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RECENT DEVELOPMENTS IN THE PREPARATION OF MIXED GAS BREATHING MEDIA—NITROX, HELIOX, AND TRIMIX

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RECENT DEVELOPMENTS IN THE PREPARATION OF MIXED GAS BREATHING MEDIA--NITROX, HELIOX, AND TRIMIX

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While both nitrox and trimix are classified as "mixed gas breathing media," the physiological rational for their respective applications is quite different.

Since the rate of nitrogen uptake by the body, under hyperbaric conditions, is a function of nitrogen partial pressure in the breathing medium, breathing a nitrox mixture containing less nitrogen than air will result in the uptake of less nitrogen than the same exposure would if air were used as a breathing medium. In practice, this would allow a diver to increase the time available at a specific depth, relative to air, without requiring decompression, i.e. an increase in "no-decompression time." It would also significantly reduce the time required for decompression, relative to air, on long dives which require decompression stops. Although the reduced nitrogen partial pressure may also reduce nitrogen narcosis, relative to air at the same depth, this factor is not of great significance in practical diving situations.

The primary reason for the addition of helium to divers breathing media is to reduce nitrogen narcosis, and normally, the primary reason for retaining nitrogen as a component of Trimix is its low cost relative to Helium. The reduction of high pressure neurological syndrome and decompression, resulting from nitrogen in the breathing gas are advantageous in some situations, normally in very deep diving. The procedures outlined in this paper are generally most applicable to Trimix diving shallower than 400 fsw.

PROCEDURES

Mixing by partial pressure remains a common technique. For situations where the gas requirements are small, and an inexpensive source of suitable gases are available, it may remain the method of choice. In the scientific, "technical," and recreational diving communities, "oxygen compatible air," oxygen, and helium, are currently being used to prepare Nitrox and Trimix breathing gas mixtures by partial pressure methods.

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The development of a continuous blender (Wells 1989a, 1989b) increased the safety and effectiveness of Nitrox preparation. This apparatus, known as the NOAA Continuous Nitrox Mixer (fig.1), blends ambient air with oxygen and provides a high pressure output of Nitrox. The original, and widely used, version of this apparatus uses pure, high pressure oxygen. More recent modifications have substituted gas separation (GS) devices (oxygen or nitrox generators) for the pure, compressed oxygen (Wells and Moroz 1993). These units offer the advantage of providing low cost, high oxygen mixtures without the problems associated with the purchase, transportation, and handling of high pressure or liquid oxygen. They are of particular advantage in remote, or other areas where oxygen availability is limited.

Two fundamentally different atmospheric gas separators are addressed. The molecular sieve based "pressure swing adsorption" (PSA) system depends on the selective adsorption-desorption of nitrogen on molecular sieve material during pressurization and depressurization with air. The "differential permeability" (DP) system depends on the differential rates of diffusion of gases through the walls of hollow fibers pressurized with air. Both systems utilize low pressure air as a gas source and produce product streams of high oxygen/low nitrogen and low oxygen/high nitrogen gases. Both of these product gases have applications in diving and hyperbaric activities. The high oxygen mixtures are used primarily with the NOAA Continuous Nitrox Mixer to produce divers breathing gas and therapeutic Nitrox mixtures. The low oxygen mixtures can be used to produce Nitrox saturation breathing mixtures.

Figure 2 shows the output characteristics of a PSA system (Wells and Moroz 1993) supplied with breathing quality low pressure air. Although carbon monoxide is concentrated in the low oxygen product gas, its concentration is normally within acceptable limits. The "back pressure" shown on the horizontal axis is the pressure of the gas in the low pressure oxygen storage tank. The low-oxygen product gas is released at atmospheric pressure, since a back pressure would significantly reduce the performance of the device.

Figure 3 shows the output characteristics of a DP system (Wells and Moroz 1993) supplied with breathing quality low-pressure air. The fractions of the respective gases in the high and low oxygen product streams are controlled by the back pressure or flow of the low oxygen product stream. This gas can be delivered at a pressure slightly less than the supply air. The high-oxygen gas is delivered at near atmospheric pressure.

Figure 4 shows a NOAA Continuous Nitrox Mixer equipped with a GS device and a feedback system (Rutkowski and Delp 1995). Both DP and PSA systems will function in this configuration if their outputs are compatible with the input requirements of the compressor. The feedback system facilitates the use of a wide range of outputs of the GS apparatus, and a capability to adjust the oxygen output of the mixer to within ± 0.1%. Best performance of the PSA system is obtained by utilizing a high-oxygen "back pressure" in the range of 30 psi and adjusting mixer input rates to control the 02 content of the final high pressure mixture (conventional method). Best performance of the DP system can be obtained by adjusting the composition of the high-02 product gas to the desired final high pressure mixer output, and compressing the entire output of the DP concentrator (Wells and Moroz 1993). Figure 5 is a flowchart that shows how both GS devices can

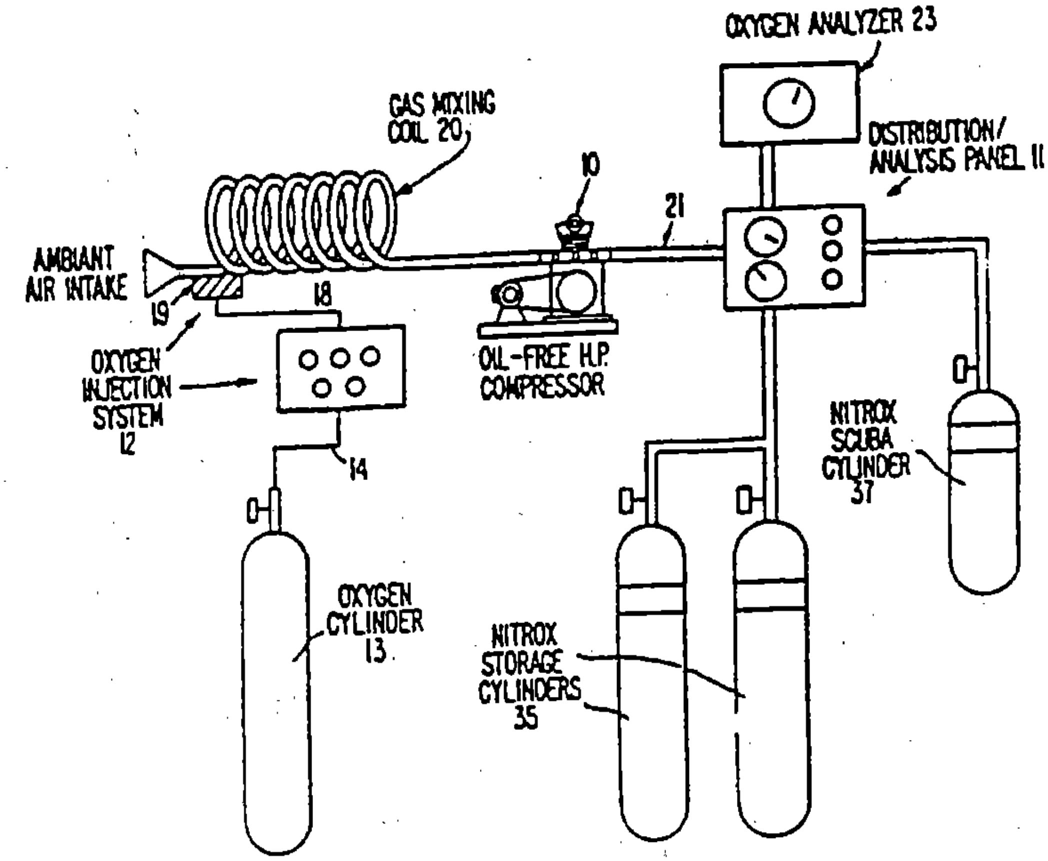


Figure 1. NOAA continuous Nitrox mixer (with oxygen cylinder).

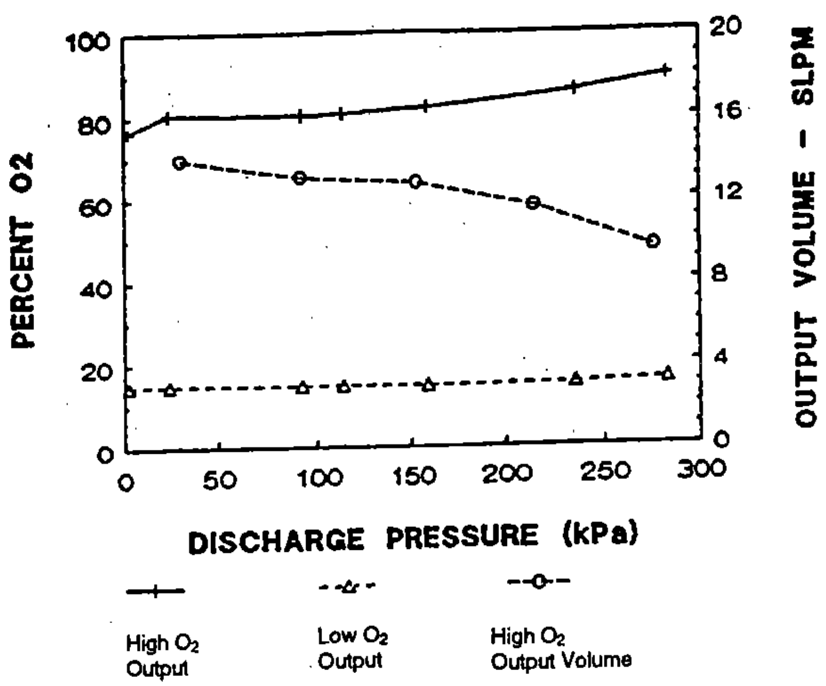


Figure 2. Pressure Swing Adsorption (PSA).

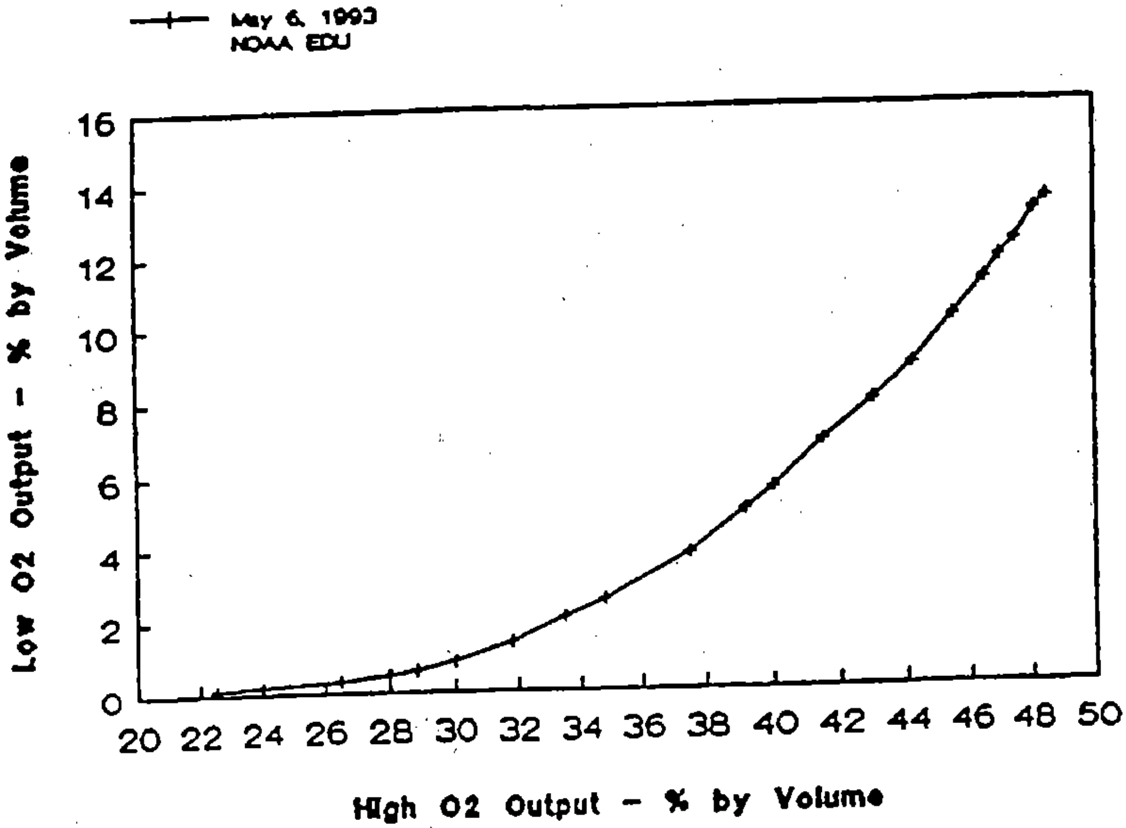


Figure 3. Differential Permeability (DP).

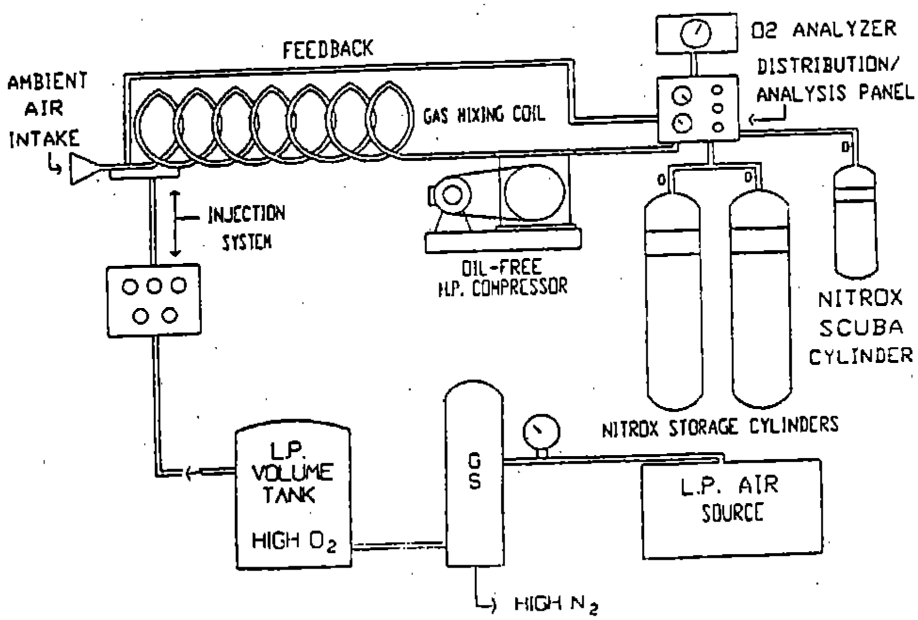


Figure 4. NOAA continuous Nitrox mixer (with gas separator and feedback).

be used to prepare high- and low-pressure Nitrox mixtures with a wide range of oxygen concentrations.

TRIMIX

In preparation for archeological dives to the wreck of the USS Monitor, a NOAA National Marine Sanctuary, located at a depth of 230 fsw, the NOAA Experimental Diving Unit developed a standard Trimix known as NOAA Trimix I (NTI), and a simple method for its preparation. NOAA Nitrox II (64%N2,36%02) was used as a decompression gas and as a "stock" mixture for the preparation of NTI. NTI consists of 32%N2, 18%02, and 50%He. Both "in-water" and "surface decompression" tables were computed by Hamilton Research, Ltd. Oxygen is used as a decompression gas at the shallow (20 and 10 ft) stops or during surface decompression.

The procedure has since been expanded to accommodate a wide range of mixtures for use at a variety of depths. The procedure is both simple and versatile because:

1. The Trimix is prepared by mixing a "standard" Nitrox mixture with He.
2. The same Nitrox mixture is used as the primary decompression gas.
3. The Nitrox can be prepared by methods that do not require using pure oxygen (described earlier in this paper).

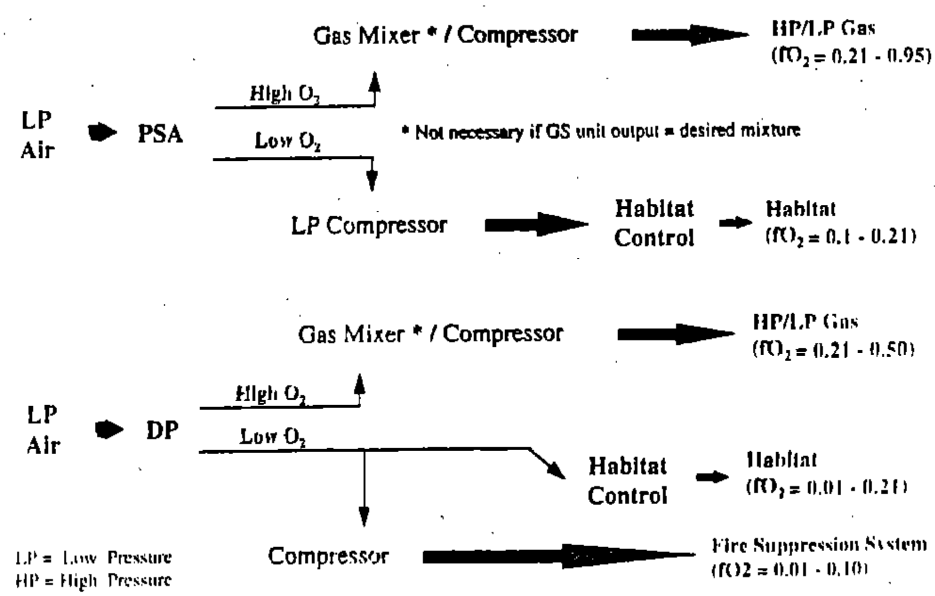


Figure 5. Gas preparation system.

The equations used to calculate the appropriate ratios of Nitrox and He required to prepare the Trimix are listed below:

(1) $$K = \frac{PO2/P}{F^{N}_{O2}}$$

where:

K = fraction of Nitrox in final Trimix;
Po2 = oxygen pressure of Trimix at depth; and
P = Pressure at depth.

(2) $$K = F^{T}O2/F^{N}_{O2}$$

where

F^{N}_{O2} = fraction of O2 in Nitrox and

F^{T}_{O2} = fraction of O2 in Trimix.

All values for pressures (P) are in atmospheres absolute (ATA).

The fractions of all gases in the Trimix can be calculated using the following expressions:

$$F^{T}_{O2} = F^{N}_{O2} x K$$

$$F_{He} = 1\text{-}K$$

where F_{He} = fraction of He in Trimix

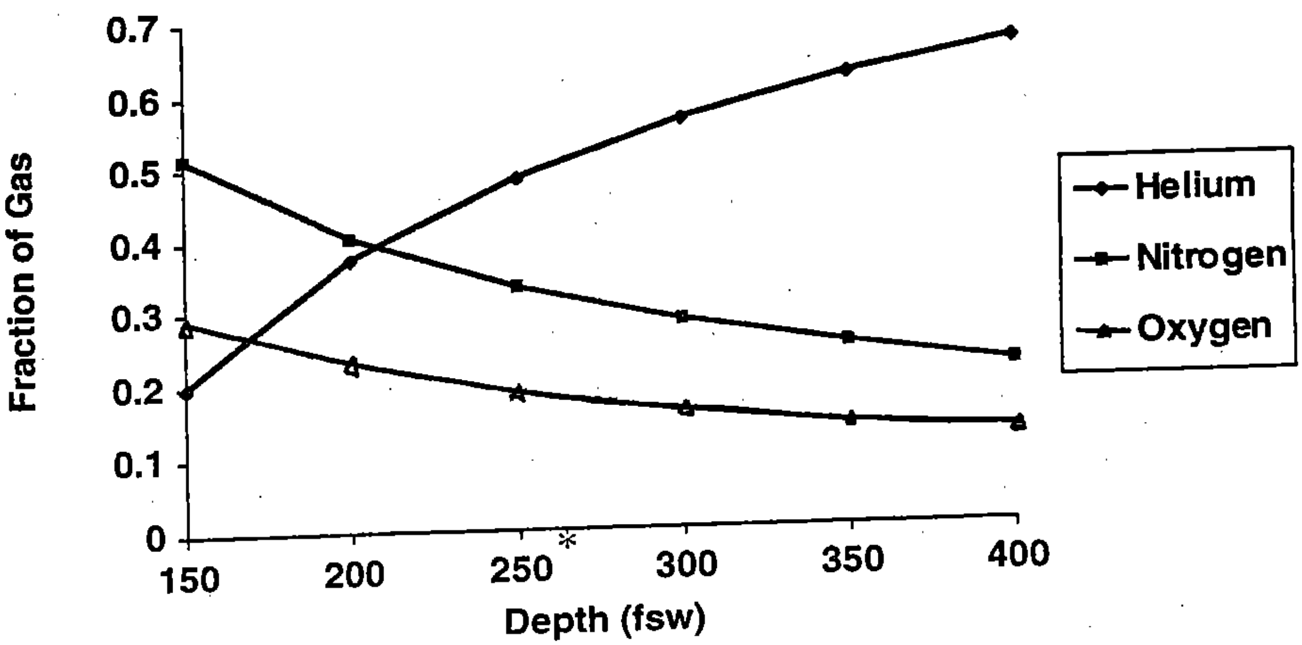
$$F_{N2} = (1\text{-}FO2)\ xK$$

where F_{N2} = fraction of N_2 in Trimix.

D (fsw)	K	1 - K
150	.802	.198
200	.629	.371
250	.518	.482
260	.500	.500
300	.440	.560
350	.383	.617
400	.339	.661

Fraction of Stock Mix $K = \frac{PO_2/P}{fO_2}$ Fraction of Helium 1 - K

Figure 6. Stock gas mix and helium fractions by depth.



* 260 fsw Maximum Depth of NOAA Trimix I

Figure 7. Relationship of gas fraction to depth.

Equation 1 is used if a particular PO2 is desired at depth. Equation 2 is used if the 02 fraction of the Trimix is specified.

Figure 6 shows values for K, using NOAA Nitrox II, when PO2 = 1.6, over the depth range 150 - 400 fsw. Figure 7 includes values for

$$F^T_{O2} , F_{N2} ,$$

and

$$F_{He}$$

under the same conditions.

The decreases in the fractions of oxygen and nitrogen in the Trimix with an increasing depth are such that the partial pressures of these gases remain constant.

K represents the fraction of the total Trimix pressure which is made up of the Nitrox mixture. I-K is that fraction of the Trimix pressure composed of Helium. Appropriate thermal considerations must be applied. The Helium should always be added to the mixing vessel before the Nitrox.

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