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APPARATUS AND METHOD FOR ENHANCING EVAPORATIVE COOLING

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Background of the Invention

1. Field of the Invention

The present invention relates generally to cooling the environment inside semi-permeable and impermeable body suits. More particularly, the present invention relates to a system and method for enhancing evaporative cooling in semi-permeable and
10 impermeable body suits.

2. Description of the Related Art

In order to function normally, a human being's core body temperature must be maintained within a narrow range of temperatures. For this reason, a human body is equipped with a number of physiological mechanisms to cool the body when body
15 temperature is increased. Body temperature is typically increased by either environmental heat stress or internal heat production (*i.e.* when the body is undergoing strenuous physical activity).

Heat is primarily removed from the human body by active cutaneous vasodilation and sweating. Cutaneous vasodilation occurs when the body increases the
20 size of blood vessels near the skin. The increased blood flow facilitates the transfer of heat from the body to the skin for dissipation to the environment. Evaporative cooling occurs during perspiration when sweat evaporates from a person's skin. Because a substantial amount of energy is required to vaporise sweat, a significant amount of metabolic heat is dissipated with the evaporation of sweat.

25 Temperature regulation is crucial to persons working in high heat stress environments. While a high heat stress environment is typically a result of hot weather, it may also be caused by a body suit. For example, in nuclear, biological and chemical (NBC) environments, persons are required to don body suits for health and safety reasons. These suits are often made of semi-permeable or impermeable material,



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severely limiting the dissipation of metabolic heat by either cutaneous vasodilation or perspiration.

A number of thermoregulatory systems have been developed to assist in the dissipation of heat from semi-permeable and impermeable suits. One such system is the Advanced Lightweight Micro-climate Cooling System (ALMCS), which was developed by the United States Army Soldier and Biological Chemical Command (SBCCOM) to provide personal cooling to personnel wearing insulative protective suits in high heat stress environments. The ALMCS is an electrically driven vapour cycle cooler that circulates a chilled fluid through a network of tubing housed by a heat transfer garment. Heat from a wearer of the garment is transferred to the chilled fluid. The fluid is then chilled again by the ALMCS and circulated back into the heat transfer garment.

One critical problem with the ALMCS is that it is heavy. By including the equivalent of a personal air conditioning unit in its specification, the ALMCS weighs approximately 5 kilograms, which is a significant additional load for the user of a body suit. The additional weight is burdensome for the user, particularly in scenarios that require physical activity (*i.e.* the user of a military body suit). Furthermore, because additional metabolic heat is generated by the user to carry the ALMCS, the cooling benefits of ALMCS may be at least partially negated.

Another limitation of the ALMCS system is the lack of humidity control for the body suit. The transfer of air in and out of the body suit is minimal, especially in suits that are designed to be impermeable. Therefore, moisture from respiration and the evaporation of sweat tends to be trapped within the suit. The retention of moisture increases the humidity of the air in the suit and retards evaporative cooling. This problem may result in the onset of a heat disorder if the cooling provided by ALMCS is insufficient for the maintenance of a constant core body temperature.

Another example of a conventional thermoregulatory system is the Personal Ice Cooling System (PICS) developed by the United States Department of Energy, which removes heat from the skin of a user by circulating cold water through a tubing incorporated into a garment worn by the user. The cold water absorbs heat from the skin of the user and becomes warm in the process. The warm water is returned to ice

bottles, worn outside the garment, where the water is chilled. This new cold water is then re-introduced into the garment to continue cooling. A separate water supply is required for the user's consumption resulting in an additional load that must be born by the user.

- 5 In view of the foregoing, it is desirable to have an apparatus and method for enhancing evaporative cooling in a semi-permeable or impermeable body suit. It is also desirable to have a micro-cooling system that is lightweight and provides humidity control of the body suit environment.

Summary of the Invention

- 10 The present invention fills these needs by providing a system and method for enhancing cooling in a body suit. It should be appreciated that the present invention can be implemented in numerous ways, including as a process, an apparatus, a system, a device or a method. Several inventive embodiments of the present invention are described below.

- 15 In one embodiment of the present invention, a micro-climate cooling system for enhancing evaporative cooling in a body suit is provided. The micro-climate cooling system includes a fan coupled to the body suit to generate a flow of air into the body suit. A dehumidifier coupled to the fan removes moisture from the flow of air. The dehumidifier preferably includes a layer of desiccant to remove moisture from the flow
20 of air. The layer of desiccant is preferably housed in a canister with a first opening to receive the flow of air and a second opening to couple the canister to the fan.

- In a preferred embodiment, the layer of desiccant is deposited in a lattice support housed by the canister. The lattice support is preferably of a hexagonal shape. Preferably, the dehumidifier includes a lid to open and close the second opening. In
25 another preferred embodiment, the micro-climate cooling system includes an air filter coupled to the dehumidifier. In yet another preferred embodiment, the fan is supported by a housing coupled to the body suit by a tube. Preferably, the micro-climate cooling system weighs less than about 3.5 kilograms.

In another embodiment of the invention, a method for enhancing evaporative cooling in a body suit is provided. The method begins by generating a flow of air into the body suit. Moisture is then removed from the flow of air by a layer of desiccant. In a preferred embodiment, the method includes defogging an eyepiece of the bodysuit
5 with the flow of air.

In yet another embodiment of the invention, a micro-climate cooling system for cooling in a body suit is provided. The micro-climate cooling system includes a fan coupled to the body suit to generate a flow of air into the body suit. A dehumidifier coupled to the fan removes moisture from the flow of air. A tubing disposed in the
10 body suit receives a flow of water from a water pack, which stores a supply of water. The flow of water provides additional cooling to the body suit. The supply of water can also be used for drinking. The flow of water may be provided by a pump or by applying pressure to the water pack.

Other aspects and advantages of the invention will become apparent from the
15 following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

Brief Description of the Drawings

The present invention will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this
20 description, like reference numerals designate like structural elements.

Figure 1 illustrates a perspective view of a subject wearing a micro-climate cooling system in accordance with one embodiment of the present invention.

Figure 2a illustrates a perspective view of a dehumidifier in accordance with one embodiment of the present invention.

25 Figure 2b illustrates a cross-sectional view of a dehumidifier in accordance with another embodiment of the present invention.

Figure 2c illustrates a perspective view of the interior of a dehumidifier in accordance with a preferred embodiment of the present invention.

Figure 3a illustrates a perspective view of a housing in accordance with one embodiment of the present invention.

Figure 3b illustrates a layout of a power source in accordance with one embodiment of the present invention.

5 Figure 3c illustrates a cross-sectional view of a housing in accordance with one embodiment of the present invention.

Figure 4 illustrates a body suit in accordance with another embodiment of the present invention.

Detailed Description of the Preferred Embodiments

10 An apparatus and method for cooling in a body suit are provided. In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be understood, however, to one skilled in the art, that the present invention may be practiced without some or all of these specific details. In other instances, well known process operations have not been
15 described in detail in order not to unnecessarily obscure the present invention.

Figure 1 illustrates a perspective view of a cooling system 12 coupled to a body suit 14 being worn by a subject 10 in accordance with one embodiment of the present invention. Micro-climate cooling system 12 is supported by subject 10 using a harness 16. Micro-climate cooling system 12 comprises a first dehumidifier 18a and a second
20 dehumidifier 18b. First dehumidifier 18a is coupled to a housing 20 and a first filter 22a. Accordingly, second dehumidifier 18b is coupled to housing 20 and a second filter 22b. Housing 20 is further coupled to a first tubing 24 and a second tubing 26.

A flow of ambient air is drawn through micro-climate cooling system 12 by a fan located inside housing 20. The air enters the system through filters 22, which
25 remove pollutants, such as pollen, dust, particulate aerosols, bacteria, and chemical agents. Thereafter, the air passes through dehumidifier 18, which includes a desiccant to remove moisture from the air. After exiting dehumidifier 18, the air is accelerated by the fan in housing 20 and blown into suit 14 via first tubing 24 and second tubing 26. First tubing 24 channels the flow of dehumidified air to an inlet 28 in the back of suit

14, while second tubing 26 channels the flow of dehumidified air to a respirator 30 to prevent fogging of an eyepiece on respirator 30. Micro-climate cooling system 12 also includes a power source to provide electrical energy to operate the fan.

By providing dehumidified air to the suit environment, the cooling effect of the subject's perspiration is greatly enhanced. Because sweat evaporates much more quickly when exposed to dry air, the subject feels cooler and more comfortable when using micro-climate cooling system 12. After being circulated within suit 14, the air absorbs moisture from the suit and exits suit 14 through a pneumatic one-way valve incorporated. A switch 32 coupled to the fan in housing 20 controls the rate at which the flow of dehumidified air is delivered into suit 14. When the fan is set at a high speed, a greater flow of air is blown into suit 14 at a higher electrical cost. In one embodiment of the present invention, the flow of dehumidified air may be set to two speeds, such as a low rate of 654 liters per minute (l/min) or a high rate of 1104 l/min.

In a preferred embodiment, each of the components of micro-climate cooling system 12 is of a modular design to allow flexibility and variety in use. For example, dehumidifier 18 may be detached from micro-climate cooling system 12 and replaced with another dehumidifier containing fresh desiccant when the desiccant in dehumidifier 18 has been expended. Harness 16 and each of the components of micro-climate cooling system 12 are preferably ergonomically designed to minimize stress on subject 10. In addition, the components are preferably designed with minimal folds and gaps to prevent the trapping of contaminants. In a preferred embodiment, micro-climate cooling system 12, including the power source, is of a manageable weight, preferably, less than 3.5 kg, and more preferably, less than 3.0 kg.

Embodiments of a dehumidifier are described in detail with reference to Figures 2a, 2b, and 2c. Figure 2a illustrates a perspective view of a dehumidifier 50 in accordance with one embodiment of the present invention. Dehumidifier 50 comprises a canister 52 with a lid 54. A first opening 56 on canister 52 receives a flow of ambient air, while a second opening 58 on lid 54 releases a flow of dehumidified air. Moisture is removed from the flow of ambient air by a desiccant housed in dehumidifier 50.

Figure 2b illustrates a cross-sectional view of a dehumidifier 60 in accordance with another embodiment of the present invention. In this embodiment, dehumidifier

60 comprises a canister 62 with a first opening 64 to receive a flow of ambient air and a second opening 66 to release a flow of dehumidified air. An interior of canister 62 includes several layers of desiccant 68. A lattice support 70 formed inside canister 62 may be used to hold the desiccant 68. The lattice support preferably has a hexagonal shape to maximize the amount of desiccant that may be packed into lattice support 70. A pair of retainers 72 placed at the ends of lattice support 70 is used to retain desiccant 68 within lattice support 70. Examples of desiccants, which may be used to remove moisture from the flow of ambient air passing through dehumidifier 60, include alumina and silica gel.

10 A preferred embodiment of the dehumidifier is illustrated in Figure 2c. Figure 2c illustrates a perspective view of the interior of a dehumidifier 80 in accordance with a preferred embodiment of the present invention. Dehumidifier 80 comprises a canister 82 with a lid. A flow of ambient air enters dehumidifier 80 through a first opening on canister 82 and exits as a flow of dehumidified air through a second opening on the lid.

15 The lid is secured to canister 82 via a plurality of screw threads 84. Canister 82 is packed with a desiccant 86. A lattice support 88 coupled to canister 82 optimises the packing of desiccant 86. Although depicted as a hexagonal lattice in this embodiment, it will be appreciated that lattice support 88 may incorporate various other geometries, such as a rectangular lattice or a square lattice.

20 A housing 100 is described in detail with reference to figures 3a, 3b, and 3c in accordance with one embodiment of the present invention. Figure 3a illustrates a perspective view of housing 100, while Figure 3c illustrates a cross-sectional view of housing 100. Figure 3b illustrates a layout of a power source or a battery pack 102 supported by housing 100.

25 With reference to Figures 3a and 3c, housing 100 supports power source 102 and a pair of fans 120. An inlet 104 at the base of housing 100 receives a flow of dehumidified air from a dehumidifier. The flow of dehumidified air is accelerated by a pair of fans 120 and blown out of housing 100 via a first outlet 106 and a second outlet 108. First outlet 106 and second outlet 108 are each coupled to tubing, which directs the flow of dehumidified air into a suit. A switch 110 coupled to pair of fans 120 controls the rate at which the flow of dehumidified air is delivered into the suit. Power

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source 102, which provides the electrical energy required to operate pair of fans 120, may be detached from housing 100 at the push of a button 112.

With reference to figures 3b and 3c, power source 102 comprises a lid 114 coupled to a casing 116 in which a pack of batteries 118, or any other suitable electrical source, is placed. In a preferred embodiment, power source 102 includes a battery
5 charger so that the electrical source need not be replaced, but may be recharged instead.

Figure 4 illustrates a body suit 150 in accordance with another embodiment of the present invention. A tubing 152 disposed in body suit 150 receives a flow of water from a water pack 154 when a pressure is applied to water pack 154. The flow of water
10 removes heat from the skin of a wearer of body suit 150 as the flow of water circulates through tubing 152.

In addition, the supply of water stored in water pack 154 may be used for drinking as well. A drinking tube 156 coupled to water pack 154 enables the wearer to drink from the supply of water stored in water pack 154. A cap 158 serves as a cover
15 for an opening in water pack 154 through which the supply of water is replenished. Because water pack 154 provides a source of water for the wearer, a separate supply of water for drinking is not required, thereby eliminating the need for an additional load in the form a separate water supply, which the wearer would otherwise have to carry.

In one embodiment, a water pump is preferably provided to circulate the flow of
20 water through tubing 152. However, if a water pump is not provided, another embodiment of the invention allows the user to apply pressure to water pack 154 for either cooling or drinking purposes or both. In such an embodiment, water pack 154 is preferably formed from a soft plastic material so that water may be dispensed simply by squeezing the pack.

Other embodiments of the invention will be apparent to those skilled in the art
25 from consideration of the specification and practice of the invention. Furthermore, certain terminology has been used for the purposes of descriptive clarity, and not to limit the present invention. The embodiments and preferred features described above should be considered exemplary, with the invention being defined by the appended
30 claims.

CLAIMS

1. A micro-climate cooling system for enhancing evaporative cooling in a body suit, comprising:
 - 5 a fan coupled to said body suit to generate a flow of air into said body suit; and
 - a dehumidifier coupled to said fan, wherein said dehumidifier is to remove moisture from said flow of air.
2. The micro-climate cooling system for enhancing evaporative cooling in
10 a body suit as recited in claim 1, wherein said dehumidifier comprises a layer of desiccant to remove moisture from said flow of air.
3. The micro-climate cooling system for enhancing evaporative cooling in a body suit as recited in claim 2, wherein said dehumidifier further comprises a canister
15 to house said layer of desiccant therein.
4. The micro-climate cooling system for enhancing evaporative cooling in a body suit as recited in claim 3, wherein said canister has a first opening to receive said flow of air and a second opening to couple said canister to said fan.
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5. The micro-climate cooling system for enhancing evaporative cooling in a suit as recited in claim 4, wherein said layer of desiccant is deposited in a lattice support housed by said canister.
- 25 6. The micro-climate cooling system for enhancing evaporative cooling in a suit as recited in claim 5, wherein said lattice support has a hexagonal shape.

7. The micro-climate cooling system for enhancing evaporative cooling in a suit as recited in claim 4, wherein said dehumidifier further comprises a lid to open and close said second opening.

5 8. The micro-climate cooling system for enhancing evaporative cooling in a suit as recited in claim 4, further comprising an air filter coupled to said dehumidifier.

9. The micro-climate cooling system for enhancing evaporative cooling in a suit as recited in claim 4, wherein said fan is supported by a housing, wherein said
10 housing is coupled to said body suit by a tube.

10. The micro-climate cooling system for enhancing evaporative cooling in a suit as recited in claim 9, wherein said micro-climate cooling system weighs less than about 3.5 kilograms.

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11. A method for enhancing evaporative cooling in a body suit, comprising:
generating a flow of air into said body suit; and
removing moisture from said flow of air, wherein said moisture is removed from said flow of air by a layer of desiccant.

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12. The method for enhancing evaporative cooling in a suit as recited in claim 11, further comprising filtering said flow of air.

13. The method for enhancing evaporative cooling in a suit as recited in
25 claim 11, further comprising defogging an eyepiece of said body suit with said flow of air.

14. The method for enhancing evaporative cooling in a suit as recited in claim 11, wherein said layer of desiccant is deposited in a lattice support.

15. The method for enhancing evaporative cooling in a suit as recited in
5 claim 14, wherein said lattice support has a hexagonal shape.

16. A micro-climate cooling system for cooling in a body suit, comprising:
a fan coupled to said body suit to generate a flow of air into said body suit;
a dehumidifier coupled to said fan, wherein said dehumidifier is to remove
10 moisture from said flow of air;
a tubing disposed in said body suit, wherein said tubing is to receive a flow of water; and
a water pack to store a supply of water, wherein said supply of water is to be used for drinking and to provide said flow of water.

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17. The micro-climate cooling system for cooling in a body suit as recited in claim 16, wherein said dehumidifier comprises a layer of desiccant to remove moisture from said flow of air.

20 18. The micro-climate cooling system for cooling in a body suit as recited in claim 17, wherein said dehumidifier further comprises a canister to house said layer of desiccant therein.

19. The micro-climate cooling system for cooling in a suit as recited in
25 claim 18, wherein said layer of desiccant is deposited in a lattice support housed by said canister, wherein said lattice support has a hexagonal shape.

20. The micro-climate cooling system for cooling in a body suit as recited in claim 17, wherein said flow of water may be provided by applying pressure to said water pack.

5 21. The micro-climate cooling system for cooling in a body suit as recited in claim 17, wherein said flow of water may be provided by a water pump.