSpace Systems Corp. is designed, when configured properly, to support two divers up to 3 hours when fully charged. System robustness is designed so all regulators and breathing system is contained in a tuff package. Open circuit equipment is open to regulator damage and entanglement where the best designed closed circuit system is streamlined like a 1968 Corvette.

Training, of course, is a prerequisite prior to buying a particular system. Training depending on divers desires such as depth which would determine gases utilized during training and depth trained at. Training using custom gases and dive tables increases the price especially if the diver wishes to be trained on open circuit technical diving, also prices vary up to $3,000.00 for a complete package. Courses can be customized to fit ones budget and still maximize fun. Shopping around and utilizing the free enterprise system is your best bet.

Is a closed circuit system for you? It might be if you want the following benefits:

- Extended bottom time.
- Minimize inert gas absorption for various dive profiles
- Maximize the elimination of inert gas narcoses.
- Maximize gas conservation.
- Minimize oxygen toxicity problems
- Minimize equipment drag
- Look cool
- Is a system in my budget.
- Increase of over all safety.

Other benefits to consider: Acoustic invisibility (fish are trying to determine what side of the food chain you are on), maximize respiratory heat retention, and the effective cost of operation per hour is $4.50 to $9.35 at any depth - compare that to an air or nitrox fill.

The down side is also an important consideration:

- Cost of a unit $5,500.00 to $20,000.00.
- The complexity of training & cost : 70 hours $1,000.00. to $2,000.00
- Diving proficiency on unit. The diver must dive the unit consistently to be prepared for any contingency.
- Equipment maintenance pre and post dive procedures and hygiene.
- Inadequate maintenance will lead to system failure and possible death or injury
- Yearly maintenance cost $50.00 to $350.00 per year.
- Cold water will reduce battery and carbon dioxide scrubber life.
- Inadequate dive planning can lead to death or injury
- Requires special decompression or custom tables

Who should train you: Seeking the best life support equipment is not the only consideration. Seeking an experienced and manufacture approved qualified instructor is also at the top of the list. When locating an instructor call the manufacturer for recommendations and find the best qualified one for you. You may need mixed gas training using trimix or someone with caving experience or wreck penetration to tailor a class to your needs. Also take into consideration will you have support for any questions that you might have at a later time, i.e. a phone call away any time.

Ask the instructor the following questions.

- Who are you to train me.
- What is your experience on C2R's
- Do you own a system ?
- How long have you owned it.
- What problems have you had with your C2R.
- How deep and how long have you been on your C2R.
- What Recognized agencies do you offer for certifications and are you active.
- Are you a factory authorized instructor and repair technician.
- Do you have parts to repair my unit if it should break during training.
- Ask for a few student references and a resume on the instructor.
- Cost of training (You get what you pay for)
- Training environment I.E. Classroom, pool , open water, housing , transportation, user friendliness of training.
- What equipment will I need for class. I.E. drysuit, pony bottle, dive gear, gas switching system for mixed gas training.
- Books for training
- How do you blend gases for training.
- Please send training info and C2R system info.
- Are there any hidden costs I should be aware of.

Beware of rubber stamped C2R instructor wanna be's They can kill.

I predict in 5 years advanced technical diving will be on Rebreathers due to the obvious benefits. Open circuit diving will always be the solid foundation for recreational diving. Go Bubblers.