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Advanced Knowledge Series: The Gas Density Conundrum

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Introduction and recap

This is the fourth in a series of articles appearing in Dive New Zealand / Dive Pacific with the aim of enhancing knowledge of selected practically important issues in diving physiology and medicine. In the first article we discussed how carbon dioxide (CO_2) is produced in the tissues during the utilisation of oxygen. CO_2 is eliminated from the body by breathing, and the more we breathe the more CO_2 is eliminated. This process of elimination is usually precisely controlled by the brain to keep CO_2 in the body at a stable level. If CO_2 levels rise, the brain will normally 'drive' more breathing to bring CO_2 back to normal and vice versa. This is a completely automatic function which takes place without us thinking about it.

This normal process of CO_2 control can be disturbed in diving because of an increase in the work required to breathe. The work of breathing increases because we are respiring a denser gas through a regulator or rebreather. In some people more than others, when the work of breathing rises the brain seems less sensitive to rising levels of CO_2 and it may fail to drive the extra breathing required to keep CO_2 levels normal. Thus, when under water, divers are prone to having body CO_2 levels rise, particularly when exercising and when the work of breathing is high. We refer to this as 'CO_2 retention'.

In the previous articles we also discussed the reasons why increasing CO_2 levels are dangerous. In particular, high CO_2 can produce symptoms such as headache, shortness of breath and anxiety. At very high levels these symptoms might lead to panic and drowning. In addition, high CO_2 levels increase narcosis and are a significant risk factor for oxygen toxicity, which is a concern for technical divers.

One obvious question that arises out of this recap of previously covered ground relates to gas density. If increased gas density is one of, if not the, main reason(s) why work of breathing increases as we go deeper, and if this in turn predisposes to CO_2 retention, then what is an acceptable gas density and how do we factor that into diving planning?

Acceptable gas density during diving

It is somewhat remarkable that although we have known about the above issues for some time, there has never been any systematic investigation of maximum allowable gas density in diving. This actually remains the case, though recently Gavin Anthony, an underwater breathing apparatus engineer from the UK, has produced the best related data and guidelines available to date.

Gavin works at a UK testing house for various life support equipment known as QinetiQ. They put various regulators and rebreathers through rigorous testing procedures using real divers immersed under water performing graded levels of exercise at different depths. Since the density of whatever gas is breathed (usually air) increases in direct proportion to depth, these tests at different depths have therefore also been, by definition, tests at different gas densities.

The QinetiQ underwater breathing tests have a predefined set of pass and fail criteria for each dive in which equipment is under test. Of substantial interest to us is the fact that one of the dive fail criteria was based around the test diver's body CO_2 levels, which can be monitored by measuring the CO_2 in the exhaled gas. If the partial pressure of CO_2 in the exhaled gas reached 8.5 kilopascals this was considered to indicate an unacceptably high level (a normal level is about 5.2 kilopascals). There is considerable justification for the choice of this particular criterion for dive failure; other studies of exhaled CO_2 in divers have shown that 8.5 kilopascals carries a high risk of sudden incapacitation.

With all of this in mind, Gavin analysed data from hundreds of test dives. He grouped the dives according to gas density and calculated the proportion of dives that failed due to high exhaled CO_2 as the gas density increased. Gas density is measured in grams per litre (g/L), and for reference, the density of air at one atmosphere is 1.29 g/L. The results were as follows:

Gas density range (g/L)	**% of dives failing due to high CO_2**
2 – 3	3.7
3.1 – 4	1.5
4.1 – 5	7.9
5.1 – 6	8.6
6.1 – 7	41.3

It is clear that there is a dramatic increase in the risk of CO_2 retention once the inhaled gas density exceeds 6 g/L. A sensible conclusion would be that we should plan our gases so that the density does not exceed this threshold.

Calculating gas density

Implementation of such a recommendation will require an appreciation of how to calculate gas density for a given respired gas at a given depth. Such calculations begin with knowledge of the density of air and the individual components of gas mixes at one atmosphere (atm).

Gas	Density at 1 atm g/L
Air	1.29
Helium	0.18
Oxygen	1.43
Nitrogen	1.25

Calculation of the density of air at a particular depth is a simple process of multiplying its density at 1 atm by the ambient pressure at the target depth. For example, the density of air at 30m (99 feet) is given by 1.29 g/L x 4 atm = 5.17 g/L.

Calculation of density for a mixed gas is achieved by using simple proportions to calculate the density of each component at 1 atm, summing the components, and multiplying this sum by the ambient pressure in atm absolute (ATA) at the target depth. For example, consider trimix 16:50 (16% oxygen, 50% helium, 34% nitrogen) intended for use at 70m (230 feet) where the ambient pressure is 8 atm. Calculating density for each component at 1 atm we use the fraction of gas in the mix multiplied by its density at 1 atm, thus, substituting in values from the density table:

0.16 (16%) x density of oxygen (1.43) = 0.23 g/L

0.50 (50%) x density of helium (0.18) = 0.09 g/L

0.34 (34%) x density of nitrogen (1.25) = 0.43 g/L

The sum of the products of these calculations is 0.75 g/L for density at 1 ATA. If this is then multiplied by 8 ATA for the ambient pressure at the planned depth (70m) we get 6 g/L. Therefore in respect of gas density this would be an acceptable mix at this depth (just). Divers are encouraged to check the density of gas they plan to breath at depth, particularly during the working phase of any dive, to try to avoid a density greater than 6g/L.

A more detailed account of these issues is nearing publication and will be available on line within the next few months.

Reference

Anthony T.G., Mitchell S.J. Respiratory physiology of rebreather diving in Pollock N.W. (ed). Proceedings of the US National Oceanographic and Atmospheric Administration 2015 Workshop on Scientific Diving. Seattle, NOAA 2015: In press.

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