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EXPERIMENTAL RESEARCHES OF THERMAL PHENOMENON DURING THE SATURATION DIVING

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Abstract— Saturation diving is based on the principle that the tissues and blood of a diver's body absorb inert gases and reach saturation point where the pressure of the dissolved gas in the blood and tissues is the same as that of the gas in the lungs. Saturation diving allows divers to remain at working depths without concern for decompression and it makes deep diving operations more efficient.
Thermal comfort during the helium –oxygen breathing mixture saturation diving, was verified by experimental determinations and calculation of thermal flux density lost. The results were compared with those obtained from the air unit diving, of the subjects with similar physical, in similar conditions of temperature and deep.

Keywords— experimental researches, saturation diving, thermal comfort.

I. SATURATION DIVING

SATURATION diving is a difficult operation, which allows the divers to leave and work long time, in a hostile environment. The divers are compressed at the „living depth", were they live for a long period. Hence they descend into the wet hyperbaric chamber, until the „working depth" and they return at the „living depth" day after day, as far as finality of tasks.

Saturation diving is based on the principle that the tissues and blood of a diver's body absorb inert gases and reach saturation point where the pressure of the dissolved gas in the blood and tissues is the same as that of the gas in the lungs. Saturation diving allows the divers to remain at working depths without concern for decompression and make deep diving operations more efficient.

The Deep diving course from Diving Center imposes prosecution of saturation diving with binary gas mixture (helium and oxygen).

II. THEORETICAL CONSIDERATIONS

The definition of half saturation period H is the appropriate time of exposure to achieve a pressure of dissolved gas [1].

p_0 = initial pressure of the disolved gas

p_i = exposure pressure of the disolved gas

H = half saturation period

$$\mathbf{p_0 + (p_i \quad p_0) / 2 = (p_i + p_0) / 2} \qquad (1)$$

Although shown as hydrogen and other inert gases can be use in breathing mixtures for deep diving, most of the experiments have been done with helium.

Helium causes problems because the thermal conductivity $k = 352(\mu cal / cmsK)$ and specific heat $c_v = 0.745([\mathrm{cal/g\,K})$ are higher than the coefficients of the nitrogen, $k = 58(\mu cal / cmsK)$ and $c_v = 0.177(\mathrm{cal/g\,K})$ and they lead to dangerous cooling of the divers.

Therefore, the comfort temperature in the hyperbaric environment increases with the total pressure of the gas and should be maintained at higher level than the level from the atmospheric air.

One of the major tasks of the life support systems of the hyperbaric facilities is to create the environment which maintains the partial pressure's level of oxygen, required level of contaminants and the thermal comfort for the divers.

There are many variables which influence the thermal comfort condition in hyperbaric environment: pressure, composition, temperature, humidity of the breathing mixture, activity level and thermal insulation of the diver's clothing.

It is impossible to consider independently the effect of any of the above mentioned variables. The thermal comfort can be influenced by the human factories (stress, fatigue).

III. THERMAL BALANCE EQUATION

The thermal balance equation for the human body of the diver is [2]:

$$\mathbf{Q_m = Q_{resp} + \dot{Q}_p + Q_r + \dot{Q}_e} \qquad (2)$$

$\dot{Q}_m$ = metabolic thermal flux, positive, calculated by Harris-Benedict relation :

$$\mathbf{Q_m = 66.4730 + 13.7516m + 5.0033h \quad 6.7550a} \qquad (3)$$

m(kg) = diver's body mass
h (cm) = diver's height
a (years) = diver's age

$\dot{Q}_{resp}$ = thermal flux lost by respiration

$\dot{Q}_p$ = thermal flux lost by skin through conduction and convection

$\dot{Q}_r$ = thermal flux lost by radiation

$\dot{Q}_e$ = thermal flux lost by evaporation

Thermal flux lost by skin results by summing the conductive flux and the convective flux [3], [4]:

$$\mathbf{\dot{Q}_p = \dot{Q}_c + Q_{cv}} \qquad (4)$$

$\dot{Q}_c$ = thermal flux lost by conduction

$\dot{Q}_{cv}$ = thermal flux lost by convection

The thermal flux lost by respiration is [5]:

$$\mathbf{Q_{resp} = \dot{Q}_v + \dot{Q}_i} \qquad (5)$$

Q_v = thermal flux lost by vaporization from breathing gas

Q_i = thermal flux lost by heating of the breathing gas

We assume thermal flux lost by radiation and evaporation failure, because the hyperbaric environment. The thermal balance equation becomes:

$$\mathbf{Q_m = Q_v + \dot{Q}_i + Q_c + \dot{Q}_{cv}} \qquad (6)$$

If the metabolic flux doesn't cover this thermal consumption, imbalance occurs which leads to the heat loss for the human body. The thermal balance equation becomes [6]

$$\mathbf{Q_m + \dot{Q}_l = Q_v + \dot{Q}_i + Q_c + \dot{Q}_{cv} \Rightarrow \dot{Q}_l =}$$

$$\mathbf{Q_v + \dot{Q}_i + Q_c + \dot{Q}_{cv} \quad Q_m} \qquad (7)$$

$\dot{Q}_l$ = total thermal flux lost by the human body

The calculation of total thermal flux lost has been fixed in a precedent scientific project [7]:

$$\mathbf{\dot{Q}_l = \Delta t_m \frac{m \times C}{\tau}} \qquad (8)$$

$$\mathbf{\dot{q} = \dot{Q}/S} \qquad (9)$$

$\dot{q}$ = thermal flux density, S = surface of human body (Dunn diagram)

$$\mathbf{\Delta t_m = t_1 \quad t_2} \qquad (10)$$

Δt_m = variation of body temperatures, before diving (t_1) and after diving (t_2)
τ = immersion time

The global coefficient of thermal transfer for diver's body was experimental calculated and we obtained in hyperbaric condition: C=0.5 $(kcal/kg\,^0C) = 2.1(kj/kg\,^0C)$ [7]. We propose to verify the thermal losses during helium - oxygen saturation diving by using C, the global coefficient of thermal transfer for diver's body. C formulas was determined at air unit diving, but the respiratory thermal loss was considered 25% Q_{total} and the breathing gas's parameters not have any influence, then it can be used for helium - oxygen too.

IV. EXPERIMENTAL DETERMINATIONS

The tests were done at Hyperbaric Complex of Diving Center, by divers from Deep diving course, during the saturation diving on 61 m and 31 m. To determinate the temperatures, we used two thermometers:

a) Temperature controller from analyse panel with two probes into the pressure chambers RTD air probe and RTD immersion probe industrial Cole – Parmer. Features: temperatures -50– 200 ^{0}C; response time 1 second; connector ANSI; material stainless steel.

b) Digital thermometer – hygrometer, mobile, with an external probe. Features: temperatures -40– 150 ^{0}C;

TABLE I
FEATURES OF DIVING AND BREATHING GAS

Parameter	Saturation 61 m	Saturation 31 m
maximal depth	71 m	38 m
compression time	61 minutes	31 minutes
velocity of compression	1 m/min	1 m/min
living depth	61 m	31 m
working depth	71 m	38 m
stationary time on living depth	46 hours	46 hours
stationary time on working depth	minimal 3 hours	minimal 3 hours
total diving time	5 days	4 days
diving table used	COMEX	COMEX
compression mixture	HeOx 5,5% until 30 m and 0,9% between 40 – 60 m	HeOx 5,5%
breathing mixture on living depth	HeOx 5,5 – 9,2% la 71 m	HeOx 5,5%
breathing mixture on working depth	HeOx 5,5 – 5,9 at 61 m	HeOx 5,5%