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EXPERIMENTAL DETERMINATIONS OF THE RESPIRATORY THERMAL LOSSES DURING THE DIVING

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Abstract: To assure the thermal security of the divers it was identified and it was bring the mathematic model of the main thermal losses by respiration. The theoretical studies were verified by experimental determinations: the variation with the deep, in the warm and cold water, of the vaporization thermal flux $\dot{Q}_v$, of the heating thermal flux $\dot{Q}_i$, of the respiratory volumetric flow $\dot{V}$ and of the respiratory thermal flux density $\dot{q}_r$. The study is finished by analyzing the thermal losses by respiration and the percent of these losses from the sum of the thermal losses, for a diver.

1. INTRODUCTION

The real divings hapen in deep cold water, the temperature is floating with the profondeur and the season.

The simulated divings evolve in barocamera where the atmosphere is same the natural sorrounding.

Death in this pretext is associated with hypothermia-induced fatty degeneration which is accompanied by series of internal complications, leading to cardio respiratory arrest due to after drop.

The respiratory thermal losses have to evaluate, so to make an appropriate choice of the respiratory gas and its temperature.

2. THEORETICAL CONSIDERATIONS

Studding the thermal phenomena which influence the diving activity, it was established that in case of a simulated or real diving, the main ways of the thermal losses are:

- by skin
- by respiration

The thermal losses by the skin were studied in a precedent work paper.

At the respiratory wayes level, the thermal flow lost is:

$$\dot{Q}_r = \dot{Q}_v + \dot{Q}_i \quad (1)$$

The thermal flow lost for the moistening of the respiratory air is:

$$\dot{Q}_v = \dot{m}_v\, l_v = x \times \rho_{aer} \times \dot{V} \times l_v \quad (2)$$

$\dot{m}$ = the mass flow of vaporous $[kg]$

l_v = the mass latent heat by vaporization of the water $\left[{}^{kj}/_{kg} \right]$

x = the humidity quantity of the mix and represents the vaporous mass from one kilo of dry air

$\dot{V}$ = the volumetric flow of the air $\left[m^3/_h \right]$

The thermal flux lost for heating of respiratory air is:

$$\dot{Q}_i = \dot{V}\,\rho_{aer} C_p (t_E - t_I) \quad (3)$$

C_p= the specific heat of the air at constant pressure $\left[J/_{kg^0K} \right]$

t_E = the temperature of the expired air [^{0}C], t_I = the temperature of the inspired air [^{0}C]

3. EXPERIMENTAL DETERMINATIONS OF THE RESPIRATORY THERMAL LOSSES

The experimental determinations were made at the hyperbaric laboratory of the Diving Center, during the simulated autonomous diving, in the hyperbaric chamber, with dry air, having the following limits:

- The hyperbaric chamber temperature and implied the inspire temperature T_I, can't be much varied, like the real temperatures of the see water. These limits were partial corrected by inspiration from a colder air tank.
- The heliox diving presumes an expensive cost of the tests; for avoiding the secondary effects of the nitrogen on the organism, the respiratory gas used deeper 60m is the heliox (mix of oxygen and helium).

For that it has chosen the first scenario of assay, with air as respiratory gas, on the established profounder.

The measurements were made in hyperbaric chamber with the following equipment:

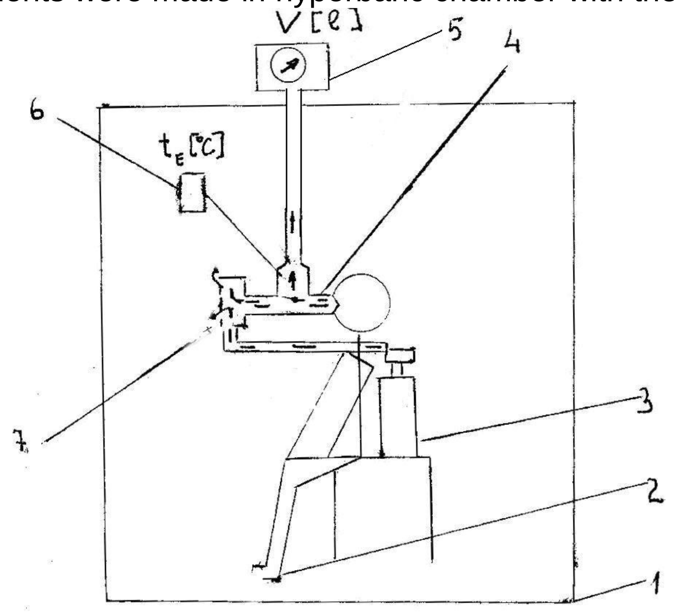

Figure 1 The scheme of the equipment used for the experimental determinations
1. hyperbaric precinct 2. diver 3. tank 4. mouthpiece 5. spirometer
6. thermometer 7. demand regulator of the mask

The test was planned by simulated diving in the hyperbaric chamber, at the profounder: surface, 9m, 21m, 30m, 51m and 60m by two subjects (divers) simultaneous.

The second diver has pursued the temperature sensor. It was collected expire, these was conducted to the spirometer Shiller at surface and it has resulted the appropriate diagram (see Fig. 3).

For each diver it was made three readings of the temperature of expired air t_E and three readings of the expired flow $\dot{V}_E$.

Figure 2 Spirometer Shiller installed at the hyperbaric chamber flooding

For each expire, the spirometer Shiller has processed the results of the measurements, like the Figure 3:

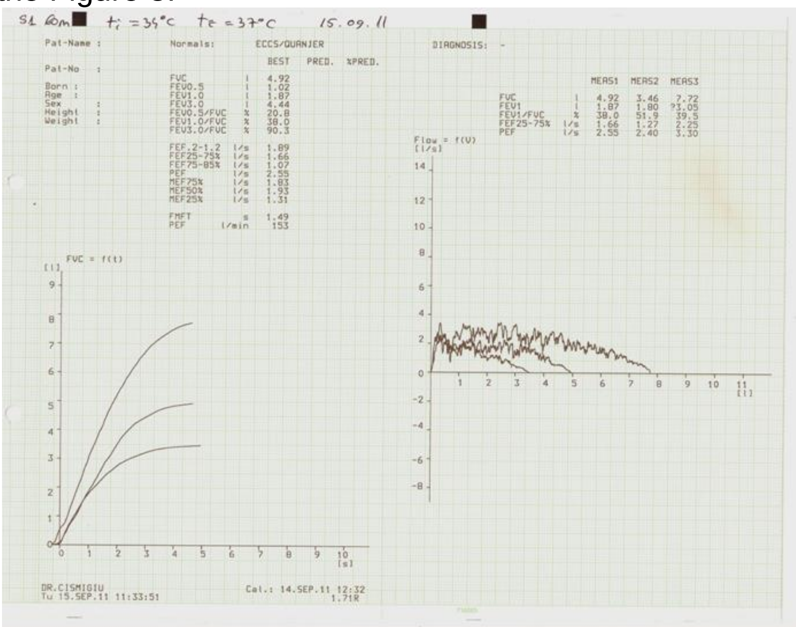

Figure 3 Diagram generated by the spirometer for a diver, at 60m profounder

Using the preceding calculus relations, for each profounder, it has determinates the following sizes: the hydrostatic pressure, the atmospheric pressure, the saturation pressure, the absolute humidity, the profounder density of the air, the underwater latent heat of the mass by vaporization of the water, the specific heat of the air at constant pressure, the constant of the gaseous for dry air and for steam.

The temperature of the air into the mouthpiece and the expired air flow was simultaneous registered. After the measurements, it calculated $\dot{Q}_v$ (the vaporization thermal flux lost for the moistening of the respiratory air), $\dot{Q}_i$ (the heating thermal flux lost for heating of the respiratory air) and the respiratory thermal flux density $\dot{q}_r$.

4. DIAGRAMS OF THE RESPIRATORY THERMAL LOSSES

At the Medicine Faculty Memorial University from Newfoundland St. John's U.S.A., were studied the sensible thermal losses of the respiratory circuit RHL$[W]$ at different profundities (fts) and different temperatures of the gas, for the respiratory flows $\dot{V}\left[{}^{l}\!/\!_{\min}\right]$ from the following diagram, Figure 4:

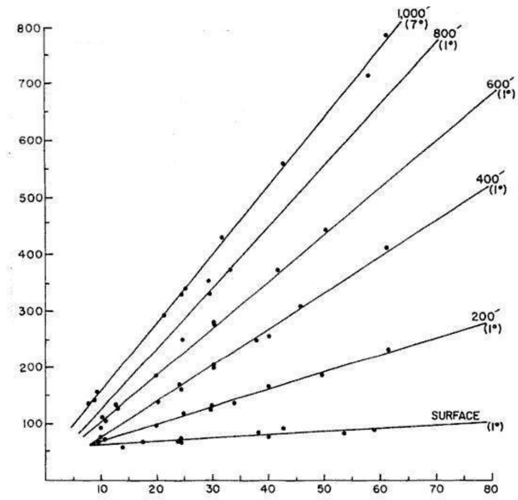

Figure 4 Respiratory thermal losses depending of cold ventilated respiratory flow at different profundities (fts)

It observes that for same respiratory flow, at same low temperature of the inspired gas, the heat lost for warming its increases the diving deep proportional.

It was analyzed the thermal phenomena which it happened during the simulated diving, in two periods: warm and cold.

To dignify the respiratory thermal phenomena, we have proposed:

- Plotting, for 6 different divers, of the diagrams by variation of the vaporization thermal flux $\dot{Q}_v$ with the deep (surface, 9m, 21m, 30m, 51m and 60m) and of the heating thermal flux $\dot{Q}_i$ and of the volumetric flow of the air $\dot{V}$.
- Plotting, for 6 different divers, of the diagrams by variation of the respiratory thermal flux density $\dot{q}_r$.

For example, it was obtained for diver S1:

- In warm period

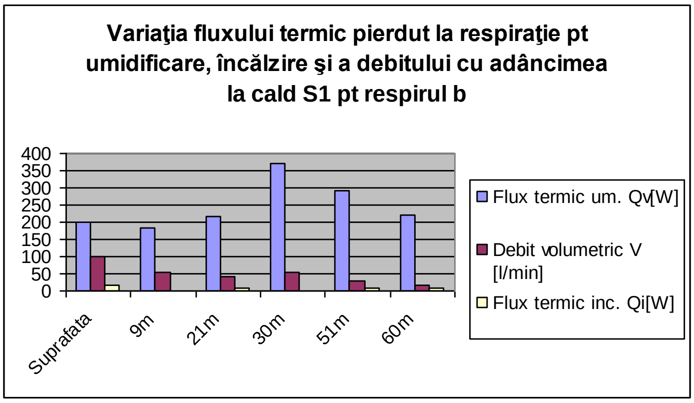

Figure 5 Respiratory thermal lost with the deep by respiration, for moistening and for heating and the variation of the volumetric flow of the gas

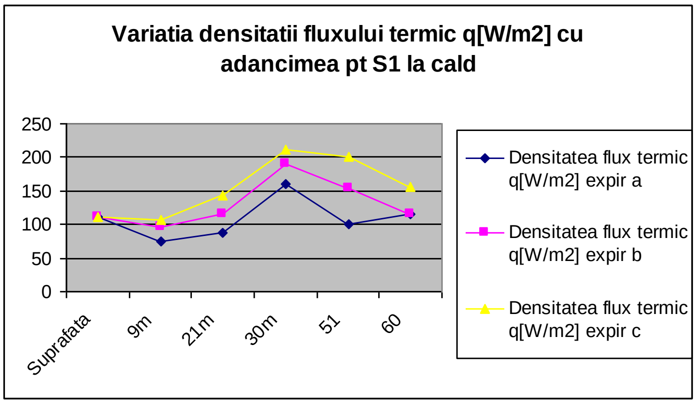

Figure 6 The thermal flux density, lost with the deep by respiration

- In cold period

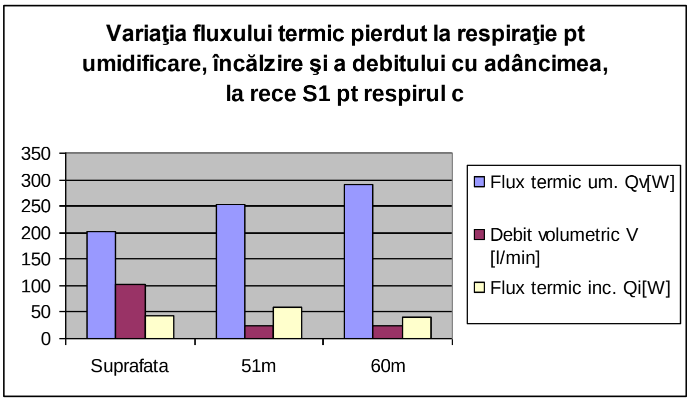

Figure 7 Respiratory thermal lost with the deep by respiration, for moistening and for heating and the variation of the volumetric flow of the gas

5. CONCLUSIONS

To avoid the thermal stress, function of the external conditions, the results of the experimental researches were the bases of the correct choose of the diving parameters.

For the same diver, it observed:

- In the warm period, at the profounder of 21 – 30m, the vaporization thermal flux $\dot{Q}_v$ dabs the maximum 300-400W, when the precinct temperature brings up very much, then it is stabilized on 200W proximate, at the deep 51-60m.

- In the cold period, the vaporization thermal flux $\dot{Q}_v$ brings up constant with the deep until 250-300W.
  The massive divers lose much heat for moistening than the skinny divers.

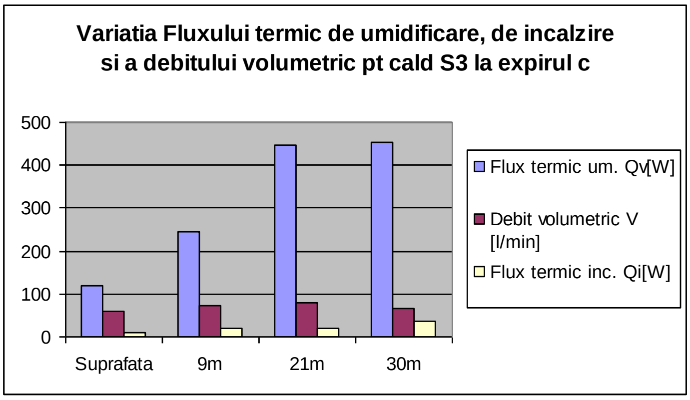

Figure 8 The heat lost by the corpulent diver S3, with the mass =100kg and h=183cm

The thermal flux lost for moistening brings up until 450 W.

For the skinny diver S4, the thermal flux lost for moistening brings up until 230 W, like down:

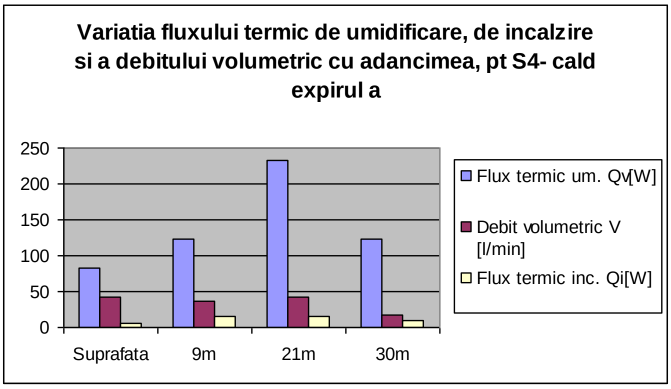

Figure 9 The heat lost by the skinny diver S4, with the mass =75kg and h=182cm

It dignifies that in the cold period, the thermal flux lost by a diver for heating has values with 30-50 W greater than the flux from the warm period (see the figures 10 and 11).

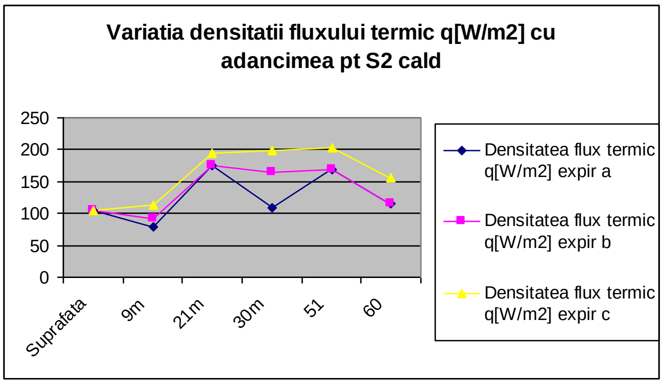

Figure 10 The total thermal flux density, lost by respiration at worm, from the diver S2

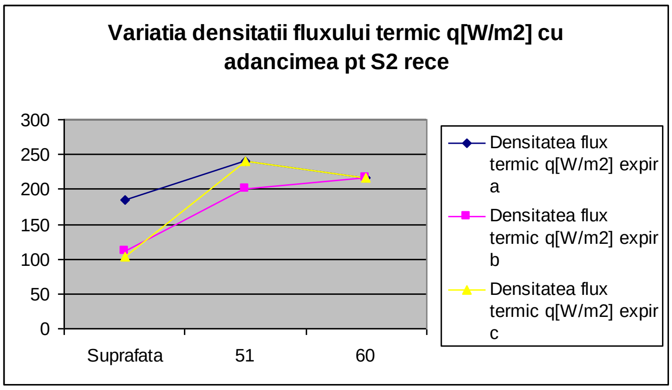

Figure 11 The total thermal flux density, lost by respiration at cold, from the diver S2

In the warm period, the thermal flux lost by respiration is stabilized on an average value of 100-150W/m^2, and in the cold period the flux has an average of 150-200W/m^2.

The calculus on average values leads to the formulas:

$$\dot{q}_t = \dot{q}_p + \dot{q}_r - \dot{q}_m = 300 + 150 - 30 = 420W/m^2$$
$$\frac{\dot{q}_r}{\dot{q}_t} = \frac{150}{420} = 0{,}35 \Rightarrow \dot{q}_r = 35\%\dot{q}_t \quad (4)$$

$\dot{q}_t$ - the total thermal flux density lost by a diver

$\dot{q}_p$ - the thermal flux density lost trought the skin by a diver, average value from an anterior paper

$\dot{q}_r$ - the thermal flux density lost trought respiration by a diver

$\dot{q}_m$ - the thermal flux density gained from methabolysm by a diver, value calculated with the relation Harris-Benedict, from an anterior paper

The percent $35\%\dot{q}_t$ of the heat lost by respiration is higher than the known percent from the books by 25-30%, because the experimental limits (the failure of the hyperbaric chamber climate leads to the excessive heating at pressuring and to a greater consumption of thermal flux for moistening of the respiratory air).

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