**What is "Technical diving"?**

Given all this, perhaps it is now possible to define technical diving. At the outset it should be pointed out that the term "technical diving" comprises so many different aspects of diving practice that SPUMS policy does not address this as a single entity.

**Technical diving**

is recreational;
it has been developed entirely by recreational divers who do it voluntarily, at their own expense and risk;
it does not meet occupational safety standards;
the term is an analogy with technical mountain climbing;
is self-contained recreational diving which may extend beyond the range of traditional recreational diving;
necessarily involves special training, discipline, experience, and commitment beyond ordinary diving;
uses special techniques and equipment, including breathing mixtures, gas management, decompression procedures, decompression stations, thermal protection, buoyancy and ascent control, propulsion, and redundancy;
requires detailed operational preparation and planning.

A technical dive involves a change in breathing mix or use of a rebreather.

The definition excludes some things. Technical diving is not;
diving with oxygen-enriched air ("nitrox");
using rebreathers in the recreational envelope (40 msw, no-stop);
and of course deep air diving.

Operational organization is imperative for all but the mildest technical dive; some good examples of how to do this are now available.[10]

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## NITROX

David Elliott

**Key Words**
Accidents, deaths, injuries, mixed gas, nitrogen, nitrox, oxygen, safety.

"Nitrox" is an easy word to use for the range of oxy-nitrogen mixtures but there are several other terms also in use. For those mixtures in which the oxygen content is greater than 21%, "Enriched Air Nitrox" (EANx) is a common term and "Oxygen-enriched air" (OEA) is another, while others (such as the one which suggests that nitrox is a "safe" version of air) are proprietary. Nitrox has also been a term used in saturation diving procedures by NOAA for mixtures in which the oxygen content is *less than* 21% and it has been suggested that the term nitrox for oxygen-rich mixtures could be ambiguous and that nitrox should be reserved for oxygen-lean mixtures.

But there is a precedent: "heliox" is also an easy word to use. The heliox mixtures used in deep diving are oxygen-lean but also 50/50 heliox, for example, is used for therapy in the Comex 30 metre table. Yet it has never been suggested that the term heliox should not be used for the oxygen-rich mixtures. So, in this paper, nitrox will refer to *any* oxy-nitrogen mixture other than air and, as this is in the context of recreational diving, nitrox will usually refer to an oxy-nitrogen mixture with more than 21% oxygen.

In fact, adoption of the broader term “nitrox” is particularly appropriate for recreational diving because, as will be shown later, there are some circumstances when, although EANx or OEA has been supplied to the breathing bag of a rebreather, the “oxygen-enriched air” which is then breathed by the diver will contain *less than* 21% oxygen.

Oxygen-enriched air has been used in military semi-closed rebreathers for more than 50 years but that is a special application which will be reviewed later. It is probable that this principle was used first in mine clearance because of the safety advantage of less noise from exhaled bubbles with a rebreather than from an open-circuit underwater breathing apparatus.

The thought occurred to several commercial diving companies some 30 or more years ago that diving with oxygen-enriched air in open-circuit breathing apparatus could shorten obligated decompression times usefully. It had positive financial benefits, particularly in tidal waters and so, in consequence of commercial secrecy, it is not easy to discover where the idea originated or how practical and safe it turned out to be in those early days. Around 1963 Micoperi, an Italian company which, with Shell, owned a North Sea diving company, used high oxygen levels for some nitrogen dives. Andre Galerne’s diving company, I.U.C., was doing much the same at around the same time, also as a discrete proprietary technique.[1]

## Equivalent air depth

The whole essence of nitrox diving is that one can ignore the oxygen content of a breathing gas for the purposes of the decompression calculation. So, when breathing an oxygen-enriched air mixture, the nitrogen uptake at depth is reduced and the uptake can be considered the same as that when breathing air at some shallower depth, the “equivalent air depth” (EAD).

The EAD can be calculated for any percentage oxygen level:-

Metric formula

$$\text{EAD [in m]} = \frac{(\text{Actual Depth} + 10) \times N_2\%}{79\%} - 10$$

or

Imperial formula

$$\text{EAD [in feet]} = \frac{(\text{Actual Depth} + 33) \times N_2\%}{79\%} - 33$$

Strictly speaking this principle is not absolutely correct because, for example, increased oxygen tensions can contribute to decompression sickness either by the effect of altering blood perfusion rates to critical tissues or, exceptionally, by contributing directly to the illness.[2] These and other theoretical concerns do not detract from the fact that the principle of EAD has served many divers well for more than 50 years.

## The advantages of EAD

The practical advantage of increasing no-stop bottom times at depth is obvious for those recreational divers who base their diving on the no-stop tables. For those planning decompression stops one advantage is that of briefer stops for any given bottom time and depth.

However, the advantage for no-stop diving is limited. At shallow depths where dive duration is limited by the volume of gas that the diver can carry, there may be no advantage of using nitrox, particularly for a single dive. At around 22 m an average diver will carry just sufficient gas to complete a dive with a duration which is around the compressed air no-stop time and so the diver could not stay there longer even if he or she were on nitrox. The benefit may come with the second dive of the day.

PADI quote no-stop times at 18 m of 56 min on air, 95 min on 32% oxy-nitrogen and 125 min on 36% oxy-nitrogen and the BSAC decompression tables have very similar durations. One other training agency quotes no-stop times at 80 feet (26 m) of 30 min on air, 45 min on 32% oxy-nitrogen and 55 min on 36% oxy-nitrogen. The USN tables would be less conservative at 40, 50 and 60 min respectively. This difference is not related to the nitrox theory or oxygen exposure but is a reflection of different underlying decompression models. These examples all illustrate the small increments of increased bottom time available and thus the need to weigh the potential advantages carefully against the costs of training, equipment and gas and the risks from other hazards.

At the deeper depths the use of oxygen-enriched air is constrained by the need to avoid oxygen neurotoxicity. PADI, BSAC and several of the technical diving agencies suggest that exposure to a $PO_2$ of 1.6 bar should be for only special contingencies, not regular recreation. One of the technical diving training agencies compares the no-stop times of air, 32% and 36% oxygen over a depth range to 40 m. These tables demonstrate the even smaller advantages to be gained in the depths which take the diver beyond the oxygen limit of $PO_2$ at 1.44 bar.

Another advantage of nitrox quoted by some agencies is that oxygen-enriched air has a potential for increased decompression safety. This is true but it is achieved as an *alternative* to using the principle of longer bottom times and shorter decompressions. By ignoring the equivalent air depth and using the air decompression tables for the actual depth dived on enriched air, the risks of decompression sickness are reduced. For a large population of divers it would be very difficult to see any improvement when using nitrox over the already very low incidence of decompression sickness when using air.[3] However spinal decompression sickness appears to be more common in, for example, those over 40 years old. At present additional safety can be achieved by using an even more conservative no-stop air table, for instance by using one's decompression computer in the altitude mode when diving at sea-level . But in effect this is a decision to surface early on a regular basis and one which can make it difficult to find buddies! In these circumstances the use of nitrox on a regular air table (or with a regular air-based computer) would provide safety and preserve friendships. I am told by its owner that there is one dive shop in the Caribbean which provides 32% nitrox specifically for increased safety, so it seems that some recreational divers are prepared to pay for this particular advantage.

While in theory a diver could compromise between the two separate advantages, a prolonged bottom time or a safer decompression, one must choose because one cannot have it both ways, as has been suggested by several technical diving training agencies.

Another claim which has been made for the safety of nitrox appears to be unsupported by any evidence. "If a diver has been breathing nitrox during the course of the dive then the chances are that their injuries will be comparatively less serious than if they had been diving on air".[4] Such misconceptions are not uncommon and I am assured that this potentially misleading error will be corrected in the next edition.

**Maximum depths with nitrox**

Oxygen toxicity theory and the accumulated experience underlying the depth limits imposed on oxygen-enriched gas mixtures have been reviewed at this meeting already.[5] Accordingly only a few special points need to be illustrated and they will be reinforced by using commercial experience of open-circuit nitrox. Professional divers dive in a safer manner than sport divers because they are required to use procedures and equipment that would not be tolerated in recreational diving. By diving with a hose they have an underwater duration not limited by a scuba tank. Hard wire communication is routine and provides an additional safety feature. Pre-dive gas analysis of premix and back-up mixes must be meticulous and, with hose-diving, an on-line gas analyser is another safety factor. Depth is continuously monitored at the surface by an on-line transducer which means that they are unlikely to be allowed to exceed the maximum depth for the particular mix in use. Should a fit occur they will not drown because they are diving with a full face mask or helmet.

Even with such constraints, $PO_2$ 1.5 bar is the maximum permitted in the North Sea. In spite of that, incidents do occur and one oxygen fit has been reported at $PO_2$ 1.52 bar and another at 1.32 bar $PO_2$. In reviewing a proposal that the $PO_2$ 1.5 bar limit could also be used by other categories of working divers, one should also consider the difference in equipment and procedures. A diving scientist is trained on scuba and, like a recreational diver, would use a half mask and an independent mouthpiece. Using nitrox in these circumstances an underwater fit, though rare, could be lethal.

There is no safe/unsafe cut-off value for oxygen. One is dealing with the probabilities of a seemingly random event. One recreational agency puts $PO_2$ 1.4 bar forward as the maximum advised; BSAC and PADI use $PO_2$ 1.44 bar. Only for exceptional tasks, such as diver rescue, would they go as far as 1.6 bar. One Technical Diving agency in its text implies using 32% oxygen at a maximum of 46 m ($PO_2$ 1.8 bar). This may have been an error and they may have meant when using their other standard mix, "28%". Even this would provide a $PO_2$ of 1.57 bar and, the greater the $PO_2$, the greater the hazard. These are examples of the potential for confusion among those who come to nitrox from air diving. And, at depths as deep as 46 m (150 ft), for what advantage? The DCIEM tables provide no-stop time at 46 m on air of 6 min and 7 min at the 28% oxygen EAD of 41 m. On each dive the hazards and costs of using nitrox need to be assessed against the benefits.

**Convulsions**

Oxygen neurotoxicity has just been well reviewed at this meeting[5] but, in regard to the nitrox training provided by some agencies, perhaps too much emphasis is being placed on a diver being able to recognise the subtle prodromal warnings, if present. Just how useful underwater acronyms, like "VENTID" and "VITBEND", might be in enabling a diver to remember the list of symptoms, then decide to abort the dive and do so safely, is uncertain. The probability is that if one recognises a prodromal symptom, it is already too late.

> *A commercial nitrox diver on $PO_2$ 1.5 bar heard a sound in his head like an "outboard engine" but he knew that there was no boat there. He felt that he was "going" and had the sense to try and wedge himself into the structure that he was on so that, if he lost consciousness, he would not sink to the bottom. He had a full oxygen fit, confirmed by a his own video camera, and he did sink to the bottom. His depth was being monitored at the surface so and he was quickly rescued, still wearing his full face mask.*

But often, there is NO warning.

If one witnesses a fit, what action should one take? Most important underwater is trying to ensure the retention of the mouthpiece, if it is still in. One international agency recommends emergency surfacing but, if the diver is in laryngeal spasm then, theoretically at least, that manoeuvre might cause pulmonary barotrauma. Another major training agency avoids this hazard and recommends waiting until the diver becomes limp before surfacing. "Near drowning is easier to treat."

If the mouthpiece is retained then there is no panic and no need to rush. The diver can be returned to the surface when the fit is over. If the mouthpiece has come out, the rescuer must choose between the possibility of near-drowning of the diver fitting at depth and that of gas embolism of the diver fitting on ascent. This decision must be made in the absence of medical advice. Quite a responsibility.

**40/60 or is it 60/40 ?**

Another convention which needs to be re-established is that in describing oxy-nitrogen, as introduced by and used by NATO, the oxygen is always first. In a 60/40 oxy-nitrogen mixture one would expect to find 60% oxygen. It is therefore worrying to find a reversal of this by some of the newer training agencies, for instance "$PO_2$ 2.4 bar in 60/40 treatment gas at 6 bar". An alternative, which is always to specify only the oxygen percentage, would seem acceptable for describing mixtures. Of course, whatever the convention may be for written texts or on labels, gas analysis is the ultimate and only acceptable indicator of oxygen content before actual use.

**Repetitive diving**

The calculations needed to predict the safe duration of a repetitive dive are fairly straightforward even if the shallower second dive is on a richer oxygen mixture. But some divers do get their repetitive calculations wrong even on air and, using nitrox, there are simply more opportunities for error. This alone justifies the need for proper training and occasional retraining of those who decide to dive with nitrox.

**Gas mixing**

The problems imposed by handling and of mixing oxygen are described elsewhere. "Top-ups" and other home brews can be lethal and the diver must always get the tanks filled by a reputable nitrox agency and *personally* witness the analysis the contents of his or her own tanks and label them accordingly.

**Conclusion**

The benefits from using equivalent air depths with open-circuit nitrox, as taught by the major recreational training agencies such as PADI, can be achieved safely provided that the diver is meticulous in following the appropriate procedures. Its advantages are however limited. There is only a narrow depth range in which nitrox can be used advantageously and the increased bottom times, which are only a little longer, come at an increased cost. At the shallower depths one cannot always take advantage of the increased bottom times on one tankful and near the maximum depth limits for each mixture there is the possibility, albeit remote, of an underwater convulsion. One wonders if the benefits are worth all the extra training, effort and cost. For some they are, but this must be a personal decision.

One must also be a little concerned about the marketing bias of a few of the agencies. For example, there is no proven advantageous reduction of nitrogen narcosis in the depth ranges used as is claimed by one. In one or two agencies there is a tendency to highlight the deeper maximum depths attainable but attainable only when using a $PO_2$ of 1.6 bar. In others there is a tendency to play down the hazards of nitrox in relation to compressed air diving. "Nitrox" says one agency "has just the same problems as diving with compressed air.". They both "have a potential for decompression sickness, the potential for trauma from handling pressurised gas and the hazards of oxygen toxicity." This is a misleading statement which is true only in absolute terms, but one which is not quantitatively true:

- when using EAD to determine decompression, the potential for decompression sickness with nitrox will approximate to that with air at that EAD.
- the potential for trauma when handling pressurised air does not include the hazard of handling oxygen and explosive mixtures.
- the hazards of oxygen neurotoxicity do not exist with compressed air diving (unless diving deeper than the recommended limits of the major training agencies).

Compressed air diving, as taught well by the wiser agencies, still has many practical advantages.

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## THE PADI ENRICHED AIR DIVER COURSE AND DSAT OXYGEN EXPOSURE LIMITS

Drew Richardson and Karl Shreeves

**Key Words**

Mixed gas, nitrogen, oxygen, recreational diving, safety, training.

### Introduction

In January 1996, PADI International released an Enriched Air Nitrox dive training program which is fully supported with educational materials for the student and instructor. This paper will review some of the philosophy, highlights, content and treatment of this topic found in the course. The purpose of the course is to familiarise divers with the procedures, safety protocols, hazards, risks, benefits and theory of no-decompression diving with oxygen enriched air containing 22% to 40% oxygen. The emphasis is on diving with EANx 32 and EANx 36 (also known as NOAA Nitrox I and II). Training emphasises the importance of proper procedures to ensure safety, and realistically balance the pros and cons of enriched air diving. Instructors are encouraged to elaborate beyond the material in the course outline to accommodate individual student interests and aspects of enriched air diving unique to the local environment.

The goals of this program are:

1 To enable a diver to plan and make no-decompression dives using enriched air blends containing 22 to 40% oxygen, remaining within accepted dive table and oxygen exposure limits.

2 To enable a diver to obtain, and care for, equipment used in enriched air diving.

3 To enable a diver to avoid the possible operational hazards and underwater hazards associated with oxygen.

There are two enriched air training dives required for certification. These may not exceed 30 metres (100 ft), or exceed a $PO_2$ of 1.4 bar, whichever is less.

### An overview of enriched air

Enriched air is any nitrogen/oxygen gas mixture with more than 21% oxygen. Enriched air is sometimes called nitrox. However, the term nitrox includes nitrogen/oxygen mixes with less than 21% oxygen, which are used by commercial divers to reduce oxygen exposure when remaining under pressure for days at a time (saturation diving). These types of nitrox are made by mixing pure nitrogen and pure oxygen, rather than by adding oxygen to air. For clarity, the terms “enriched air” or “enriched air nitrox” are preferred by PADI.

Most of the special training one needs to dive safely with and handle enriched air relates to its higher oxygen content. The primary application of enriched air is to extend no-decompression limits beyond those of normal air. Based on US National Oceanic and Atmospheric Administration (NOAA) tests, Navy tests dating back more than 50 years, 20 years field experience by scientific divers and field experience in thousands of recreational dives, the no-decompression limits for enriched air are generally considered as reliable as those for normal air tables and computers. However, there is a trade off. As one reduces nitrogen exposure, one increases oxygen exposure. Therefore, much of what needs to be taught to students deals with keeping oxygen exposure within safe limits. Practically speaking, depending upon the dive depth and breathing rate, dives may be limited by enriched air supply rather than no-decompression limits. Therefore, in some cases, planned dive profiles and planned repetitive dives may not be able to take advantage of the additional time enriched air offers.

Decompression limits for EANx are calculated using the equivalent air depth (EAD) which is the shallower depth at which an air breathing diver would be exposed to the same partial pressure of nitrogen. The diver using EANx uses the time available at the EAD for calculating the time available at the deeper depth.

Because one absorbs less nitrogen using enriched air, one might expect that using enriched air within normal air no-decompression limits would substantially improve safety. This is probably *not* true. The decompression illness (DCI) incidence rate is already so low that it is unlikely that