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(71) Applicant *(for all designated States except US)*: **CAITIN, INC.** [US/US]; 41900 Christy Street, Fremont, California 94538 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **HARMAN, Jayden David** [US/US]; C/O CAITIN, INC., 41900 Christy Street, Fremont, California 94538 (US). **DEBUS, Kristian** [US/US]; C/O CAITIN, INC., 41900 Christy Street, Fremont, California 94538 (US). **GIELDA, Thomas** [US/US]; C/O CAITIN, INC., 41900 Christy Street, Fremont, California 94538 (US). **TOMASI, Don** [US/US]; C/O CAITIN, INC., 41900 Christy Street, Fremont, California 94538 (US).

(74) Agents: **KLINE, Keith** et al.; CARR & FERRELL LLP, 120 Constitution Drive, Menlo Park, California 94025 (US).

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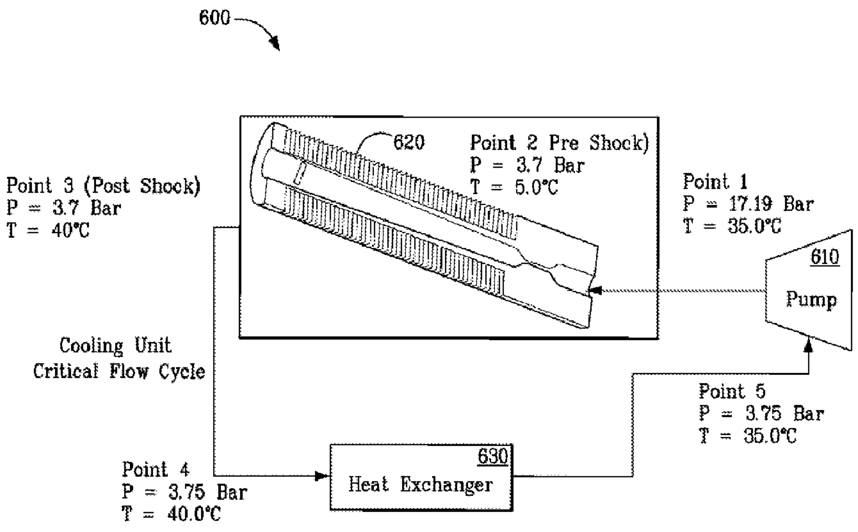

FIG. 6

(57) Abstract: A supersonic cooling system operates by pumping liquid into an evaporator situated in a working fluid flow path. Because the cooling system pumps liquid, the compression cooling cycle that generates the cooling power does not require the use of a condenser. An evaporator of the cooling system operates in the critical flow regime and forms a compression wave to facilitate a phase change in a working fluid. The pressure in the evaporator remains almost constant and then 'jumps' or 'shocks up' to an increased pressure as the working fluid exits the evaporator.

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COOLING SYSTEMS UTILIZING A SUPERSONIC COOLING CYCLE

BACKGROUND OF THE INVENTION

Field of the Invention

[01] The present invention generally relates to cooling systems. The present invention more specifically relates to utilizing a supersonic cooling system to remove heat from various heat producing sources.

Description of the Related Art

[02] In a prior art vapor compression system, a gas is compressed so that the temperature of that gas is increased beyond that of the ambient temperature. The compressed gas is then run through a condenser and turned into a liquid. The condensed and liquefied gas is then taken through an expansion device, which drops the pressure and the corresponding temperature. The resulting refrigerant is then boiled in an evaporator. This vapor compression cycle is generally known to those of skill in the art.

[03] FIGURE 1 illustrates a vapor compression system **100** as might be found in the prior art. In the prior art vapor compression system **100** of FIGURE 1, compressor **110** compresses the gas to (approximately) 238 pounds per square inch (PSI) and a temperature of 190° F. Condenser **120** then liquefies the heated and compressed gas to (approximately) 220 PSI and 117 ° F. The gas that was liquefied by the condenser **120** is then passed through the expansion valve **130** of FIGURE 1. By passing the liquefied gas through expansion valve **130**, the pressure is dropped to (approximately) 20 PSI. A corresponding drop in temperature accompanies the drop in pressure, which is reflected as a temperature drop to (approximately) 34 ° F in FIGURE 1. The refrigerant that results from dropping the pressure and temperature at the expansion valve **130** is boiled at evaporator **140**. Through boiling of the refrigerant by evaporator **140**, a low temperature vapor results, which is illustrated in FIGURE 1 as having (approximately) a temperature of 39 ° F and a corresponding pressure of 20 PSI.

[04] The cycle related to the system **100** of FIGURE 1 is sometimes referred to as the vapor compression cycle. Such a cycle generally results in a coefficient of performance (COP) between 2.4 and 3.5. The coefficient of performance, as reflected in FIGURE 1, is the evaporator cooling power or capacity divided by compressor power. It should be noted that the temperature and pressure references that are reflected in FIGURE 1 are exemplary and illustrative.

[05] FIGURE 2 illustrates the performance of a vapor compression system like that illustrated in FIGURE 1. The COP illustrated in FIGURE 2 corresponds to a typical home or automotive vapor compression system—like that of FIGURE 1—operating in an ambient temperature of (approximately) 90 ^{o} F. The COP shown in FIGURE 2 further corresponds to a vapor compression system utilizing a fixed orifice tube system.

[06] Such a system **100**, however, operates at an efficiency rate (*i.e.*, COP) that is far below that of system potential. To compress gas in a conventional vapor compression system **100** like that illustrated in FIGURE 1 typically takes 1.75 - 2.5 kilowatts for every 5 kilowatts of cooling power generated. This exchange rate is less than optimal and directly correlates to the rise in pressure times the volumetric flow rate. Degraded performance is similarly and ultimately related to performance (or lack thereof) by the compressor **110**.

[07] Haloalkane refrigerants such as tetrafluoroethane (CH_2FCF_3) are inert gases that are commonly used as high-temperature refrigerants in refrigerators and automobile air conditioners. Haloalkane refrigerants have also been used to cool over-clocked computers. These inert, refrigerant gases are more commonly referred to as R-134 gases. The volume of an R-134 gas can be 600-1000 times greater than the corresponding liquid.

[08] In light of the theoretical efficiencies of systems using haloalkanes or other fluids, there is a need in the art for an improved cooling system that more fully recognizes system potential and overcomes technical barriers related to compressor performance.

[09] Moreover, a vapor compression system as known in the art generally includes a compressor, a condenser, an evaporator, and an expansion device. Apart from issues of non-optimal efficiency, simply the combined weight of these elements may be a detriment to the efficacy of the prior compression cooling cycle in non-stationary cooling systems.

SUMMARY OF THE CLAIMED INVENTION

[010] One embodiment of the cooling system disclosed herein is a personal cooling unit. The personal cooling unit disclosed herein includes a garment, the garment including a cooling fluid circulation path to carry cooling fluid throughout the garment. The cooling fluid circulation path may include a manifold coupled to a cooling fluid supply. The cooling fluid circulation path may include one or more branches coupled to the manifold.

[011] The unit further includes at least one pump that maintains the flow through the cooling fluid circulation path and a fluid flow path. The unit also includes an evaporator that operates in the critical flow regime of the circulatory fluid in the fluid flow path. The evaporator generates a compression wave that shocks the maintained fluid flow, thereby changing the pressure of the maintained fluid flow and exchanging heat introduced into the circulatory fluid flow. No heat is added to the circulatory fluid flow before the circulatory fluid flow passes through the evaporator. The evaporator may use one or more tubes/nozzles, and may generate approximately 300 watts of cooling power at 38^{o} C ambient.

[012] A heat exchanging mechanism may be thermally coupled to the fluid flow path. The heat exchanging mechanism may utilize at least a portion of an external surface of the control pack to vent heat to the atmosphere via convection from the surface. The heat exchanging mechanism may include one or more vents. A plurality of fins may be employed in the vents.

[013] A control pack may be mounted on the body of the user. A thermostat may be included in the control pack to control the temperature of the unit. The control pack may further include a battery, and a solar cell that may be used to power the unit or to recharge the battery.

[014] Operating conditions within the unit may include the pump raising the pressure of the circulatory fluid flow from approximately 20 PSI to approximately 100 PSI. In certain embodiments, the pressure may be raised to pressures in excess of 100 PSI, such as 300 or 500 PSI.

[015] A personal cooling unit as disclosed herein may include a pump that maintains a fluid flow of a fluid through the unit, and an evaporator that effects a phase change in the fluid. The unit may establish a compression wave in the fluid by passing the fluid from a high pressure region to a low pressure region, the velocity of the fluid being equal to or greater than the speed of sound in the fluid. The fluid is cooled during a phase change so that heat may be transferred from the unit by thermally coupling one or more fins between the fluid and the ambient atmosphere.

[016] Operating conditions in the evaporator may include a pressure drop in the cooling liquid to approximately 5.5 PSI. A corresponding phase change results in a lowered temperature of the cooling liquid. The pressure change may occur within a range of approximately 20 PSI to 100 PSI, or the increased pressure may be in excess of 100 PSI, such as 300 or 500 PSI.

[017] Another embodiment of the cooling system disclosed herein is a portable cooling unit. The portable cooling unit includes a pump that maintains a circulatory fluid flow through a flow path. The unit also includes an evaporator that operates in the critical flow regime of the circulatory fluid. The evaporator generates a compression wave that shocks the maintained fluid flow, thereby changing the pressure of the maintained fluid flow and exchanging heat introduced into the circulatory fluid flow. No heat is added to the circulatory fluid flow before the circulatory fluid flow passes through the evaporator. The evaporator may use one or more tubes/nozzles, and may generate 20-80 watts of cooling power.

[018] The unit further includes a storage compartment, the storage compartment receiving items to be cooled or maintained at a temperature below ambient. The storage compartment may form a housing for the pump and the evaporator. An external surface of the storage compartment may effectuate convection and further exchange heat introduced into the unit.

[019] The unit may be powered by an adapter such as for a vehicle battery. Moreover, the unit may be powered by a self-contained battery pack. The unit may use a solar cell as a direct power source or as a means of charging a battery pack.

[020] Operating conditions within the unit may include the pump raising the pressure of the circulatory fluid flow from approximately 20 PSI to approximately

100 PSI. In certain embodiments, the pressure may be raised to pressures in excess of 100 PSI, such as 300 or 500 PSI.

[021] A portable cooling unit as disclosed herein may include a storage compartment that receives items to be cooled or maintained at a temperature below ambient. The unit may also include a pump that maintains a fluid flow of a fluid through the unit, and an evaporator that effects a phase change in the fluid. The unit may establish a compression wave in the fluid by passing the fluid from a high pressure region to a low pressure region, the velocity of the fluid being greater than or equal to the speed of sound in the fluid. The fluid is cooled during a phase change so that heat may be transferred from the unit by thermally coupling one or more fins between the fluid and the ambient atmosphere.

[022] Operating conditions in the evaporator may include a pressure drop in the cooling liquid to approximately 5.5 PSI. A corresponding phase change results in a lowered temperature of the cooling liquid. The pressure change may occur within a range of approximately 20 PSI to 100 PSI, or the increased pressure may be in excess of 100 PSI, such as 300 or 500 PSI.

[023] Still another embodiment of the cooling system disclosed herein is a battery cooling unit. The battery cooling unit includes a cooling fluid circulation path in thermal contact with at least one battery cell in a battery pack. The cooling fluid circulation path may include a cooling jacket. The cooling jacket may be thermally coupled to at least a portion of the battery pack. The cooling jacket may include a plurality of receptacles, each receptacle receiving a cell of the battery pack, or the cooling jacket may surround an exterior of the battery pack. A housing of the cooling jacket may be rigid or flexible, depending on the parameters of a given application.

[024] The battery cooling unit further includes a pump that maintains a circulatory fluid flow through the cooling fluid circulation path and a working fluid flow path. The unit also includes an evaporator that operates in the critical flow regime of the circulatory working fluid. The evaporator generates a compression wave that shocks the maintained fluid flow, thereby changing the pressure of the maintained fluid flow and exchanging heat introduced into the circulatory fluid flow. The evaporator may use one or more tubes/nozzles.

[025] Operating conditions within the unit may include the pump raising the pressure of the circulatory working fluid flow from approximately 20 PSI to approximately 100 PSI. In certain embodiments, the pressure may be raised to pressures in excess of 100 PSI, such as 300 or 500 PSI.

[026] A battery cooling unit according to the technology disclosed herein may include a cooling fluid circulation path in close proximity to at least one battery cell in a battery pack. The unit may include a pump that maintains a fluid flow through a working fluid flow path, and at least one evaporator that operates in the critical flow regime of the working fluid and generates a compression wave that shocks the maintained fluid flow, thereby changing the pressure of the maintained fluid flow to cool the working fluid, the evaporator being in close proximity to the at least one battery cell so that heat is removed from the battery cell via conduction.

[027] Another battery cooling unit may include a series of single tube evaporators aligned in parallel, each tube being in close proximity to a battery cell. This allows the working fluid of the evaporators to remove heat from the battery cells via conduction.

BRIEF DESCRIPTION OF THE DRAWINGS

[028] FIGURE 1 illustrates a vapor compression system as might be found in the prior art.

[029] FIGURE 2 shows the performance of a vapor compression system like that illustrated in FIGURE 1.

[030] FIGURE 3 illustrates an exemplary cooling system in accordance with an embodiment of the present invention.

[031] FIGURE 4 illustrates an exemplary cooling system in accordance with another embodiment of the present invention.

[032] FIGURE 5 illustrates performance of a cooling system like that illustrated in FIGURES 3 and 4.

[033] FIGURE 6 illustrates the operation of a single evaporator tube / nozzle cooling system.

[034] FIGURE 7 illustrates a personal cooling unit mounted on the back of a user.

[035] FIGURE 8 illustrates a personal cooling unit mounted on the leg of a user.

[036] FIGURE 9 illustrates a personal cooling unit utilizing a tight fitting garment.

[037] FIGURE 10 illustrates a portable cooling unit.

[038] FIGURE 11 illustrates a battery cooling unit utilizing a cooling jacket surrounding a battery pack.

[039] FIGURE 12 illustrates a battery cooling unit utilizing a cooling jacket surrounding the individual cells of a battery pack.

[040] FIGURE 13 illustrates a method of operation for a cooling system utilizing a supersonic cooling cycle.

DETAILED DESCRIPTION

[041] FIGURE 3 illustrates an exemplary cooling system **300** utilizing a supersonic cooling cycle in accordance with an embodiment of the present invention. The cooling system **300** does not need to compress a gas as otherwise occurs at compressor **110** in the prior art vapor compression system **100** illustrated in FIGURE 1. Cooling system **300** operates by pumping liquid. Because cooling system **300** pumps liquid, the compression cooling system **300** does not require the use of a condenser **120** as does the prior art compression system **100**. Compression cooling system **300** instead utilizes a compression wave. The evaporator of cooling system **300** operates in the critical flow regime where the pressure in an evaporator tube will remain almost constant and then 'jump' or 'shock up' to the ambient pressure.

[042] The cooling system **300** of FIGURE 3 recognizes a heightened degree of efficiency in that the pump **320** of the system **300** is not required to draw as much power as the compressor **110** in a prior art compression system **100** like that illustrated in FIGURE 1. A compression system designed according to an embodiment of the presently disclosed invention may recognize exponential performance efficiencies. For example, a prior art compression system **100** as illustrated in FIGURE 1 may require 1.75-2.5 kilowatts to generate 5 kilowatts of cooling power. Prior art compression system **100** therefore may operate at a coefficient of performance (COP) of less than 3. A system **300** like that illustrated in FIGURE 3 may pump fluid from approximately 14.7 to approximately 120 PSI with the pump drawing power at approximately 500W (0.5 kilowatts), with the system **300** also generating 5 kilowatts of cooling power. The system **300** may therefore operate with a COP of 10. As a result of the cycle illustrated in FIGURE 3, and the resultant increased efficiencies, system **300** may utilize many working fluids, including but not limited to water.

[043] The cooling system **300** of FIGURE 3 may include a housing **310**. The general shape of housing **310** of FIGURE 3 is akin to that of a pumpkin. The particular shape or other design features of housing **310** may be a matter of aesthetics and convenience with respect to where and how the system **300** is installed. The design of the housing **310** may be influenced by the facility in which the system **300** is installed, or by the equipment or machinery to which the system **300** is coupled. Functionally, housing **310** encloses pump **330**, evaporator **350**, and the attendant accessory equipment or flow paths (*e.g.*, pump inlet **340** and evaporator tube **360**). Housing **310** also contains the working fluid to be used by the system **300**.

[044] Housing **310**, in an alternative embodiment, may also encompass a secondary heat exchanger as in system **400,** which is illustrated in FIGURE 4. The secondary heat exchanger is not necessarily contained within the housing **310**. In such an embodiment, the outer surface area of the system 400—that is, the housing **310**—may be utilized in a cooling process through forced convection on the external surface of the housing **310**.

[045] Pump **330** may be powered by a motor **320**, which may be external to the system **300** and which is located outside the housing **310** in FIGURE 3. Motor **320** may alternatively be contained within the housing **310** of system **300**. Motor **320** may drive the pump **330** of FIGURE 3 through a rotor drive shaft with a corresponding bearing and seal or magnetic induction, whereby penetration of the housing **310** is not required. Other motor designs may be utilized with respect to motor **320** and corresponding pump **330** including synchronous, alternating (AC), and direct current (DC) motors. Other electric motors that may be used with system **300** include induction motors; brushed and brushless DC motors; stepper, linear, unipolar, and reluctance motors; and ball bearing, homopolar, piezoelectric, ultrasonic, and electrostatic motors.

[046] Pump **330** establishes circulation of a compressible working fluid through the interior fluid flow paths of system **300**, the flow paths being contained within the housing **310**. Pump **330** may circulate the working fluid throughout system **300** through the use of vortex flow rings. Vortex rings operate as energy reservoirs whereby added energy is stored in the vortex ring. The progressive introduction of energy to a vortex ring via pump **330** causes the corresponding ring vortex to function at a level such that energy lost through dissipation corresponds to energy being input.

[047] Pump **330** operates to raise the pressure of a liquid being used by system **300** from, for example, 20 PSI to 100 PSI or more. Some systems may operate at an increased pressure of approximately 300 PSI. Other systems may operate at an increased pressure of approximately 500 PSI.

[048] Pump inlet **340** introduces a liquid to be used in cooling and otherwise resident in system **300** into pump **330**. Fluid temperature may, at this point in the system **300**, be approximately 95 F.

[049] The working fluid introduced to pump **330** by inlet **340** traverses a primary fluid flow path to nozzle / evaporator **350**. Evaporator **350** induces a pressure drop (*e.g.*, to approximately 5.5 PSI) and phase change that results in a low temperature. The working fluid further 'boils off' at evaporator **350**, whereby the resident liquid may be used as a coolant. For example, the liquid coolant may be water cooled to 35-45^{o} F (approximately 37^{o} F as illustrated in FIGURE 3).

[050] As noted above, the system **300** (specifically evaporator **350**) operates in the critical flow regime, thereby generating a compression wave. The working fluid exits the evaporator **350** via evaporator tube **360** where the fluid is 'shocked up' to approximately 20 PSI because the flow in the evaporator tube **360** is in the critical regime. In some embodiments of system **300**, the nozzle / evaporator **350** and evaporator tube **360** may be integrated and/or collectively referred to as an evaporator.

[051] The working fluid of system **300** (having now absorbed heat for dissipation) may be cooled at a heat exchanger to assist in dissipating absorbed heat, the temperature of the fluid being approximately 90-100^{o} F after having exited evaporator **350**. Instead of a heat exchanger, however, the housing **310** of the system **300** (as was noted above) may be used to cool via convection. FIGURE 5 illustrates an exemplary performance cycle of a cooling system utilizing a supersonic cooling cycle such as the systems illustrated in FIGURES 3 and 4. The operating steps of the method utilized in system 300 are described in further detail below with reference to FIGURE 13.

[052] FIGURE 6 illustrates the operation of an exemplary cooling system **600** that utilizes a supersonic cooling cycle. The system **600** utilizes a small pump **610**,

which may be of any type, and at least one evaporator or tube **620**. The tube **620** may have a converging – diverging conformation. The tube **620** functions as the evaporator in the system **600**. FIGURE 6 illustrates a supersonic cooling system **600** in which a single evaporator tube **620** is utilized, a configuration that may typically be implemented in installations requiring a cooling power of, for example, 300 watts. In various configurations of the system **600**, more than one evaporator tube **620** may be employed (as illustrated in FIGURES 3 and 4) depending on the requirements of a given application.

[053] A heat exchanger **630** may be employed in a fluid flow path in the system **600** to remove heat from the system. When the cooling system **600** is employed as a personal cooling system, the heat exchanger **630** is utilized in the transfer of heat away from the body of the user of the system.

[054] The pump **610** raises the pressure of a fluid in the system **600**. Various fluids, including water, may be used in the system. Other refrigerants such as green refrigerant R134a may also be used. The pressure of the fluid may be raised from 20 PSI to in excess of 100 PSI. The fluid flows through the tube **620** of the evaporator. Pressure drop and phase change that occur as the fluid is accelerated through the tube **620** result in a lowered temperature of the fluid in the tube **620** and provide the cooling power for the system **600**.

[055] Critical flow rate, which is the maximum flow rate that can be attained by a compressible fluid as that fluid passes from a high pressure region to a low pressure region (*i.e.*, the critical flow regime), allows for a compression wave to be established and utilized in the critical flow regime. Critical flow occurs when the velocity of the fluid is equal to or greater than the speed of sound in the fluid.

[056] In critical flow, the pressure in the channel may not be influenced by the exit pressure, and at or near the channel exit, the fluid will 'shock up' to the ambient condition. In critical flow the fluid will also stay at the low pressure and temperature corresponding to the saturation pressure.

[057] In cooling system **600**, the cooled working fluid is passed through heat exchanger **630** to effectuate a heat transfer to the atmosphere. The operating steps of the method utilized in system **600** are further described below with reference to FIGURE 13.

[058] FIGURE 7 illustrates an exemplary embodiment of a cooling system **600**, a personal cooling unit **700**. FIGURE 7 shows a full body garment **710** used in one implementation of the personal cooling unit **700**. It will be recognized by those skilled in the art that the garment chosen may cover any part of the body chosen by the user. Suitable garments for various configurations of the personal cooling unit **700** include, but are not limited to, full body garments such as overalls or jumpsuits, vests, shirts, pants, and hats. In short, any part of the body that the user desires to cool may be matched to a garment equipped with the personal cooling unit **700.**

[059] The garment **710** of the cooling unit **700** includes a cooling fluid circulation path **920** (see FIGURE 9) thermally coupled to the fluid flow path of the working fluid of the supersonic cooling cycle of the unit. The cooling fluid circulation path **920** carries cooling fluid throughout the garment. As the cooling fluid flows through the cooling fluid circulation path **920**, the cooling fluid is subject to warming due to ambient and body heat. In units utilizing a full body garment, warming of the fluid in the cooling fluid circulation path **920** can be a significant problem. Therefore, the cooling fluid circulation path **920** may be a manifolded capillary system to reduce the length of any given branch in the unit. Minimizing the lengths of the branches in the cooling fluid circulation path **920** reduces the possibility of the cooling fluid absorbing too much heat to properly cool the user.

[060] A control pack **720** may include a thermostat to control the temperature of the unit. The unit will typically be operated to maintain a temperature in the garment of between 12°C and 24°C. The thermostat controlled operating temperature of the cooling unit **700** ensures a comfortable and uniform temperature throughout the unit **700**. The control pack **720** may also include an on/off switch that controls the power supply to the cooling unit **700**. The user may control the temperature in the cooling unit **700** by simply turning the power on and off as necessary to maintain a comfortable temperature.

[061] Heat may be vented from the cooling unit **700** via vents **730** in the surface of the control pack **720**. The vents **730** may be a series of fins to increase the surface area available for heat transfer. The vents may also be holes, slots, or any other construction that would facilitate the transfer of heat.

[062] Personal cooling unit **700** may be powered by a 12 or 24 volt power supply. The personal cooling unit **700** may be powered by self-contained batteries or by a solar cell. A solar cell may also be used to charge the self-contained batteries. Those skilled in the art will recognize that many power supply configurations may be utilized in the personal cooling unit **700**.

[063] As depicted in FIGURE 7 personal cooling unit **700** may have the control pack **720** mounted on the back of the user, akin to a backpack. However, the position in which the control pack **720** is mounted may vary with a given application. The mounting of the control pack **720** is a matter of choice of the user of the unit. The unit may be mounted on the user's back as shown in FIGURE 7 or on the leg as shown in FIGURE 8. The control pack **720** may be mounted at any location that is convenient for the user.

[064] FIGURE 9 illustrates a personal cooling unit **900** that utilizes a tight fitting garment **910**. Garment **910** may be made from a stretchable fabric such as Spandex, Lycra, etc., to hold the cooling fluid in the cooling fluid circulation path **920** in close proximity to the body of the user.

[065] A manifolded cooling fluid supply **930** routes cooling fluid cooled by the working fluid in the fluid flow path through the cooling fluid circulation path **920**. The cooling fluid circulation path **920** is thermally coupled to the fluid flow path of a supersonic cooling cycle. The cooling fluid circulation path **920** may trace, as illustrated in FIGURE 9, the main arteries of the body of the user. Positioning the cooling fluid circulation path **920** so that it traces the main arteries of the user may increase the efficiency of heat dissipation from the body of the user.

[066] Personal cooling unit **900** combines the tight fitting garment **910** with a cooling fluid circulation path **920** that traces the main arteries of the user. Users of the personal cooling unit **900** may therefore experience improved efficiency of heat removal due to the cooling unit **900** maintaining close proximity between the cooling fluid in the circulation path **920** and areas of significant heat accumulation from the body of the user, i.e. the main arteries.

[067] FIGURE 10 shows an exemplary embodiment of a portable cooling unit **1000** that utilizes the supersonic cooling cycle. Portable cooling unit **1000** may be powered by a 12 volt power supply, such as a car battery. An adapter **1010** that plugs into a power outlet such as those commonly found in vehicles may be provided with the portable cooling unit **1000**. Portable cooling unit **1000** may also be powered by self-contained batteries or a solar cell. A solar cell may also be used to charge the self-contained batteries. Those skilled in the art will recognize that many power supply configurations may be utilized in the portable cooling unit **1000**.

[068] The housing **1020** of the cooling unit **1000** may include one or more fins **1030**. The fins **1030** may be coupled to the working fluid in the portable cooling unit **1000**, and may be open to the atmosphere. The fins **1030** may therefore be used as a radiator to transfer heat from the interior of the unit **1000** to the exterior atmosphere.

[069] FIGURE 11 illustrates a battery cooling system **1100** that may be utilized in conjunction with the supersonic cooling cycle as illustrated in FIGURE 4. The cooling cycle shown in FIGURE 4 may be adapted to utilize the single nozzle cycle depicted in FIGURE 6. A cooling fluid circulation path of the system **1100** routes the secondary cooling fluid through battery cooling system **1100**. The battery cooling system **1100** may be used to cool high power battery packs, including but not limited to those that may be utilized in EV (electric vehicle) or HEV (hybrid electric vehicle) applications.

[070] A battery pack **1110** may be cooled by a cooling jacket **1120** in an implementation of the battery cooling system **1100** as illustrated in FIGURE 11. In this configuration, the cooling jacket **1120** surrounds the exterior of battery pack **1110**. It should be noted that the cooling element, cooling jacket **1120,** may accommodate whatever fluid is chosen to be used as the cooling fluid. Water and other fluids may be used as the cooling fluid in the system **1100**.

[071] Cooling jacket **1120** may include either a rigid or a flexible housing. The choice of housing depends on the requirements of a given application. The cooling fluid circulation path routes the cooling fluid through the cooling jacket **1120.** The cooling fluid in the circulation path removes heat from the battery pack. The cooling fluid flows into the cooling jacket **1120** through an inlet **1130,** and out of the jacket **1120** through an outlet **1140.**

[072] Battery cooling system **1100** may be powered from the battery pack which it is cooling, or from an independent volt power supply, typically a 12 or 24 volt power supply. If an independent power supply is utilized, the power supply may be self-contained batteries or a solar cell. A solar cell may also be used to charge self-contained batteries. Those skilled in the art will recognize that many power supply configurations may be utilized in the battery cooling system **1100**.

[073] FIGURE 12 shows a battery cooling system **1200** with a battery pack that includes a plurality of battery cells **1210**. In battery cooling system **1200**, the cooling jacket **1220** includes a plurality of receptacles **1230**. Each receptacle **1230** may receive a battery cell **1210**. The cooling fluid circulation path of cooling system **1200** flows around one or more of the battery cells **1210** contained in receptacles **1230** to remove heat from the battery pack. The cooling fluid flows into the cooling jacket **1220** through an inlet **1240,** and out through an outlet **1250.**

[074] FIGURE 13 illustrates a method of operation **1300** for the cooling cycles utilized in the systems disclosed herein. In step **1310**, a pump raises the pressure of a liquid. The pressure may, for example, be raised from 20 PSI to in excess of 100 PSI. As mentioned above, the increased pressure may be 300 PSI or even 500 PSI. In step **1320**, fluid flows through the nozzle / evaporator tube(s). Pressure drop and phase change as the fluid accelerates through the evaporator result in a lower temperature as fluid is boiled off in step **1330**.

[075] Critical flow rate, which is the maximum flow rate that can be attained by a compressible fluid as that fluid passes from a high pressure region to a low pressure region (*i.e.*, the critical flow regime), allows for a compression wave to be established and utilized in the critical flow regime. Critical flow occurs when the velocity of the fluid is equal to or greater than the speed of sound in the fluid. In critical flow, the pressure in the channel will not be influenced by the exit pressure and at or near the channel exit, the fluid will “shock up” to the ambient condition. In critical flow the fluid will also stay at the low pressure and temperature corresponding to the saturation pressures. In step **1340,** upon the fluid exiting the evaporator tube, the fluid "shocks up" to 20 PSI. A heat exchanger may be used in optional step **1350**. Cooling may also occur via convection on the surface of the housings of the cooling systems that utilize the supersonic cooling cycle.

[076] While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. The descriptions are not intended to limit the scope of the invention to the particular forms set forth herein. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments. It should be understood that the above description is illustrative and not restrictive. To the contrary, the present descriptions are intended to cover such alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims and otherwise appreciated by one of ordinary skill in the art. The scope of the invention should, therefore, be determined not with reference to the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.

CLAIMS

WHAT IS CLAIMED IS:

1. A personal cooling system comprising:

a garment including a cooling fluid circulation path to carry a cooling fluid throughout the garment, the circulation path being thermally coupled to a fluid flow path;

a pump that maintains a fluid flow of a working fluid through the fluid flow path, the pump also maintaining flow of the cooling fluid through the cooling fluid circulation path ;

an evaporator that operates in the critical flow regime of the working fluid and generates a compression wave that shocks the maintained fluid flow in the fluid flow path, thereby changing the pressure of the maintained fluid flow to cool the fluid;

a heat exchanging mechanism to transfer heat from the system.

2. The personal cooling system of claim 1, further comprising a control pack, the control pack including a battery to power the system.

3. The personal cooling system of claim 1, further comprising a control pack, the control pack including a thermostat to control the temperature of the system.

4. The personal cooling system of claim 1, further comprising a control pack, the control pack including a solar cell to charge the battery.

5. The personal cooling system of claim 1, further comprising a control pack, an external surface of the control pack including at least one vent.

6. The personal cooling system of claim 5, wherein the heat exchanging mechanism comprises a plurality of fins to increase the surface area of the heat exchanging mechanism.

7. The personal cooling system of claim 1, wherein a single tube is utilized in the evaporator.

8. The personal cooling system of claim 1, wherein the evaporator generates approximately 300 watts of cooling power.

9. The personal cooling system of claim 1, further comprising a manifold coupling a cooling fluid supply to the cooling fluid circulation path, the cooling fluid circulation path including one or more branches coupled to the manifold.

10. The personal cooling system of claim 1, wherein the garment is made from a stretchable fabric fitted to hold the cooling fluid circulation path in close proximity to the body of a user.

11. The personal cooling system of claim 1, wherein the cooling fluid circulation path traces major arteries of the body of a user.

12. A personal cooling system comprising:

a garment including a cooling fluid circulation path thermally coupled to a fluid flow path;

a pump that maintains a fluid flow of a working fluid through a fluid flow path and through the cooling fluid circulation path; and

an evaporator that effects a phase change in the working fluid, wherein the evaporator establishes a compression wave in the working fluid by passing the working fluid from a high pressure region to a low pressure region, the velocity of the fluid being greater than or equal to the speed of sound in the working fluid, the working fluid being cooled during a phase change, the cooled working fluid cooling the cooling fluid in the cooling fluid circulation path, thereby cooling the user of the personal cooling system.

13. The system of claim 12, wherein the garment is made from a stretchable fabric fitted to hold the cooling fluid circulation path in close proximity to the body of a user.

14. The system of claim 12, wherein the working fluid is water.

15. The system of claim 12, wherein the evaporator induces a pressure drop in the working fluid to approximately 5.5 PSI, a corresponding phase change resulting in a lowered temperature of the working fluid.

16. The system of claim 12, wherein a pressure change within the fluid flow of the working fluid occurs within a range of approximately 20 PSI to 100 PSI.

17. The system of claim 12, wherein a pressure change within the fluid flow of the working fluid involves a change to an excess of 100 PSI.

18. The system of claim 12, wherein the cooling fluid circulation path traces major arteries of the body of a user.

19. The system of claim 12, wherein the pump raises the pressure of the fluid flow from approximately 20 PSI to approximately 100 PSI.

20. The system of claim 12, wherein the pump raises the pressure of the fluid flow to more than 100 PSI.

21. A portable cooling unit comprising:

a pump that maintains a circulatory fluid flow through a flow path;

an evaporator that operates in the critical flow regime of a circulatory fluid and generates a compression wave that shocks the maintained fluid flow, thereby changing the pressure of the maintained fluid flow with no heat being added to the circulatory fluid flow before the circulatory fluid flow passes through the evaporator;

a heat exchanging mechanism thermally coupled to the circulatory fluid flow; and

a storage compartment, the storage compartment receiving items to be cooled or maintained at a temperature below ambient, wherein the cooling unit is readily transportable.

22. The portable cooling unit of claim 21, wherein the storage compartment forms a housing for the pump and the evaporator.

23. The portable cooling unit of claim 22, wherein at least a portion of an external surface of the storage compartment serves as the heat exchanging mechanism by effectuating convection from the interior of the unit to the atmosphere.

24. The portable cooling unit of claim 21, wherein the heat exchanging mechanism is a radiator.

25. The portable cooling unit of claim 21, wherein a single tube is utilized in the evaporator.

26. The portable cooling unit of claim 25, wherein the cooling unit generates approximately 80 watts of cooling power.

27. The portable cooling unit of claim 21, wherein the unit is battery powered.

28. The portable cooling unit of claim 27, wherein the battery is charged by a solar cell.

29. The portable cooling unit of claim 21, wherein the unit is powered by a solar cell.

30. The portable cooling unit of claim 21, wherein the pump raises the pressure of the circulatory fluid flow from approximately 20 PSI to approximately 100 PSI.

31. The portable cooling unit of claim 21, wherein the pump raises the pressure of the circulatory fluid flow to more than 100 PSI.

32. A portable cooling system comprising:

a storage compartment, the storage compartment receiving items to be cooled or maintained at a temperature below ambient;

a pump that maintains a fluid flow of a fluid through the system; and

an evaporator that effects a phase change in the fluid, wherein the system establishes a compression wave in the fluid by passing the fluid from a high pressure region to a low pressure region, the velocity of the fluid being greater than or equal to the speed of sound in the fluid, the fluid being cooled during a phase change so that heat is transferred from the system by thermally coupling one or more fins between the fluid and the ambient atmosphere, and wherein the cooling unit is readily transportable.

33. The system of claim 32, further comprising a pump inlet that introduces a cooling liquid maintained within the housing to the pump, and wherein the cooling liquid is a part of the circulatory fluid flow.

34. The system of claim 32, wherein the evaporator induces a pressure drop in the cooling liquid to approximately 5.5 PSI, a corresponding phase change resulting in a lowered temperature of the cooling liquid.

35. The system of claim 33, wherein the cooling liquid is water.

36. The system of claim 32, wherein a pressure change within a fluid flow of the fluid occurs within a range of approximately 20 PSI to 100 PSI.

37. The system of claim 32, wherein a pressure change within a fluid flow of the fluid involves a change to an excess of 100 PSI.

38. The system of claim 32, wherein a pressure change within a fluid flow of the fluid involves a change to less than 20 PSI.

39. The system of claim 32, wherein the pump raises the pressure of the circulatory fluid flow from approximately 20 PSI to approximately 100 PSI.

40. The system of claim 32, wherein the pump raises the pressure of the circulatory fluid flow to more than 100 PSI.

41. A battery cooling system comprising:

a cooling fluid circulation path thermally coupled to a working fluid flow path and to at least one battery cell in a battery pack;

a pump that maintains a fluid flow through the working fluid flow path;

an evaporator that operates in the critical flow regime of the working fluid and generates a compression wave that shocks the maintained fluid flow, thereby changing the pressure of the maintained fluid flow to cool the fluid; and

a heat exchanging mechanism thermally coupled to the fluid flow path, the heat exchanging mechanism removing heat from the battery pack.

42. The battery cooling system of claim 41, further comprising a cooling jacket, the cooling jacket being thermally coupled the working fluid flow path and to at least a portion of the battery pack.

43. The battery cooling system of claim 42, wherein the cooling jacket includes a plurality of receptacles, each receptacle receiving a cell of the battery pack.

44. The battery cooling system of claim 42, wherein the cooling jacket surrounds the battery pack.

45. The battery cooling system of claim 42, wherein the cooling jacket comprises a rigid housing.

46. The battery cooling system of claim 42, wherein the cooling jacket comprises a flexible housing.

47. The battery cooling system of claim 41, wherein the heat exchanging mechanism comprises a plurality of fins to increase the surface area of the heat exchanging mechanism.

48. The battery cooling system of claim 41, wherein a single tube is utilized in the evaporator.

49. The battery cooling system of claim 41, wherein the pump raises the pressure of the fluid flow from approximately 20 PSI to approximately 100 PSI.

50. The battery cooling system of claim 41, wherein the pump raises the pressure of the fluid flow to more than 100 PSI.

51. A battery cooling system comprising:

a fluid flow path that passes in close proximity to at least one battery cell in a battery pack;

a pump that maintains a fluid flow through the fluid flow path;

at least one evaporator that operates in the critical flow regime of the fluid and generates a compression wave that shocks the maintained fluid flow, thereby changing the pressure of the maintained fluid flow to cool the fluid, the cooled fluid removing heat from the battery cell via conduction.

52. The system of claim 51, wherein the at least one evaporator comprises a series of single tube evaporators aligned in parallel with a plurality of battery cells, each single tube evaporator removing heat from the aligned battery cell.

53. The system of claim 51, further comprising a pump inlet that introduces a cooling liquid to the pump, and wherein the cooling liquid is a part of the fluid flow.

54. The system of claim 53, wherein the cooling liquid is water.

55. The system of claim 53, wherein the evaporator induces a pressure drop in the cooling liquid to approximately 5.5 PSI, a corresponding phase change resulting in a lowered temperature of the cooling liquid.

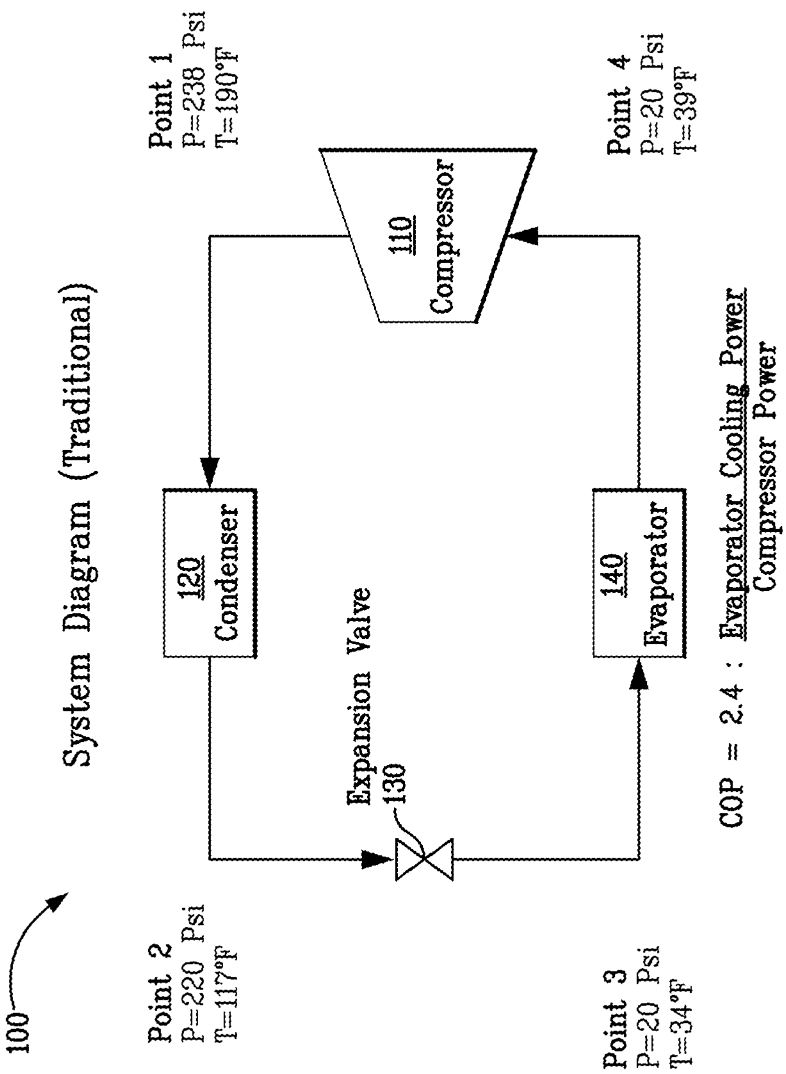
56. The system of claim 53, wherein a pressure change within the fluid flow of the fluid occurs within a range of approximately 20 PSI to 100 PSI.

57. The system of claim 53, wherein a pressure change within the fluid flow of the fluid involves a change to an excess of 100 PSI.

58. The system of claim 53, wherein a pressure change within the fluid flow of the fluid involves a change to less than 20 PSI.

59. The system of claim 53, wherein the pump raises the pressure of the fluid flow from approximately 20 PSI to approximately 100 PSI.

60. The system of claim 53, wherein the pump raises the pressure of the fluid flow to more than 100 PSI.



System Diagram (Traditional)
100
Point 1
P=238 Psi
T=190°F
110
Compressor
Point 4
P=20 Psi
T=39°F
120
Condenser
Expansion Valve
130
140
Evaporator
Point 2
P=220 Psi
T=117°F
Point 3
P=20 Psi
T=34°F
COP = 2.4 : Evaporator Cooling Power / Compressor Power

FIG. 1

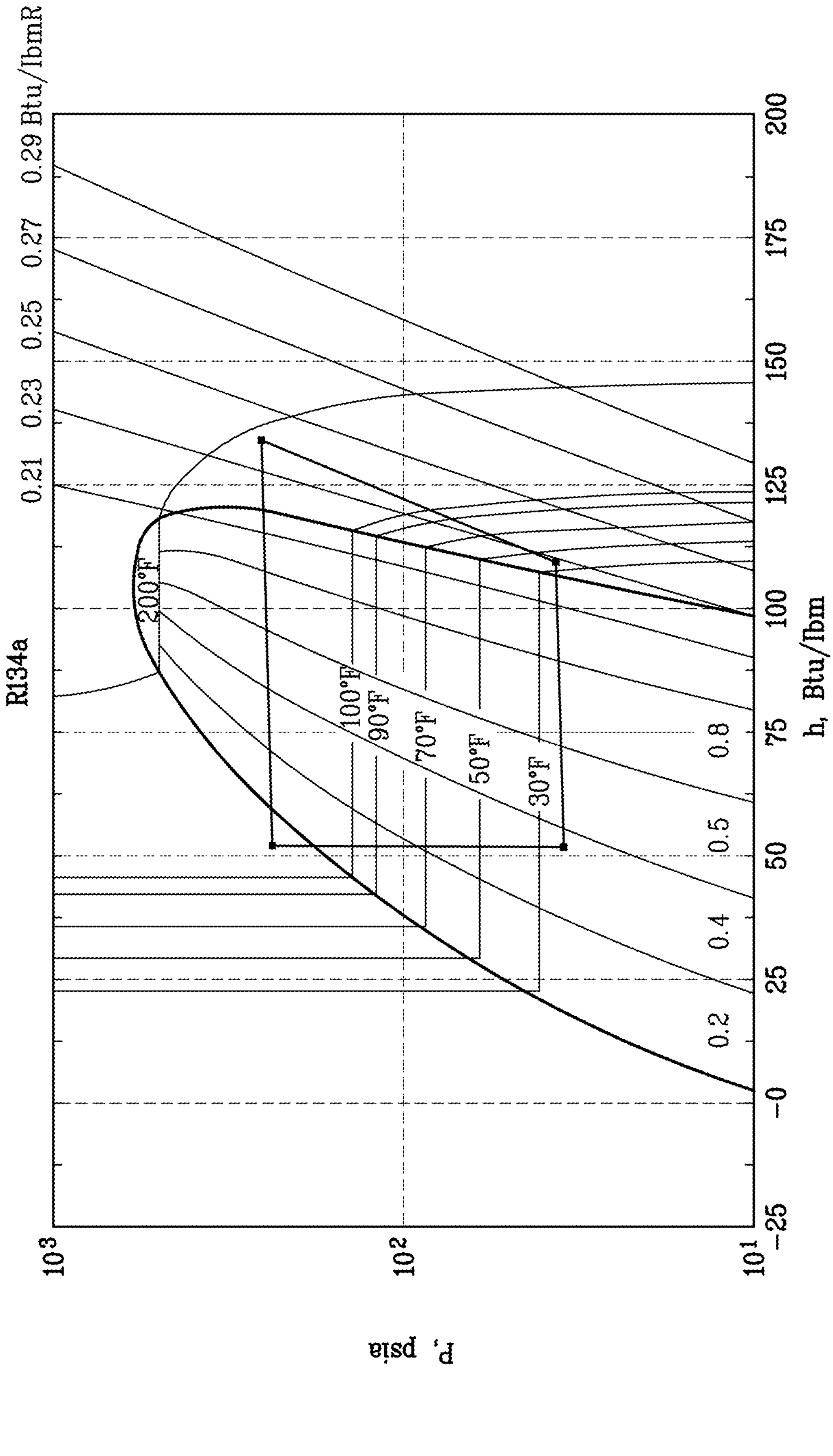

R134a
P, psia
h, Btu/lbm
0.21
0.23
0.25
0.27
0.29 Btu/lbmR
0.2
0.4
0.5
0.8
200°F
100°F
90°F
70°F
50°F
30°F

FIG. 2

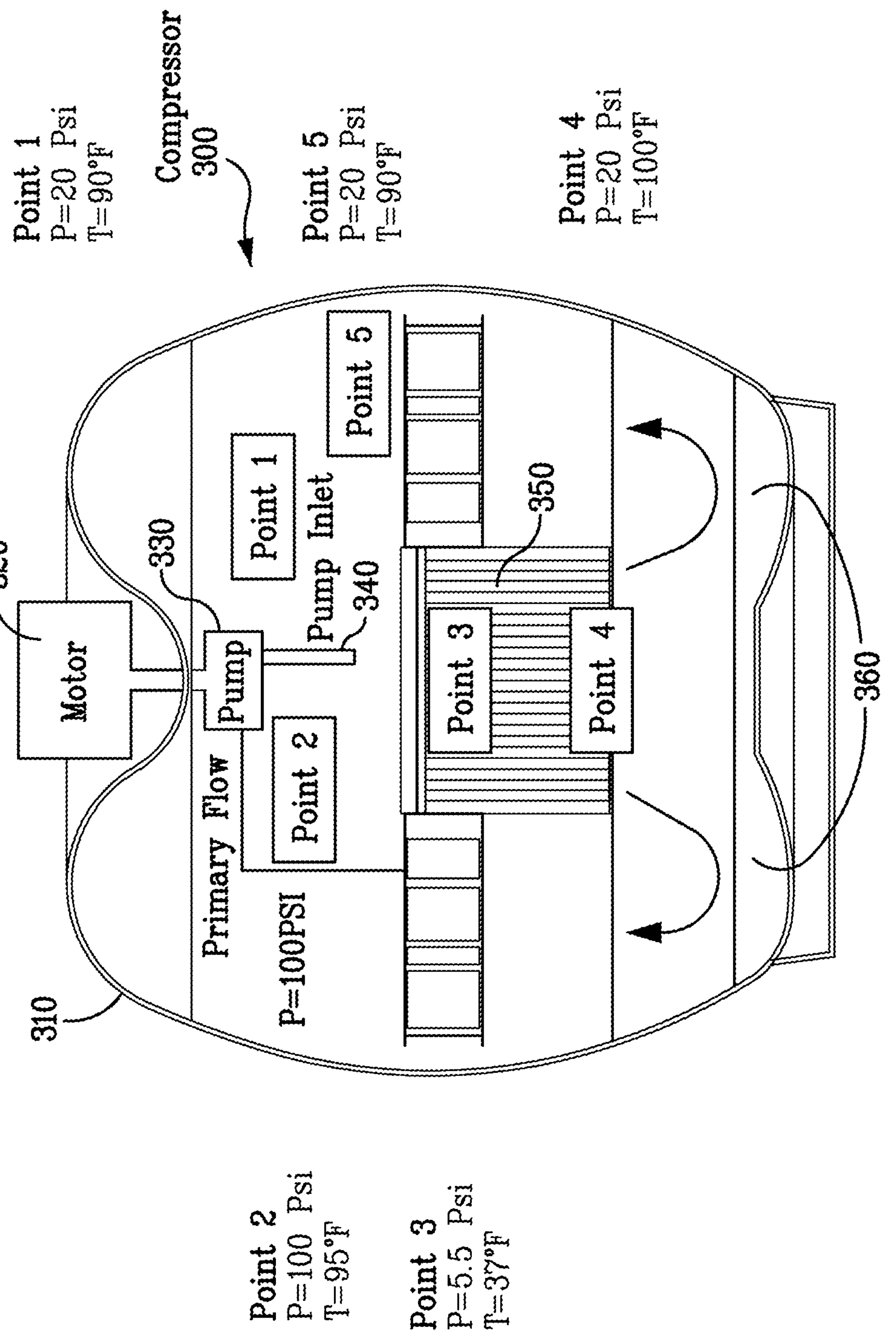

Point 1
P=20 Psi
T=90°F
Compressor
300
Point 5
P=20 Psi
T=90°F
Point 4
P=20 Psi
T=100°F
320
Motor
330
Pump
Point 1
Pump Inlet
340
Point 5
350
Point 2
Primary Flow
P=100PSI
Point 3
Point 4
310
360
Point 2
P=100 Psi
T=95°F
Point 3
P=5.5 Psi
T=37°F

FIG. 3

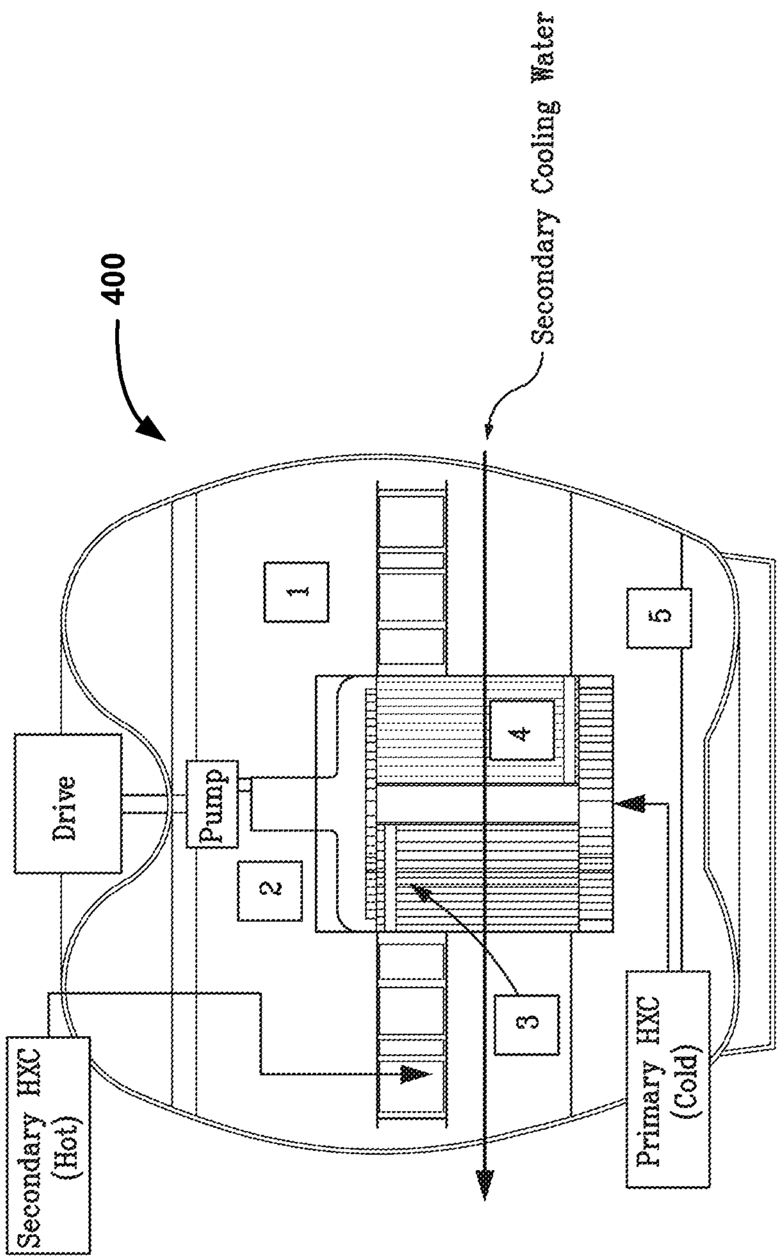

400
Secondary Cooling Water
Drive
Pump
1
2
3
4
5
Secondary HXC
(Hot)
Primary HXC
(Cold)

FIG. 4

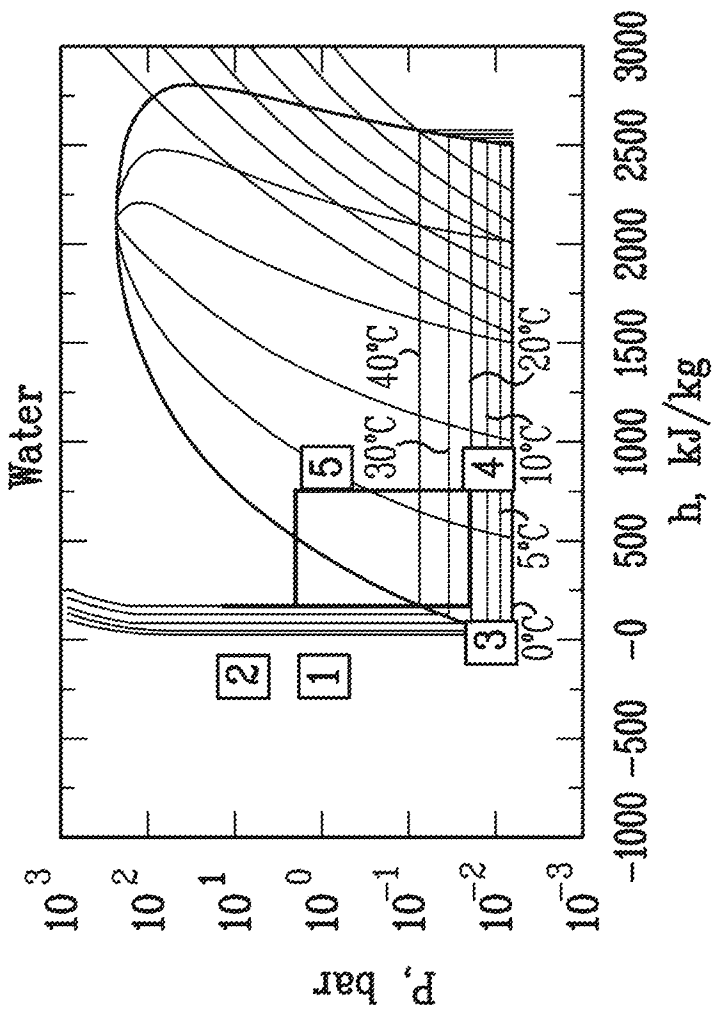

Water
h, kJ/kg
P, bar
0°C
5°C
10°C
20°C
30°C
40°C
1
2
3
4
5
−1000
−500
−0
500
1000
1500
2000
2500
3000
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}

FIG. 5

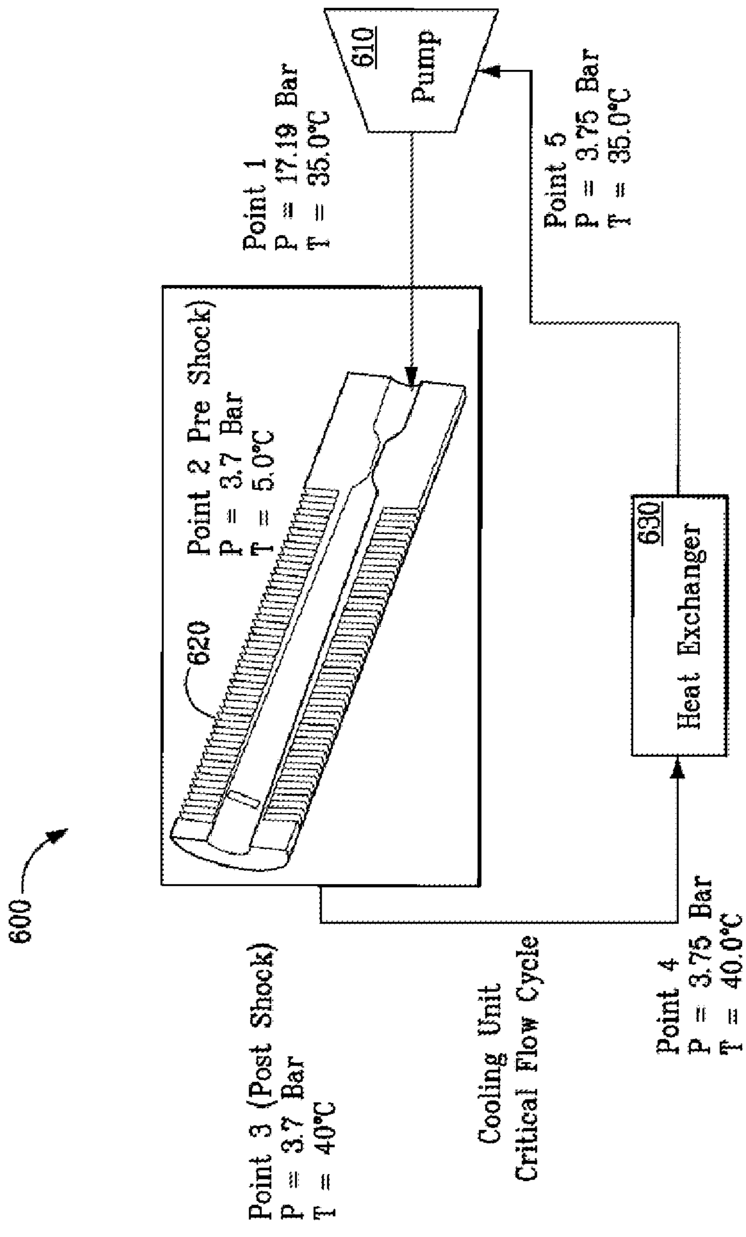

600
610
Pump
620
630
Heat Exchanger
Point 1
P = 17.19 Bar
T = 35.0°C
Point 2 Pre Shock)
P = 3.7 Bar
T = 5.0°C
Point 3 (Post Shock)
P = 3.7 Bar
T = 40°C
Point 4
P = 3.75 Bar
T = 40.0°C
Point 5
P = 3.75 Bar
T = 35.0°C
Cooling Unit
Critical Flow Cycle

FIG. 6

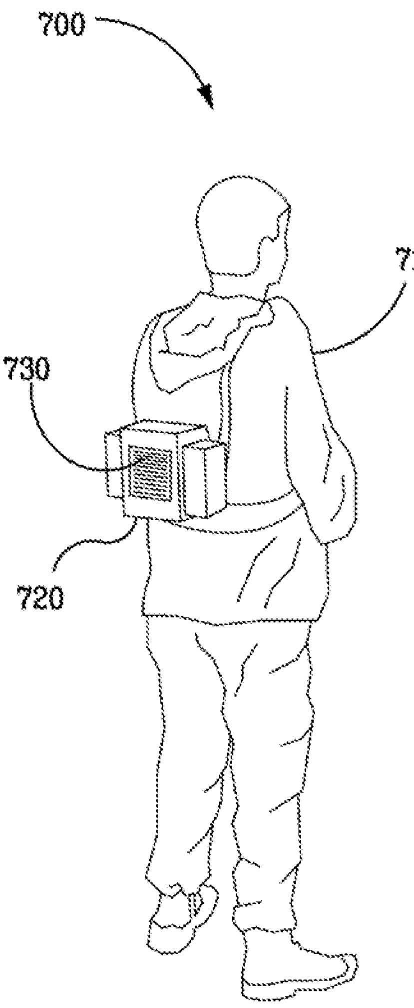


FIG. 7

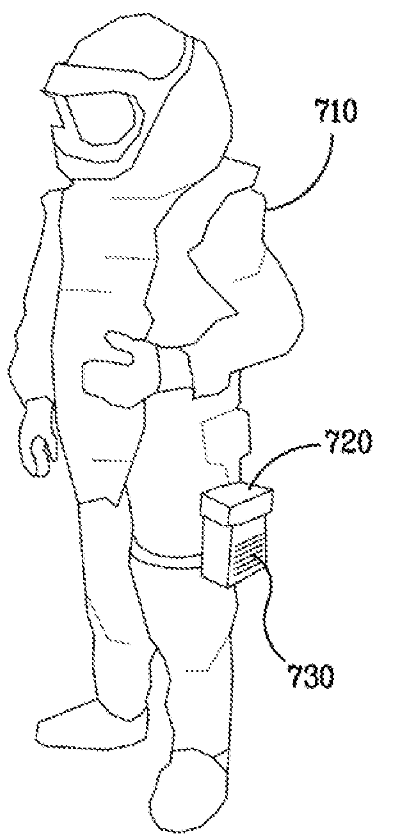


FIG. 8

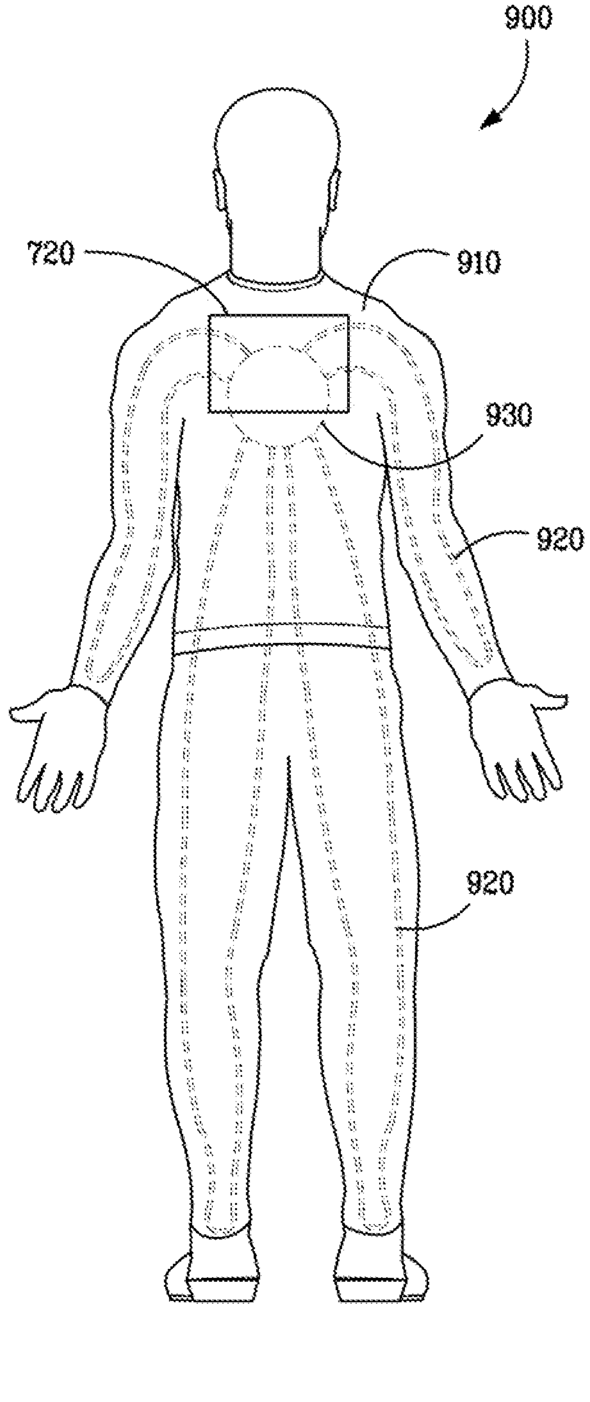


FIG. 9

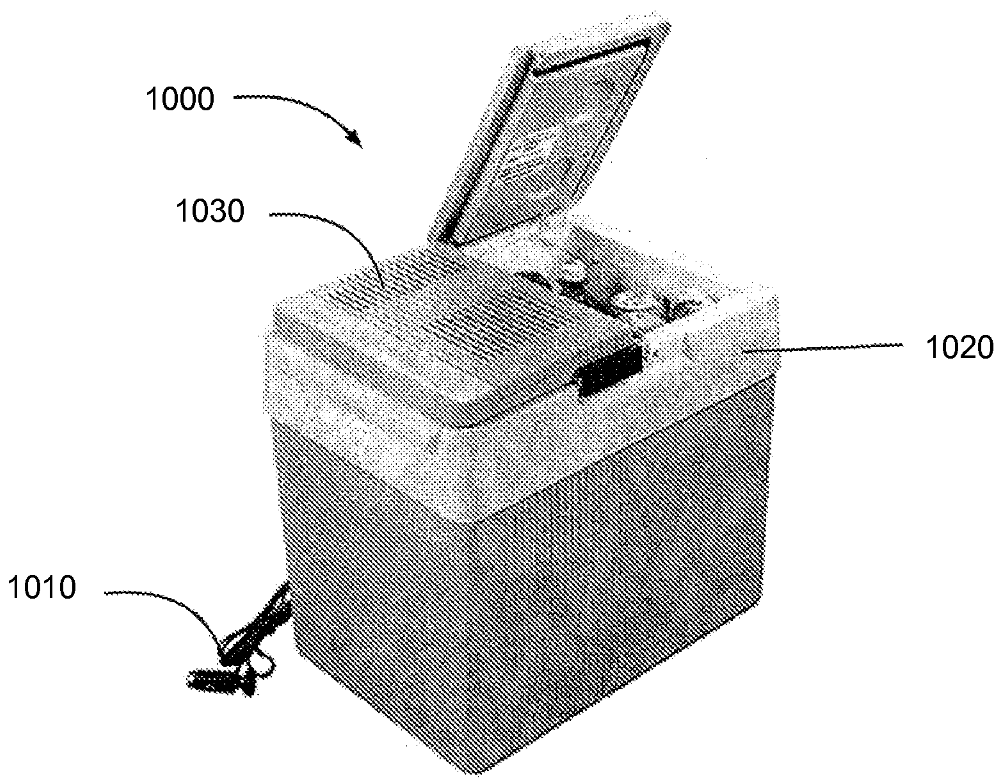


FIG. 10

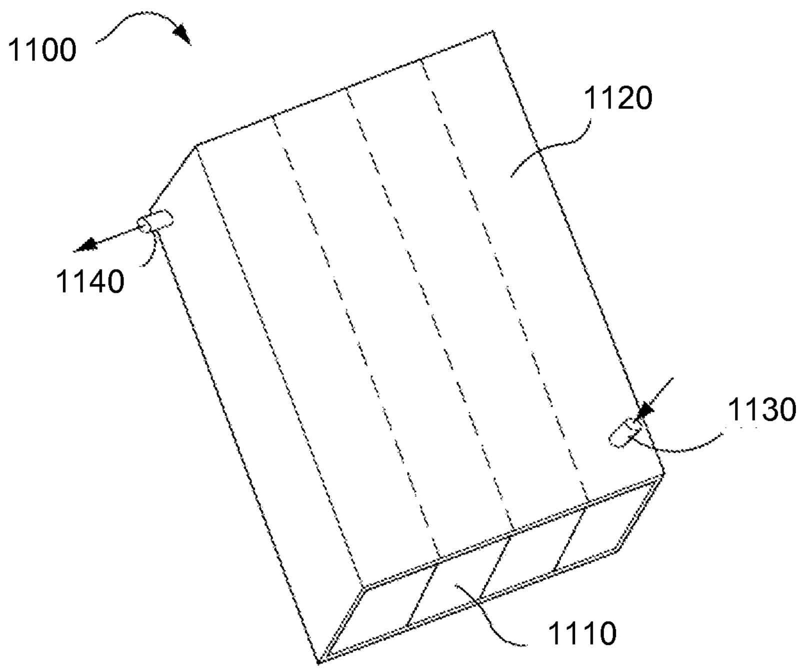


FIG. 11

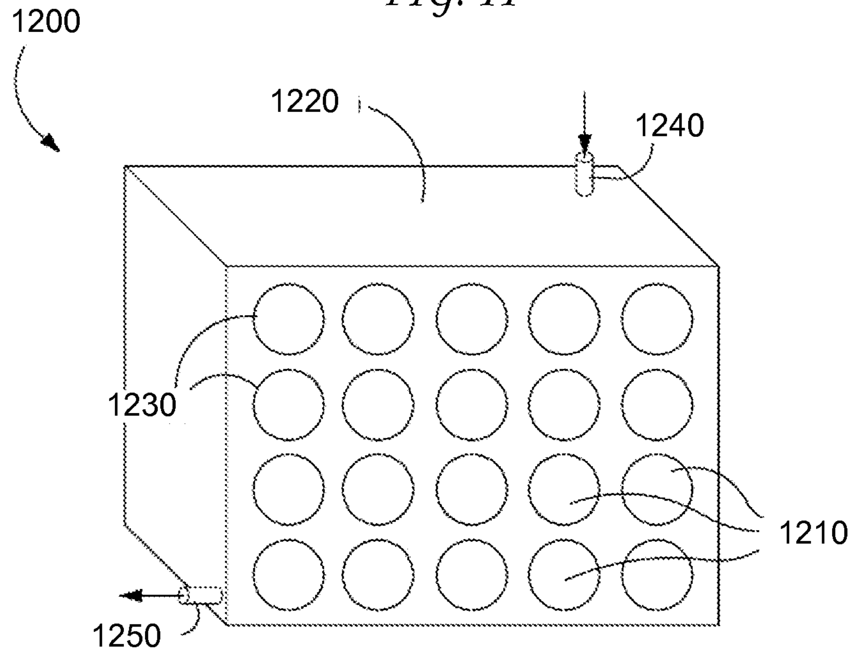


FIG. 12

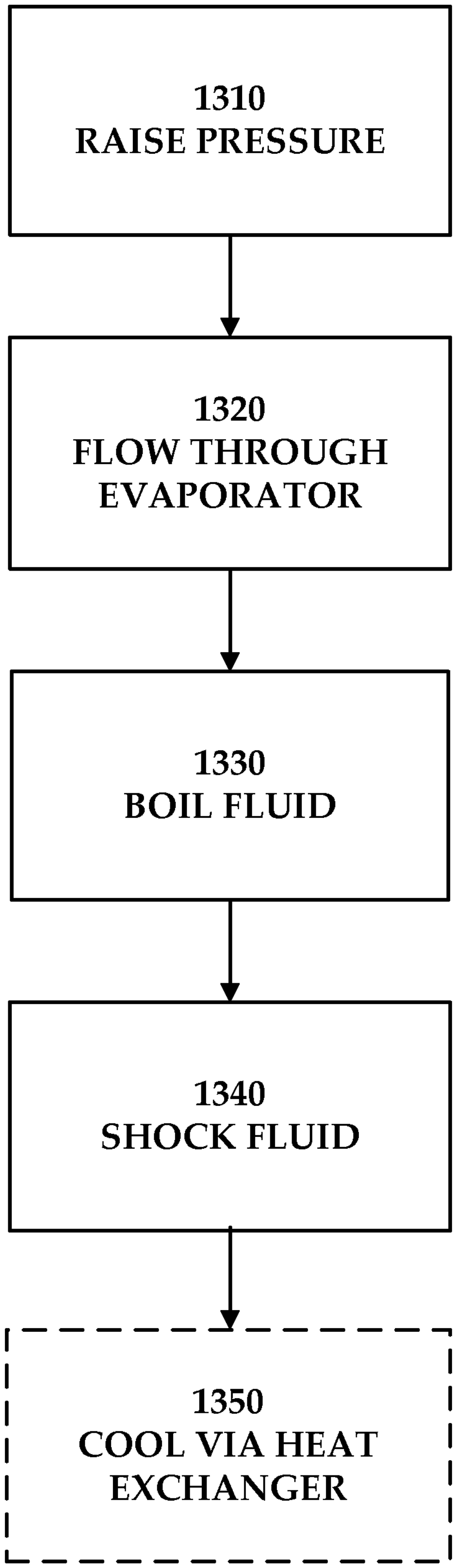

1310
RAISE PRESSURE
1320
FLOW THROUGH
EVAPORATOR
1330
BOIL FLUID
1340
SHOCK FLUID
1350
COOL VIA HEAT
EXCHANGER

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/027845

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - A41D 13/005 (2011.01)
USPC - 62/259.3

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - A41D 13/002, 13/005; A61F 7/00; B64G 6/00 (2011.01)
USPC - 2/458; 62/259.3; 165/46; 607/108

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatBase

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 1 080 648 A2 (GRAHAM) 07 March 2001 (07.03.2001) entire document	1-20
Y	US 3,621,667 A (MOKADAM) 23 November 1971 (23.11.1971) entire document	1-20
Y	US 2006/0191049 A1 (ELKINS et al) 31 August 2006 (31.08.2006) entire document	2, 3
Y	US 2007/0271939 A1 (ICHIGAYA) 29 November 2007 (29.11.2007) entire document	4
Y	US 4,998,415 A (LARSEN) 12 March 1991 (12.03.1991) entire document	5, 6
Y	US 3,425,486 A (BURTON et al) 04 February 1969 (04.02.1969) entire document	11, 18

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 July 2011	25 JUL 2011

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/027845

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See extra sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-20

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees need to be paid.

Group I, claims 1-20 are drawn to a personal cooling system.
Group II, claims 21-40 are drawn to a portable cooling unit.
Group III, claims 41-60 are drawn to a battery cooling system.

The inventions listed in Groups I, II and III do not relate to a single general inventive concept under PCT Rule 13.1, because under PCT Rule 13.2 they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I, a personal cooling system comprising a garment including a cooling fluid circulation path to carry a cooling fluid throughout the garment, are not present in Groups II, III; the special technical features of Group II, a portable cooling unit comprising a storage compartment, the storage compartment receiving items to be cooled, wherein the cooling unit is readily transportable, are not present in Groups I, III; and the special technical features of Group III, a battery cooling system comprising a fluid flow path thermally coupled to at least one battery cell in a battery pack, and removing heat from the battery pack, are not present in Groups I, II.

Since none of the special technical features of the Group I, II and III inventions are found in more than one of the inventions, unity is lacking.