

TITLE

SYSTEMS AND METHODS FOR TWO-PHASE IMMERSION COOLING

FIELD

[0001] The present disclosure relates to systems and methods for two-phase immersion cooling including materials suitable for use in such systems and methods.

BACKGROUND

[0002] Two-phase immersion cooling (2PIC) is one of the emerging technologies for thermal management of high heat density IT equipment and power electronics. In these systems, electronic components of IT equipment and power electronics are in direct contact with a heat transfer fluid so material compatibility and thermal stability of the components in contact with the heat transfer fluid are critical. Particularly in 2PIC of servers, hardware reliability is directly correlated with (1) compatibility between the fluid and information technology (IT) components or power electronics and (2) thermal stability of the fluid in the presence of metals present in the system.

[0003] Reaction of heat transfer fluids in 2PIC systems may cause deterioration of materials used in functional components of such systems. Deterioration may generate impurities in the system and/or reduce durability and/or reliability of such functional components, and/or lead to contamination of the fluid with impurities as they are degraded.

[0004] Material compatibility in 2PIC can be subdivided in two groups: (1) primary compatibility due to direct interactions between the material and fluid causing change in material properties and contamination of the fluid; and (2) secondary or material-material compatibility when the fluid acts as a vector transporting materials extracted from one component to another. Certain materials are incompatible with heat transfer fluids used in 2PIC systems, which means that in the presence of the heat transfer fluid, or in the presence of the heat transfer fluid with moisture and/or air, materials interact with the fluid in a way that is detrimental to the performance of the system.

[0005] Additionally, some heat transfer fluids have high global warming potential (GWP). New environmental regulations have industry looking for heat transfer fluids with low GWP.

[0006] Thus, a 2PIC system in which a heat transfer fluid is compatible with the materials in the system is desired as well as methods for cooling electronic devices within a 2PIC system.

SUMMARY

[0007] This invention relates to a 2PIC system in which a heat transfer fluid and materials are compatible in such a way to enhance performance of the 2PIC system for cooling electronic devices immersed therein.

[0008] In a first embodiment of this invention, there is provided an immersion cooling system comprising (i) an apparatus which comprises a housing which defines an internal cavity and in which is positioned a main fluid tank, which contains a heat transfer fluid comprising E-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, (E-HFO-153-10mczz); a liquid level for the fluid which extends across the tank; a vapor space above the liquid level within the internal cavity of the housing; a condensing coil positioned within the vapor space above the main fluid tank; a buffer fluid tank which is connected to and in liquid communication with the main fluid tank, wherein within the buffer fluid tank is positioned a circulating pump through which the fluid flows to and through a check valve; a filter positioned downstream of the buffer fluid tank into which the fluid flows from the check valve, wherein the circulating pump, check valve and filter are each connected by piping; a lid which covers an open area of the housing; and (ii) an electronic device located within and at least partially immersed within the fluid of the main fluid tank, wherein the materials used in the tanks, circulating pump check valve, filter, piping, lid and seals located within and external to the housing and the electronic device are made of materials compatible with the heat transfer fluid.

[0009] In another embodiment, there is provided a method for cooling an electronic device. The method includes at least partially immersing an electronic device in a heat transfer fluid within an immersion cooling system; transferring heat from the electronic device by circulating the heat transfer fluid through the system;

wherein the immersion cooling system comprises (i) an apparatus which comprises a housing which defines an internal cavity and in which is positioned a main fluid tank, which contains a heat transfer fluid comprising E-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, (E-HFO-153-10mczz); a liquid level for the fluid which extends across the tank; a vapor space above the liquid level within the internal cavity of the housing; a condensing coil positioned within the vapor space above the main fluid tank; a buffer fluid tank which is connected to and in liquid communication with the main fluid tank, wherein within the buffer fluid tank is positioned a circulating pump through which the fluid flows to and through a check valve; a filter positioned downstream of the buffer fluid tank into which the fluid flows from the check valve, wherein the circulating pump, check valve and filter are each connected by piping; a lid which covers an open area of the housing; and (ii) an electronic device located within and at least partially immersed within the fluid of the main fluid tank, wherein the materials used in the tanks, circulating pump check valve, filter, piping, lid and seals located within and external to the housing and the electronic device are made of materials compatible with the heat transfer fluid.

[0010] Other features and advantages of the present invention will be apparent from the following more detailed description, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Figure 1 is a perspective view of an immersion cooling apparatus, according to an embodiment for the system and method of this invention.

[0012] Figure 2 is a perspective view of an electronic device.

DETAILED DESCRIPTION

[0013] Large scale computer server systems can perform significant workloads and generate large amounts of heat during their operation. A significant portion of the heat is generated from their operation. Due in part to the amount of heat generated, these systems are typically mounted in stacked configurations with large internal cooling fans and heat dissipating fins. As the size and density of these

systems increases the thermal challenges are even greater, and eventually outpace the ability for forced air systems.

[0014] Two-phase immersion cooling is an emerging cooling technology for the high-performance cooling market as applied to high performance server systems. It relies on the heat absorbed in the process of vaporizing a heat transfer fluid to a gas.

[0015] Certain heat transfer fluids used in immersion cooling have been found to interact with materials used in components of an immersion cooling system including housing, pumps, seals and tubing used for circulating the heat transfer fluid as well as materials used for components of an immersion cell and an electronic device being cooled within the cell, such as but not limited to a computer server, a battery or a power electronic device, so that the components may lose effectiveness. For example, the fluid may react with the material by causing substances to be extracted from the materials and contaminate the fluid and/or by causing degradations of the physical properties of the materials, which may lose functionality thus affecting reliability and performance of the system. Consequently selection of materials to be used in both the immersion cell and electronic device are critical.

[0016] The present invention has been made in view of the foregoing, and it is an object of the enhance performance of an immersion cooling system by providing a system comprising components, which components are comprised of particular materials. By selection of materials, performance of the system is improved.

[0017] In a first embodiment of this invention, there is provided an immersion cooling system comprising (i) an apparatus which comprises a housing which defines an internal cavity and in which is positioned a main fluid tank, which contains a heat transfer fluid comprising E-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, (E-HFO-153-10mczz); a liquid level for the fluid which extends across the tank; a vapor space above the liquid level within the internal cavity of the housing; a condensing coil positioned within the vapor space above the main fluid tank; a buffer fluid tank which is connected to and in liquid communication with the main fluid tank, wherein within the buffer fluid tank is positioned a circulating pump through which the fluid flows to and through a check valve; a filter positioned downstream of the buffer fluid tank into which the fluid flows from the check valve, wherein the circulating pump, check valve and filter are each connected by piping; a lid which covers an open area

of the housing; and (ii) an electronic device located within and at least partially immersed within the fluid of the main fluid tank, wherein the materials used in the tanks, circulating pump check valve, filter, piping, lid and seals located within and external to the housing and the electronic device are made of materials compatible with the heat transfer fluid.

[0018] In another embodiment of this invention, there is provided a method for cooling an electronic device, which method comprises at least partially immersing an electronic device from which heat is generated in a heat transfer fluid within an immersion cooling system; transferring heat generated from the electronic device by circulating the heat transfer fluid through the system; wherein the immersion cooling system comprises (i) an apparatus which comprises a housing which defines an internal cavity and in which is positioned a main fluid tank, which contains a heat transfer fluid comprising E-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, (E-HFO-153-10mczz); a liquid level for the fluid which extends across the tank; a vapor space above the liquid level within the internal cavity of the housing; a condensing coil positioned within the vapor space above the main fluid tank; a buffer fluid tank which is connected to and in liquid communication with the main fluid tank, wherein within the buffer fluid tank is positioned a circulating pump through which the fluid flows to and through a check valve; a filter positioned downstream of the buffer fluid tank into which the fluid flows from the check valve, wherein the circulating pump, check valve and filter are each connected by piping; a lid which covers an open area of the housing; and (ii) an electronic device located within and at least partially immersed within the fluid of the main fluid tank, wherein the materials used in the tanks, circulating pump check valve, filter, piping, lid and seals located within and external to the housing and the electronic device are made of materials compatible with the heat transfer fluid.

[0019] In embodiment, the buffer fluid tank, filter, circulating pump, and associated piping are located within the internal cavity of the housing. In an alternative embodiment, the buffer fluid tank, filter, circulating pump, and associated piping are located outside of the housing, while connected to and in liquid communication with the main fluid tank.

[0020] In the immersion cooling system and method disclosed herein, the materials used in the apparatus (tanks, barrier, circulating pump check valve, filter, piping, lid and seals located within and external to the housing) and the electronic device are made of materials compatible with the heat transfer fluid.

[0021] For a material to be “compatible with the heat transfer fluid” as used herein means the performance of the material and/or electronic device does not change over a period of time of at least a year or at least two years or at least 5 years. Performance indicators include temperature of the electronic device is unchanged, no signal losses in communication cables/connectors, no swelling of seals, no voltage drop, no increase acidity of the heat transfer fluid, no significant increase in non-volatile residues, no loss of system functioning, no loss of component functionality. Examples of loss of functionality include but not limited to a failed circulating pump, a loss of seal of the lid and consequently loss of fluid by evaporation, breakage of plastic tubing and cable/wire insulation, increase in signal strength attenuation.

[0022] In one embodiment, “compatible with the heat transfer fluid” may be determined by measuring the change in weight of the material over a period of time. More specifically in accelerated testing (per testing protocol set forth in the Examples) there is less than 20% change in weight of the materials or less than 15% change in weight of the materials or less than 10% change in weight of the materials or less than 5% change in weight of the materials. By “change in weight” includes both increase in weight (positive change in weight) and decrease in weight (negative change in weight).

[0023] Sealing components are provided in the circulating pump, check valve and filter which are made of elastomeric or fluoroelastomeric materials compatible with the heat transfer fluid. Such materials are selected from the group consisting of neoprene rubber, epichlorohydrin butyl rubber, Ethylene propylene diene monomer (EPDM), fluorosilicone, nitrile rubber, natural rubber, silicone rubber, ethyl vinyl acetate, butyl rubber, fluoropolymer elastomer (including, but not limited to Viton™, FKM fluoroelastomers).

[0024] Piping may be made of metal-based or polymeric materials compatible with the heat transfer fluid. The polymeric material may be selected from the group

consisting of nylon resin, polyamide-imide resin, polytetrafluoroethylene (PTFE), High Density Poly Ethylene (HDPE), polyurethane, polypropylene, polyphenylene Ether (PPE), polyvinyl chloride (PVC), silicone, polystyrene, polyester (including, but not limited to polyethylene terephthalate (PET)). The metal-based material may include one or more of aluminum, copper, carbon steel, galvanized steel, stainless steel, indium, silver, tin.

[0025] In the present invention, the immersion cooling system and method are also compatible with metals used in the electronic device and/or the components of the system located within the housing (pump, filter, check valve). The metal components may be chosen from one or more of aluminum, copper, carbon steel, galvanized steel, stainless steel, indium, silver, tin.

[0026] The electronic device comprises or may be selected from the group consisting of, high-capacity energy storage devices, datacenter servers, insulated-gate bipolar transistor (IGBT) devices, telecommunication infrastructure, military electronics, televisions (TVs), cell phones, monitors, drones, automotive batteries, electric powertrains, including, but not limited to electric vehicles (EVs), power electronics, avionics devices, power devices and displays. In one embodiment, the electronic device is a high-capacity energy storage devices. In one embodiment, the electronic device is one or more datacenter or computer servers. In one embodiment, the electronic device is an insulated-gate bipolar transistor (IGBT) device.

[0027] In one embodiment, the electronic device comprises telecommunication infrastructure. In one embodiment, the electronic device comprises military electronics. In one embodiment, the electronic device comprises televisions. In one embodiment, the electronic device comprises a cell phone. In one embodiment, the electronic device comprises a monitor. In one embodiment, the electronic device comprises drones. In one embodiment, the electronic device comprises an automotive battery. In one embodiment, the electronic device comprises an electric powertrain. In one embodiment, the electronic device comprises an electric powertrains for an electric vehicle. In one embodiment, the electronic device comprises power electronics. In one embodiment, the electronic device comprises

avionics devices. In one embodiment, the electronic device comprises power devices. In one embodiment, the electronic device comprises and displays.

DESCRIPTION OF THE DRAWINGS

[0028] Figure 1 is a perspective view of one embodiment of an immersion cooling apparatus of this invention. The immersion cooling system comprises a housing, defining an internal cavity. The housing may be made of stainless steel or galvanized steel or aluminum or plastic or composite material or naturally-derived materials or wood or wood products or ceramics.

[0029] There is an opening (not shown) at the top of the housing, which during operation of the system, is covered by a lid. The lid is attached to the housing through an o-ring seal. The o-ring enhances the barrier of the lid between the fluid from within the housing to the atmosphere. The o-ring is made of neoprene rubber, epichlorohydrin butyl rubber, Ethylene propylene diene monomer (EPDM), fluorosilicone, nitrile rubber, natural rubber, silicone rubber, ethyl vinyl acetate, butyl rubber, fluoropolymer elastomer (including, but not limited to Viton™, FKM fluoroelastomers).

[0030] Alternatively, the buffer tank, filter, circulating pump, plastic tubing may be placed outside the housing of the main tank, but still connected to and in liquid communication with the main fluid tank.

[0031] The lid further allows access, when removed, to the components of the immersion cooling system within the housing. The condition of the heat transfer fluid, the pump, the valve, and the circulation pump as well as the electronic device may be periodically monitored for their condition or removed for service as need.

[0032] Within the housing are positioned a main fluid tank and a buffer fluid tank, each containing a heat transfer fluid wherein the fluid is E-HFO-153-10mczz. A barrier separates the main fluid tank from the buffer fluid tank. The barrier may be made of stainless steel or galvanized steel, or aluminum or plastic or composite or natural products or wood or wood products or ceramics. A liquid level above the barrier allows the fluid to overflow across the barrier, as shown in Figure 1 with the bent arrow. A vapor space lies above the liquid level spanning the area of the cavity of the housing across the main fluid tank and the buffer fluid tank.

[0033] Within the barrier fluid tank and near the lower end of this tank is positioned a circulation pump, which during operation of the immersion cooling system, such as in the method disclosed herein, circulates the fluid within and across the buffer fluid tank and the main fluid tank using a motor (not illustrated) located within the pump. An o-ring seal is illustrated within the pump that provides a barrier between low and high pressure compartments of the pump. The o-ring is made of neoprene rubber, epichlorohydrin butyl rubber, Ethylene propylene diene monomer (EPDM), fluorosilicone, nitrile rubber, natural rubber, silicone rubber, ethyl vinyl acetate, butyl rubber, fluoropolymer elastomer (including, but not limited to Viton™, FKM fluoroelastomers).

[0034] The heat transfer fluid flows into and out of the circulation pump through piping. In one embodiment, the piping comprises a polymeric material selected from the group consisting of nylon resin, polyamide-imide resin, polytetrafluoroethylene (PTFE), High Density Poly Ethylene (HDPE), polyurethane, polypropylene, polyphenylene Ether (PPE), polyvinyl chloride (PVC), silicone, polystyrene, polyester (including, but not limited to polyethylene terephthalate (PET)). In one embodiment, the piping comprises a metal-based material selected from the group consisting of aluminum, copper, carbon steel, galvanized steel, stainless steel, indium, silver, and tin.

[0035] From the circulation pump the heat transfer fluid flows through piping in and through a check valve and from the check valve through piping to a filter located above the liquid level. An o-ring seal is located within the check valve that provides isolation between the upstream and the downstream of the valve when the check valve is in the closed position. The o-ring is made of neoprene rubber, epichlorohydrin butyl rubber, Ethylene propylene diene monomer (EPDM), fluorosilicone, nitrile rubber, natural rubber, silicone rubber, ethyl vinyl acetate, butyl rubber, fluoropolymer elastomer (including, but not limited to Viton™, FKM fluoroelastomers).

[0036] From the filter, the heat transfer fluid flows through piping into the vapor space and downward to the main fluid tank. An o-ring seal is located within the filter that provides a barrier between the interior filter chamber and the outside of the filter housing. The o-ring is made of neoprene rubber, epichlorohydrin butyl rubber,

Ethylene propylene diene monomer (EPDM), fluorosilicone, nitrile rubber, natural rubber, silicone rubber, ethyl vinyl acetate, butyl rubber, fluoropolymer elastomer (including, but not limited to Viton™, FKM fluoroelastomers).

[0037] Although not shown in Figure 1, an electronic device is at least partially immersed in the heat transfer fluid within the main fluid tank.

[0038] Figure 2 is a perspective view of a Server Board, which can be a device in the system and method and of this invention.

[0039] In Figure 2 there is provided a power supply unit ("PSU"), a graphic processing unit ("GPU"), and a central processing unit ("CPU"). These units are interconnected and provide transfer through across the device. A motherboard provides connectivity throughout the server. As illustrated, but not meant to be limiting, the motherboard has two RAM (memory) slots, which the processing unit accesses to system and program information. Cables connect system components to PSU. The arrows indicate communication links between the components of the server.

[0040] Materials used in the immersion cooling system and method disclosed need to be compatible with the heat transfer fluid. Fluid-material interactions may be due to:

[0041] Extraction: when fluid extracts compounds from plastics and elastomers such as plasticizers. This may result in shrinking, stiffening of materials and fluid contamination.

[0042] Absorption: when fluid is absorbed by the material causing weight gain, swelling and potential softening.

[0043] The present invention provides an immersion cooling system and method that overcomes issues with sensitive components with a compatible combination of heat transfer fluid and materials.

[0044] In one embodiment, the heat transfer fluid is compatible an o-ring seal between the lid and the housing. Failure of compatibility of heat transfer fluid with the lid o-ring may lead to fluid loss/vapor leak. Materials suitable for the o-ring seal include elastomers and fluoroelastomers. For example, EPDM and fluoroelastomers such as those sold under the "Viton" trademark.

[0045] In one embodiment, the heat transfer fluid is compatible with tubing / piping materials. Failure of compatibility of heat transfer fluid with tubing / piping materials may lead to cracking and fluid loss or potentially circulation/filtration failure and therefore contamination buildup within the system. Materials suitable for the tubing / piping materials include, for example, silicone, polypropylene.

[0046] In one embodiment, the heat transfer fluid is compatible with check valve o-ring. Failure of compatibility of heat transfer fluid with check valve o-ring may lead to failure of the check valve and pumping issues and/or loss of circulation/blockage. Materials suitable for the check valve o-ring include elastomers and fluoroelastomers. For example, EPDM and fluoroelastomers such as those sold under the "Viton" trademark as well as nitrile rubber, including Buna rubber (acrylonitrile butadiene rubber or NBR).

[0047] In one embodiment, the heat transfer fluid is compatible with pump seals. These seals may be o-rings or gaskets. Failure of compatibility of heat transfer fluid with pump seals may lead to failure of the pump. Materials suitable for the pump seal include elastomers and fluoroelastomers. For example, EPDM and fluoroelastomers such as those sold under the "Viton" trademark as well as nitrile rubber, including Buna rubber (acrylonitrile butadiene rubber or NBR).

[0048] In one embodiment, the heat transfer fluid is compatible with o-ring present in the filter. Failure of compatibility of heat transfer fluid with the filter o-ring may lead to reduction of filtration efficiency. Materials suitable for the pump seal include elastomers and fluoroelastomers. For example, EPDM and fluoroelastomers such as those sold under the "Viton" trademark.

[0049] When these compatibility of the heat transfer fluid and the materials of the immersion cooling system fail, there may be a concomitant decrease in the purity of the fluid, which may cause adverse effects (e.g. deterioration of dielectric properties, stability of the system, cause deposits components within the system, et al.)

[0050] When the electronic device comprises a high-capacity energy storage devices or datacenter server, additional issues may be encountered, which are addressed by the immersion cooling system and method of this invention.

[0051] In one embodiment, the electronic device comprises cables and the heat transfer fluid is compatible with cables within the electronic device. Failure of compatibility of heat transfer fluid with cables may lead to contamination of the fluid and further lead to loss of the wire insulation and insulation cracking. It can also impact the dielectric properties of the cable jacketing and lead to a reduction of signal strength and/or potential for signal interference. These further may lead to other adverse impacts on performance. Materials suitable for the cables in the electronic device include, for example, PVC, LDPE, fluorinated ethylenepropylene copolymer (FEP), polyether ether ketone (PEEK), or Low Smoke Zero Halogen materials.

[0052] In one embodiment, the electronic device comprises capacitors and the heat transfer fluid is compatible with materials of the capacitors. Failure of compatibility of heat transfer fluid with capacitors may lead to rupture of the capacitors and loss of functionality. Other issues include contamination of fluid. Materials suitable for the capacitors include elastomers and fluoroelastomers, including EPDM.

[0053] In one embodiment, the electronic device comprises connectors and the heat transfer fluid is compatible with materials of the connectors. The connectors are necessary to maintain contact between the performing components (e.g., GPU, motherboard). Failure of compatibility of heat transfer fluid with connectors may lead to breakage and loss of contact or reduced/looser mating contact and overall loss of functionality of the electronic device. Materials suitable for the capacitors include elastomers and fluoroelastomers, including polypropylene.

[0054] In one embodiment, the electronic device comprises a battery seal and the heat transfer fluid is compatible with the battery seal. Failure of compatibility of heat transfer fluid with the battery seal may lead to leakage of battery materials and loss of power to electronic device. Materials suitable for the battery include silicone or polyurethane or PET.

[0055] Based on the foregoing, the immersion cooling system and method disclosed herein provide superior performance and long-term stability of operation.

EXAMPLES

[0056] Materials as well as the heat transfer fluid used in the immersion cooling system and method disclosed herein were both tested.

[0057] Material compatibility and thermal stability tests were performed by exposing materials to E-HFO-153-10mczz. The following tests were conducted:

Example 1. Sealed tube tests: plastics and elastomers were soaked in a sealed tube in at 80°C for 2 weeks.

[0058] Results for Sealed tube testing are provided in Table 1. Me% is mass% of extraction and Ma% is mass% of absorption as calculated by the equation below. Me% = NVR (non-volatile residue). In the equation, MF_f is the final mass of the material being tested after fluid has evaporated, MF_i is the initial mass of the material being tested before fluid has evaporated, M_i is the initial mass of material being tested; and Me is the mass of material extracted by the fluid. Me% is mass% of extraction, meaning the percentage of mass of material extracted by the fluid relative to the initial mass of the material being tested. Ma% is mass% of absorption, meaning the percentage of mass of fluid absorbed by the material relative to the initial mass of the material being tested. The fluid being tested is E-HFO-153-10mczz.

- Me%: mass% of extraction

$$Me\% = \frac{MF_f - MF_i}{M_i} \times 100\%$$
- Ma%: mass% of absorption

$$Ma\% = \frac{(M_f - M_i) + Me}{M_i} \times 100$$

TABLE 1. SEALED TUBE TESTING RESULTS

Material	Me%	Ma%
Neoprene C1276 -70	0.8	0.4
Epichlorohydrin	0.3	0.1
butyl rubber	0.4	2.2
EPDM	0.1	1
Fluorosilicone	0.8	3.2
HNBR nitrile	0.2	1.3
NBR nitrile	0.7	0.6
Fluorocarbon FKM	0	12.9
neoprene C0873-70	0.2	0.3
Natural Rubber	0.3	0.7
Silicon Rubber	0.3	0.1
nylon resin Zytel	0	-0.4
polyamide-imide	0	-0.4
polyphenylene sulfide	0	0
nylon 6.6 (Zytel 101)	0	-0.4
PTFE	0.1	3.8
Epoxy-glass	0	0
HDPE	0	0.4
Polyurethane	2.2	1.3
Polypropylene	0	1.5
Polycarbonate	0	0
PEEK	0	-0.1
Bakelite	0	-0.8
Thermo Epoxy	0.6	-0.7
Solder Flux (Resin)	0.2	0.5
Solder Mask	6.2	-0.7
PVC wire	4.8	-0.5
Tygon 06409-16	4.1	0.8
nitrile gloves	0.1	10.7
Viton™ o ring	0.1	4.2
EPDM o ring	16.6	-0.7
Silicone tubing	2.4	-0.5
FEP	0.1	-0.1

[0059] As can be seen from Table 1, E-HFO-153-10mczz is compatible with the materials tested.

Example 2. Soxhlet extraction: plastics and elastomers were exposed to the fluids in a Soxhlet extractor for 48 hours.

[0060] Results for Soxhlet extraction are provided in Table 2.

TABLE 2. SOXHLET EXTRACTION TEST RESULTS

Material	Me %	Ma(%)
PVC -1	1.5	0.5
PVC -2	2	-0.1
PVC -3	3.8	0.5
PVC -4	1.5	0.5
LDPE	0.1	0.1
PP -1	2.8	2.9
PP -2	0.1	0.3
EVA	0.5	0.1
Nylon	0	0.4
VLDPE -1	0.5	0.2
VLDPE -2	0.3	0
VLDPE -3	0.5	-0.1
LDPE -1	0.1	0.2
LDPE -2	0.3	0.1
NBR	0.6	0.1
PMMA	0.1	-0.3
Epoxy resin-1	0	-0.3
Epoxy resin-2	0	-0.2
Epoxy resin-3	0	-0.3
Phenlic resin	0.1	0.1
Polycarbonate	0	-0.1
PTFE	0.1	1.5

[0061] As can be seen from Table 2, E-HFO-153-10mczz is compatible with the materials tested.

Example 3

[0062] Thermal Stability: metals (Al, Cu, and carbon steel) were exposed to liquid and vapor of the heat transfer fluid in a sealed tube with and without air and moisture at 175°C for 1 week. Fluoride and chloride ion concentrations were assessed as well as acidity. (<MDL indicates less than method of detection limit.)

[0063] Results for testing are provided in Table 3.

TABLE 3. THERMAL STABILITY RESULTS

Moisture (ppm)	Air (mmHg)	[F ⁻]	[Cl ⁻]	Acidity (equiv. HCl ppm)
0	0	<MDL	<MDL	12.6
0	481	<MDL	<MDL	12.3
saturation point	0	<MDL	<MDL	10.4
saturation point	481	<MDL	<MDL	4.6

[0064] As can be seen from Table 3, E-HFO-153-10mczz is compatible with the metals tested.

Example 4

[0065] Comparisons were made with respect to a commercial fluid Novec™ 649, dodecafluoro-2-methylpentan-3-one (CF₃CF₂C(O)CF(CF₃)₂) performing the Soxhlet extraction and Thermal Stability tests.

[0066] The Soxhlet Extraction Test was performed in the same manner as stated above in Example 2. Table 4 provides results.

TABLE 4. COMPARISON SOXHLET EXTRACTION TEST RESULTS

Material	153-10mczz		Novec™ 649	
	Me %	Ma %	Me %	Ma %
Tygon plastic tubing 06409-16	4.1	0.8	0.7	-4.5
EPDM o ring	16.6	-0.7	29.5	16.7
FEP (Fluorinated ethylene propylene)	0.1	-0.1	2.5	4
Low Smoke, Zero Halogen Cable	0.04	0.06	0.04	0.5

[0067] As can be seen from Table 4, E-HFO-153-10mczz is compatible the materials tested, and shows better compatibility than Novec® 649, except with respect to the tubing. It should be noted that the compatibility of E-HFO-153-10mczz with the tubing is still in the acceptable range.

[0068] The Thermal Stability Test was slightly modified from Example 3 in that metals (Al, Cu, and carbon steel) were exposed to liquid and vapor of the heat

transfer fluid in a sealed tube with and without air and moisture at 150°C for 1 week.

Table 5 provides results.

TABLE 5. THERMAL STABILITY RESULTS

Conditions		E-HFO-153-10mczz			Novec™ 649		
Moisture (ppm)	Air (mmHg)	F ⁻ (ppm)	Cl ⁻ (ppm)	Acidity (ppm equiv HCl)	F ⁻ (ppm)	Cl ⁻ (ppm)	Acidity (equiv HCl ppm)
0	0	<MDL	<MDL	<MDL	49.87	<MDL	401
Saturation	240	<MDL	<MDL	<MDL	66.25	<MDL	954

[0069] As can be seen from Table 5, E-HFO-153-10mczz shows better compatibility than Novec™ 649 with the metals tested.

[0070] While the invention has been described with reference to one or more embodiments, it will be understood by those skilled in the art that various changes may be made, and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention is not limited to the particular embodiments disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. In addition, all numerical values identified in the detailed description shall be interpreted as though the precise and approximate values are both expressly identified.

CLAIMS

What is claimed is:

- 1, An immersion cooling system comprising (i) an apparatus which comprises a housing which defines an internal cavity and in which is positioned a main fluid tank, which contains a heat transfer fluid comprising E-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, (E-HFO-153-10mczz); a liquid level for the fluid which extends across the tank; a vapor space above the liquid level within the internal cavity of the housing; a condensing coil positioned within the vapor space above the main fluid tank; a buffer fluid tank which is connected to and in liquid communication with the main fluid tank, wherein within the buffer fluid tank is positioned a circulating pump through which the fluid flows to and through a check valve; a filter positioned downstream of the buffer fluid tank into which the fluid flows from the check valve, wherein the circulating pump, check valve and filter are each connected by piping; a lid which covers an open area of the housing; and (ii) an electronic device located within and at least partially immersed within the fluid of the main fluid tank, wherein the materials used in the tanks, circulating pump check valve, filter, piping, lid and seals located within and external to the housing and the electronic device are made of materials compatible with the heat transfer fluid.
2. The immersion cooling system of claim 1 wherein sealing components are provided in the circulating pump, check valve and filter which are made of elastomeric or fluoroelastomeric materials compatible with the heat transfer fluid.
3. The immersion cooling system of claim 2 wherein the sealing components are made of elastomeric or fluoroelastomeric materials selected from the group consisting of neoprene rubber, epichlorohydrin butyl rubber, Ethylene propylene diene monomer (EPDM), fluorosilicone, nitrile rubber, natural rubber, silicone rubber, ethyl vinyl acetate, butyl rubber, fluoropolymer elastomer (including, but not limited to Viton™, FKM fluoroelastomers).
4. The immersion cooling system of any of claims 1-3 wherein the piping comprises a polymeric material selected from the group consisting of nylon resin, polyamide-imide resin, polytetrafluoroethylene (PTFE), High Density Polyethylene (HDPE), polyurethane, polypropylene, polyphenylene Ether

(PPE), polyvinyl chloride (PVC), silicone, polystyrene, polyester (including, but not limited to polyethylene terephthalate (PET)).

5. The immersion cooling system of claim 4, wherein the piping comprises silicone or polypropylene.
6. The immersion cooling system of any of claims 1-5 wherein electronic device comprises or is selected from the group consisting of high-capacity energy storage devices, datacenter servers, insulated-gate bipolar transistor (IGBT) devices, telecommunication infrastructure, military electronics, televisions (TVs), cell phones, monitors, drones, automotive batteries, powertrains for electric vehicles (EVs), power electronics, avionics devices, power devices and displays.
7. The immersion cooling system of any of claims 1-6 wherein an o-ring seal between the lid and the housing comprises an elastomer or fluoroelastomer, chosen from EPDM and fluoroelastomers.
8. The immersion cooling system of any of claims 1-7, wherein the heat transfer fluid is compatible with check valve o-ring and the check valve o-ring comprises an elastomer or fluoroelastomer.
9. The immersion cooling system of claim 8 wherein the check valve o-ring comprises EPDM, fluoroelastomers, or nitrile rubber.
10. The immersion cooling system of any of claims 1-9, wherein the heat transfer fluid is compatible with pump seals, wherein the seals are o-rings or gaskets.
11. The immersion cooling system of claim 10, wherein the seals comprise EPDM, fluoroelastomers, or nitrile rubber.
12. The immersion cooling system of any of claims 1-11, wherein system comprises a filter having an o-ring and the heat transfer fluid is compatible with the filter o-ring and filter o-ring comprises an elastomer or fluoroelastomer.
13. The immersion cooling system of any of claims 1-12, wherein the electronic device comprises a high-capacity energy storage devices or datacenter server.

14. The immersion cooling system of claim 13, wherein the electronic device comprises cables and the heat transfer fluid is compatible with cables within the electronic device.
15. The immersion cooling system of claim 14, wherein the cables comprise PVC, LDPE, fluorinated ethylenepropylene copolymer (FEP), polyether ether ketone (PEEK), or Low Smoke Zero Halogen materials.
16. The immersion cooling system of claim 13, wherein the electronic device comprises capacitors and the heat transfer fluid is compatible with capacitors within the electronic device.
17. The immersion cooling system of claim 16, wherein the capacitors comprise elastomers and fluoroelastomers.
18. The immersion cooling system of claim 13, wherein the electronic device comprises connectors and the heat transfer fluid is compatible with materials of the connectors within the electronic device.
19. The immersion cooling system of claim 18, wherein the connectors comprise elastomers and fluoroelastomers.
20. The immersion cooling system of claim 18, wherein the connectors comprise polypropylene.
21. The immersion cooling system of claim 13, wherein the electronic device comprises a battery seal and the heat transfer fluid is compatible with the battery seal.
22. A method for cooling an electronic device, which method comprises at least partially immersing an electronic device from which heat is generated in a heat transfer fluid within an immersion cooling system; transferring heat generated from the electronic device by circulating the heat transfer fluid through the system; wherein the immersion cooling system comprises (i) an apparatus which comprises a housing which defines an internal cavity and in which is positioned a main fluid tank, which contains a heat transfer fluid comprising E-1,1,1,2,2,5,5,6,6,6-decafluoro-3-hexene, (E-HFO-153-10mczz); a liquid level for the fluid which extends across the tank; a vapor space above the liquid level

within the internal cavity of the housing; a condensing coil positioned within the vapor space above the main fluid tank; a buffer fluid tank which is connected to and in liquid communication with the main fluid tank, wherein within the buffer fluid tank is positioned a circulating pump through which the fluid flows to and through a check valve; a filter positioned downstream of the buffer fluid tank into which the fluid flows from the check valve, wherein the circulating pump, check valve and filter are each connected by piping; a lid which covers an open area of the housing; and (ii) an electronic device located within and at least partially immersed within the fluid of the main fluid tank, wherein the materials used in the tanks, circulating pump check valve, filter, piping, lid and seals located within and external to the housing and the electronic device are made of materials compatible with the heat transfer fluid.

23. The method of claim 22 wherein sealing components are provided in the circulating pump, check valve and filter which are made of elastomeric or fluoroelastomeric materials compatible with the heat transfer fluid.
24. The method of claim 23 wherein the sealing components are made of elastomeric or fluoroelastomeric materials selected from the group consisting of neoprene rubber, epichlorohydrin butyl rubber, Ethylene propylene diene monomer (EPDM), fluorosilicone, nitrile rubber, natural rubber, silicone rubber, ethyl vinyl acetate, butyl rubber, fluoropolymer elastomer (including, but not limited to Viton™, FKM fluoroelastomers).
25. The method of any of claims 22-24, wherein the piping comprises a polymeric material selected from the group consisting of nylon resin, polyamide-imide resin, polytetrafluoroethylene (PTFE), High Density Poly Ethylene (HDPE), polyurethane, polypropylene, polyphenylene Ether (PPE), polyvinyl chloride (PVC), silicone, polystyrene, polyester (including, but not limited to polyethylene terephthalate (PET).
26. The method of claim 25, wherein the piping comprises silicone or polypropylene.
27. The method of any of claims 22-26, wherein electronic device comprises or is selected from the group consisting of high-capacity energy storage devices, datacenter servers, insulated-gate bipolar transistor (IGBT) devices,

telecommunication infrastructure, military electronics, televisions (TVs), cell phones, monitors, drones, automotive batteries, electric powertrains, power electronics, avionics devices, power devices and displays.

28. The method of any of claims 22-27, wherein an o-ring seal between the lid and the housing comprises an elastomer or fluoroelastomer, chosen from EPDM and fluoroelastomers.
29. The method of any of claims 22-28, wherein the heat transfer fluid is compatible with check valve o-ring and the check valve o-ring comprises an elastomer or fluoroelastomer.
30. The method of claim 29 wherein the check valve o-ring comprises EPDM, fluoroelastomers, or nitrile rubber.
31. The method of any of claims 22-30, wherein the heat transfer fluid is compatible with pump seals, wherein the seals are o-rings or gaskets.
32. The method of claim 31, wherein the seals comprise EPDM, fluoroelastomers, or nitrile rubber.
33. The method of any of claims 22-32, wherein system comprises a filter having an o-ring and the heat transfer fluid is compatible with the filter o-ring and filter o-ring comprises an elastomer or fluoroelastomer.
34. The method of any of claims 22-33, wherein the electronic device comprises a high-capacity energy storage devices or datacenter server.
35. The method of claim 34, wherein the electronic device comprises cables and the heat transfer fluid is compatible with cables within the electronic device.
36. The method of claim 35, wherein the cables comprise PVC, LDPE, fluorinated ethylenepropylene copolymer (FEP), polyether ether ketone (PEEK), or Low Smoke Zero Halogen materials.
37. The method of claim 34, wherein the electronic device comprises capacitors and the heat transfer fluid is compatible with capacitors within the electronic device.

38. The immersion cooling system of claim 37, wherein the capacitors comprise elastomers and fluoroelastomers.
39. The method of claim 34, wherein the electronic device comprises connectors and the heat transfer fluid is compatible with materials of the connectors within the electronic device.
40. The method of claim 39, wherein the connectors comprise elastomers and fluoroelastomers.
41. The method of claim 40, wherein the connectors comprise polypropylene.
42. The method of claim 34, wherein the electronic device comprises a battery seal and the heat transfer fluid is compatible with the battery seal.