VARIANTS FOR AN EXPERIMENTAL INSTALLATION FOR PREPARATION, IN CONTINUOUS FLOW, OF BREATHABLE GASEOUS MIXTURES

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Rezumat. *Lucrarea prezintă câteva scheme propuse pentru realizarea unei instalații experimentale (IE) de preparare a amestecurilor respiratorii sub sau supraoxigenate care au stat la baza realizării documentației de execuție model funcțional a IE, în funcție de necesitățile operative ale proceselor specifice scufundărilor profesionale (respectiv: compresia și decompresia scafandrilor, procese executate fie în camerele hiperbare ale Laboratorului Hiperbar al Centrului de Scafandri fie real - în mediul subacvatic). Este prezentată și o schemă echivalentă a evoluției parametrilor gazelor pure componente pentru fiecare ramură a instalației în parte. Instalația poate fi folosită la scufundările unitare (cu alimentare de la suprafață / cu preparare locală a amestecurilor respiratorii) sau la scufundările de sistem, în cadrul Laboratorului Hiperbar sau la bordul navelor pentru scafandri, pe timpul scufundărilor reale sau simulate pentru prepararea în flux continuu a amestecurilor sintetice, binare / ternare specifice scufundărilor profesionale în scopul uşurării muncii echipei de suprafață sau în scopul creşterii randamentului scufundării.*

Abstract. *This paper presents several schemes proposed for the experimental installation (EI) for the preparation of under or over-oxygenated breathing gaseous mixtures, which underpin the completion of the functional modelling documentation for the EI, depending on the operational necessities imposed by the extensive diving processes (respectively: dives compression and decompression, processes executed during professional dives, in the hyperbaric chambers of the Hyperbaric Lab. of the Diving Center, or real - in the marine environment). An equivalent scheme regarding the evolution of the parameters of the component pure gases for each plant branch are also presented. The installation can be used in unitary diving (with surface feed or local preparation of the breathing mixtures) or in system diving, inside the Hyperbaric Laboratory or on board of the diving vessels, during real or simulated diving for a continuous-flow preparation of the synthetic, under or over-oxygenated, binary or ternary gas mixtures, specific to professional diving, in order to facilitate the team work which covers the surface or in order to increase the yield of diving.*

Keywords: hyperbaric complex, breathing mixtures, continuous flow, under or over-oxygenated synthetic gas, binary / ternary gaseous mixture, professional diving.

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1. Introduction

Starting from the operational needs of the Romanian Navy - Diving Center, several schemes of experimental installations (EI), for the preparation of binary or ternary breathing gaseous mixtures, were developed.

These schemes of the EI may be used for autonomous professional diving, for the systems diving, respectively for those simulated or real which are performed in the hyperbaric laboratories of the Diving Center or Diving Squadron.

The principle of preparing breathing gaseous mixtures in the EI ensures that an invariable flow rate is injected, having the pressure of the gaseous mixture from a pressurized enclosure (constant mass flow) while ensuring the permanent control of this flow.

Fig. 1. - The Hyperbaric Complex of the Diving Center seen from behind.

The installation delivers an invariable gas mixture flow regardless of the gas pressure value inside the storage cylinders.

b) **a)** **c)**

Fig. 2. - The Experimental Installation for Preparation, in Continuous Flow, of the Breathable Gaseous Mixtures – a) and the Mixing Chamber – b), c).

The installation can be used in unitary diving or in system diving, inside the Hyperbaric Laboratory or on board of diving vessels, during real or simulated diving for a continuous-flow preparation of the synthetic, under or over-oxygenated gas mixtures, specific to professional diving, in order to facilitate the team work which covers the surface or in order to increase the yield of diving.

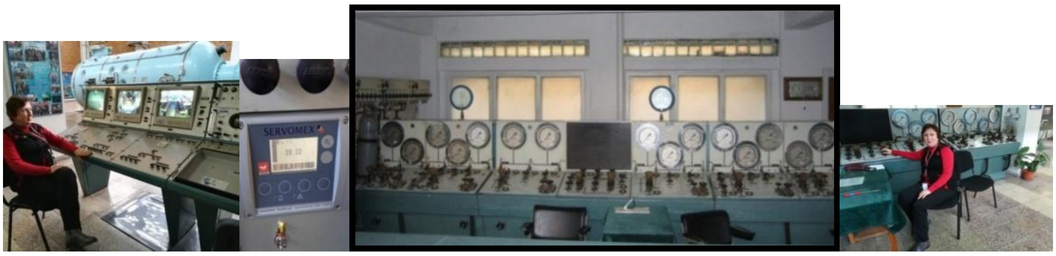


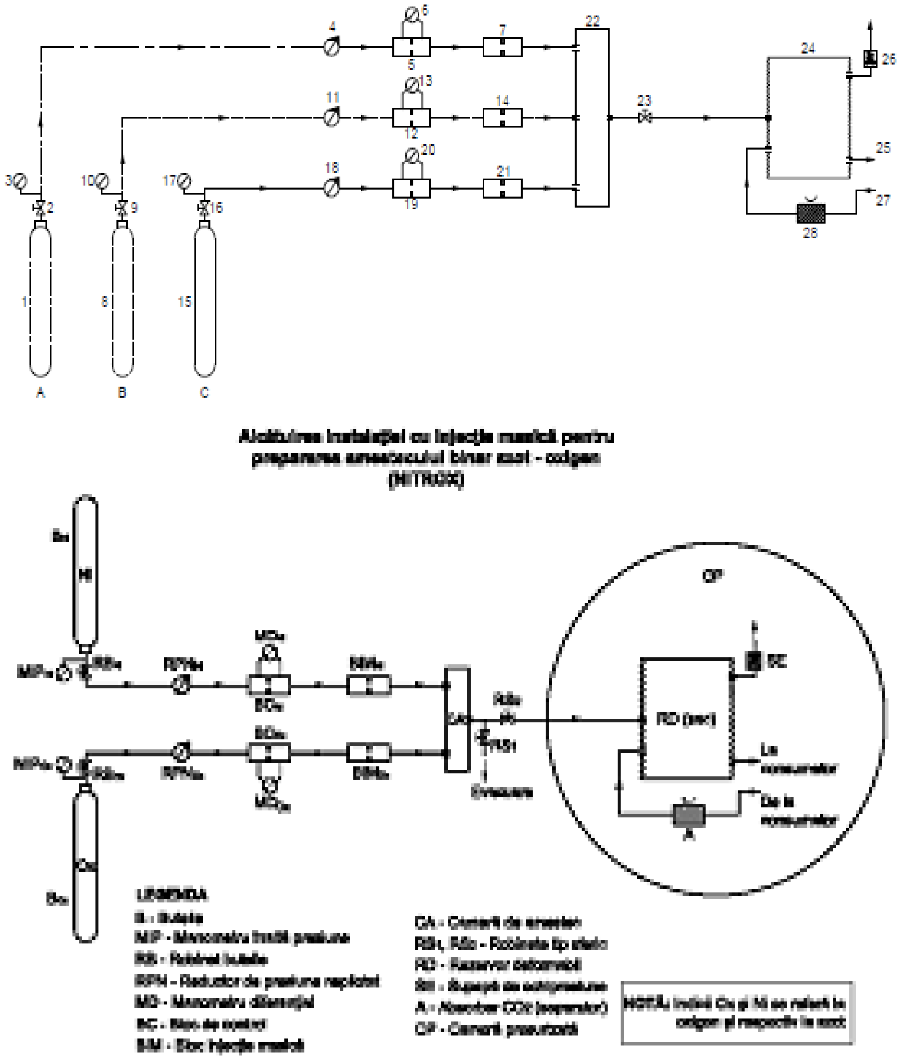
Fig. 3. - Command and Control Equipment of the Hyperbaric Laboratory of the Romanian Navy Diving Center.

2. Ways of Carrying out the Proposed Experimental Installation

This chapter describes the possible ways of carrying out an experimental installation for preparation, in continuous flow, of the diving breathable gaseous mixtures.

Depending on the type of respiratory mixture to be prepared, the plant will have resources to form the binary mixtures two lines A and C or B and C, and for the ternary mixtures, all three A, B and C lines. Line C is for oxygen, and lines A and B respectively of the inert gases used to form the respiratory mixture.

The installation for the preparation of the respiratory mixtures intended for professional diving, which is the subject of the present paper, can be carried out in two distinct modes, namely: in the mode intended for the autonomous immersion appliances (Figure 4) and for providing the respiratory mixtures necessary for supplying the pressurized enclosures of the chamber type or for diving missions which require supplying the divers from the surface (Figure 4). The presentation of the autonomous diving installation, Figure 4, line (A) for inert gas (e.g. helium), has as a first element the storage cylinder (1) provided with the valve (2) through which the gas is introduced into the circuit.



(a) (b)

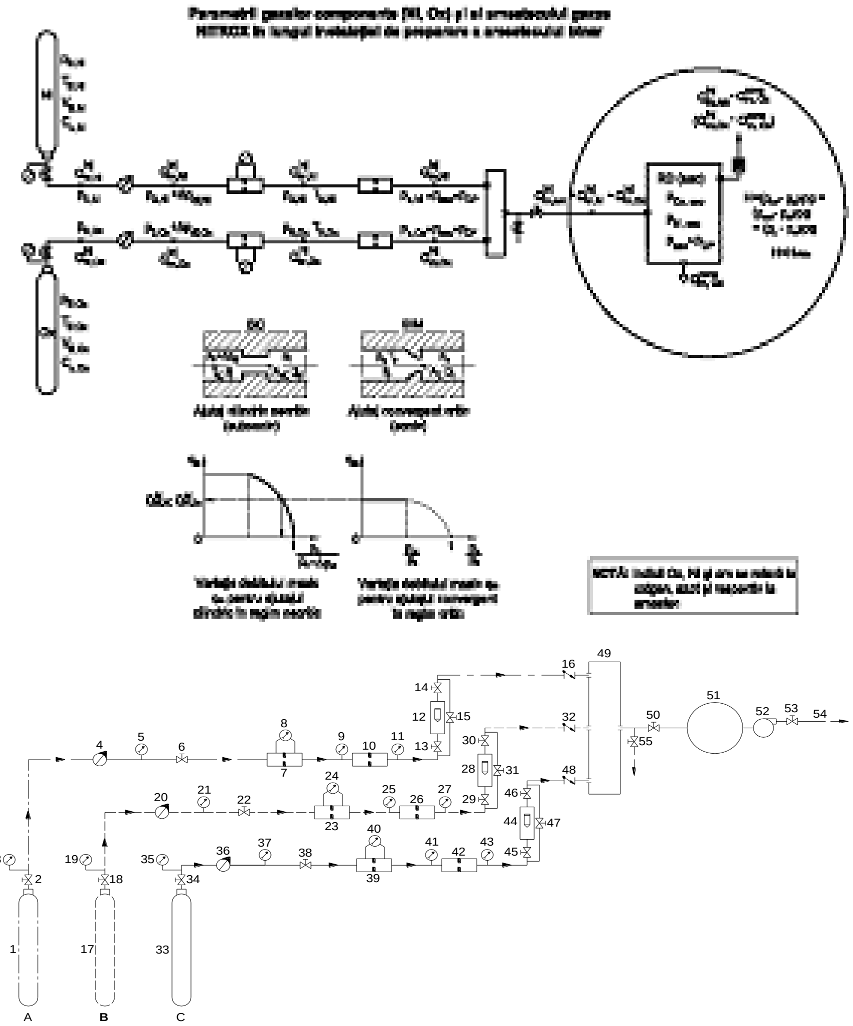
Fig. 4. – Schemes of the installations for preparation of ternary (a) and binary (b) breathing gaseous mixtures intended for autonomous diving.

The process of checking the pressure value at which the gas is supplied is done helped by the high-pressure gauge (3). In order to reduce the pressure from the high-pressure level existent in the pure gas storage cylinders, an ungoverned pressure regulator has been provided at the average pressure level with reference to the atmospheric pressure (4). The correct operation of line (A) is verified by means of the control block (5), which has as main element a micro-nozzle operating in the subsonic field. The difference of pressure when the fluid crosses this element is tracked through the differential pressure gauge (6). In order to deliver a constant mass flow rate to the mixing chamber (22), line (A) was provided with a mass injection unit (7) equipped with a convergent-divergent micro-nozzle that operates in the critical (sonic) range.

Lines (B) and (C) have a similar structure to line (A), the differences consisting of the type of circulated gases and the values of the characteristic measures, an aspect which may require devices and components that operate at different intervals. Line (B), used for distributing and injecting the second inert gas (e.g., nitrogen) is composed of the gas storage cylinder (8), the intake cock (9), the high pressure manometer (10) an ungoverned pressure regulator with reference to the atmospheric pressure (11), the control unit (12) to which the differential pressure manometer is associated (13) as well as the mass injection unit (14). In the case of line (C), intended for the distribution and injection of oxygen, the gas inlet from the storage cylinder (15) into the circuit is made by opening the valve (16). The pressure at which the gas is delivered is checked by means of the high-pressure manometer (17) preceding the ungoverned pressure reducer (18), which has as reference the atmospheric pressure. Similar to the other two lines, the correct operation of the line (C) is checked by means of the differential control unit (19) – differential pressure manometer (20). The injection of oxygen at constant mass flow is made possible via the injection block (21).

The actual formation of the binary or ternary mixtures takes place in the mixing chamber (22). Hence, by adjusting the tap (23), the formed mixture is delivered to the respiratory bag (24) which needs to take over the variations in volume and pressure resulting from breathing, to reduce the internal gas pressure to the hydrostatic pressure corresponding to the depth of immersion, as well as to ensure that gas is stored at the desired breathing parameters. From the respiratory bag, the mixture is distributed to the consumer in the amount and pressure required by the breather (25). The gas exhaled by the diver is a mixture of oxygen and carbon dioxide, and the purge cartridge (28) is provided on the exhalation circuit (27) for retaining the latter. It provides for the retention of carbon dioxide in the respiratory mixture. As with the decrease in the depth of dive (when the diver returns to the surface) a gas surplus appears in the respiratory bag, an outlet valve (26) is provided in order to ensure the evacuation of this surplus.

The presentation of the installation, in its non-immersible version, is designed for the preparation of breathing mixtures for dry hyperbaric medium such as hyperbaric complexes or hyperbaric laboratories on board divers' ships or on marine platforms in order to be used when the divers, who work in the underwater medium, are provided, from the surface, with synthetic breathing mixtures (Figure 5). The installation has three distinct lines for the distribution and injection of the mixture's gaseous components. Lines (A) and (B) correspond to the used inert gases and line (C) for oxygen. In the case of preparing a binary mixture, line (A) or line (B) will be active in conjunction with line (C) and all three lines will be produced for ternary mixtures.



(a) **(b)**

Fig. 5. - Scheme of the installation for preparation of binary (a) and ternary (b) breathing gaseous mixtures intended for supplying pressurized enclosures of hyperbaric chamber type placed within the hyperbaric complexes of Diving Center and Diving Squadron.

Line (A) is fed with the gas stored in the cylinder (1) by opening the intake valve (2). The supply pressure is checked with a high-pressure manometer (3). For a first change in pressure from the delivery value, situated in the category of high pressure, an ungoverned pressure regulator at a medium pressure was provided (4), with reference to atmospheric pressure.

Downstream of this, a medium pressure manometer (5) was arranged to check the pressure change. The value of the gas flow through the line (A) is adjusted by actuating the needle adjusting valve (6).

The transition from the average values of the pressure to low values necessary to supply the injection block (10) and checking of the correct operation of line (A) is done via the control block (7) and the associated differential pressure gauge (8). The value of the gas pressure at the inlet and outlet of the mass injection unit (10) is read from the manometers (9) and (11) respectively.

Checking the flow of injected gas is done with the help of a flow meter (12). To facilitate operations such as replacing this device without unloading line (A), separating taps (13) and (14) are provided and, for bypassing the flow meter, the alternating circuit valve is used (15).

At the downstream end of line (A) there is an SS_{Ni} (16) direction valve, which prevents the possibility of penetrating line (A) from the reverse flow direction of another gas or a gas mixture formed in the initiating phase of the installation.

Line (B), intended for the second inert gas is fed from the gas tank (17) as soon as the valve (18) is opened. This line is similar to line (A).

Oxygen is distributed through the line (C). Its structure is similar to that of lines (A) and (B) and components have the same functionality. In the order of their succession, the constituent elements are: the storage gas tank (33), the valve (34), the high pressure manometer (35), the ungoverned stage I pressure regulator (36), having as reference the atmospheric pressure, the medium pressure manometer (37), the needle control tap (38), the control block (39) to which the differential pressure manometer is attached (40), the manometer (41) for measuring the pressure of the gas at the control unit outlet, the mass injection unit (42), the manometer (43) for checking the gas pressure value after injection, the rotameter (44) and the separating taps (45), (46) and the bypass route with the tap (47). The last element is the SS_{Ox} direction valve (48).

The three lines (A), (B) and (C) converge to the mixing chamber (49) in which the binary or ternary breathable mixture is formed, depending on the number of components used and implicitly the number of active lines (Figure 7, c) – where the mixing chamber made for experimental installation is presented in the project).

After the mixing chamber, the separating cock (50), the storage chamber (51) and the suppressor (52) are provided to increase the pressure of the synthetic breathing gaseous mixture delivered to the consumer at the values corresponding to the depth of immersion. A separating cock (53) which isolates the assembly / pressure lifting assembly from the supply delivery circuit of the mixture to the consumer (54) is provided for coupling to or disconnecting the system from various special delivery systems of the respiratory mixture. The drain valve (55) is provided to drain the system - it was no longer featured on the scheme. To test the method of preparation of the breathing mixtures, theoretically studied and the operation of the experimental installation having the principle of operation proposed in the paper, an experimental installation based on the structure shown in Figure 5 was designed (Figure 5, a) for binary synthetic breathing mixtures type “HELIOX” or “NITROX” and b) for ternary synthetic breathing mixtures). The experimental plant falls within the category of those intended for the continuous preparation of binary and ternary air mixtures resulting from the association of pure nitrogen, helium and oxygen gas stored in cylinders. The construction mode in which this installation is to be carried out is intended for operation in a dry environment.

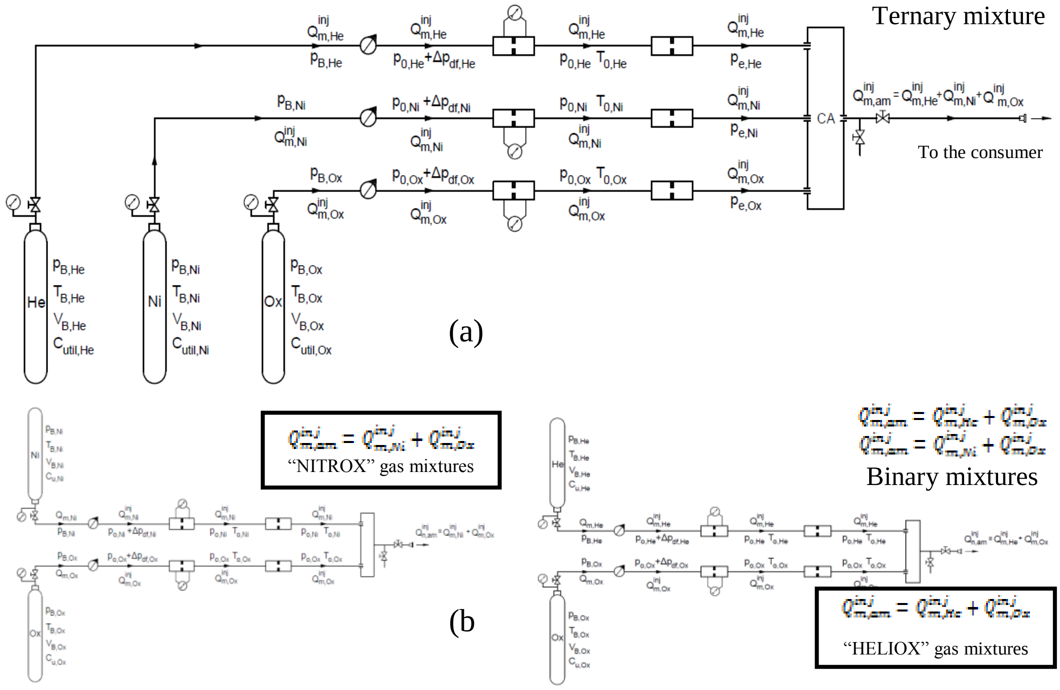


Fig. 6. – Parameters of the pure gases injected - nitrogen (Ni), helium (He), oxygen (Ox) and of the synthetic breathing mixture - “NITROX”, “HELIOX” and “TRIMIX” along the preparation EI, in continuous flow, of the synthetic, respiratory, ternary / binary gas mixtures.

After the mixing chamber (CA) (49), in which the pure gases injected in the desired proportion and pressure of the synthetic mixture, to isolate the EI from the potential consumer, a ball valve (RS) for separation has been added. The connection of any type of apparatus and mixer to the experimental plant is made by means of the quick coupler with which the experimental installation has been provided. The EI emptying is done with the help of a drain cock.

Following the passage of the component gases, shown in Figure 6 a) and b), changes in the determining parameters for the formation of the binary or ternary mixture are observed.

The main parameters of nitrogen and helium vary along the injection line from storage values to values resulting from changes caused by the presence of IE constituents. Thus, in the case of pressure, three successive changes are recorded: the first one, from the storage value of $p_{B,Ni}$ to the medium value of $p_{0,Ni} + \Delta p_{df,Ni}$; the second one, from $p_{0,Ni} + \Delta p_{df,Ni}$ to $p_{0,Ni}$, produced as a result of pressure measurement by means of differential methods; the third one produced by the presence of the BIM mass injection block, whereby the pressure is reduced to the injection pressure in the mixing chamber on Ni.

In the case of oxygen, similar changes take place as in the case of helium and nitrogen. In terms of pressure, the physical measurement with the greatest influence in the preparation of respiratory mixtures, this is recorded along the experimental installation the same changes as the other two gases: helium and nitrogen. Thus successive changes in the pressure value occur.

First, from the value at which the gas is stored in the cylinder, $p_{B, Ox}$ at the medium value of $p_{0,Ox} + \Delta p_{df,Ox}$, followed by the decrease to $p_{0,Ox}$, and subsequently to the injection pressure value in the mixing chamber, $p_{e,Ox.}$

a) b) c) d)

Fig. 7. a) & b) EI for the Continuous Preparation of Mixtures,
c) Mixing Chamber, d) Flow Meter.

As for the flow rates of the three gases $Q^{inj}_{m,\ He}$, $Q^{inj}_{m,\ Ni}$ respectively $Q^{inj}_{m,\ Ox}$, they are kept at quasi constant values across each EI line, ultimately resulting the total flow of the TRIMIX respiratory mixtures, namely: $Q^{inj}_{m,\ am} = Q^{inj}_{m,\ He} + Q^{inj}_{m,\ Ni} + Q^{inj}_{m,\ Ox}$.

The installation, which is the subject of this study, was conceived in two constructive modes that use the same operating principle that is based strictly on the thermo-hydration phenomena for the proper dosing of the gases that form the mixture.

Both in the mode for the autonomous immersion apparatus and in the non-measurable version usable in the hyperbaric centers (laboratories), the installation consists, according to Figures 4 and 5, of three distinct lines (A), (B) and (C) each intended for one gas – part of the respiratory mixture. Each of these distribution-injection lines are characterized by three different pressure steps, namely high-pressure stage I, medium pressure stage II and low pressure stage III, the latter comparing the gas injection pressure values.

Stage I consists of the unpressurised pressure reducer having as reference the atmospheric pressure according to Figure 4 referred to as (4), (11), (18) respectively (4), (20), (36) according to Fig. 5 and the corresponding manometers for checking the pressure value (3), (10), (17) of Fig. 4 intended for high pressures respectively according to Fig. 5, (3), (19), (35).

The stage II comprises the control block (5), (12), (19) see Figure 4, respectively (7), (23), (39) see Figure 5, having as main element a cylindrical micro-nozzle, operating in a non-critical (subsonic) mode, which ensures the measurement and control of the flow in the injection lines, managing at the same time a pressure drop Δp, which, in the subcritical field, depends on the injected mass flow. Attached to the control blocks are the differential pressure gauges (6), (13), (20), Figure 4, respectively (8), (24), (40), Figure 5, which indicate this pressure difference. According to the diagram in Figure 5, for this installation, manometers (5), (21), (37) were also provided for measuring the average pressures.

In order to regulate the flow on the three lines, the taps / valves (6), (22) and (38) have been provided in the dry-running installation (Figure 5).

The pressure stage III comprises the mass injection unit, in which there is a converging micro-jet nozzle which, in the minimum sectional area, operates in a critical mode, thus ensuring constant injection of a constant mass flow throughout the operation of the installation.

The preparation EI of continuous binary and ternary gaseous mixtures prepared and tested in the LH has had the role of experimentally validating the mathematical modelling and showing that the underlying principle of such installations is correctly and valid.

The two types of installations shown above and having as a principle the EI will have to be built to the specific thermodynamic dimensions and parameters of each of the two types of installations.

Notations and/or **Abbreviations**

B = gas cylinder;
BC = control block / unit;
BIM = mass injection block;
BIMC = mass injection block and control;
CA = **CAm** = mixture room / chamber;
CR = fast coupling;
He = Helium;
EI = experimental installation;
IPA = plant for mixtures' preparation;
LH = Hyperbaric Laboratory;
MD = differential manometer;
MIP = high pressure manometer;
Ni = Nitrogen;
Ox = Oxygen;
RB = cylinder valve;
RBS = ball valve for separation;
RG = drain valve;
RS = spherical valve;
RPN = unmanned pressure reducer;
TED = testing **-** development assessment;
N = nitrogen line;
H = helium line;
O = oxygen line;
NB = nitrogen gas cylinder;
HB = helium gas cylinder;
OB = oxygen gas cylinder;
Ssg = safety valve;
FAm = filter for breathing mixture;
REv = exhaust valve;
CRp = exhaust valve;
NR1 ÷ NR5 = valves / taps on the nitrogen line;
HR1 ÷ HR5 = valves / taps on the helium line;
OR1 ÷ OR5 = valves / taps on the oxygen line;
NM1 ÷ NM4 = manometers on the nitrogen line;

HM1 ÷ HM4 = manometers on the helium line;
OM1 ÷ OM4 = manometers on the oxygen line;
NRP = unmanned pressure reducer on the nitrogen line;
HRP = unmanned pressure reducer on the helium line;
ORP = unmanned pressure reducer on the oxygen line;
NBc = control block / unit on the nitrogen line;
HBc = control block / unit on the helium line;
OBc = control block / unit on the oxygen line;
NBi = injection block / unit on the nitrogen line;
HBi = injection block / unit on the helium line;
OBi = injection block / unit on the oxygen line;
NRt = rotameter / flowmeter on the nitrogen line;
HRt = rotameter / flowmeter on the helium line;
ORt = rotameter / flowmeter on the oxygen line;
NSs = direction valve on the nitrogen line;
HSs = direction valve on the helium line;
OSs = direction valve on the oxygen line;
NFi = nitrogen line filter;
HFi = helium line filter;
OFi = oxygen line filter;

R E F E R E N C E S

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