

**OPTIMIZATION OF DIVING WITH “NITROX” OVER-OXYGENATED  
BREATHING MIXTURES, TO DEPTHS OF 15 ÷ 50 METRES****Mircea DEGERATU\*, Simona RUS\*\*, Ana ION\*\*\*****\*Technical University of Civil Engineering Bucharest, Romania,****\*\*Diving Center, Constanta, Romania,****\*\*\*“Mircea cel Bătrân” Naval Academy of Constanta, Romania,**

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***Abstract:** The efficiency of diving activities carried out by divers should be increased. Improving the efficiency of interventions made with divers at depths greater than 15m has brought into focus the problem of increasing underwater working time by using over-oxygenated synthetic breathing mixtures in order to optimize the relation between working time and duration of decompression. The "NITROX" binary mixture best meets the requirements of diving at depths within the range of 15 to 50 meters. NITROX is used for depths in the range of 15 to 50 m. When this mixture is used, the decompression time shortens and the respiratory resistance decreases. Therefore, the use of NITROX leads to an improvement in diving efficiency, by increasing underwater working time, and by reducing the decompression time.*

**Keywords:** streamlining of divers interventions, binary synthetic breathing mixtures, immersion depth, diver's breath, inert gas.

**1. Introduction**

The efficiency of diving activities carried out by divers should be increased. Improvement of the efficiency of interventions with divers, at depths greater than 15m, have brought into focus the problem of increasing the underwater working time, by using over oxygenated synthetic breathing mixtures, in order to optimize the relation between working time and duration of decompression. The "NITROX" binary breathing mixture is the gas that best meets the requirements of diving at depths within the range of 15 to 50 meters.

The increased safety ensured by the over oxygenated synthetic breathing mixtures, which comprise inert nitrogen gas, drew attention to the need to further research on diving with NITROX, which proved to be superior to breathing mixtures with air.

**2. Objectives**

The main objectives of the study are:

- increasing of diving safety by reducing the

decompression time;

- raising the divers' level of comfort by means of NITROX mixtures, which are superior to air mixtures since they use binary mixtures with nitrogen inert gas, which has a high partial oxygen pressure; the former types of mixtures have important consequences over divers' activity;
  - increasing the diving efficiency as the ratio of underwater working time, and the amount of time necessary for diving, work and decompression; this is a fundamental desideratum for autonomous diving (for which the respiratory mixture reserve is limited) and for surface-supplied gas;
- Therefore, we reiterate the main objective of this study: raising the efficiency of divers' interventions, to depths between 15 and 50 meters, using synthetic over-oxygenated breathing mixtures by means of nitrogen inert gas, which tends to reduce the ratio of effective working time, and the duration of decompression.

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### 3. Case Study

For this study we took into consideration eight blends of NITROX mixtures, as follow: 60/40, 50/50, 40/60, 36/64, 32.5 / 67, 32/68, 30/70 and 28/72 (O<sub>2</sub> [%] / N<sub>2</sub> [%]).

As it can be observed, the concentration of O<sub>2</sub> is higher than the concentration of O<sub>2</sub> (21%) existing in air, and is between 28% and 60%.

The results of calculations were summarized in the tables below (figure 4, 5, 6, 7).

#### 3.1. Generalities about air breathing mixtures

Normally, air is the gas used for diving in

safe conditions, up to 57 meters.

Air is a natural breathing mixture. It has to be clean, dry and filtered; it does not have to contain any oil, water or other contaminants, above the levels required by professional standards.

If air is used as a breathing mixture at depths greater than 57 meters, divers' lives can be threatened; in returning to surface fatigue problems may arise. It is therefore necessary to adapt the level of decompression, i.e. to stop the diver at different depths levels, for a certain period of time, so as the body gradually can adapt to the atmospheric pressure (to reduce the remaining inert gas bubbles).

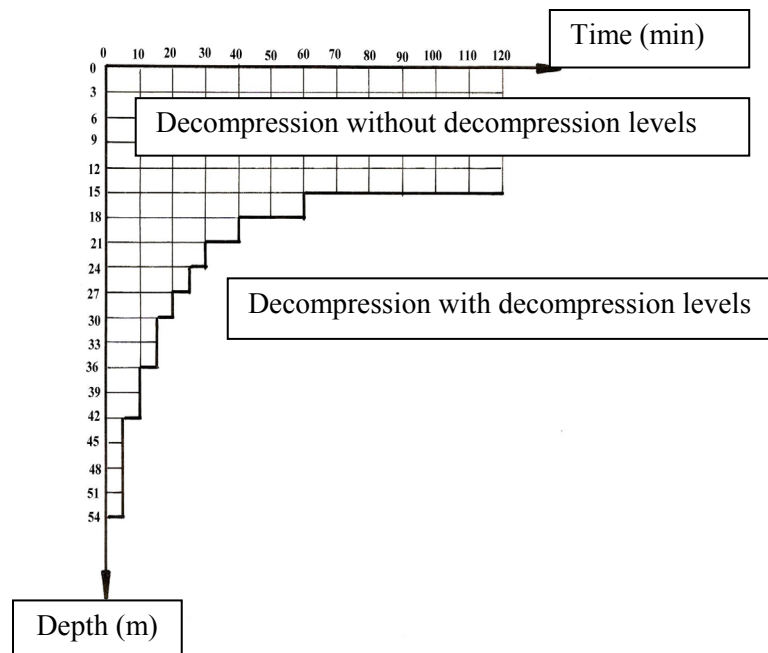


Figure 1: Use of diving air tables depending on depth and duration of dive

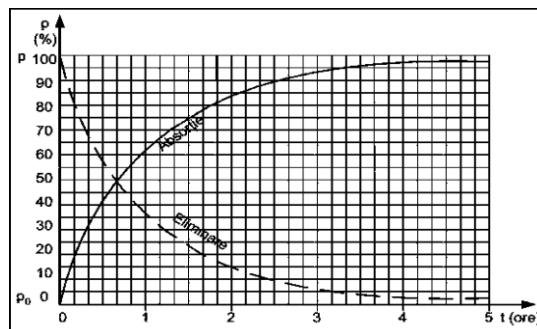


Figure 2: The theoretical curves of absorption and elimination of nitrogen from human tissue

This study intends to contribute to the improvement of diving efficiency by at least

10% (we are referring to the advantage of diving with NITROX over diving with air)

using respiratory gas mixtures and specific NITROX decompression tables. Therefore, figure 2 [1, p. II-1] shows the theoretical curves of absorption and elimination of nitrogen from human tissue resulting from the tests.

Decompression is that stage of diving in which the diver returns to the atmospheric pressure.

It is the stage in which the reversible process of releasing the inert gas dissolved in the tissues (desaturation) and its elimination through the lungs takes place.

Desaturation, as can be seen in the figure above (figure 2), is an exponential function which is initiated when the diver starts to ascent towards the decompression site; the desaturation process is interrupted when the diver starts to breath normally.

The decompression speed is given by the rate of elimination of the inert gas dissolved in the body tissues during exposure to pressure.

Figure 3 [1, p. II-10] shows the variation of the partial pressure of inert gas according to time, in a tissue with saturation period  $H$ , during decompression in a period of time

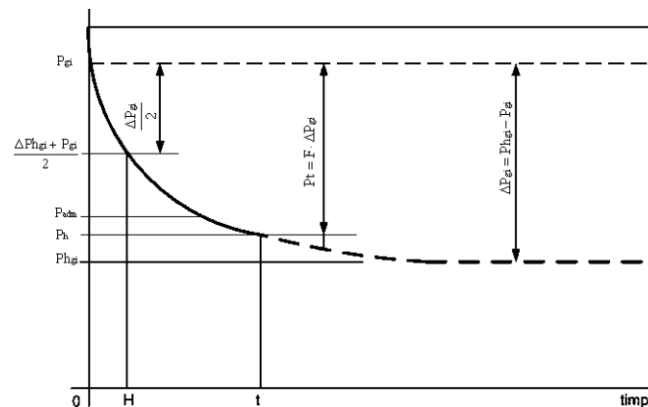


Figure3: Variation of the inert gas partial pressure in a  $H$  period tissue, during decompression, for a time " $t$ " measured in minutes

Research has shown that this can stand true for certain diving depths and specific periods of immersion depths and can effectively use certain NITROX mixtures for other diving depths and durations.

### 3.2. Generalities about "NITROX" over-oxygenated breathing mixtures

" $t$ ", measured in minutes, in accordance with the partial pressure of the inert gas  $P_{hgi}$ .

The desaturation curve is asymptotic to the partial pressure of inert gas, and it stops at a value  $\leq$  to the maximum allowable voltage,  $P_{adm}$  of inert gas dissolved in the tissue.

In diving with binary over-oxygenated mixtures, a significant decrease in the time needed for diver's return to normal air is observed (table no. 1), as compared to the situation when compressed air is used.

Decompression time is calculated by adding the times for each level listed in the diving tables (irrespective of the mixture used, i.e. air or synthetic mixtures) usually used in the diving process, according to the breathing mixture.

Following this line, the present study will demonstrate that by replacing air with NITROX binary mixtures, at different depths and for different periods of time ( $t_s = t_c + t_i$ ), the decompression stage ( $t_d$ ) will be shorter, thus improving diving efficiency.

This approach represents a novelty in our country.

The divers' gas cylinders are filled with NITROX (used only for this type of mixture); the maximum depth of immersion and the type of respiratory mixture is written on the cylinders. NITROX is used for depths in the range 15 to 50 m. By using this mixture, the decompression time shortens, and the respiratory resistance

decreases.

Therefore, the use of NITROX leads to an improvement of diving efficiency, by increasing the underwater working time, and by reducing decompression.

The purpose of this paper is to study the ways of increasing diving efficiency by using NITROX binary mixtures.

For NITROX dives, special tables are used for decompression; the values in the tables correspond to a depth lower than the real depth; it is called equivalent depth, calculated by formula (1).

Divers can use autonomous open, closed, semi-closed and mixed-circuit devices.

The calculation formula for the equivalent depth is:

$$h_{ech} = h \frac{(p_{N_2})_{am}}{(p_{N_2})_{air}} \quad (1)$$

where:  $h_{ech}$  = equivalent depth,  $h$  = depth of immersion (m),  $(p_{N_2})_{am}$  = partial pressure of nitrogen in the breathing mixture (bar (sc. abs.)),  $(p_{N_2})_{air}$  = partial pressure of nitrogen in the air (bar (sc. abs.)).

The partial pressures of nitrogen in the breathing mixture and in the air are calculated with the following relations:

$$(p_{N_2})_{am} = (r_{N_2})_{am} \cdot p \quad (2)$$

$$(p_{N_2})_{air} = (r_{N_2})_{air} \cdot p \quad (3)$$

where,  $(r_{N_2})_{am}$  = the volumetric participation of  $N_2$  in the breathing mixture,  $(r_{N_2})_{air}$  = volumetric participation of  $N_2$  in the air,  $p$  = the pressure corresponding to the depth of immersion [bar (abs. sc.)].

The researchers and engineers working in the CPSA Lab. and Hyperbaric Laboratory, belonging to the Diving Center, an also to the Technical University of Civil Engineering of Bucharest, among others, have made many attempts, over time, in the Hyperbaric Laboratory; here, leaving behind the old decompression process, which took into account the equivalent depth, they calculated specialized diving decompression tables for diving on "NITROX" type breathing mixtures, along with decompression tables for diving on NITROX mixtures under saturation, based on a calculation method similar to the method used to calculate decompression table after diving with compressed air. This new method is more efficient than the method that used the equivalent depth.

Table 1 [3, p. 113] shows a comparison between the over-oxygenated NITROX breathing binary gas mixtures and air during decompression periods.

These mixtures are considered over-oxygenated because  $O_2$  has a higher concentration, i.e. 21% ( $O_2$  in air).

Table 1 Comparison between over-oxygenated "NITROX" and air during decompression periods

100 minute diving at a depth of 30 meters				
Breathing mixture used for decompression	Air	"NITROX" over-oxygenated breathing mixtures		
		30% $O_2$	40% $O_2$	50% $O_2$
Total duration of decompression	88,4	45,6	20,8	2,8

A permanent care should be taken concerning the  $O_2$  partial pressure; it should not exceed the toxicity limit.

The breathing mixture should be checked before each dive, so as to correspond to the depth planned; also, the dosage of the synthetic breathing mixture should be correctly adjusted. Using a wrong gas dosage can lead to hypoxia or hyperoxia, i.e. lack of oxygen, or intoxication with

oxygen, which may endanger the divers' lives.

### 3.3. The study

The study involved conducting hundreds of calculations whose results were placed in tables, such as those in fig. 4, 5, 6, 7. They will briefly be presented in the paragraph below.

All research has focused on calculations regarding:



Figure 7: Optimization of diving efficiency (see and figure 6)

In the case of diving with open-circuit breathing apparatus, using NITROX type over-oxygenated binary mixtures, the recommended maximum partial pressure of oxygen in the mixture,  $p_{O_2max}$ , should be between 1.4 and 1.6 bar; the value of 1, 4 bar is recommended for amateur diving.

In our application, for professional diving, the upper limit of oxygen partial pressure  $P_{O_2}^{max} = 1,5$  bara was selected (toxicity limit). For this value table 2 shows the maximum depth of immersion  $h_{max}$  for different NITROX type breathing mixtures.

Table 2 The maximum depth for diving with different "NITROX" types mixtures

The maximum depth $h_{max}$ [m] for $p_{O_2}^{max} = 1.5$ bara (bara = bar in absolute scale)						
NITROX ( $O_2 / N_2$ )						
50 / 50	40 / 60	36 / 64	32.5 / 67.5	32 / 68	30 / 70	28 / 72
20	27	31	36	36	40	43

In this paper, the method of the equivalent depth was used, and initially, the depth correction calculation based on an approximate relation was made; after that, the depth corrections were also carried out with a real calculation relation.

To calculate the tables through the equivalent depth method, we started from the tables (LH82) for diving with air; the calculation was carried out in the Hyperbaric Laboratory; such calculations are common activities of the Diving Center. As aforementioned, this approach is new, its result showing that a special type of NITROX mixture will be used for diving at certain depths, while for the other ranges of diving and duration, compressed air will be used.

The approximate calculus relations are:

$$(h_{c,e}^{am-aer})^{ac} = h \cdot \frac{P_{N_2}^{am}}{P_{N_2}^{aer}} \quad (4)$$

$$(h_{c,e,3}^{am-aer})^{ac} = (h_{c,e}^{am-aer})^{ac} + (0...3) \quad (5)$$

The calculus relations are:

$$(\eta_s^{am})^{ac} = \frac{t_1}{(t_t^{am})^{ac}}, \quad (6)$$

$$\eta_s^{aer} = \frac{t_1}{t_t^{aer}}, \quad (7)$$

$$(\Delta\eta)^{ac} = (\eta_s^{am})^{ac} - \eta_s^{aer}. \quad (8)$$

### 3.4. Optimization of diving activities using NITROX type breathing mixtures

The study involved conducting hundreds of calculations and placing the results in tables such as those presented in figure 4, 5, 6 and 7.

Starting from the tables 3.7 simplifications were made with the aim of increasing the efficiency of diving with NITROX binary mixtures, for different depths of immersion, and there has resulted figure 7 (shown in the above 4.7 table) as a synthesis on  $(\Delta\eta_s)^{ac}$

optimization.

What we had in view throughout the study was the partial pressure of oxygen in NITROX type mixtures; the pressure was not allowed to exceed 1.5 bar (toxicity limit - see § 3.3), and the total dive time ( $t_t$ ) was not allowed to exceed the time limit exposure to different oxygen partial pressures in NITROX breathing mixtures. The  $O_2$  partial pressure of 1.5 bar did not exceed 1,5 bar; this value was considered when the specific calculations were made for professional divers'.

From tables 3.1 ÷ 3.8 simplifications were made, having in view the increase of the efficiency of diving with NITROX type binary mixtures, for different depths of immersion. The result (on  $\Delta\eta_s$  optimization) can be seen in synthesis table (these tables are not presented in present paper).

What the authors have had in view throughout the study was that the partial pressure of the oxygen in the NITROX type mixtures be no higher than 1.5 bar (see § 3.2) and the total diving time ( $t_t$ ) not exceed the exposure time limit to different oxygen partial pressures of the oxygen contained in the NITROX type breathing mixtures. The partial pressure of  $O_2$  did not exceed the value of 1.5 bar, which is the reference value taken into consideration in professional divers underwater work.

#### 4. Comments and conclusions

New opportunities have been revealed with regard to immersion, which led to the desire of a continuous improvement of techniques

in diving activities. This paper has established at what depths and underwater working time can this method of using NITROX type breathing apparatus be applied for open circuit diving apparatus, so that the diving efficiency can have a significant effect.

The present study focused on the calculation of the diving depth limit, of decompression time ( $t_d = t_r$ ) calculated for air, and for the eight types of NITROX binary mixtures studied, for different working depths (h), as well as for different immersion times  $t_s$ , so as to determine a significant increase of diving.

In the end, we determined the values of the increase in efficiency  $(\Delta\eta)^{ac}$  resulting from the unitary diving with open - circuit breathing apparatuses that used synthetic, binary, and over-oxygenated breathing mixtures, of NITROX type, against the use of compressed air as a natural breathing mixture. For this, the efficiency of diving with air  $\eta_s^{aer}$ , along with that of diving with NITROX type binary mixtures  $(\eta_s^{am})^{ac}$  were calculated; all these results were shown in tables, devised for this purpose (see figure 7). These tables showed what types of diving would increase the efficiency by at least 8%. The results of all these calculations were noted in tables, and summarized in the paper's figures 4, 5, 6, and 7.

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