Why Rebreather Testing is Important

In the last 10 years, rebreathers in sport diving are fast becoming the norm. Early units used by technical divers were modified ex-military systems or rather questionable pre-production units that were made in low numbers before disappearing from the market within six months. Times have changed. Today, PADI and other training organizations offer technical and recreational rebreather courses, and new rebreathers have entered the market specifically for recreational divers. Rebreathers continue to advance in sophistication and performance with CO2 sensors and automated checklists becoming standard. Rebreathers are becoming even more main-stream.

While advancements are a good thing, statistically, more users equals more incidents – even if the *overall rate* is low. Open-circuit scuba regulators are deemed *life support* but in the main their failure mode acts like a light switch. They either work or they don't, so your responses are limited – basically, you need another regulator (an AAS, a backup second stage, etc.). Rebreathers are also obviously life support but differ in that they potentially have several failure modes, some of which result in diver confusion that can slow and reduce the correct response. Commonly, 'diver error' enters the equation with rebreathers, and design philosophies diverge with respect to how much one should attempt to engineer out mistakes (you may not be able to design them all out, but you can eliminate or reduce the consequences of many).

This divergence shows that divers need a standard to help them compare rebreathers, and manufacturers need a standard to help them design them, similar to that globally adopted with scuba regulators (EN250). The standard provides a yardstick against which you can compare a rebreather's characteristics – a way to tell if it is "taller" than another in some respect, and whether it is "tall enough" against commonly agreed minimums.

So what is 'diver error'?. The diver made a mistake, but why? Well in Europe the standard that attempts to define and provide guidance to engineer around and deal with diver error and other issues with rebreathers is currently **CE EN14143:2003**, and no it's not perfect. No standard is perfect, whether it is CE or a Navy standard. But, it *is* a *very* good guide. If you can design, test and produce a rebreather to this standard, or invest in a rebreather that meets it if you're a diver, you have gone a very long way towards your goal. A rebreather that doesn't meet a standard either needs to be redesigned to meet it, provide testing and justification as to why it does not need to or (perhaps) be limited in its application to less demanding diving. But, in that case, you will probably still need a standard, albeit a less stringent one that defines the limited application.

If you are thinking of buying, building or selling a rebreather in Europe, you need to understand CE EN14143:2003 (there is a new one under review but it is not approved yet). Rebreather design is covered under the European Personal Protective Equipment Directive, 89/686/EEC. These products require Article 10 EC Type Examination and Certification from a Notified Body meeting either EN14143 or a manufacturer's Technical Specification which still has to be assessed by a Notified Body to ensure the product meets the Basic Health and Safety Requirements of the Directive.

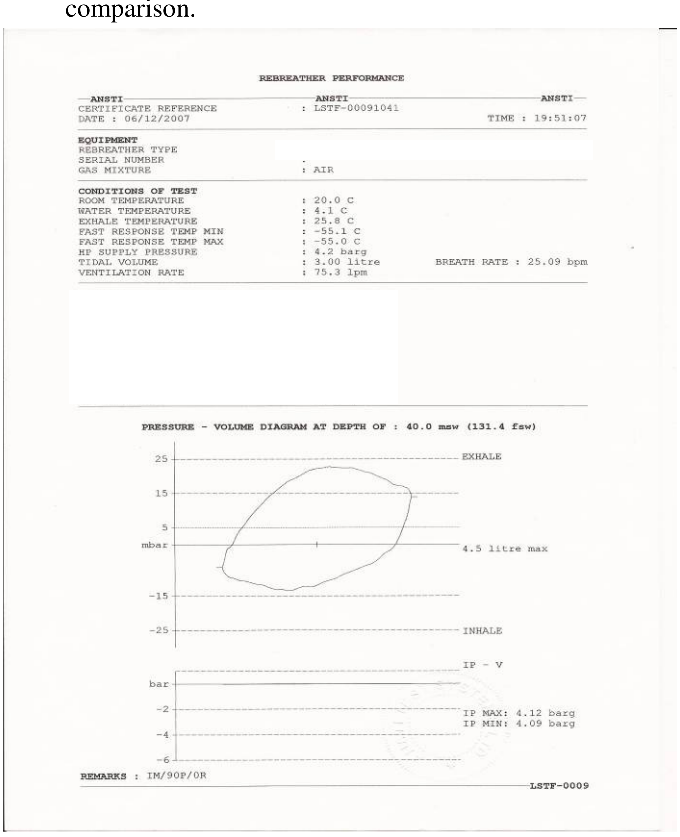
EN 14143 is what is known as the 'harmonized standard' and has more than 100 isolated tests that must occur for the rebreather to be fully compliant. These range across everything from Work of Breathing to performance in freezing conditions (-20 degrees C). Besides objective unmanned testing, the rebreather is also tested with a range of test diver trials, though 95 percent of the tests are unmanned because firstly; no life support should be primarily tested on people 'in the field' and secondly unmanned testing is a very controlled and monitored event designed to test and accurately report on the performance of individual components and the unit as a whole at the probably limits that either the diver can attain or the equipment could be subjected to in use.

As discussed manufacturers may elect to use their own Technical Specification instead of EN14143 (although many Notified Bodies will insist on the harmonised standard being used), but this is not always the best method because it can result in a reduced test set of tests being undertaken and with the product not being fully validated in the end from a safety perspective. Even if unit design does not exactly fit the EN14143 test requirement, the regulations allow for reasonable adjustment with justification and assessment, so the majority of the tests can still be conducted. It doesn't do much good to have a standard and then not test to it as much as possible – it's like having a yardstick, but leaving it in the closet and guessing at length.

To put a rebreather on the market, the manufacturer must also have Article 11 certification from a Notified Body. This can be either be 11A, based on annual product sampling and testing (which basically means every year you must submit rebreathers for testing again to ensure you can keep making the same thing), or 11B where the companies manufacturing and quality management quality control system is audited annually. The latter is normally associated with ISO9001:2008. **So, to make and/or sell a rebreather in Europe you need both EN14143 (or an approved Technical Specification) and a quality control and manufacturing system** like ISO that is independently audited. It is a breach of European Law if you as a manufacturer do not comply with all of the above.

The downside is it is very expensive to conduct the full range of CE testing and maintain the manufacturing system but this should never be an excuse. It's easy to see why this is an important issue for manufacturers, but it is for divers as well. As a diver, you are buying life-support equipment, so it is wise to ensure that a rebreather has been tested as fully as possible and can demonstrate that it does what the specifications say it can. Secondly some life-insurers are getting wise to rebreather issues and may choose not to insure divers, or instructors, or both, if diving or using units that don't reasonably meet testing criteria. Training organizations may also elect to only allow test-compliant rebreathers to be used on courses.

CE EN14143:2003 is a European standard, but some kind of testing and manufacturing standard will eventually be accepted globally (as it was for scuba regulators). There is now a body of global rebreather manufacturers called the Rebreather Education and Safety Association (RESA), and they are taking this on. In the meantime, especially outside Europe, how does a diver know which rebreather to choose? There are several base line tests that *must* be conducted to validate the rebreather performance. While these tests don't necessarily assure safety by themselves, they do allow an "apples-to-apples" comparison.


REBREATHER PERFORMANCE

ANSTI — ANSTI — ANSTI

CERTIFICATE REFERENCE : LSTF-00091041
DATE : 06/12/2007 TIME : 19:51:07

EQUIPMENT
REBREATHER TYPE
SERIAL NUMBER
GAS MIXTURE : AIR

CONDITIONS OF TEST

ROOM TEMPERATURE	: 20.0 C
WATER TEMPERATURE	: 4.1 C
EXHALE TEMPERATURE	: 25.8 C
FAST RESPONSE TEMP MIN	: -55.1 C
FAST RESPONSE TEMP MAX	: -55.0 C
HP SUPPLY PRESSURE	: 4.2 barg
TIDAL VOLUME	: 3.00 litre BREATH RATE : 25.09 bpm
VENTILATION RATE	: 75.3 lpm

PRESSURE - VOLUME DIAGRAM AT DEPTH OF : 40.0 msw (131.4 fsw)

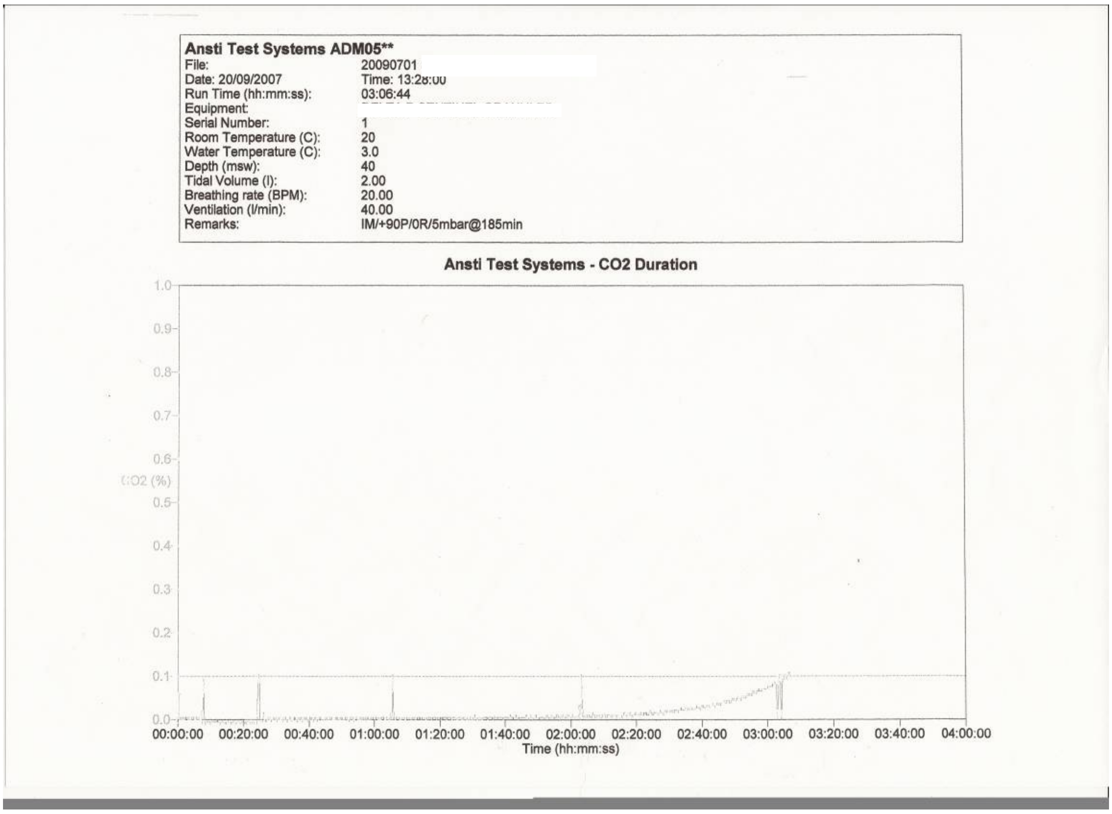
REMARKS : IM/90P/0R

LSTF-0009

Resistive Work of Breathing (WOB). This is the effort required to push gas around the circuit. Normally the tests are conducted at the operating depth in water (40m for an air diluent and 100m for a trimix unit), with the unit in the vertical and horizontal positions (some units vary massively in their WOB in the different positions). Another test rotates the unit (hydrostatic test) but if the design is reasonable and the resistive tests are good, the hydrostatic work of breathing normally passes. The graph shows a typical of WOB curve at the maximum ventilation rate of 75liters/min in the vertical position. The maximum allowed peaks of the loop are +/- 25mb and the maximum workload should be 2.75joules/liter +/- (3% test variation allowed) in 4 degree centigrade water.

CO2 Absorbent Duration Also conducted at the operating depths of the unit (40m and 100m), carbon dioxide is fed into the loop at a constant rate and temperature to assess how long the scrubber will last. In CE a CO2 production rate of 1.6l/min is assumed in 4 degrees centigrade water. This is a continuous high rate, but because depth, temperature and work rate affect duration (oxygen consumption/CO2 generation), this extreme allows for varying diving conditions. Time is quoted to the 5mb CO2 point on the curve, which in the 40m test below equates to 0.1% of CO2. This 5mb point defines the duration of the canister (in the case below 185 mins). A further measurement is taken at 10mb and deemed as the extreme limit. **Different units should be compared at the 5mb point when specifying canister endurance.**

If the depth, temperature, CO2 rate and 5mb point are not compared exactly you cannot do a 'like for like' comparison.



Partial Pressure of Oxygen (PO2) Tracking Control Test. This test has several important points. If a rebreather does not have a linked decompression system and the diver uses an external fixed PO2 computer, then the rebreather PO2 controller must maintain the PO2 within tight limits (+/- 0.1 PO2). If the rebreather does have an on-board decompression computer, this is not so much of an issue because the computer can keep up with the actual PO2 in the loop. **Both the internal and any external decompression computers and controllers should also be tested and certified under EN14143@2003.**

This test also defines how well the unit deals with rapid descents and rapid ascents, especially how much the PO2 peaks and falls. **Even units without a PO2 controller** must pass this test. The PO2 should not peak past 1.6 on descent and should not fall below 0.21 on ascent. The descent rate for the test is 30m/min and ascent rate is 20m/min. If a setpoint controller is fitted, ideally the unit should recover to setpoint within 1 minute.

Inspired Partial Pressure of Carbon Dioxide. Even if the CO2 absorbent canister is perfect and the mushroom valves work well, if the gas space in a rebreather mouthpiece is too big, dead air spaces can exist that allow CO2 to accumulate and be re-breathed. Therefore, this test is a volume test for the mouthpiece that measures the CO2 at the end of each breath at two different depths and a low and high ventilation rate. The acceptance limit is 15mb of *volume weighted* CO2.

Mushroom Valve Test. This test checks the most important part of the rebreather, the humble mushroom valve. With all the rest of the systems working perfectly, if these valves do not, gas does not circulate and the rebreather does not function and potentially becomes dangerous very quickly.

The primary test for mushroom valves is a negative test to see if they invert through the valve carrier and do not seal or become stuck or damaged (any failure will generate hypercapnia very quickly). The test applies a negative pressure of greater than 60mb for 10 seconds, during which time the valve must not leak or deform detrimentally.

There are other tests, but these are the basics safety ones in CE testing. As international standards develop, new tests will emerge, and the standards applied here will change. If you're part of the rebreather community – whether a diver, manufacturer or involved in instruction, you owe it to yourself to be familiar with rebreather testing standards and procedures. **It is the most objective way to compare rebreathers.**