Volume XXI 2018
ISSUE no.1
MBNA Publishing House Constanta 2018

Scientific Bulletin of Naval Academy

SBNA PAPER • OPEN ACCESS

Aspects regarding the maintenance of climate inside the hyperbaric chamber of the Diving Center

To cite this article: T Stanciu, Scientific Bulletin of Naval Academy, Vol. XXI 2018, pg. 77-84.

Available online at www.anmb.ro

ISSN: 2392-8956; ISSN-L: 1454-864X

doi: 10.21279/1454-864X-18-I1-011

Aspects regarding the maintenance of climate inside the hyperbaric chamber of the Diving Center

T Stanciu[1]

[1]Diving Center, 1 May Bd., Constanta, Romania

Abstract: The climate conditioning of a hyperbaric chamber is extremely important, as the health or even lives of the divers depend on it. Climate conditioning consists of controlling and maintaining the following factors inside the enclosure:

- Temperature
- Humidity
- The parameters of the breathing gas

In this paper I have analyzed some of the aspects regarding the thermo-hygrometric phenomena and the composition of the breathing gas mix, phenomena that accompany any dive in saturation. The variation in temperature and humidity under pressure and during decompression differs from the unitary dives with Nitrox, because of helium, the main component of breathing gas. When planning the dive, one must take into account the presence of atmospheric air in the hyperbaric chamber at the beginning of the compression process, in order to avoid hyperoxia.

1. Introduction

The climate control equipment, in the diving center's barometric chambers aim at monitoring temperature, humidity and the gas concentrations in the breathing gas mix, during simulated dives.

1.1 Temperature

The enclosure temperature is controlled by two professional sensors, COLE PALMER. One of them is submerged in the wet room, and the other is placed in one of the dry rooms, for atmospheric measurements. The sensors are connected to the digital thermometer in the control rack, at the surface.

The heating is done with a hot water circuit system. The preheated water is pushed in the caisson through a pump. The reheated water goes through a heating changer installed in the climate conditioner and gives off heat to the gas mix. That is then pushed to the climate conditioner changers through a ventilator, which is part of the heating and climate conditioning ensemble.

1.2 Humidity

Humidity is permanently monitored by classic hygrometers in the two dry rooms and in the wet simulator.

A classic hygrometer is equipment composed out of two thermometers with alcohol, placed on the same support. One of them measures dry temperature, the other is coated in an absorbent material, placed in water, and measures the wet temperature. Evaporated water cools down the second thermometer, so its temperature is lower than that of the one not placed in water. The only exception occurs when the humidity in the atmosphere is 100%, thus the water doesn't evaporate anymore and the wet thermometer doesn't cool down in this case. The temperatures are equal. Through the difference in temperatures and referencing the dry temperature, the humidity in the atmosphere is obtained.

The stable value of humidity in the breathing gas is maintained through a climate controller fixed on an independent chassis of the caisson, which position is different for the two caissons, but is always under an inferior bunk.

Excess humidity in the caisson is permanently collected through a cold water circuit. The condensation is gathered from the bottom of the climate controller, from where it is further poured, through an exit filter outside. The climate controller is connected through a passing at 2" from the hull, through a flexible pipe and a valve of 2". This display allows the treatment of the atmosphere in both the hyperbaric precincts. The condensation of water vapor is evacuated outside through a purge system This system contains a purge valve and a tube, which extremity is found at the lower side of the caisson. Both hyperbaric precincts are equiped with a purge system.

1.3 Breathing gas parameters

In a breathing mix, the vital component is oxygen. The other gases are diluents of the oxygen. If on the surface, the gas mix contains oxygen of a certain concentration c%, during the pressurization, the partial pressure of oxygen is modified after the formula:

$$ppO_2 = p_i \times c\% \quad (1)$$

P_i– absolut pressure in the enclosure

c%- oxygen concentration

For maintaining the necessary concentration of oxygen, a regeneration of the atmosphere is done through a filter made of soda lime, which absorbs the carbon dioxide. This function is done by typical diving simulation equipment, called Scrubber. The exhaled gas is absorbed by a powerful ventilator and is redirected towards the canisters of soda lime. This is where a chemical reaction takes place, and the carbon dioxide is eliminated. The ventilator is placed at the base of the ensemble. Over it, is the canister of soda lime.

The partial pressure of the carbon dioxide mustn't go over 15 mbar, but instead it must be maintained at the recommended level of 6 mbar.

Figure 1 Scrubber Sub Tech for regenerating the gas in the hyperbaric enclosure

One of the equipment is placed in the hyperbaric precinct and the other in the access chamber.

The exhaled gas is continuously recycled by the equipment and is transformed in breathable gas, under the requested parameters. The gas exhaled in the atmosphere of the room is taken through the canister with soda lime, with the help of a high speed ventilator. The carbon dioxide is eliminated through a chemical reaction between it self and soda lime.

The ventilator is built in the bottom section of the Scrubber and it represents the main support for the canister of soda lime. The ensemble is placed vertically with the help of the specially designed support arms in the hyperbaric chamber.

The proliferation of bacterial infections is stopped by using a system called AEROVAP. It is a thermal antibacterial aerosols generator. The aerosols are volatized continuously in the enclosure, by recharging the system with a pill, which is thermally activated. One pill allows the system to work for 5 days.

2. The evolution of the physical parameters which influence the climate conditioning of the hyperbaric chamber

2.1 Temperature

During simulated dives, while pressurizing, the temperature in the chamber rises with a speed that is dependent on the compression speed.

During decompression the temperature decreases.

The composition of the atmosphere also influences the variation of temperature in the chamber. The mixture of HeOx determines a much faster cooling of the diver's body. The helium causes problems because the specific heat at constant pressure Cp and the specific heat at constant volume Cv are larger compared with the ones of the nitrogen which is in the composition of air and lead to a dangerous cooling of the divers. [1]

The comfort temperature in the hyperbaric environment rises with the total pressure of the gas and that is why it should be maintained at a level higher than the one at the atmospheric pressure.

2.2 Humidity

Humidity depends on temperature and pressure, parameters which determine the modification of the state of aggregation. The change in phase comes with an energy exchange with the ambient environment, and the latent heat L [J]. The three phases: solid, liquid and gas coexist in the triple point τ. The change processes of the aggregation state are highlighted in Fig.2.

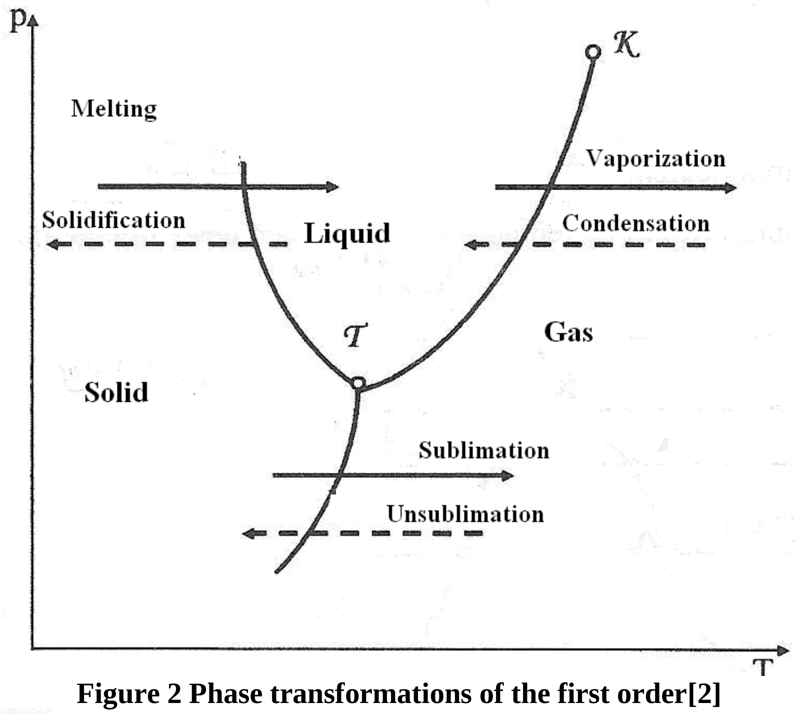

Figure 2 Phase transformations of the first order[2]

processes accompanied by the receiving of latent heat from the outside medium

Processes accompanied by the giving of latent heat from the outside medium

Over the critical point K, only the gas state exists. Between the τ points and K (critical point) the liquid state coexists with the gas state. The isobaric cooling of moist unsaturated air leads to the saturation of the mix with water. The temperature at which the partial pressure of the vapors becomes equal to the saturation pressure is called *temperature of the dew point. The temperature of the dew point (τ)* is the saturation temperature of the humid air which cools down and maintains its constant absolute humidity *x* [3]. Cooling lower than this dew point leads to the transformation of water vapors into liquid.

For each breathable air mixture, it is important to determine the dew point temperature in order to avoid vapor condensation. Excessive humidity in diving air is not allowed. Increased humidity makes breathing more difficult and in cold times it can produce a freezing of the airways, cooling of the body, irritation of the sinuses.

2.3 The evolution of oxygen

The gas in the pressure chamber is supplemented, in order to replace the losses, as well as to increase the depth. The added gas contains oxygen and its adding will raise the partial pressure of the oxygen ppO_2. The variation in pressure is:

$$\Delta pO_2 = \Delta p_i \times c\% \tag{2}$$

Δp_i –the variation of pressure in the enclosure

c% – the added oxygen concentration

Divers who are in the middle of a dive in saturation consume oxygen permanently. In the hyperbaric complex of the Diving Center, pure oxygen is added in the atmosphere manually, in order to maintain a good value of the partial pressure of oxygen, ppO_2. For supplementing oxygen the following rule is applied:

- *10 cm O_2 raises the partial pressure ppO_2 with 10 mbar*.

For each diver who is in saturation in a chamber, 0.7 m^3 of oxygen are added daily. This is the quantity of oxygen utilized metabolically by each diver and it does not depend on depth.

Compression and decompression are done with the help of diving tables. In some tables, the partial pressure of the oxygen is raised at a higher level before starting decompression, and then maintained throughout decompression.

Every time the gas is eliminated out the chamber, oxygen is lost, the partial pressure drops and a supplement of oxygen must be introduced. While the depth decreases in the chamber, the oxygen represents a higher percentage out of the total volume, and the volume of eliminated oxygen increases. The volume of oxygen that must be supplemented increases accordingly.

The partial pressure of the oxygen pO_2 used during decompression is between 400 and 600 mbar (0.4 – 0.6 bar) for dives up to 300 mH_2O. Practically, there is no more oxygen supplemented after the concentration hits 23% - 24%, due to fire hazard.

3. Experimental determinations of the physical parameter variations in the hyperbaric enclosure during a saturated dive with heliox

The hyperbaric complex of the Diving Center is composed out of two dry chambers and a wet simulator and is equipped with climate control installations. The variation of the physical parameters in the breathing mix has been studied during saturated dives with HeOx. Measurements of the temperature, humidity and of the partial pressures concerning the gas have been made for a saturation of 30 mH_2O and 60 mH_2O were made during compression, but also decompression. Saturation's characteristics of 60 mH_2O are:

3.1 Dive characteristics

- Maximum depth, 71 meters;
- Compression time length, 61 minutes;
- Compression speed, 1 m/min;
- Stage depth, 61 meters;
- Work level, 71 meters;

- Stage depth length, 46 hours;
- Decompression time length, 35 hours ;
- Time length of the work rounds in water, minim 3 hours;
- Total dive length, 4 days .
- Diving table used, COMEX;

3.2 Respiratory mixtures used

- Compression mixture, HeOx 5,5% up to 30 m ; 0,9% between 40 – 60 m
- Breathing mixture at work level, HeOx 5,5 – 9,2% at 71 m
- Breathing mixture at stage depth HeOx 5,5 – 5,9 at 61 m
- Therapeutic mixtures , heliu-oxigen, as follows:

18/82 HeOx

- 23/77;HeOx
- 50/50;HeOx
- pure oxygen.

3.3 Parameters that have to be maintained

- pp O_2 – stage depth - 380 - 420 mbar
- work level - 420 - 750 mbar;
- decompression - 600 mbar up to 15 m and 24% up to the surface level
- ppCO_2 - maximum 6 mbar;
- humidity - 60-80%
- decompression speeds :

- between 71 – 61 m 1 m/min
- between 61 – 55 m , jumpfor the final decompression 1 m/min
- between 55 – 20 m - 35 m/min
- between 20 – 10 m - 40 m/min
- between 10 – 5 m - 45 m min
- between 5 – 0 m - 50 m/min

4. Obtained results

4.1 The relative variation diagrams for temperature and humidity in the hyperbaric enclosure during compression and decompression at saturation with Heliox

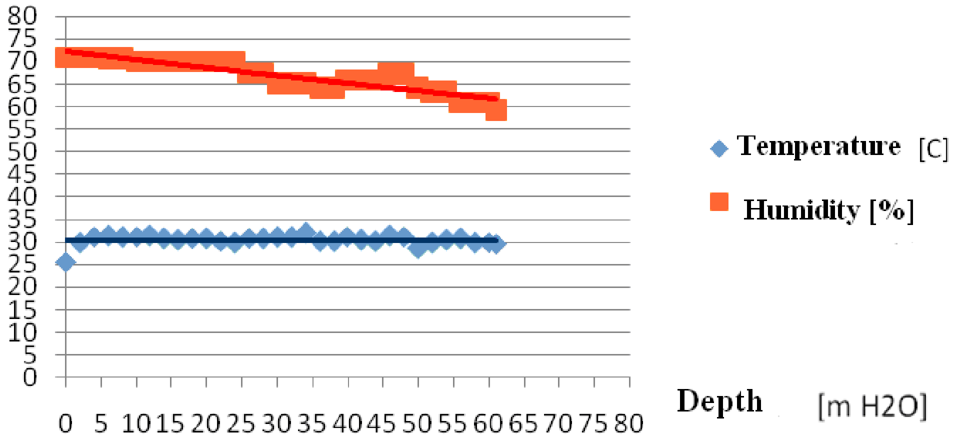

Figure 3 Temperature and humidity for compression during saturation at 61m stage depth

Temperature and humidity were monitored inside the hyperbaric chamber throughout the compression process, when stopping at the stage depth and during decompression, from meter to meter in the water column. The graphs of the variations of temperature and humidity inside the hyperbaric chamber during compression were drawn, as well as during decompression for the two saturations at 31 mH_2O and 61 mH_2O .

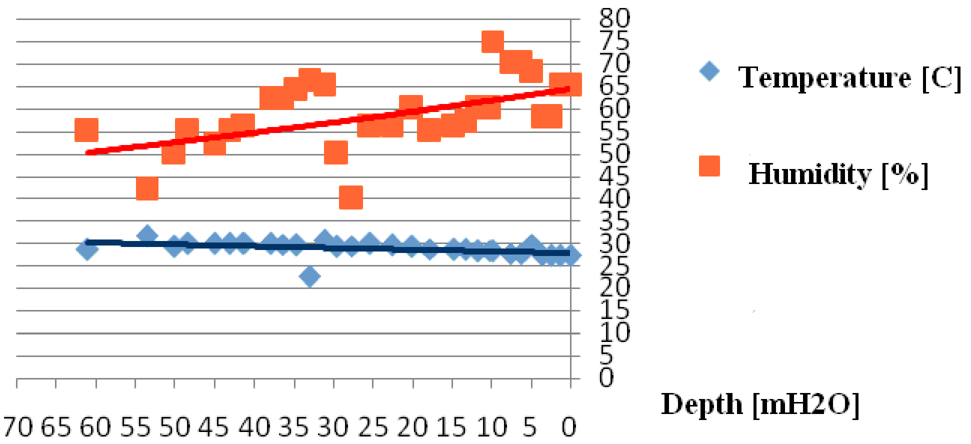

Figure 4 Temperature and humidity for decompression during saturation at 61m stage depth

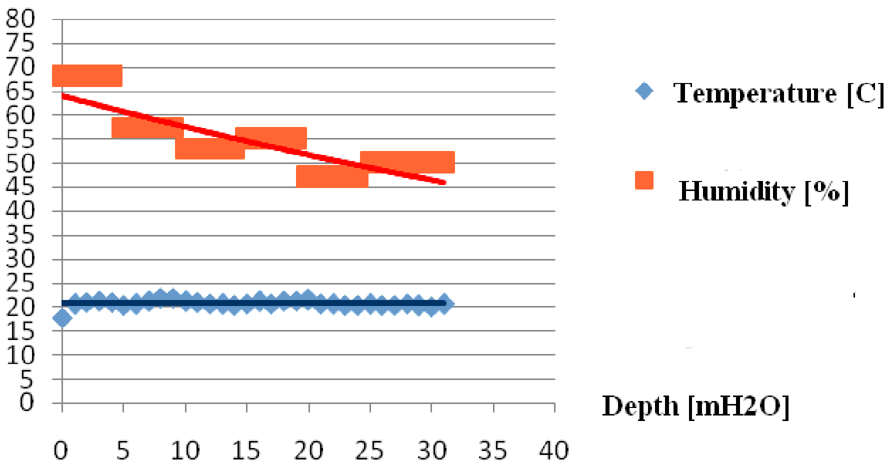

Figure 5 Temperature and humidity for compression during saturation at 31m stage depth

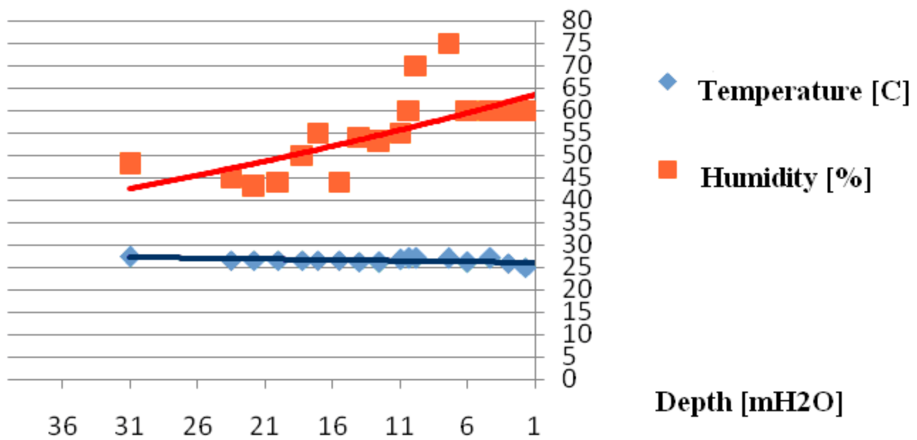

Figure 6 Temperature and humidity for decompression during saturation at 31m stage depth

4.2 The variation of the partial pressures of the gases which are found in the hyperbaric chamber during a dive in saturation with Heliox

Because of the existing air at atmospheric pressure (nitrox mix 79/21) in the caisson, over which the Heliox compression mix was introduced, the partial pressure variations of the gases in the mix were calculated, in relation with the total pressure of the mix, using the following calculations: [4]

$$ppOx = (170.35525 \times 10^{-6} p^2 + 54.637571 p) : (3412.3224 \times 10^{-6} p + 0.56512) \tag{3}$$

$$ppN = (269.65994 p) : (341.3224 \times 10^{-6} p + 0.56512) \tag{4}$$

$$ppHe = (3239.6331 \times 10^{-6} p^2 - 323.96331 p) : (3412.3224 \times 10^{-6} p + 0.56512) \tag{5}$$

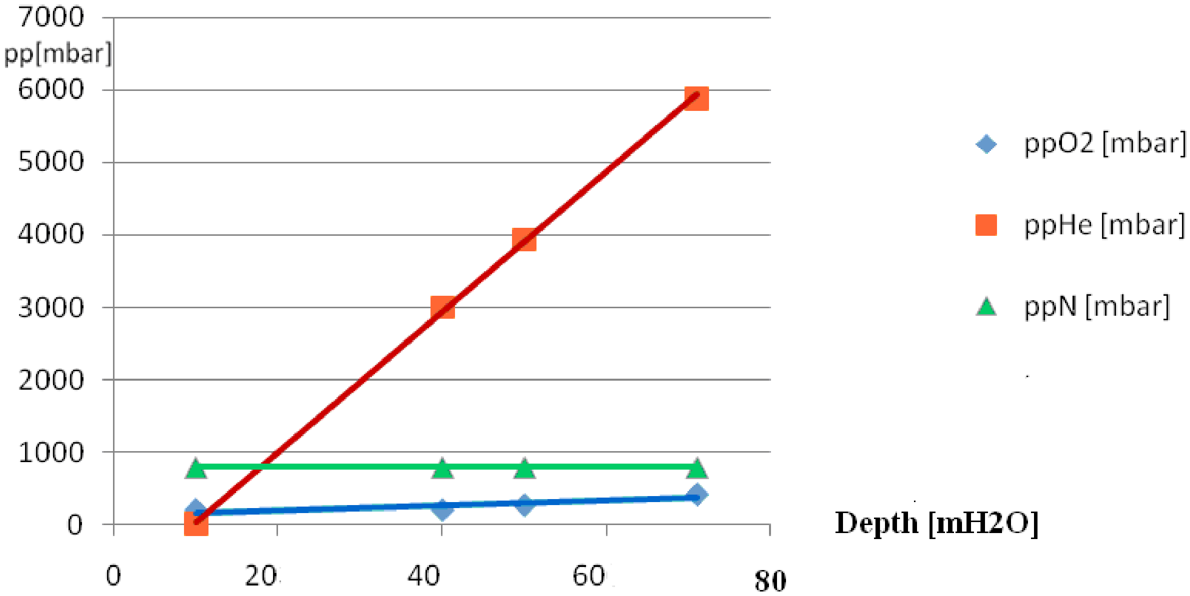

Figure 7 Evolution of gas partial pressures of the respiratory mix used at saturation at 61 m stage depth

It is important to keep track of these values throughout the whole dive, because the increase in partial pressure of the oxygen pp_{ox} in the mix is limited. Going over a certain value may cause the appearance of hyperoxia. The domain of partial pressures of oxygen between 0.21 – 0.42 bar is considered a normooxic domain. [5]

5. Conclusions

An increase in temperature can be seen simultaneously with a decrease in humidity during compression. During decompression, the phenomenon is reversed, temperature decreases and humidity increases, but the initial values at the beginning of the saturation are not reached.

Helium, the diluting gas of oxygen, influences temperature variation. It does not increase as much during compression with nitrox.

Humidity does not increase that much. On the contrary, at the end of compression, it decreases below the recommended limit of 60%.

The partial pressure of oxygen reaches, at the end of compression, 419 mbar. This value is within the recommended limits of stage depth.

The partial pressure of nitrogen remains constant at 790 mbar, because this gas isn’t introduced in the hyperbaric chamber again.

The breathing mix, which is very rich in helium, Heliox 95/5, used for compression, determines the abrupt and constant increase of partial pressure in helium up to 5900 mbar.

Climate monitoring of hyperbaric habitats is vital for divers, so dive preparation and dive planning activities must comply with the recommended rules. [6]

References

[1] Goodman 1971 *Hyperbaric respiratory heat loss study* (Westinghouse Research Report, USA Office of Naval Research Report)
[2] Constantin A 2002 *Termotehnică* (Constanţa Ovidius University Press), cap 9, p 153
[3] Leonăchescu N. 1981 *Termotehnică* (Bucureşti Editura Didactică şi Pedagogică), cap 8 pp168-169
[4] Diaconu M, Degeratu M., Stanciu T 2014 *Procedura de evaluare a scafandrilor pentru scufundările profunde* (București Sesiunea AOSR)
[5] Degeratu M, Petru A, Georgescu Şt, Ioniţă S 2008 *Tehnologii hiperbare pentru scufundări unitare şi în saturaţie* (Bucureşti MATRIX ROM), cap. 4 pp 102
[6] Statul Major al Marinei Militare 1996 *Norme privind pregătirea, organizarea şi protecţia muncii în activitatea de scufundare.*