Almost everything you wanted to know about oxygen-enriched air, uhh, "nitrox," but were too busy mixing it up to ask.

by R.W. Bill Hamilton

It has been just over a decade since the introduction to the scientific diving community of an organized way of diving while breathing gas mixtures that are richer in oxygen than the 0.2095 percent found in atmospheric air.

Some operational advantages (and some problems) can be gained by the use of oxygen-enriched air mixes. These advantages are entirely a matter of reduced decompression obligation. The price for this is special effort in mixing and handling the breathing gas, an increased probability of oxygen toxicity, and the need for appropriate training.

With both PADI and the British Sub-Aqua Club initiating programs for limited and responsible training in the use of oxygen-enriched air, or nitrox, the practice is now firmly a part of recreational diving, and is a maturing technology. It is worthwhile to have a look at where we are now and to reflect on how we got here.

Background

Credit for introducing the modern practice of oxygen-enriched air diving belongs to Dr. J. Morgan Wells, who has recently retired from the National Oceanic and Atmospheric Administration, US Department of Commerce, where he served as Diving Officer and later head of NOAA's Experimental Diving Unit. The method using 32% oxygen was documented in the second edition of the *NOAA Diving Manual* (1979), which also included derived decompression tables and methods for preparing the gas mixtures; this was later extended in the third edition (1991) to include 36% oxygen and more details on mixing.

The use of oxygen-nitrogen diving gas mixtures other than air was not new with NOAA. References to oxygen-enriched mixes go back to the last century. The concept had been studied intensively by the US Navy in the 1950s, particularly by Dr. Ed Lanphier, who was also chief architect of the 1959 edition of the *US Navy Diving Manual*. Although the benefits to decompression were known, the main reason for the USN's interest in O2-N2 mixes was for use in rebreathers. Interestingly, during his studies, Lanphier uncovered the individual physiological sensitivity of the "CO2 retainer," and because of the greater density and hence higher CO2 retention of O2-N2 mixtures, he concluded that heliox (oxygen-helium) mixtures might be a better choice (1958).

Commercial application of oxygen-enriched air mixtures was practiced from the 1960s, particularly by Andre Galerne's International Underwater Contractors, but at the time this was kept as a proprietary technique (Galerne, et al, 1984). Galerne's secret was that he knew that a proper decompression table could be prepared by considering only the nitrogen component of the mix. Others suspected it, but he had done it, so had a lead over competitors. It was not widely used; for one reason, it was not well understood by clients, but mainly because of the cost and complexity of making, analyzing, and handling the mixtures and training for their use more than offset the benefits. When equipment for on-line mixing of oxygen and air was developed, enriched air techniques came to be used extensively by a few operators. One project using a commercial mixer made by Dräger involved over 5,000 working dives (Hartung et al, 1982).

While Morgan Wells gets credit for introducing these techniques for diving with special O2-N2 gas mixes (and for confusing the terminology by calling them "nitrox"), the credit or blame, in the eyes of some, for introducing this concept to recreational diving belongs clearly to Dick Rutkowski, a close friend of Wells and colleague in the initial development within NOAA. Rutkowski began in about 1985 to apply and teach the NOAA techniques to civilian scuba-trained divers. His course was responsibly delivered (give or take a couple of myths), and popular because it included an interesting dive as part of the deal. For a variety of reasons, perhaps including Rutkowski's rather aggressive style and the perceived threat to others' "turf," the new practice was not well received by the recreational diving community, and an extensive and almost bizarre set of things "wrong" with nitrogen-oxygen diving (some correct, some totally wrong) was widely promulgated.

By early 1992, there was enough controversy to provoke a workshop on the question of enriched air in recreational diving. Conceived by *aquaCORPS*'s Michael Menduno and jointly sponsored with the Scuba Diving Resource Group, the pre-DEMA workshop presented accumulated experience, reviewed mixing problems and myths, defined problems, and set out to establish mixing and handling rules, and to promote a dedicated tank connector.

What's in a name?

Interestingly, the US Navy and most of the earlier practitioners of oxygen-nitrogen diving called it "nitrogen-oxygen" or "N2-O2" diving [Note that we use the North Sea convention specifying oxygen component first&endash;**see sidebox**]. Commercially, it was for the most part called that or "enriched air." The term "nitrox" was used originally to mean the gas mixture in an undersea habitat, because, to avoid oxygen toxicity, it had less oxygen than air. Wells, an early investigator and user of habitat diving techniques, had used the term "nitrox" this way in its original meaning, but he picked it up again to describe his 32% oxygen mixture.

The Harbor Branch Workshop, conducted by the Harbor Branch Oceanographic Institution in 1987 and paid for by NOAA, collected and attempted to coordinate the current status of O2-N2 diving (Hamilton et al, 1988). The term "enriched air nitrox" or "EANx" was selected as a compromise; it is less imprecise than "nitrox" alone, but retains "Nx" for the popular "nitrox" term. The term "oxygen-enriched air" (OEA) is more accurately descriptive still.

Logical or not, it is now commonly referred to as enriched air nitrox (EAN), or simply, nitrox. Specific mixes are denoted by their oxygen content, e.g., EAN 32, EAN 36, et cetera.

Diving with nitrox is occasionally called technical diving. In the sense that it has been slightly outside the domain of traditional recreational diving, this usage may make sense, but in the minds of serious technical trimix divers, single-mix diving with air, enriched or not, hardly qualifies as technical diving, especially if done without decompression stops. To the purist, technical diving has to involve at least one change of breathing mix during the dive as a minimum requirement (and much more), and enriched air diving as it is normally practiced rarely includes this maneuver. One of the technical training organizations has a category of "technical nitrox" diving, which involves decompression techniques, but this usage does not help clarify these terms much.

Mixing and handling

There are a number of successful methods of making nitrox mixtures [See "Blending Wars"&endash;ed]. The most common way to is to add oxygen to air. Any handling of high-pressure oxygen has to be done with special care, and while procedures are well worked out, they are demanding. Industrial standards exist for air and pure oxygen, but there are none for O2-N2 mixtures in between. Another problem in the nitrox development years was that there were no purity standards for air to be mixed with oxygen, because to mix oily air with high-pressure oxygen is asking for trouble.

In order to follow industrial practice with gas cylinders, it is preferred to have a unique tank connector for each gas category. Although several have been proposed for nitrox, none have been developed for mixtures in the range 25 to just under 100% oxygen.

Still another controversial matter is a prevailing practice of handling mixtures with less than 40% oxygen using the same procedures and equipment as for air. This practice, which seems never to have been specifically tested in the laboratory, was suggested by the US Navy and has been used for many years without clear evidence of problems. It is acknowledged that the 40% limit was arbitrary, but it seems to be working. Divers and others relying on this "rule" are strongly encouraged to clean the equipment thoroughly, maintain cleanliness, and use an oxygen-compatible lubricant, such as Christo-Lube, for all surfaces contacted by the high oxygen mixes.

Once a mix is made, it is incumbent on the diver to analyze the mix and ensure that the tank is properly labeled, and where it is a factor, to make certain that the mix is used under the intended conditions. There have been several fatalities of technical divers who have used a high-oxygen mix at the wrong depth.

Two myths or common misunderstandings have grown up around analysis. One is that two analyzers should be used. The truth is, a far better practice is to use one analyzer properly. If you think you need two, it is likely that you are not using either one of them correctly. Another myth is that gases have to be used within a couple of weeks because they may separate, or in the case of trimix, that "the helium will leak out." Actually, once gases are mixed, they will not separate.

Hazards of oxygen

From the diver's perspective, the biggest problem with enriched air diving is the threat of oxygen toxicity. This manifests itself in two ways. By far the most serious is toxicity of the central nervous system (CNS), which can cause a convulsion and can strike without warning. This is invoked by short exposures (minutes) to relatively high levels of oxygen, above about 1.3 atm PO2 (oxygen partial pressure). The other, now being called "whole body" toxicity, primarily affects the lungs and has been traditionally thought of as "pulmonary" or "lung" toxicity. It may follow many hours of exposure to levels low enough to be tolerated for longer periods but above a threshold of about 0.5 atm PO2. Symptoms include chest and airway soreness, coughing, and a reduction in vital capacity, but a number of other non-lung symptoms such as headache, fatigue, paresthesias, and other aches and pains have also been noted. This toxicity develops over time and comes on faster at higher oxygen levels.

Toxicity can be controlled, or reversed, by reducing the exposure intensity or stopping it altogether.

For many years, the only recognized limits for oxygen exposure were those in the *USN Diving Manual*. There were some valid aspects to these limits, but they were more political than physiological in origin, and did not deal with exposures to multiple levels, nor provide for recovery. Addressing the need for a better standard, NOAA sought advice from experts in producing a new set of limits for the 1991 edition of their manual. These limits, which provide maximum exposure times for different levels of oxygen (PO2s), are realistic and deal with both short exposures and daily limits. No recovery provisions are included, but this is taken into account in the limits for a full day. The highest level allowed is 1.6 atm, for which the allowed time is 45 min. This is appropriate for a non-working diver with no tendency for CO2 buildup, but experience seems to tell us that for the untethered mouthpiece diver during the working phase of a dive, an upper exposure limit of 1.5, or better 1.4 atm, gives a greater margin of safety and costs little in extra decompression. This safety margin is further improved by having a full-face mask, communications, a tether, a standby diver, and a chamber at the surface (all standard for commercial divers).

Some training organizations have devised procedures for interpolating between the different levels and durations of exposure. This proportional concept had been proposed by Kenyon and Hamilton (1989) in order to solicit reactions from the diving medical community (with no significant response, pro or con). The method considers the approach of a diver's exposure toward the limit, implemented as a fraction of the limit, the "O2 limit fraction," or as a percentage of the limit (the "oxygen clock"), called CNS%. There is no evidence that this interpolation is physiologically proper, but considering the somewhat arbitrary nature of the limits, they are used with confidence. The limits themselves are more problematic.

A further development in this process deals with recovery, the "decay" of this fraction or percentage during periods when the exposure is less than 0.5 atm PO2. This was developed first for the Bridge dive computer, using a halftime decay of about 90 min. That is, every 90 min the O2 limit fraction decays (is reduced) halfway back toward 0; this may be overly conservative, but a good starting point considering the limited data available. A linear rather than exponential decay would not be unreasonable.

The available algorithms are estimated average levels for operational diving, but do not guarantee in any sense that a given individual at a given time is protected from toxicity. A troublesome characteristic of human tolerance of exposure to oxygen is that individual sensitivity varies widely. Unfortunately, we have to expect an occasional convulsion, or an individual now and then to feel some chest tightness or even soreness at the end of an exposure calculated to be tolerable.

Another oxygen problem that deserves mention is hypoxia, or too low an oxygen level. Hypoxia is particularly dangerous because it induces a sense of euphoria that may prevent corrective action from being taken. It is relatively rare in air diving, but it has proven to be one of the major hazards of mixed-gas diving. Mixes used for enriched air diving usually begin with air, so there are rarely any gases on hand with inadequate oxygen levels. However, any diving with rebreathers or with mixes using inert gases can result in a diver receiving a hypoxic mix. Proper procedures, a high level of discipline, and extreme caution are needed.

The decompression advantage

The main reason for using oxygen-enriched air is to gain a decompression advantage. This is based on the valid principle that only the inert, or nitrogen, component of a gas mixture is involved in the requirement for decompression. With nitrox, the allowable no-stop time is increased, less decompression time is needed, and a given dive using nitrox as the breathing gas but with a decompression table based on air will be more reliable or have a lower predicted decompression sickness incidence (PDCS).

In fact, for a given time-depth combination requiring stops, diving with nitrox not only results in a shorter decompression, this dive also will have a lower PDCS. This is not just "nitrox hype." The reason is based on the established and empirical premise that, everything else being equal, longer and deeper air dives with excessive gas loadings require more than proportionally longer decompressions, especially when calculated with Haldanian methods. The converse of this is that shorter dives with shorter decompressions lower gas loadings and are less likely to cause DCS. The enriched air dive has a shorter decompression. It is entirely reasonable to expect divers who receive the shorter, higher-oxygen decompression to feel better afterwards. (See Figure 1.)

Using enriched air tables

The basic method of getting a decompression table for enriched air is to use an "equivalent" air table. That means to select an air table for a bottom depth that results in the same nitrogen partial pressure (hence the term, equivalent air depth, or EAD).

This is calculated by determining the PN2 at the current dive's bottom depth using the current enriched air mix, then finding the depth that gives that PN2 with air and decompressing with the air table for that depth, which will be shallower and thereby require less decompression (see "Speak Mix Man" p. **XX**). This method is actually quite conservative and apply best to dives requiring stops.

The tables printed in the NOAA manual are USN tables calculated with the EAD method.

However, the EAD method does not take full advantage of the decompression possibilities of enriched air. To optimize decompression requires tables calculated specifically for nitrox. This can be done with one of the "do-it-yourself" decompression programs or with a dive computer capable of handling enriched air. Figure 2 shows a comprehensive cave dive analysis.

Optimal depth range

The most effective range for the use of enriched air is between about 50-115 f/15-35 m, but it is promoted as being useful to as deep as 165 f/50 m. Beyond about 115 feet, the decompression gain is minimal, but the risk of catastrophic oxygen toxicity problems increases greatly. This is because as depth increases, the cost of an analytical or mixing deviation is magnified, and as distance from the surface increases, the difficulty of effecting a successful rescue decreases.

At 60 f/18 m, where one can use EAN 50, the no-stop time goes from one hour to essentially unlimited. This has been found to be operationally tolerable for a six-day work week (Oernhagen and Hamilton, 1989).

Using enriched air as a decompression gas

One very successful application of oxygen-enriched air is for use as a decompression mix from a deeper dive using air or trimix as the bottom mix. On such dives a switch is made at a depth selected to give a tolerable PO2 with the nitrox after switching, and is usually maintained until oxygen breathing begins at about 20 f/6 m. It does not matter too much what the oxygen fraction of the intermediate mix is; the benefit to decompression will be about the same if the switch is made according to the same PO2 criterion for the switch. Some operators use a enriched air mix of, say, 80% oxygen for the "oxygen breathing" portion of the dive to avoid a PO2 slightly higher than 1.6 at 20 f/6 m. See Figure 3.

Narcosis relief and other myths

Some nitrox promoters have advanced other benefits that are not so clear cut. One of these myths is that enriched air causes less narcosis than air; the assumption being that narcosis can be calculated in the same manner as decompression, looking only at the inert gas. From a theoretical point of view, oxygen is at least as narcotic as nitrogen. The evidence on this issue is scanty, and what little there is shows no difference. The best approach, at least until more data become available, appears to be to regard the narcotic potency of nitrox being the same as of air.

Another, even more exotic, phenomenon is that enriched air increases sexual prowess. The story is that diving fishermen using air were fatigued at the end of the day, and with enriched air they felt better. The comparison here is subjective and anecdotal, but the concept that a better quality decompression leaves a diver in better shape is entirely valid.

One of the early "anti-nitrox" myths stated imprecisely by Dr. Peter Bennett of DAN and promptly misinterpreted was that a diver "could not be treated for DCS from nitrox diving." This was in reference to the possibility, extant but extremely improbable, that the diver's oxygen exposure would preclude treatment with hyperbaric oxygen. While the treating facility would have to monitor and deal with any development of whole-body oxygen toxicity, this is always the case. There were actually facilities that stated they would not treat divers who had been diving with nitrox until this misunderstanding was corrected. DCS following a nitrox dive should be treated in exactly the same way an air dive would be, considering the other variables.

Finally, a word about "safety." Recreational decompression procedures are all "safe" in the sense that there is an extremely low probability of encountering DCS, and in particular of being injured by it. Enriched air reduces that probability still more. Calculations notwithstanding, it seems ludicrous to promote that this is "safer" when the difference in incidence could not be detected except by a controlled test program involving hundreds or even thousands of dives. Further, the possibility of being injured by decompression sickness from a properly conducted dive is truly trivial compared to some of the other things that can go wrong in diving, or bowling for that matter.

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What it the primary concern regarding enriched air nitrox and equipment? What are recommendations for using equipment, other than cylinders, which enriched air up to 40% oxygen? (Consider local regulations in your response if appropriate). Primary concern: high oxygen content may cause fire, explosion, or deterioration due to oxidation. Common dive community guidelines allow for use of BDCs, SPGs, and alternate air sources to be used with Nitrox up to 40%. It is the same in our area. What is the potential hazard of improper enriched air filling procedure? Not knowing the correct oxygen percentages. Fire, explosion, deterioration. List the markings that, according to broadly accepted dive practices, you should have on a scuba cylinder used for nitrox. Short-term memory lasts up to 40 seconds. It allows us to reproduce freshly received information without consulting the original source. It is reliable but limited in capacity: for a long time, it was thought that it can only store 7Â±2 things at once.Â However, modern researchers think that the number proposed by Miller is too high â€" and the actual capacity of our short-term memory is closer to 4Â±1 units of information. Fredy Jacob â€" Unsplash. Long-term memory is fundamentally different.Â While thereâ€™s still a lot we donâ€™t know about the human brain, it would be wrong to assume that these memory types exist in isolation from one another. Richard Atkinson and Richard Shiffrin were among the first to propose a theory of how they might be connected. Sensory memory is engaged first. There are no reviews yet. Be the first one to write a review. 155 Previews. 6 Favorites. Purchase options. Better World Books. DOWNLOAD OPTIONS. download 1 file. Want to join? Log in or sign up in seconds.| English.Â Butane burns cleanly and disperses almost immediately. You pretty much have to either shoot it up your nose or contain it, maybe by putting a bag over your head. Dont do that.Â Helieox mixes require More experience and knowledge but are better for the body and make the dice safer if the diver is experienced. permalink.