D5 DIVER THERMAL PROTECTION IN COLD WATER: A NEW APPROACH

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Abstract

Background: Diver thermal protection is an important issue in all forms of diving as most waters are above or below the thermal neutral temperature of homoeothermic man, even in diver insulation suits.

Methods: The present study determined the capability of an active diver thermal protection system (DTPS) to protect divers (n = 3, 18-30 yrs old) in water temperatures from 10°C to 40°C at rest and exercise, its energy requirements and the effect of insulation thickness. The DTPS was run from a battery pack. Divers wore a tube suit perfused at 30°C (critical water temperature) under either a 3 mm or 6 mm thick wet suit and the DTPS and scuba at 4 fsw at rest or during exercise for 1-4 hrs (thermal steady state). Measurements of core, skin, and tube suit inlet and outlet temperatures were measured along with heat flux and VO2.

Results: The DTPS maintained core temperature at ± 0.5°C, skin temperatures 25-30°C and digit temperatures 22–25°C, even in 10°C. The metabolic heat production at rest averaged 105W and exercise 698W. Suit energy requirement ranged from 244-366W, with the latter in 10°C; with 11%, 32%, 17%, 6%, 22% and 12% to the head, torso, arms, hands, legs and feet respectively. The metabolism was not affected by the insulation layer when using the DTPS, however the heating/cooling was twice as high in the 3mm vs. the 6mm wetsuit.

Conclusion: The DTPS maintained thermal balance and comfort of divers in water as low as 10°C for up to four hours with current battery technology both at 4 fsw and at least to 50 fsw, based on the 3mm wetsuit data. The DTPS is autonomous, has few moving parts with redundant systems, does not use consumables and may be useful in hot water as well.

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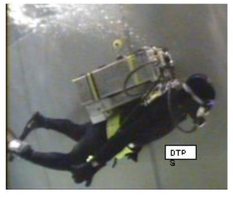
Background and Goals

- Diver thermal protection influences most dive planning as most of the waters of the world are either below or above that temperature that is thermal neutral for man, even in wet suits, while dry suit and surface supply heating limits mobility. Diving in warm water is very problematic as to date no effective cooling system is available.
- A recent NAVSEA sponsored symposium concluded that no current system was adequate, physiological solutions had not been found and thus an engineering solution was needed.
- Using ONR/NAVSEA funding a diver thermal protection system was developed that had the potential to:
  - Provide thermal protection and comfort and come-home capability
  - Be operationally reliable under the wide range of diving scenarios with few moving parts and renewable power supply
  - Maintain core temperature within ± 1.0°C, and skin temperatures above 20°C and below 35°C
  - Operational water temperatures 5°C to 40°C, down to 350 fsw while maintaining mobility

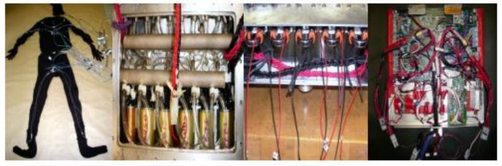
- The goal of the current study was to determine the efficacy and effectiveness of the prototype DTPS at protecting divers in water temperatures of 5°C to 40°C and determine the power requirements and battery capacity to provide this protection.

Methods:



- The present study was carried out in water temperatures 5°C to 40°C with three divers at rest and during exercise.
- Experiments were conducted in a wet suit without and with the DTPS.
- To evaluate the effect of body insulation, the experiments were conduced in a 3 mm and 6.5 mm wet suit. The 3 mm data also represented the effect of the insulation of a 6.5 mm wet suit compressed at a depth of 50 fsw.
- The divers wore a prototype DTPS, including a tube suit under the wet suit, a backpack that encompassed the active heating/cooling system and held the scuba tanks in place and a power source (surface supplied or battery modules).
- Skin temperatures and core temperature were measured continuously along with the inlet and outlet temperature to the tube suit. The tube suit inlet and outlet temperatures along with measured flow rate and oxygen consumption were used to calculate heat exchange and power requirements.
- Power requirements were measured during the steady state of each experiment, usually 30-90 min into the dive, for a 30-60 min period.
- All data were recorded continuously digitally and calculated "off-line".

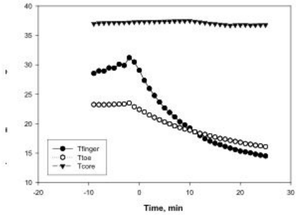
DTPS Components



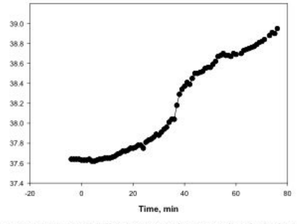
- The divers wore a six zone tube suit shown in the left panel.
- Each zone of the tube suit was perfused with 30°C water at a flow of 500 ml/min from the DTPS.
- The DTPS incorporated six circulating pumps (middle left panel) , five thermal electric coolers (TEC, middle right panel) to heat and cool the circulating water and a controller (left panel) that turned the TECs on-off to maintain the water temperate at 30°C in a manifold from which the water was pumped to the tube suit. Water from the tube suit returned to a second manifold from which the water flowed into the TECs.
- For a complete description of DTPS see poster #D6.

Diver in wet suit without active protection

Submersion in 10°C water in a foam neoprene wet suit at rest



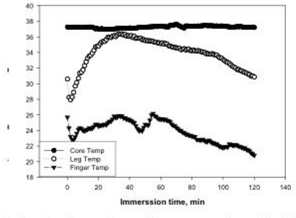
Submersion in 40°C water wearing a foam neoprene wet suit at rest



- In cold water the divers core and skin temperature decrease exponentially to a steady state that is below the acceptable standards within 30 min, core in 60 min.
- In hot water the divers core and skin temperatures rises to unacceptably high levels with in 60 min.
- In both cold and hot the dive would be limited in useful time to 30-60 min.

Diver resting in 12°C water

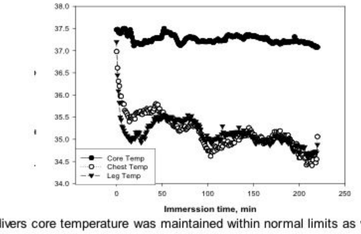
Submersion in 12°C with 32°C perfusion from free-swim DTPS



- In this graph the diver is wearing a 6.5 mm wet suit and the DTPS.
- Core temperature is maintained at normal, 37°C
- Skin temperatures are maintained above the critical temperatures for manual dexterity.
- Steady state is reached in two hours.
- The diver is both thermally protected and comfortable

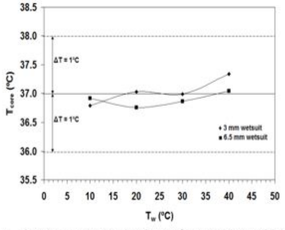
Diver exercising in 40° C water

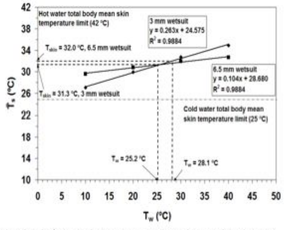
Submersion in 40°C with 32°C perfusion from free-swim DTPS



- The divers core temperature was maintained within normal limits as were all skin temperatures.
- Steady state is reached in about 100 min.

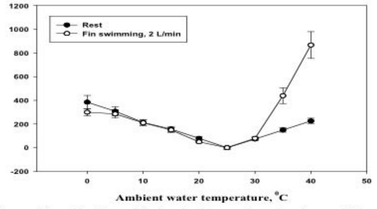
Steady State Body temperatures during submersion with DTPS in water of various temperatures





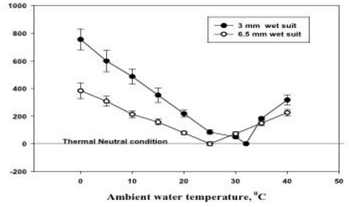
- Core temperature is shown for a resting subject in the left panel demonstrating thermal balance.
- Mean skin temperatures are shown for a resting subject in the right panel.
- Thermal neutral temperatures were 25.2 and 28.1in the 3mm and 6.5 mm wet suits, respectively.
- These data demonstrate the importance of body insulation in thermal protection, even in warm water.

Power required to keep diver thermal neutral during fin swimming



- Heating/cooling power requirement is related to ambient water temperature, low temp. high power or high temp. high power.
- Thermal neutral band (0 power required) at rest = 25-28°C
- Thermal neutral band (0 power required) during exercise = 20-28°C
- During exercise in the cold power requirements was not significantly affected, however in the warm it significantly increased the power requirement to keep the diver thermally neutral.
- Total electrical power will depend on heater/chiller efficiency

Heating/cooling power required to keep diver thermal neutral at rest



- Heating/cooling power requirement is related to ambient water temperature, low temp. high power or high temp. high power.
- Thermal neutral band (0 power required) at rest = 25-32°C
- Total electrical power will depend on heater/chiller efficiency

Summary and Conclusions

- The results demonstrated the efficacy and effectiveness of the Diver Thermal Protection System (DTPS) in providing thermal balance and comfort to the diver in water temperatures from 5 to 40°C wearing a standard wet suit in shallow water.
- The DTPS also protected divers in dives that simulated 50 fsw (3 mm wet suit data).
- Increased insulation reduced the power requirement, even in warm water.
- The power to run the DTPS can be supplied from a variety of sources, including a modular battery system.
- The DTPS can be worn by free swimming divers, without significant increases in oxygen consumption and drag at speeds typical of most dives.
- The heating/cooling power requirement is similar at rest and during exercise in cold water, however significantly greater in warm water, placing increased demand on power.
- Total electrical power will depend on heater/chiller efficiency (coefficient of performance)