D6 AN ACTIVE SYSTEM TO THERMALLY PROTECT DIVERS IN COLD WATER

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ABSTRACT

BACKGROUND: Physiological protection of divers in cold water has not worked, suggesting an engineering approach.

MATERIALS AND METHODS: Technology for a diver thermal protection system (DTPS) was evaluated and an active DTPS manufactured.

RESULTS: The DTPS technology is comprised of active heating/cooling units incorporated in a backpack and a tube suit (MedEng) that the diver wears under a wet or dry suit. The DTPS can be powered from any source (32 volts DC). The DTPS has six pumps (B&D Pumps, Inc., UGP-2000P (24VDC)) that circulate water through the tube suit. Heating is by five thermal electric modules (Peltier effect) (TEC, Supercool US, Inc., DL-290-24) in parallel, with their inlet supplied form a manifold that receives water returning from the tube suit and the outlet feeds from a manifold that perfuses the tube suit. A programmable controller varies the power to the TECs to achieve a selected outlet manifold temperature. The tube suit was designed and commercially built and has six independent zones (head, torso, arms, hands, legs, feet) that are perfused at optimal flows of 0.5-1.0 L/ min. The system can be powered by surface supplied current, generator, or batteries; or, in the free swimming mode, by multiple modular battery packs. The latter are "sticks" of eight lithium ion batteries (Panasonic 18650) that are encased in pressurized tubes and nine sticks are bundled in aluminum triangles that fit in the curvatures around scuba tanks. The DTPS is 18" by 13" by 3" and although it weights 44 kg in air it is neutrally buoyant in water. In its experimental mode, in addition to the manifolds, the tube suits inlet and outlet temperatures are measured and thus serves as a total body calorimeter.

CONCLUSIONS: Using the battery packs this DTPS has protected divers in a wide range of submersed water temperatures for up to four hours.

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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 that reviewed past and current diver thermal protection concluded that no current system was adequate, physiological solutions had not been found and thus an engineering solution was needed, which was the aim of the present ONR/NAVSEA funded project.
- Criterion for system operation:

Provide both thermal protection and comfort with come home capability
Operationally reliable under the wide range of diving scenarios with few moving parts and renewable power supply
Core temperature controlled within ± 1.0°C
Skin temperatures controlled between above 20°C and below 35°C
Operational water temperatures 5°C to 40°C
Operational depths down to 350 fsw
Mobility equivalent to that of diving with UBA and a wet suit

Background and Methods

Reviewed:
all current thermal protections systems, and concluded that none met the established performance criterion.
all potential engineering solutions; including insulations, heating and cooling methodologies (electrical resistance, vapor compression, phase change materials, fuel cells, batteries, etc)

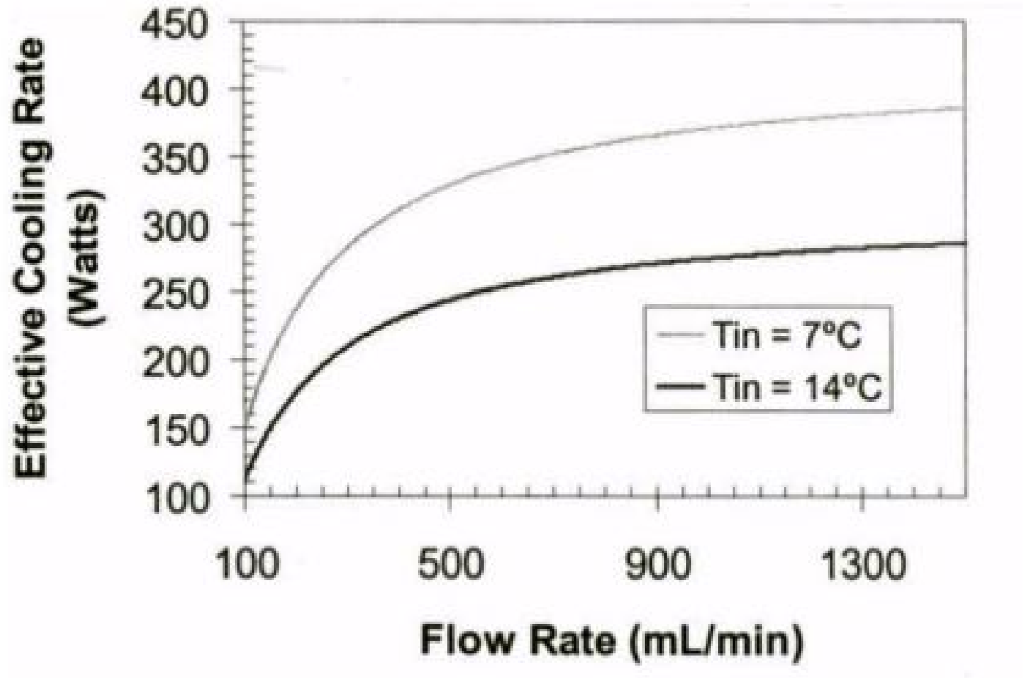
Tested and Rejected:
Hybrid aerogel insulation as too rigid with improved protection only below 100 fsw.
Zoned panel style liquid garment did not have an advantage over tube suits.
electrical resistance heating and vapor compression cooling as inefficient and technically unreliable.
Phase Change Materials as their power was only 52-55 Wh/kg, requiring a large volume of material and
slow charge and discharge rates limited applicability.
Fuel cell as power supply was 178 Wh/kg, while batteries are now 160 and will go to 320. Fuel cell
tested was also unreliable and had a short life expectancy with many moving parts.

Tested and Accepted:
Wet suit and dry suit technology
Six zone tube suit as system-to-body heat exchanger
Six circulating pumps to pump water through the tube suit
Thermal electric heat exchangers (TEC).
Power supplies:
system power requirements to operate TECs most effectively
surface supply by house current, generator or other renewable sources
battery technology identified and tested selecting and developing standard litium ion cells into a
modular unit with appropriate power capabilities

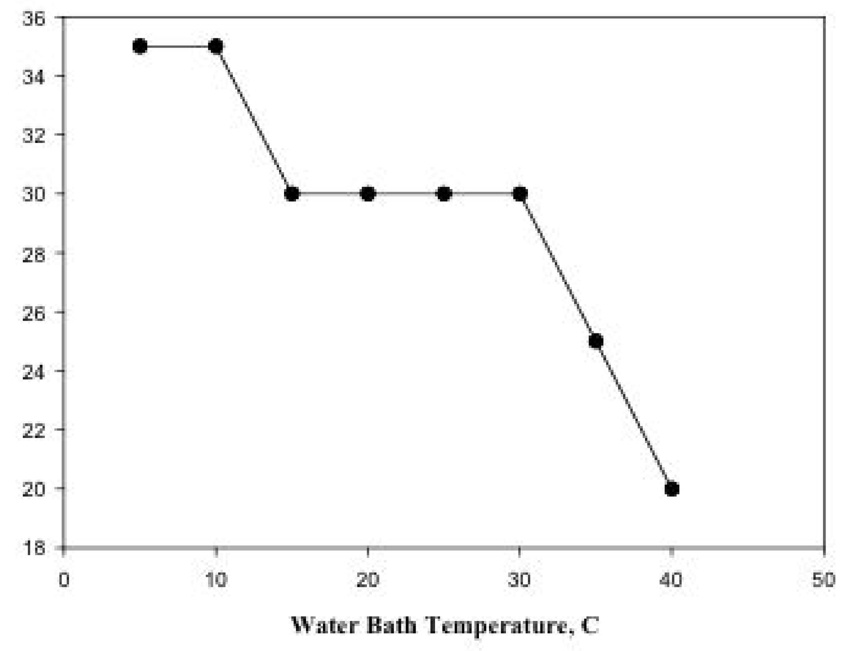
Six zone tube suit

- Liquid tube suit with tube density designed and engineered to maximize heat exchange and produced by Med-Eng.
- Six zones (head, torso, arms, hands, legs, feet) with independent inlet and outlet flows
- Each zone is perfused independently from a common manifold in the DTPS and the returns all go to a common return manifold in the DTPS.
- The zoned concept allows each zone, and the total body, to be optimally heated/cooled while conserving the power required to heat/cool

Tube Suit Performance

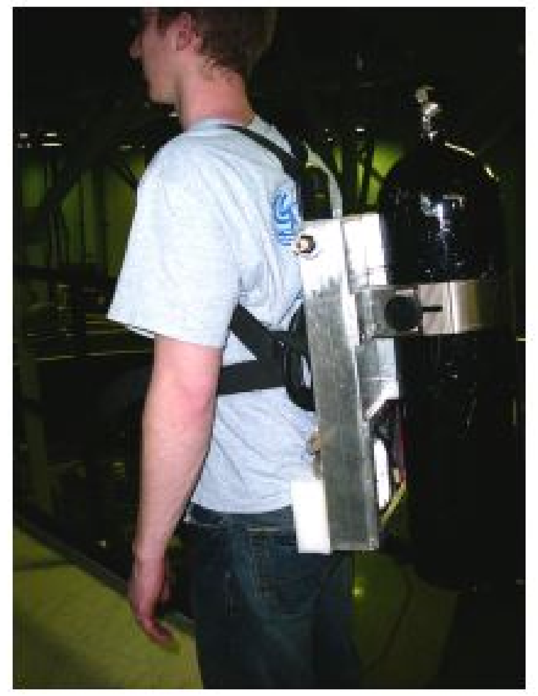


- This figure shows the relationship between water flow rate through the tube suit and heat exchange.



- This figure shows the relationship between the suit perfusion temperature (suit inlet) needed to keep the diver in thermal balance and comfort and the water temperature the subject is submerged in using surface supplied heater/chillers.
- Based on these data, and the figure above, a flow rate of 500 ml/min and a perfusion temperature of 30°C was chosen for the DTPS.

DTPS- Backpack

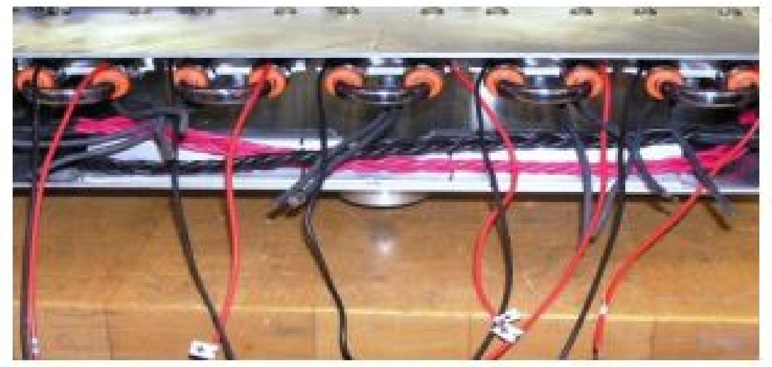


- The backpack contains all components needed to heat/cool and the pumps used to circulate the water through the tube suit.
- The backpack also holds the scuba tank (as shown) and the battery packs (see figures to the left).
- See the following figures for description of individual components.

Backpack Pump/Manifold Layout

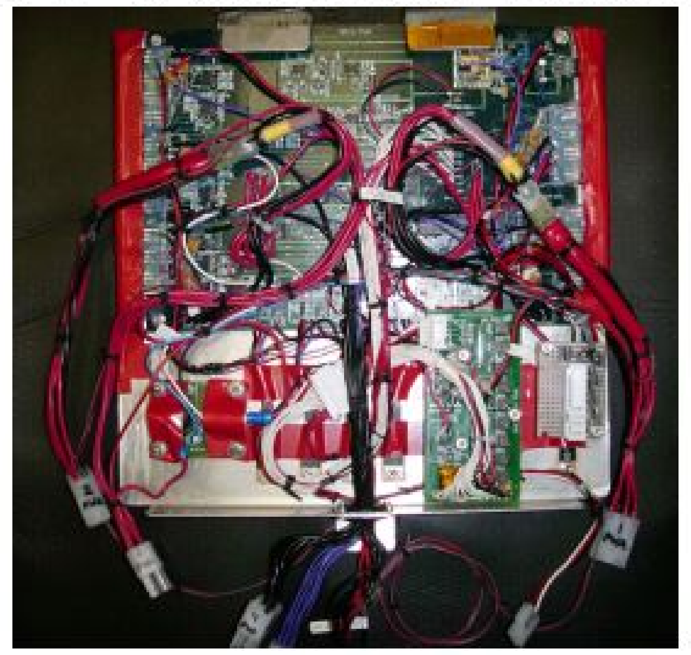
- Upper part of photo shows the inlet (upper) and outlet (lower) manifolds of the DTPS.
- The manifolds are connected to the TECs, pumps and indirectly to the tube suit.
- At the bottom of the photo shows the arrangement of the six pumps that draw water from the outlet manifold and perfuse the six zones of the tube suit.

TECs and their Position and Attachment



- At left is shown a single thermal electric heat exchanges that both heats and cools circulating water.
- At right is the positioning of the TECs.
- The TECs operate by the Peltier effect and require 24 volts and 14.2 amps.
- Heating or cooling is accomplished by reversing their polarity.

DTPS Controller Board

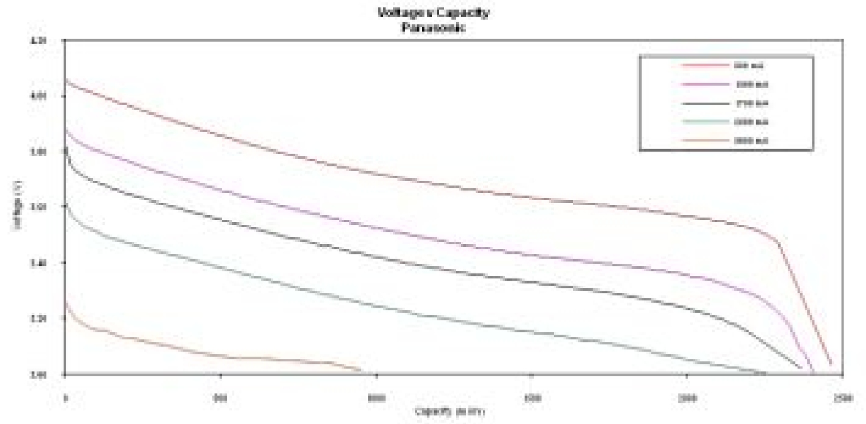


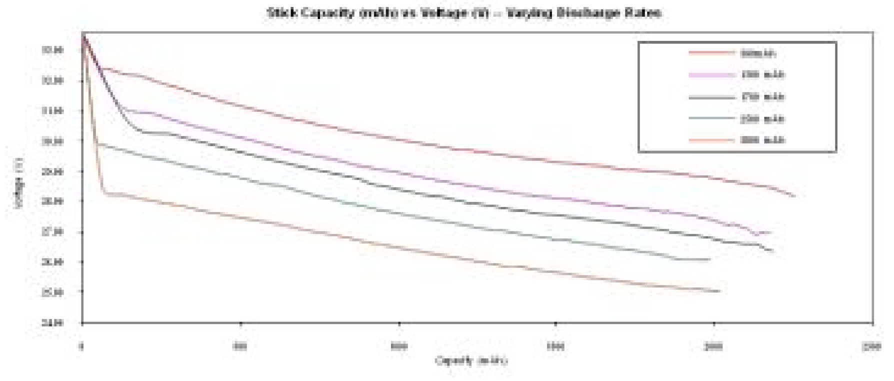
- The controller board senses the water temperature in the outlet manifold.
- The controller turns on-off the duty cycle of all of the TECs to heat/cool the manifold temperature to 30°C to perfuse the tube suit.
- Patent application filed.

Power supply for the DTPS

- The DTPS can be operated to protect a tethered diver using surface supply current, generators and marine batteries, as well as the battery modules described in the following figures.
- After testing and development a fuel cell was rejected as a power source in favor of batteries for the free swimming diver.
- Initial development utilized lithium polymer batteries in two modules with balancing circuits and a charger system.
- This system has been replaced by lithium ion batteries that have been integrated into sticks of nine batteries (Battery Specialties) and charging/balancing circuits, which in-turn have been integrated into battery modules incorporating nine sticks.
- The battery sticks and modules have been incorporated into pressure resistant tubes and modules and tested to 500 fsw.

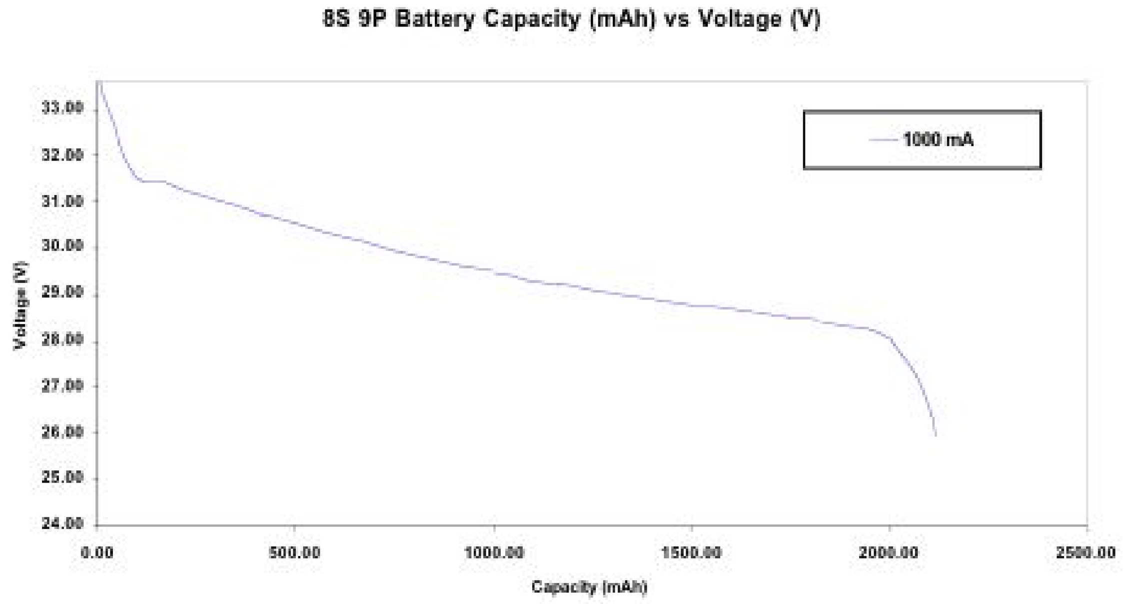
Battery module development





- The top panel shows a single cell tested with variable discharge rates giving a total capacity of between 900 and 2400 mAh.
- The lower panel shows the battery stick with eight individual cells in series with a control and electrical protection card. The data to its right shows the capacity of the stick as a function of its discharge rate. The capacity of the stick is consistent with that of the combination of the eight individual cells.

Battery module development, cont.



- The top left panel shows the nine sticks and protective cards incorporated into a triangular pressure resistance battery module.
- The photo at the top right shows how the battery modules fit on a backpack that also serves to hold two scuba tanks.
- In the lower panel the discharge rate that the DTPS will require was used to test the capacity of a single battery module.
- Dive protocols will dictate if the diver is required to carry one or more modules, up to six without changing the footprint or drag of the system.

Conclusions

- A prototype DTPS has been developed, constructed and tested that can both warm and cool the diver.
- The DTPS system can be powered by a variety of sources, including surface supply, marine batteries and battery modules.
- The DTPS can be re-configured to fit various applications from the free swimming, surface supply, closed circuit, transported diver and is adaptable to multiple diver thermal protection during transport.
- Thermal protection and comfort has been achieved with the DTPS (see poster #D5).