Rebreather Fundamentals

By Kevin Gurr for Ouroboros rebreather website www.rebreathers.co.uk

It has become increasing apparent in recent years that there is a lot of mis-information with regard to the fundamental principles which govern safe rebreather operations. This is partly due to a lack of precise information from manufacturers and partly due to mis-use and abuse by divers in general.

Fundamentals

In order to understand what makes a safe rebreather, firstly one must understand the fundamental properties that govern a rebreather design. This can be divided into 4 areas.

1. The resistive work of breathing (WOB) within the rebreather
2. The hydrostatic WOB of the unit when submerged
3. The absorbent duration
4. The oxygen control dynamics

Looking at each in turn.

The Resistive Work of Breathing

This is purely a result of the gas flow restrictions within the unit. In other words how much the size of the pipes and orifices generate a resistance to breathing. Such things as small mouthpiece mushroom valves, small hoses, counter lungs with insufficient volume or room to expand and long absorbent paths within a canister are common elements which go to make up a resistive breathing circuit.

Resistive WOB is also a function of gas density and hence depth. The deeper the dive and the higher the gas density the greater the WOB. WOB is also a function of ventilation or breathing rate. The more gas flow (higher breathing rate) the more resistances is generated. A rebreather that breaths OK on the surface may well not at 40m on an air diluent. This why current European Standards (EN) Central European test standards) and military test standards insist on a resistive WOB measurement at depth and with different ventilation rates and in at least two orientations (swimming positions).

WOB is also subdivided into two areas of concern. The first is a short-term effect (breath by breath) and the second long term (over a dive). The rebreathers pressure/volume (PV) diagram is normally like a sideways ellipse, as you breathe out it starts from the bottom left and moves to the top right. The reverse is true on inhale. If the ellipse is thin (narrow in the middle) then the energy (joules/liter) consumed within the breathing cycle may be small and the long term energy expended also small, however the higher the angle of the ellipse from horizontal and there will be a restrictive feeling at the end each breath. This can produce much laboured breathing and a poor short term ‘feel’ to the rebreather. This is a function of the unit’s design in a specific area.

The Hydrostatic WOB
This is the result of the resistive WOB and the effects of the position of the counter lungs about the body when the rebreather and diver are submerged in water. For example, a back mounted counter lung rebreather may have a good resistive WOB but when in a horizontal (face down) swimming position the distance, hence pressure difference between the counter lungs and the lung centroid, may when combined with the resistive WOB create an excessive pressure which the diver has to suck against in order to take a breath. In this case the inhale pressure would be excessive (because the diver is inhaling gas from a lower pressure) and the exhale would be easy having breathed out into a lower pressure.

Chest mounted counter lungs have the reverse affect in the same swim position.

It would seem a perfect solution is an over-shoulder counter lung upon which any hydrostatic effects have little result. However if a rebreather has a poor resistive WOB anyway, the combination of this and any minimal hydrostatic WOB can still mean the unit has a highly restive breathing circuit and hence have a laboured breathing 'feel'.

In summary a rebreathers WOB can only be quantified under a range of hydrostatic (rotating) positions with additional measurements at depth. Furthermore, assessing a unit under a range of surface conditions at undefined ventilation rates is inadequate as it is only under stressful conditions (and normally at depth) that we generate high work-rates and this is precisely when the rebreather needs to have a low WOB.

Absorbent duration
This is a greatly misunderstood area. Many manufacturers quote durations based on simple surface trials which is insufficient and potential dangerous. Absorbent life is primarily affected by the following;

1. Amount (Kg or Lbs) of material
2. Type of absorbent material, its granule size and shape (which in turn affects the WOB) and its grade or usage type.
3. Water temperature
4. The absorbent canisters ability to insulate against the water temperature
5. The amount of CO_2 generated by the diver
6. The gas density/depth
7. The style and design of canister

The standard CE test for a canister is done at 40m with oxygen in nitrogen gas mixtures and at 100m with a helium based gas as diluents, in 4 degrees centigrade water temperature at a CO_2 generation rate of 1.6 l/min and a ventilation rate of 40l/min. Some navies test canister at around 18m and with as low as 0.5l/min CO_2 generation. The CO_2 breakthrough figure is referenced to 5mb.

The range of depths, gas densities, CO_2 rates and water temperatures used in each case can, dependant on the canister design, give markedly different durations. What is certain from the data available is that canister durations measured at the surface are dangerously inaccurate for predicting overall dive durations. It can be easily shown that for most axial and even radial canisters the efficiency of the canister decreases significantly with depth. One canister measured went from 77% efficient in 15m to 49% efficient in 40m. The 15m duration was 3 hours while the 40m duration was 1 hour and 50 minutes.

The ‘saving grace’ of currently available designs is that most people cannot maintain rates of 1.6 l/min CO_2 or seldom dive in 4-degree water. However data suggests that as a method of specifying canister duration, a single hourly rate independent of primarily depth and gas density, is insufficient and a range of diving parameter curves may be better employed to specify a unit’s duration. In other words in order to assess a rebreather’s suitability for one type of diving over another, it would seem appropriate to test a unit at a range of depths with at least air and trimix as gases. To provide a safety margin water temperature and CO_2 generation rate should remain constant.

Oxygen control system
This can be a mechanical or an electronically controlled device. Which ever is chosen it is important that the control of the oxygen level is maintained within certain limits. If decompression is to be conducted using tables or a fixed PO_2 dive computer, the limits must be accurately maintained. Rapid excursions to and from depth must also not generate excessively low or high PO_2’s. Ideally any such limits reached should generate an alarm, as it cannot be relied upon that the diver will notice especially in a multi-tasking situation. Some rebreather designs, due to high flow rates within the oxygen circuit, can generate massive PO_2 spikes sufficient to cause convulsions in a short space of time if left unchecked, this is an undesirable design feature should an addition valve fail. Within the CE and most Navy tests is a PO_2 tracking control test as well as an upper and lower limit test after rapid depth changes. With units employing a constant minimum feed of oxygen, which is supplemented by the diver, this minimum should not generate the upper and lower test limits specified.

Myths
In addition to and as a result of the above there is the issue of ‘diver abuse’, in particular with canister duration rules. This mainly occurs because of a lack of understanding and information. Common myths seem to be;

1. ‘If I use all my canister duration I can just scrape the top off the absorbent and add a bit and get more time’.
2. ‘When I have used up all the time on the absorbent I can just dry it out and use it again’.
3. ‘As long as I fill a canister and seal it I can use the absorbent anytime in the future’.
4. ‘If I partly use a canister I can seal it and use the rest at anytime and get the same duration’.
5. ‘If I fully use a canister I can leave it 24 hours to recover and then get more time’.
6. ‘I can use my canister at any depth and get the same duration’.
7. ‘I can use my rebreather with any gas and get the same duration’.
8. ‘I can use my canister in any water temperature and get the same duration’.
9. ‘If I run out of absorbent time underwater I will get a small headache and have time to deal with it’.

All of these assumptions have problems in varying degrees of severity. The bottom line is that while the sport of rebreather diving is increasing, unless the education curve follows it, there will be more incidents, most of them avoidable and some of them lethal.