University at Buffalo The State University of New York | REACHING OTHERS

D52 Effect of Pressure on Heating and Cooling Requirements for Thermal Protection of Wet-suited Divers

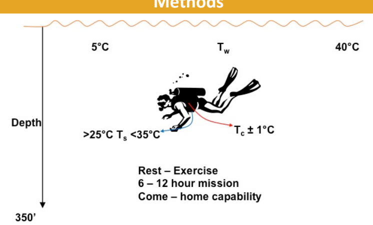
David R Pendergast, Ed.D. and David Hostler, PhD, NRP

Departments of Physiology and Biophysics and Exercise and Nutrition Sciences, Center for Research and Education in Special Environments, University at Buffalo[1]

Introduction

- Diving is often performed in water above and below the temperature that is thermally neutral. Insulation plays an important role in thermal regulation. For diving, foam neoprene is the insulation currently used in the construction of wetsuits.
- The rubber component of the foam is typically neoprene rubber, or polychloroprene (thermal conductivity, kr = 0.100-0.192 W/(m-K), [1-5]) and the gas component is nitrogen or air (kg= 0.026 W/(m-K), [6]). The entrapped nominally stagnant gas within the neoprene rubber results in a lowered thermal conductivity. Convection in the cells is typically insignificant due their small size.
- When a diver submerges, the gas cells compress with increasing depth, which reduces the porosity of the insulation and changes the size and shape of the gas cells reducing the thickness and increasing thermal conductivity. The combined effects lead to a large reduction in the thermal resistance as a function of depth.
- Previous studies have directly measured the thermal properties of foam neoprene insulation under hydrostatic pressure. The thickness and thermal conductivity of foam neoprene wetsuit insulation was measured under hydrostatic loading to a pressure of 1.2 MPa (107 msw, meters of sea water). The experimental program consisted of using a custom built thermal conductivity meter (Anter Corp model QuicklineTM 16) placed inside a spherical hyperbaric chamber.
- The purpose of the present study was to determine the effect of hydrostatic compression of a 6.5 mm wet suit on the power required to maintain thermal balance of divers down to a depth of 120 fsw in a hyperbaric chamber.

Methods



Methods

Aim

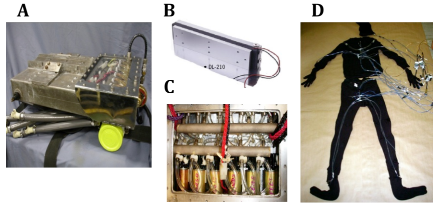
- Minimize the impact of thermal issues in dive planning

Purpose

- Engineer, build, and test a Diver Thermal Protection System (DTPS) and develop its use as a total body and regional calorimeter

Design

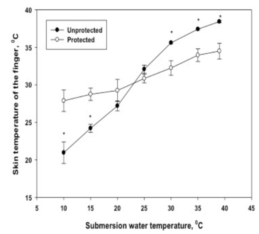
- The DTPS is a diver worn backpack (A). Internally the DTPS's heating/cooling elements are Thermal Electric Coolers (B). Six TECs are inside the back pack as are a manifold system (C) and six pumps that send circulating water to a six zone tube suit (D).
- The system is controlled by a microprocessor that can be pre-programed. The manifolds and each zone of the suit are equipped with thermocouples that are used to control the TECs and calculate the power required to heat/cool the diver to prevent heating/cooling. The conditioned water is circulated such that each zone gets 500 ml flow and the water temperature was controlled at 30°C.



- 8 experienced male divers completed experiments at 4, 55, and 120 fsw in a hyperbaric chamber submersed in water with temperatures from 10 to 39°C.
- Subjects began with a resting immersion and then fin swam for one hour (50% VO2 max.) before returning to the surface using the Navy decompression tables.
- Subjects breathed air from a simulated scuba set-up with -15 cm static lung load.
- Skin, inlet, and outlet temperatures of the DTPS were measured continuously (thermistor), as was core temperature (Ingestible pill).
- Data were collected via BioPac and analyzed by computer.

Results

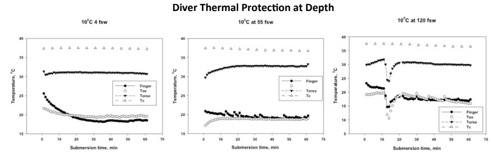
Diver Thermal Protection with DTPS



Finger temperature plotted as a function of water temperature for subjects in a 6.5 mm wet suit and the DTPS on (protected) and off (unprotected). Unprotected, temperature approaches ambient water temperature. While protected, temperature is maintained in acceptable ranges.

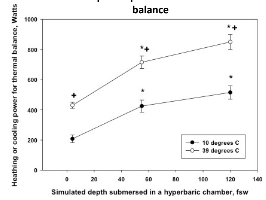
- n = 8 male divers
- 6.5 mm wet suit
- Swimming
  - 2.0 l/min
  - 3.0 hrs
- Unprotected did not protect in either cold (hand/ feet) or hot (core) water
- Protected maintained Tcore at 37°C and Tskin >25°C and <35°C

Diver Thermal Protection at Depth



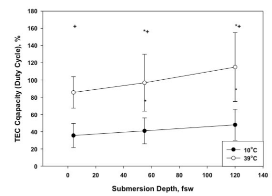
Core and the average finger and toe temperature plotted as a function of time in 4 fsw (left panel) 55 fsw (middle panel) and 120 dsw (right panel) in 10oC ambient water. Subjects were wearing the DTPS. Core temperature was maintained and digit temperatures were above that needed to maintain dexterity. Insulation was decreased due to the hydrostatic compression of the 6.5 mm wet suit. However, the subjects' was thermally protected in 10oC water by the DTPS at all depths.

Effect of depth on power to maintain thermal balance



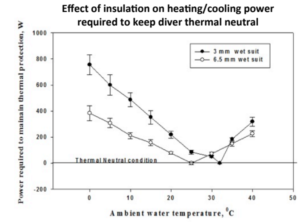
The calculated power to heat/cool the circulating water temperature to perfuse the diver with 30oC to maintain skin and core temperatures plotted as a function of depth for two ambient water temperatures (10°C and 39°C). The * indicates a significant increase in power requirement as a function of depth at each ambient temperature. The + indicates that the cooling (30°C) required more power than cooling (10°C).

Effect of Depth on TEC Capacity, duty cycle



The TEC in the DTPS is turned on and off (duty cycle) to maintain 30°C water in the tube suit to heat or cool the body. This figure plots the duty cycle as a function of depth for the 10°C and 39°C ambient water. Duty cycle increases in both ambient temperatures. In 10°C at the deepest depth the TEC's still have significant reserve, thus could protect at colder or deeper water temperature. In 39°C water at 120 fsw the TEC's have reached their maximal capacity.

Effect of insulation on heating/cooling power required to keep diver thermal neutral



The power requirement to thermally protect the divers is plotted as a function of ambient water temperatures for a 6.5 and 3 mm wet suit. As can be seen, the power requirement in cold and warm water is significantly greater in the thinner wet suit. This also shows that the power requirement approaches zero at the thermal neutral ambient water temperature with both thickness suits.

Conclusions

- The DTPS provided thermal protection at all depths and water temperatures and provided calorimeter data.
- In the cold waters, the DTPS had reserves, however at 29°C it was operating at full capacity.
- As expected, due to the compression of the foam neoprene wet suit, the power requirement in cold and warm water was greater at 55 and 120 fsw, with the most significant change between 4 and 55 fsw.
- The heat/cooling of the six zone was not different at depth than it was near the surface.
- The reduction in insulation of the suit results in divers not being protected at depth.
- The reduction in insulation of the suit requires great heating/cooling power by an active system.

Funding

- This study was funded by Naval Sea Systems Command and Office of Naval Research