

Land vs. Water Rebreather Controller Differences

Version 11

Overview

Land based mixed gas closed circuit rebreathers will become more commonplace as these systems deliver the greatest benefits based on current breathing systems technologies. The closed circuit rebreather (CCR) is not a new breathing system. The underwater cousin is well known as is the criteria for operation for the underwater based rebreather controller.

What is not generally realized is that there are significant differences between successful implementations of land and water based closed circuit rebreathers. Understanding the application and environmental differences between these two uses is critical to designing control and interface systems that successfully meet user requirements.

This paper outlines these differences to make clear that the use of an underwater rebreather controller for land based applications will result in a system that will not function as needed or desired. A rebreather that meets land based needs requires a controller that is designed from ground-up to serve the requirements of a land based mixed gas closed circuit rebreather.

The three areas of significant difference are: Oxygen Control, Failure Management, and User Information.

Oxygen Management

The primary difference between land and underwater applications of a CCR with respect to Oxygen is that the land application seeks the minimum level of Oxygen acceptable whereas the underwater application seeks the maximum. Calibration requirements follow the application. Underwater use requires calibration with high levels of Oxygen, whereas land use requires only calibration with Air (21% O₂).

Underwater Application: Maximum safe PO₂

- PO₂ setpoint is typically greater than 1.0ATA. A setpoint of 1.6ATA is the maximum safe level.
- Diver determined goals
 1. Minimize diluent (inert gas) in-order to minimize decompression obligation
 2. Balance Oxygen exposure time versus inert gas exposure time
 3. Balance Oxygen pressure versus ambient pressure; choosing the proper maximum pressure of Oxygen based on water depth and/or workload. A lower O₂ setpoint is chosen due to the difficulty in maintaining high O₂ to diluent ratios in shallow water.
- Maximize in-water times with minimum decompression obligation.
- Time is limited when PO₂ > .5 ATA (Oxygen toxicity).
- Requires near setpoint calibration (typically 100% O₂ = 1ATA)
- Calibration requires user involvement and validation.

Land Application: Minimum safe PO₂

- PO₂ setpoint of 0.21ATA to 0.30ATA is desirable.
- No maximum exposure limit when PO₂ < 0.5 ATA (Oxygen toxicity)

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- No oxidation reaction danger when $PO_2 < 0.24$ ATA
- Allows User independent Air calibration standard

Although land based rebreathers have allowed Oxygen levels as high as 100% (1.0ATA), it is much more desirable to maintain a near-normoxic level for human respiration and long term exposure.

Failure Information versus Failure Management

The underwater user must be provided with sufficiently detailed information and must be properly skilled in failure management to balance all relevant system, environment, and biological related parameters to ensure survival back to surface. Due to the high level of inter-relation of diving life support system, biological and environment parameters (such as depth, PO_2 , decompression obligation, time to surface, Oxygen toxicity, dehydration, fatigue, etc.), it is not yet possible to predict the best failure management path. Therefore the user is given Failure Information with which to personally make the Failure Management decision.

Land application rebreather users have no significant system, environment, or biological interactions. While each of these are obviously important in their own realm, they do not greatly interact with the proper and correct choices to made in controlling the level of Oxygen nor is there any significant effect on determining proper and correct failure related choices. The Land-Based rebreather controller can therefore effectively self-handle the Failure Management and inform the user in a high-level manner without the need to resort to detailed system management information.

Some highlights of the differences can be found below.

Underwater Application: Failure Information

- Automatic redundancy/failure management is usually limited by the level of complex system – user - environment interactions.
- Requires high skill level of the user to manage the failure(s).
- Failure information must indicate what is wrong, rather than specific management solutions.

Land Application: Failure Management / Mission Completion

- Allows high levels of automatic redundancy/failure management
- Allows all system information to be translated to remaining duration (example: Normal operation, <20% time remaining, <5 minutes remaining, Bail Out)
- Allows the user to operate with no expertise in failure management. The user must simply assess the remaining duration information and relate it to the environment egress requirements and possibly use an open circuit bailout system as a last resort.

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User Information

In traditional underwater ECCR's, the user receives Oxygen level (PO₂) information. This is typically from each individual sensor as well as an aggregate of all sensors. The reason for this is that the user must manage and act upon the information from the rebreather to maintain and sustain life.

For Land based applications, the absolute level of Oxygen is no longer important within broad parameters. System duration, the overall length of time that the user can remain on the breathing system becomes the critical operational parameter. Duration information is inferred from Oxygen levels as well as from other system level and functional parameters.

This represents a fundamental difference in information requirements. A land based user's primary system focus is the remaining time the system is capable of supporting life. Failure management is reduced to simply bailing-out of the system on complete failure. Therefore land based rebreather users do not need the detail to make system management type decisions.

Underwater Application: Oxygen Level and Detail

- Specific O₂ display information validates PO₂
 1. Both upper (1.6ATA) and lower (0.21ATA) limits are life critical.
 2. O₂ Level is necessary to correlate to decompression profile.
- Low-level sensor data is transmitted to the diver to validate sensor operation.
- Specific/Descriptive failure data
 1. Allows diver determination of the best failure path management and decision.
 2. Display sensor data, even if errors are detected, to allow the diver the best possible ability of managing the failure(s).
 3. Divers are required to be sufficiently skilled in managing their life support systems with flawed or minimal data. Basing their decisions on parameters that include dive profile, depth, previous readings, loop inflation level, cylinder pressure readings, etc.

Note: The user environment generally has more variables outside of rebreather sensing and control; relating to decompression, overhead environment and path to surface management. Therefore the diver must be given detailed information and must self-manage or oversee any deviation from normal. Divers must regularly maintain failure management skills and behaviors.

Land Application: Time Remaining (Duration)

- - All low-level info is converted to high-level duration information
 1. Sensor failure/discrepancy/limit violations => Effect on Duration
 2. Power supply failure/limit violations => Effect on Duration

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3. Hardware failure => Effect on Duration
4. Scrubber usage => Duration
5. Oxygen limit violations => Duration Calculation
6. Gas supply exhaustion => Duration Calculation
7. Solenoid failure => Duration Calculation

Note: Explicit Oxygen level no longer has additional implications to life support management beyond maintenance within broad limits imposed by minimum life support on the low end and oxidation (fire/health) danger standards on the high end. All system failures and limitations may be handled on a comparable basis and related to duration. The duration information in turn may be distilled to one of several distinct levels (Normal Operation, Less than 20% time remaining, Less than 5 minutes remaining, and Bail Out (no time remaining)).

Underwater rebreather controllers cannot completely summarize the system information into duration information as there are many other unique factors specific to the underwater environment that preclude this land application necessity.

Summary

It is our belief that a complete and well designed land application mixed gas closed circuit rebreather will incorporate the next generation of rebreather controllers that have been specifically designed for land use. There are significant differences, as outlined above, that warrant a completely dedicated rebreather controller when these breathing systems are applied to land use. These differences also allow a significant improvement to the usability of a CCR system for land use thru redundancy and active failure management. Laguna Research, Inc has designed and implemented such controllers and offers a wide variety of customization paths for OEM customers who are in the land based rebreather market.