

TITLE

ORGANIC HEAT TRANSFER SYSTEM, METHOD AND FLUID

BACKGROUND OF THE INVENTION

5 **[0001]** The disclosed technology relates to a heat transfer fluid and a heat transfer system and heat transfer method employing the heat transfer fluid. In particular, the technology relates to a heat transfer fluid with low electrical conductivity, low flammability, and low freeze point that provides excellent peak temperature reduction in a heat transfer system, such as that for cooling a power system of an electric vehicle or computer electronics.

10 **[0002]** The operation of a power source generates heat. A heat transfer system, in communication with the power source, regulates the generated heat, and ensures that the power source operates at an optimum temperature. The heat transfer system generally comprises a heat transfer fluid that facilitates absorbing and dissipating the heat from the power source. Traditional aqueous heat transfer fluids, which generally consist of
15 water and a glycol, are prone to freezing. Traditional heat transfer fluids can also exhibit extremely high conductivities, often in the range of 3000 micro-siemens per centimeter ($\mu\text{S}/\text{cm}$) or more. This high conductivity produces adverse effects on the heat transfer system by promoting corrosion of metal parts, and also in the case of power sources where the heat transfer system is exposed to an electrical current, such as in fuels cells,
20 computer electronics, or the like, the high conductivity can lead to short circuiting of the electrical current and to electrical shock.

25 **[0003]** Although battery packs are designed to provide high levels of safety and stability, situations can arise where a portion of a battery pack experiences a local thermal condition which generates significant heat. When the temperature is great enough and sustained, the local thermal condition can transform into a runaway thermal condition affecting wide areas of the battery pack, and sometimes the entire battery pack under certain circumstances.

[0004] Current battery pack designs include an integrated and isolated cooling system that routes coolant throughout the enclosure. When in good working order, the coolant from the cooling system does not come into contact with the electric potentials protected within. It does happen that sometimes a leak occurs and coolant enters into
5 unintended parts of the enclosure. If the coolant is electrically conductive, it can bridge terminals having relatively large potential differences. That bridging may start an electrolysis process in which the coolant is electrolyzed and the coolant will begin to boil when enough energy is conducted into the electrolysis. This boiling can create the local thermal condition that can lead to the runaway thermal condition described above. Short-
10 ing of equipment is also a common problem associated with these systems.

[0005] A need exists for a heat transfer system and method employing an inexpensive heat transfer fluid with a low electrical conductivity and freeze point.

SUMMARY OF THE INVENTION

[0006] The disclosed technology, therefore, solves the problem of safety concerns
15 in the cooling of electrical componentry, as well as faster charging and increased computing power output, among other things, by operating the electrical componentry while immersed in a heat transfer fluid.

[0007] The method and/or system will be particularly useful in the transfer of heat from battery systems, such as those in an electric vehicle, or the transfer of heat from a
20 computer electronics.

[0008] However, the method and/or system will also find use for other electrical componentry, such as, for example, in aircraft electronics, other computer electronics, invertors, DC to DC convertors, AC to DC convertors, chargers, phase change invertors, electric motors, electric motor controllers, and DC to AC invertors.

DETAILED DESCRIPTION OF THE INVENTION

[0009] Various preferred features and embodiments will be described below by way of non-limiting illustration.

[0010] The disclosed technology provides a method of cooling electrical componentry by contacting, or immersing, the electrical componentry directly with a composition comprising hydrocarbon (in some cases isoparaffinic) oil and oxygenate and operating the electrical componentry.

5 **[0011]** Electrical componentry includes any electronics that utilize power and generate thermal energy that must be dissipated to prevent the electronics from overheating. Examples include computer electronics, such as aircraft electronics, computer servers, microprocessors, uninterruptable power supplies (UPSs), power electronics (such as IGBTs, SCRs, thyristers, capacitors, diodes, transistors, rectifiers and the like), energy
10 storage devices, and the like. Further examples include invertors, DC to DC convertors, AC to DC convertors, chargers, phase change invertors, electric motors, electric motor controllers, and DC to AC invertors.

[0012] While several examples of electrical componentry have been provided, the heat transfer fluid may be employed in any assembly or for any electrical componentry to provide
15 an improved heat transfer fluid with cold temperature performance without significantly increasing the electrical conductivity and potential flammability of the mixture.

[0013] The method and/or system will be particularly useful in the transfer of heat from battery systems, such as those in an electric vehicle such as an electric car, truck or even electrified mass transit vehicle, like a train or tram. The main piece of electrical
20 componentry in electrified transportation is often battery modules, which may encompass one or more battery cell stacked relative to one another to construct the battery module. Heat may be generated by each battery cell during charging and discharging operations, or transferred into the battery cells during key-off conditions of the electrified vehicle as a result of relatively extreme (i.e., hot) ambient conditions. The battery module will
25 therefore include a heat transfer system for thermally managing the battery modules over a full range of ambient and/or operating conditions. In fact, operation of battery modules can occur during the use and draining of the power therefrom, such as in the operation of the battery module, or during the charging of the battery module. The charging system, including the alternator, regulator, charging cables, and fuses may also generate heat and

the method and/or system can be employed therewith as well. With regard to charging, the use of the heat transfer fluid can allow the charging of the battery module to at least 75% of the total battery capacity restored in a time period of less than 15 minutes.

5 [0014] Similarly, electrical componentry in electrified transportation can include fuel cells, solar cells, solar panels, photovoltaic cells and the like that require cooling by the heat transfer fluid. Such electrified transportation may also include traditional internal combustion engines as, for example, in a hybrid vehicle.

10 [0015] Electrified transportation may also include electric motors as the electrical componentry. Electric motors may be employed anywhere along the driveline of a vehicle to operate, for example, transmissions, axles and differentials. Such electric motors can be cooled by a heat transfer system employing the heat transfer fluid.

[0016] The method and/or system will also be particularly useful in the transfer of heat from computer electronics, such as computer servers, and other computer electronics.

15 [0017] The method and/or system can include providing a heat transfer system containing electrical componentry requiring cooling. The heat transfer system will include, among other things, a bath in which the electrical componentry may be situated in a manner that allows the electrical componentry to be in direct fluid contact with the heat transfer fluid. The bath will be in fluid communication with a heat transfer fluid reservoir and
20 a heat exchanger.

[0018] The electrical componentry may be operated along with operating the heat transfer system. The heat transfer system may be operated, for example, by circulating the heat transfer fluid through the heat transfer system via pumping or via natural circulation.

25 [0019] For example, the heat transfer system may include means to pump cooled heat transfer fluid from the heat transfer fluid reservoir into the bath, and to pump heated heat transfer fluid out of the bath through the heat exchanger and back into the heat

transfer fluid reservoir. In some embodiments, the heat transfer system may employ natural circulation to drive fluid flow. Natural circulation includes flow where the density changes as a result of heat input, driving fluid flow due to gravity. In this manner, while the electrically componentry are operated, the heat transfer system may also be operated to provide cooled heat transfer fluid to the electrical componentry to absorb heat generated by the electrical componentry, and to remove heat transfer fluid that has been heated by the electrical componentry to be sent to the heat exchanger for cooling and recirculation back into the heat transfer fluid reservoir.

[0020] Dielectric constant (also called relative permittivity) is an important feature of a heat transfer fluid for an immersion cooling system. To avoid issues with electrical current leakage, the heat transfer fluid into which the electrical componentry is immersed may have a dielectric constant of 5.0 or lower as measured according to ASTM D924. The dielectric constant of the heat transfer fluid can also be less than 4.5, 4.0, 3.0, 2.5, or less than 2.3 or less than 1.9.

[0021] The heat transfer fluid can also have a kinematic viscosity measured at 100°C of at least 0.7 cSt, or at least 0.9 cSt, or at least 1.1 cSt, or from 0.7 to 7.0 cSt, or from 0.9 to 6.5 cSt, or even from 1.1 to 6.0 cSt as measured according to ASTM D445_100. For a given chemical family being pumped at a given power, higher viscosity fluids are typically less effective at removing heat, given higher resistance to flow. The same phenomena also occurs for natural convection systems.

[0022] Immersion heat transfer fluids need to flow freely at very low temperatures. In one embodiment the heat transfer fluid has a pour point of at least -10 °C, or at least -25 °C, or at least -30 °C, or at least -40 °C, or at least -50 °C as measured according to ASTM D5985. In one embodiment, the heat transfer fluid has an absolute viscosity of no more than 900 cP at -30 °C, or no more than 500 cP at -30 °C, or no more than 100 cP at -30 °C as measured according to ASTM D2983.

[0023] The heat transfer fluid contains hydrocarbon (in some cases isoparaffinic) oil and oxygenate.

[0024] The hydrocarbon (e.g., isoparaffinic) oil has a flash point of at least 50 °C as measured according to ASTM D92 and or ASTM D93, of at least 60 °C, or at least 75 °C, or at least 100 °C, or at least 150 °C, or at least 200 °C, or at least 250 °C.

[0025] Hydrocarbon oils [including Isoparaffins (or isoparaffinic oils)] are saturated hydrocarbon compounds containing at least one hydrocarbyl branch or at least one saturated 5 or 6 membered hydrocarbyl ring, sufficient to provide fluidity to both very low and high temperatures. Hydrocarbon oils (Isoparaffins) of the invention may include natural and synthetic oils, oil derived from hydrocracking, hydrogenation, and hydrofinishing of refined oils, re-refined oils or mixtures thereof. Hydrocarbon oils of include isoparaffinic oils (or isoparaffins), i.e. branched acyclic hydrocarbons, or cycloparaffinic oils (or cycloparaffins, also called naphthenic oils).

[0026] Synthetic isoparaffin oils may be produced by isomerization of predominantly linear hydrocarbons to produce branched hydrocarbons. Linear hydrocarbons may be naturally sourced, synthetically prepared, or derived from Fischer-Tropsch reactions or similar processes. Isoparaffins may be derived from hydro-isomerized wax and typically may be hydro-isomerised Fischer-Tropsch hydrocarbons or waxes. In one embodiment oils may be prepared by a Fischer-Tropsch gas-to-liquid synthetic procedure as well as other gas-to-liquid oils.

[0027] Suitable isoparaffins may also be obtained from natural, renewable, sources. Natural (or bio-derived) oils refer to materials derived from a renewable biological resource, organism, or entity, distinct from materials derived from petroleum or equivalent raw materials. Natural sources of hydrocarbon oil include fatty acid triglycerides, hydrolyzed or partially hydrolyzed triglycerides, or transesterified triglyceride esters, such as fatty acid methyl ester (or FAME). Suitable triglycerides include, but are not limited to, palm oil, soybean oil, sunflower oil, rapeseed oil, olive oil, linseed oil, and related materials. Other sources of triglycerides include, but are not limited to algae, animal tallow, and zooplankton. Linear and branched hydrocarbons may be rendered or extracted from vegetable oils and hydro-refined and/or hydro-isomerized in a manner similar to synthetic oils to produce isoparaffins.

[0028] Another class of isoparaffinic oils includes polyalphaolefins (PAO). Polyolefins are well known in the art. In one embodiment, the polyolefin may be derivable (or derived) from olefins with 2 to 28 carbon atoms. By derivable or derived it is meant the polyolefin is polymerized from the starting polymerizable olefin monomers having
5 the noted number of carbon atoms or mixtures thereof. In embodiments, the polyolefin may be derivable (or derived) from olefins with 3 to 24 carbon atoms. In some embodiments, the polyolefin may be derivable (or derived) from olefins with 4 to 24 carbon atoms. In further embodiments, the polyolefin may be derivable (or derived) from olefins with 5 to 20 carbon atoms. In still further embodiments, the polyolefin may be derivable
10 (or derived) from olefins with 6 to 18 carbon atoms. In still further embodiments, the polyolefin may be derivable (or derived) from olefins with 8 to 14 carbon atoms. In alternate embodiments, the polyolefin may be derivable (or derived) from olefins with 8 to 12 carbon atoms.

[0029] Often the polymerizable olefin monomers comprise one or more of propylene, isobutene, 1-butene, isoprene, 1,3-butadiene, or mixtures thereof. An example
15 of a useful polyolefin is polyisobutylene.

[0030] Polyolefins also include poly- α -olefins derivable (or derived) from α -olefins. The α -olefins may be linear or branched or mixtures thereof. Examples include mono-olefins such as propylene, 1-butene, isobutene, 1-pentene, 1-hexene, 1-heptene,
20 1-octene, 1-nonene, 1-decene, etc. Other examples of α -olefins include 1-decene, 1-undecene, 1-dodecene, 1-tridecene, 1-tetradecene, 1-pentadecene, 1-hexadecene, 1-heptadecene, 1-octadecene, and mixtures thereof. An example of a useful α -olefin is 1-dodecene. An example of a useful poly- α -olefin is poly-decene.

[0031] The polyolefin may also be a copolymer of at least two different olefins, also known as an olefin copolymer (OCP). These copolymers are preferably copolymers
25 of α -olefins having from 2 to about 28 carbon atoms, preferably copolymers of ethylene and at least one α -olefin having from 3 to about 28 carbon atoms, typically of the formula $\text{CH}_2=\text{CHR}_1$ wherein R_1 is a straight chain or branched chain alkyl radical comprising 1 to 26 carbon atoms. Preferably R_1 in the above formula can be an alkyl of from 1 to 8

carbon atoms, and more preferably can be an alkyl of from 1 to 2 carbon atoms. Preferably, the polymer of olefins is an ethylene-propylene copolymer.

[0032] Where the olefin copolymer includes ethylene, the ethylene content is preferably in the range of 20 to 80 percent by weight, and more preferably 30 to 70 percent by weight. When propylene and/or 1-butene are employed as comonomer(s) with ethylene, the ethylene content of such copolymers is most preferably 45 to 65 percent, although higher or lower ethylene contents may be present.

[0033] The hydrocarbon (e.g., isoparaffinic) oils may be substantially free of ethylene and polymers thereof. The composition may be completely free of ethylene and polymers thereof. By substantially free, it is meant that the composition contains less than 50 ppm, or less than 30 ppm, or even less than 10 ppm or 5 ppm, or even less than 1 ppm of the given material.

[0034] The hydrocarbon (e.g., isoparaffinic) oils may be substantially free of propylene and polymers thereof. The hydrocarbon (e.g., isoparaffinic) oils may be completely free of propylene and polymers thereof. The polyolefin polymers prepared from the aforementioned olefin monomers can have a number average molecular weight of from 140 to 5000. The polyolefin polymers prepared from the aforementioned olefin monomers can also have a number average molecular weight of from 200 to 4750. The polyolefin polymers prepared from the aforementioned olefin monomers can also have a number average molecular weight of from 250 to 4500. The polyolefin polymers prepared from the aforementioned olefin monomers can also have a number average molecular weight of from 500 to 4500. The polyolefin polymers prepared from the aforementioned olefin monomers can also have a number average molecular weight of from 750 to 4000 as measured by gel permeation chromatography with polystyrene standard.

[0035] The isoparaffin oil can be a saturated hydrocarbon compound containing 8 carbon atoms up to a maximum of 50 carbon atoms and having at least one hydrocarbyl branch containing at least one carbon atom. In one embodiment, the saturated hydrocarbon

compound can have at least 10 or at least 12 carbon atoms. In one embodiment, the saturated hydrocarbon compound can contain 14 to 34 carbon atoms with the proviso that the longest continuous chain of carbon atoms is no more than 24 carbons in length.

5 **[0036]** In embodiments, the isoparaffin oil will have a longest continuous chain of carbon atoms of no more than 24 carbons in length.

10 **[0037]** In embodiments, the saturated hydrocarbon compound can be a branched acyclic compound with a molecular weight of 140 g/mol to 550 g/mol as measured by size exclusion chromatography (SEC also called gel permeation chromatography or GPC), liquid chromatography, gas chromatography, mass spectrometry, NMR, or combinations thereof, or from 160 g/mol to 480 g/mol.

15 **[0038]** Mineral oils often contain cyclic structures, i.e. aromatics or cycloparaffins also called naphthenes. In one embodiment, the isoparaffin comprises a saturated hydrocarbon compound free of or substantially free of cyclic structures. By substantially free, it is meant there is less than 1 mol% of cyclic structures in the mineral oil, or less than 0.75 mol%, or less than 0.5 mol%, or even less than 0.25 mol%. In some embodiments, the mineral oil is completely free of cyclic structures.

20 **[0039]** In embodiments, the hydrocarbon oil can be a cycloparaffinic oil (cycloparaffins). Cycloparaffins may be obtained from mineral oil. Cycloparaffins contain at least one saturated hydrocarbyl 5- or 6-membered ring. Cycloparaffinic oils may contain at least 29 weight percent polycycloparaffins, i.e. 2 or more edge-sharing rings.

25 **[0040]** The hydrocarbon (e.g., isoparaffinic) oil is the base compound of the heat transfer fluid. As such, the hydrocarbon (e.g., isoparaffinic) oil makes up the balance of the composition after adding all oxygenate and other additives. The hydrocarbon oil may be present in an amount of at least 60 weight %, at least 70 weight %, at least 80 weight %, at least 90 weight %, or at least 95 weight % of the composition. That is to say, the hydrocarbon oil may be present in an amount of from 60 to 99 wt.%, or even from 70 to 98.5 wt.%, or from 80 to 98 wt.%, or from 90 to 97 or 97.5 wt.%. In some embodiments, the hydrocarbon oil

may be present in an amount of from 80 to 99 wt.%, or even from 81 to 98.5 wt.%, or from 82 to 98 wt.%, or from 83 to 97 wt.%, or 84 to 97.5 wt.%.

Oxygenate

5 **[0041]** The composition will also include an oxygenate substance that can act synergistically with the hydrocarbon (e.g., isoparaffinic) oils to effect improved heat transfer, reduced kinematic viscosity, reduced low temperature viscosity, or increased flash point.

10 **[0042]** As used herein, oxygenate refers to organic (i.e., carbon containing, also known as hydrocarbon) compounds containing oxygen as one of their components. Oxygenates, as used herein, include hydrocarbons having at least 1 aprotic or protic oxygen for every 2 carbon atoms, or for every 3 carbon atoms, or for every 4 carbon atoms, or for every 5 carbon atoms, or even for every 6 carbon atoms. Oxygenates also include hydrocarbons having at least 1 aprotic or protic oxygen for every 7 carbon atoms, or 1 aprotic or protic oxygen for every 8 carbon atoms, or at least 1 aprotic or protic oxygen
15 for every 12 carbon atoms. Oxygenates also include hydrocarbons having at least 1 aprotic or protic oxygen for every 16 carbon atoms, or 1 aprotic or protic oxygen for every 20 carbon atoms.

20 **[0043]** Oxygenates can include, for example, alcohols, ester oils and ether oils. The oxygenate may be included in the heat transfer fluid at from about 1 to about 45 wt.%, or in some instances, from about 1.5 to about 40 wt.%, or about 2 to about 35 wt.%. The oxygenate may also be included in the heat transfer fluid at from about 2.5 to about 30 wt.% or about 3 to about 25 wt.%. In some embodiments, the oxygenate may be included in the heat transfer fluid at from 1 to about 20 wt.%, or in some instances from about 1.5 to about 19 wt.%, or about 2 to about 18 wt.%. The oxygenate may also be included in the
25 heat transfer fluid at from about 2.5 to about 17 wt.%, or 3 to about 16 wt.%.

[0044] Alcohols suitable for use in the heat transfer fluid include monohydric alcohols, for example, ethanol, methanol, propylene alcohol derivatives such as n-buta-

nol and tert-butanol, as well as isopropyl alcohol; higher branched alcohols include isomers of pentanol, hexanol, heptanol, octanol, decanol, dodecanol, tetradecanol, hexadecanol and combinations thereof. Examples of branched alcohols include 2-ethylhexanol, iso-octanol, iso-decanol, and isododecanol. Alcohols as used herein also encompass
5 polyols, such as, for example propylene glycol, ethylene glycol, 1,4-butanediol, pentaerythritol, trimethylolpropane.

[0045] Ethers suitable for use as oxygenates in the heat transfer fluid include those made from petrochemical feedstocks as well as renewable feedstocks. Examples include methyl tertiary butyl ether (MTBE), tertiary amyl methyl ether (TAME), ethyl tertiary
10 butyl ether (ETBE), and tertiary amyl ethyl ether (TAEE). Other ether examples include tert-hexyl methyl ether (THEME), dioctyl ether and diisopropyl ether. Polyethers are also considered herein in the term “ethers,” including, for example, diethylene glycol dibutyl ether. Low molecular weight oligomers of polyalkylene glycols (i.e. polyalkylene oxides) may also be suitable, including polyethylene glycol (PEG), polypropylene glycol
15 (PPG), and mixed polymers thereof. Polyethers include alkylene oxide polymers and oligomers containing 1 to 20 repeat units, or 2 to 10 repeat units, or 2 to 5 repeat units of ethylene oxide, propylene oxide, n-butylene oxide, or mixtures thereof. Suitable polyether compounds include: 5,8,11,14-tetraoxaicosane; 1-(2-(2-butoxypropoxy)propoxy)propan-2-yl acetate; 2-(2-(2-(hexyloxy)ethoxy)ethoxy)ethyl oleate; 1-
20 ((1-((1-butoxypropan-2-yl)oxy)propan-2-yl)oxy)butane; 7,10,13,16,19-pentaoxaheptacosane; 2-(2-(2-(hexyloxy)ethoxy)ethoxy)ethyl 3,5,5-trimethylhexanoate; and combinations thereof.

[0046] The oxygenate may also be a polyalkylene glycol esters by reacting polyalkylene glycols with fatty acids, such as, for example, caprylic acid, myristic acid, palmitic acid, stearic acid, and the like.
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[0047] In some instances, the oxygenate may be an alcohol or an ether and may be included in the heat transfer fluid at from about 1 to about 45 wt.%, or in some instances, from about 1.5 to about 40 wt.%, or about 2 to about 35 wt.%. Alcohol or ether oxygenates

may also be included in the heat transfer fluid at from about 2.5 to about 30 wt.% or about 3 to about 25 wt.%.

[0048] Ester oils suitable for use as oxygenates in the heat transfer fluid include, for example, esters of monocarboxylic acids with monohydric alcohols; di-esters of diols with monocarboxylic acids and di-esters of dicarboxylic acids with monohydric alcohols; polyol esters of monocarboxylic acids and polyesters of monohydric alcohols with polycarboxylic acids; and mixtures thereof. Esters may be broadly grouped into two categories: synthetic and natural.

[0049] Synthetic esters suitable for use as oxygenates in the heat transfer fluids may comprise esters of monocarboxylic acid (such as acetic acid, propionic acid, neopentanoic acid, 2-ethylhexanoic acid) and dicarboxylic acids (e.g., phthalic acid, succinic acid, alkyl succinic acids and alkenyl succinic acids, maleic acid, azelaic acid, suberic acid, sebacic acid, fumaric acid, adipic acid, linoleic acid dimer, malonic acid, alkyl malonic acids, and alkenyl malonic acids) with any of variety of monohydric alcohols (e.g., butyl alcohol, pentyl alcohol, neopentyl alcohol, hexyl alcohol, octyl alcohol, iso-octyl alcohol, nonyl alcohol, decyl alcohol, isodecyl alcohol, dodecyl alcohol, tetradecyl alcohol, hexadecyl alcohol, 2-ethylhexyl alcohol, ethylene glycol, diethylene glycol monoether, and propylene glycol). Specific examples of these esters include dibutyl adipate, di(2-ethylhexyl) sebacate, di-n-hexyl fumarate, dioctyl sebacate, diisooctyl azelate, diisodecyl azelate, dioctyl phthalate, didecyl phthalate, dieicosyl sebacate, the 2-ethylhexyl diester of linoleic acid dimer, and the complex ester formed by reacting one mole of sebacic acid with two moles of tetraethylene glycol and two moles of 2-ethylhexanoic acid. Other synthetic esters include those made from C₅ to C₁₂ monocarboxylic acids and polyols and polyol ethers such as neopentyl glycol, trimethylolpropane, pentaerythritol, dipentaerythritol, and tripentaerythritol. Esters can also be monoesters of mono-carboxylic acids and monohydric alcohols.

[0050] Suitable esters also include esters of hydroxy-substituted carboxylic acids, such as tartaric acid, malic acid, glycolic acid, and hydroxy fatty acids (e.g. 12-hydroxysearic acid) in combination with monohydric alcohols as above.

[0051] Natural (or bio-derived) esters refer to materials derived from a renewable biological resource, organism, or entity, distinct from materials derived from petroleum or equivalent raw materials. Natural esters suitable in the heat transfer fluids include fatty acid triglycerides, hydrolyzed or partially hydrolyzed triglycerides, or transesterified triglyceride esters, such as fatty acid methyl ester (or FAME). Suitable triglycerides include, but are not limited to, palm oil, soybean oil, sunflower oil, rapeseed oil, olive oil, linseed oil, and related materials. Other sources of triglycerides include, but are not limited to, algae, animal tallow, and zooplankton.

[0052] In some instances, the oxygenate may be an ester, which may be included in the heat transfer fluid at from about 1 to about 20 wt.%, or in some instances from about 1.5 to about 19 wt.%, or about 2 to about 18 wt.%. Ester oxygenates may also be included in the heat transfer fluid at from about 2.5 to about 17 wt.%, or 3 to about 16 wt.%.

Heat Transfer Additives

[0053] The heat transfer fluid can also include heat transfer additives. One class of heat transfer additive includes, for example, metal and non-metal particles. Particles of the invention are generally dispersed solids, often dispersed in the presence of one or more stabilizers or surfactants. The particles of the invention are often sub-micron in size and are also referred to as nanoparticles.

[0054] For metal nanoparticles, the metal of the metal nanoparticles can include an alkaline earth metal, for example, magnesium, calcium, strontium, and barium.

[0055] The metal of the metal nanoparticles can include a transition metal, for example, scandium, yttrium, titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum, tungsten, manganese, technetium, rhenium, iron, ruthenium, osmium, cobalt, rhodium, iridium, nickel, palladium, platinum, copper, silver, gold, zinc, and cadmium.

[0056] The metal of the metal nanoparticles can include a lanthanide series or actinide series metal, for example, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium,

thulium, ytterbium, lutetium, thorium, protactinium, and uranium).

[0057] The metal of the metal nanoparticles can include a post-transition metal, for example, aluminum, gallium, indium, thallium, tin, lead, bismuth, and polonium.

[0058] The metal of the metal nanoparticles can include a metalloid, for example,
5 boron, silicon, germanium, and antimony.

[0059] In certain embodiments, the metal can include aluminum. In embodiments, the metal can include iron. The metal can also include ruthenium. The metal can include cobalt. The metal can include rhodium. The metal can include nickel. The metal can include palladium. The metal can include platinum. The metal can include silver. The
10 metal can include gold. The metal can include cerium. The metal can include samarium. The metal can include tungsten.

[0060] The metal nanoparticles can be present in their pure form, or, as an oxide, carbide, nitride or mixture of any of these materials or combination of materials.

[0061] For example, the metal nanoparticles can be iron oxide (e.g., Fe_2O_3 , Fe_3O_4), cobalt oxide (e.g., CoO), zinc oxide (e.g., ZnO), cerium oxide (e.g., CeO_2), and titanium oxide (e.g., TiO_2). Boron Oxide (e.g., B_2O_3) is another metal nanoparticle that may be employed. Aluminum Oxide (e.g., Al_2O_3) is another metal nanoparticle that may be employed. Magnesium oxide (e.g., MgO) is another metal nanoparticle that may be employed. Tungsten oxide (e.g., W_2O_3 , WO_2 , WO_3 , W_2O_5) is another metal nanoparticle
15 that may be employed.
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[0062] Examples of metal carbide metal nanoparticles can include iron carbide (e.g., Fe_3CH_4), cobalt carbide (e.g., CoC , Co_2C , Co_3C), zinc carbide (e.g., ZnC), cerium carbide (e.g., CeC_2), and titanium carbide (e.g., TiC). Boron carbide (e.g., B_4C) is another metal nanoparticle that may be employed. Aluminum carbide (e.g., Al_4C_3) is another metal nanoparticle that may be employed. Tungsten carbide (e.g., WC) is another
25 metal nanoparticle that may be employed.

[0063] Examples of metal nitride metal nanoparticles can include iron nitride (e.g., Fe_2N , Fe_3N_4 , Fe_4N , Fe_7N_3 , Fe_{16}N_2), cobalt nitride (e.g., Co_2N , Co_3N , Co_4N), zinc nitride

(e.g., Zn_3N_2), cerium nitride (e.g., CeN), and titanium nitride (e.g., TiN). Boron nitride (e.g., BN) is another metal nanoparticle that may be employed. Aluminum nitride (e.g., AlN) is another metal nanoparticle that may be employed. Tungsten nitride (e.g., WN , W_2N , WN_2) is another metal nanoparticle that may be employed.

5 **[0064]** The nanoparticles can also include non-metal nanoparticles. Such non-metal nanoparticles can be present in the form of oxides, carbon, carbides, nitrides or mixture of any of these materials or combination of materials. For example, the non-metal nanoparticles can be graphene oxide or diamond.

10 **[0065]** The nanoparticle can have a D50 particle size of less than 1000 nm. In some embodiments, the nanoparticles can have a D50 particle size of less than 700 nm. The nanoparticle can have a D50 particle size of less than 500 nm. The nanoparticle can have a D50 particle size of less than 250 nm. The nanoparticle can have a D50 particle size of less than 100 nm. The nanoparticle can have a D50 particle size of less than 75 nm. The nanoparticle can have a D50 particle size of less than 50 nm. The nanoparticle
15 can have a D50 particle size of 0.01 nm to 1000 nm. The nanoparticle can also have a D50 particle size of 0.1 nm to 100 nm. The nanoparticle can have a D50 particle size of 1 nm to 75 nm. The nanoparticle can have a D50 particle size of 10 nm to 50 nm. D50 particle sizes can be measured by Dynamic Light Scattering according to ASTM E2490 - 09(2015).

20 **[0066]** The nanoparticle can have an average aspect ratio of from 1 to 5000. As used herein, the “average aspect ratio” refers to the average ratio of the length of the particles in a nanoparticle mixture to the width of the particles in the mixture. The term “average” is intended to mean that any and all aspect ratios may be present, but that the average aspect ratio over the aggregate is in the disclosed range. The measurement
25 method for determining the length and width for the average aspect ratio are not critical so long as the same measurement method is used for both the measurements. The nanoparticle can also have an average aspect ratio of from 1 to 2500. The nanoparticle can also have an average aspect ratio of from 1 to 1000. The nanoparticle can also have an average aspect ratio of from 1 to 500. The nanoparticle can also have an average aspect

ratio of from 1 to 250. The nanoparticle can also have an average aspect ratio of from 1 to 100. The nanoparticle can also have an average aspect ratio of from 1 to 50. The nanoparticle can also have an average aspect ratio of from 1 to 25. The nanoparticle can also have an average aspect ratio of from 1 to 10. The nanoparticle can also have an average aspect ratio of from 10 to 5000. The nanoparticle can also have an average aspect ratio of from 25 to 5000. The nanoparticle can also have an average aspect ratio of from 50 to 5000. The nanoparticle can also have an average aspect ratio of from 100 to 5000. The nanoparticle can also have an average aspect ratio of from 250 to 5000. The nanoparticle can also have an average aspect ratio of from 500 to 5000. The nanoparticle can also have an average aspect ratio of from 1000 to 5000. The nanoparticle can also have an average aspect ratio of from 2500 to 5000.

[0067] In general, the nanoparticle will be selected to have a thermal conductivity greater than the thermal conductivity of the heat transfer fluid. In some embodiments, the heat transfer fluid can include a particle having a minimum thermal conductivity of greater than 5 W/m-K. In some embodiments, the heat transfer fluid can include a nanoparticle having a thermal conductivity of 10 W/m-K or greater. In some embodiments, the heat transfer fluid can include a nanoparticle having a thermal conductivity of 30 W/m-K or greater. In some embodiments, the heat transfer fluid can include a nanoparticle having a thermal conductivity of 250 W/m-K or greater. In some embodiments, the heat transfer fluid can include a nanoparticle having a thermal conductivity of 500 W/m-K or greater. In some embodiments, the heat transfer fluid can include a nanoparticle having a thermal conductivity of 1000 W/m-K or greater. As used herein, thermal conductivity can be measured by ASTM D7896-19.

[0068] The heat transfer fluid can include the at least one nanoparticle at a concentration of from 0.5 to 30 wt% based on the weight of the heat transfer fluid. In some embodiments, the heat transfer fluid can include the at least one nanoparticle at a concentration of from 0.75 to 25 wt%. In some embodiments, the heat transfer fluid can include the at least one nanoparticle at a concentration of from 1 to 20 wt%. In embodiments, the heat transfer fluid can include the at least one nanoparticle at a concentration of from 1.25 to

15 wt%. In some embodiments, the heat transfer fluid can include the at least one nanoparticle at a concentration of from 1.5 to 10 wt%.

[0069] However, when dosing the nanoparticle, care should be taken not to exceed the dielectric constant constraints for the heat transfer fluid. Generally, this will not be an issue except where more electrically conductive nanoparticles are employed, such as nanoparticles in the form of pure metals, and generally at high levels, such as 10 wt% or more. Where there is concern, the heat transfer fluid can be formulated and the dielectric constant of the dispersion tested.

[0070] The nanoparticles are often dosed with a surfactant suitable to associate with nanoparticles and keep the nanoparticles dispersed in the heat transfer fluid, as would be readily apparent to those of skill in the art. Surfactants can include any surfactant or dispersant now known or still to be created.

[0071] In one embodiment, the heat transfer fluid can include a hydrocarbon oil, one or more polyether oxygenates, and one or more metal or non-metal particles.

15 **Performance Additives**

[0072] The heat transfer fluid may also include a rheology modifier, such as, for example, a high molecular weight polymer. In one embodiment, the polymer may be prepared by polymerizing an alpha-olefin monomer, or mixtures of alpha-olefin monomers, or mixtures comprising ethylene and at least one C3 to C28 alpha-olefin monomer, in the presence of a catalyst system comprising at least one metallocene (e.g., a cyclopentadienyl-transition metal compound) and an alumoxane compound.

[0073] Suitable polymers of the olefin polymer variety include ethylene propylene copolymers, ethylene-propylene-alpha olefin terpolymers, ethylene-alpha olefin copolymers, ethylene propylene copolymers further containing a non-conjugated diene, and isobutylene/conjugated diene copolymers, each of which may be subsequently supplied with grafted carboxylic functionality.

[0074] Ethylene-propylene or higher alpha monoolefin copolymers may consist of 15 to 80 mole % ethylene and 20 to 85 mole % propylene or higher monoolefin, in some

embodiments, the mole ratios being 30 to 80 mole % ethylene and 20 to 70 mole % of at least one C3 to C10 alpha monoolefin, for example, 50 to 80 mole % ethylene and 20 to 50 mole % propylene. Terpolymer variations of the foregoing polymers may contain up to 15 mole % of a non-conjugated diene or triene.

5 **[0075]** In these embodiments, the polymer substrate, such as the ethylene copolymer or terpolymer, can be an oil-soluble, substantially linear, rubbery material. Also, in certain embodiments the polymer can be in forms other than substantially linear, that is, it can be a branched polymer or a star polymer. The polymer can also be a random copolymer or a block copolymer, including di-blocks and higher blocks, including tapered blocks and
10 a variety of other structures. These types of polymer structures are known in the art and their preparation is within the abilities of the person skilled in the art.

[0076] The polymer of the disclosed technology may have a number average molecular weight (by gel permeation chromatography, polystyrene standard), which can typically be 2,000 to 500,000, 10,000 to 300,000, 50,000 to 250,000, or 9,000 to 55,000, or
15 11,000 to 52,000, or 40,000 to 50,000.

[0077] Another useful class of polymers is that constituted by polymers prepared by cationic polymerization of, e.g., isobutene or styrene. Common polymers from this class include polyisobutenes obtained by polymerization of a C4 refinery stream having a butene content of 35 to 75 mass %, and an isobutene content of 30 to 60 mass %, in the
20 presence of a Lewis acid catalyst such as aluminum trichloride or boron trifluoride, aluminum trichloride being suitable. Suitable sources of monomer for making poly-n-butenes are petroleum feedstreams such as raffinate II. These feedstocks are disclosed in the art such as in U.S. Pat. No. 4,952,739. Polyisobutylene is a suitable polymer for the present invention because it is readily available by cationic polymerization from butene streams
25 (e.g., using AlCl₃ or BF₃ catalysts).

[0078] It is known that polyisobutylene can be prepared by cationic polymerization with the aid of boron halides, in particular boron trifluoride (E.P.-A 206 756, U.S. Pat. No. 4,316,973, GB-A 525 542 and GB-A 828 367). The polymerization of the isobutylene

can be controlled so that polyisobutylenes having number average molecular weights (Mn) far higher than 1,000,000 can be obtained.

5 **[0079]** In one embodiment the olefin polymer is a copolymer of olefins with 4 or more carbon atoms. In one embodiment, the olefin polymer (polyolefin) comprises 50 to 100% by weight of units derived from at least one olefin monomer having four or more carbon atoms. In typical embodiments the olefins may be unsaturated aliphatic hydrocarbons such as butene, isobutylene (or isobutene), butadiene, isoprene, or combinations thereof.

10 **[0080]** The polyolefin polymer of the present invention may have a number average molecular weight (by gel permeation chromatography, polystyrene standard) of 20,000 to 10,000,000; 100,000 to 1,500,000; or 200,000 to 1,000,000. In other embodiments the olefin polymer is polyisobutylene with number average molecular weight of at least 50,000, at least 100,000, or at least 250,000 up to 850,000, 600,000, or 500,000. Specific ranges include 250,000 to 750,000 or 250,000 to 500,000.

15 **[0081]** The polymer can be present on a weight basis in the heat transfer fluid at 0.001 to 1%, or 0.003 to 0.8%, or 0.005 to 0.5%, or 0.01 to 0.1%, or 0.02% to 0.05%, for example 0.003% to 0.1% or even 0.003% to 0.01%. In another embodiment, the polymer additive can be present in the heat transfer fluid at concentrations of no more than 500ppm (parts per million), or no more than 300ppm, or no more than 100ppm, or 10ppm to 50ppm, 20 or even 20 to 40ppm. The concentration of the polymer in the heat transfer fluid is measured on an oil free basis.

25 **[0082]** Other conventional additives may also be present, for example antioxidants, corrosion inhibitors, fluorelastomer seal reconditioning agents, lubricity additives, flow improvers, or any combination thereof. Supplemental additives may be present in amounts from 0.01 to 2 weight percent, or 0.025 to 2 weight percent, or 0.03 to 1 weight percent, or 0.035 to 0.5 weight percent of the composition.

[0083] Various embodiments of the compositions disclosed herein may optionally comprise one or more additional performance additives. These additional performance additives may include one or more flame retardants, smoke suppressants, antioxidants, combustion suppressants, metal deactivators, flow additives, corrosion inhibitors, foam inhibitors, demulsifiers, pour point depressants, seal swelling agents, and any combination or mixture thereof. Typically, fully-formulated heat transfer fluids may contain one or more of these performance additives, and often a package of multiple performance additives. In one embodiment, one or more additional additives may be present at 0.01 weight percent up to 3 weight percent, or 0.05 weight percent up to 1.5 weight percent, or 0.1 weight percent up to 1.0 weight percent.

[0084] A thermal management system as disclosed herein may remove heat at a rate that allows for rapid charging of a battery. The target for high-speed charging includes 120 to 1000 kW. The resulting heat generated during battery charging and discharging can result in heat generated in the pack in excess of 10 kw.

[0085] Heat captured by the fluid may be recaptured and recycled into other functional uses, such as the heating of a building or automobile interior.

[0086] As used herein, the term "hydrocarbyl" is used in its ordinary sense, which is well-known to those skilled in the art. Specifically, it refers to a group having a carbon atom directly attached to the remainder of the molecule and having predominantly hydrocarbon character. Examples of hydrocarbyl groups include:

[0087] hydrocarbon substituents, that is, aliphatic (e.g., alkyl or alkenyl), alicyclic (e.g., cycloalkyl, cycloalkenyl) substituents, and aromatic-, aliphatic-, and alicyclic-substituted aromatic substituents, as well as cyclic substituents wherein the ring is completed through another portion of the molecule (e.g., two substituents together form a ring);

[0088] substituted hydrocarbon substituents, that is, substituents containing non-hydrocarbon groups which, in the context of this invention, do not alter the predominantly hydrocarbon nature of the substituent (e.g., halo (especially chloro and fluoro), hydroxy, alkoxy, mercapto, alkylmercapto, nitro, nitroso, and sulfoxy);

[0089] hetero substituents, that is, substituents which, while having a predominantly hydrocarbon character, in the context of this invention, contain other than carbon in a ring or chain otherwise composed of carbon atoms and encompass substituents as pyridyl, furyl, thienyl and imidazolyl. Heteroatoms include sulfur, oxygen, and nitrogen.

5 In general, no more than two, or no more than one, non-hydrocarbon substituent will be present for every ten carbon atoms in the hydrocarbyl group; alternatively, there may be no non-hydrocarbon substituents in the hydrocarbyl group.

[0090] It is known that some of the materials described above may interact in the final formulation, so that the components of the final formulation may be different from
 10 those that are initially added. For instance, metal ions (of, e.g., a detergent) can migrate to other acidic or anionic sites of other molecules. The products formed thereby, including the products formed upon employing the composition of the present invention in its intended use, may not be susceptible of easy description. Nevertheless, all such modifications and reaction products are included within the scope of the present invention; the
 15 present invention encompasses the composition prepared by admixing the components described above.

[0091] The invention herein is useful for cooling electrical componentry during operation, which may be better understood with reference to the following examples.

EXAMPLES

20 **[0092]** A series of oil-miscible fluids utilizing hydrocarbon oil in combination with oxygenate were evaluated for their ability to disperse and conduct thermal energy. The hydrocarbon fluids range from simple isoparaffinic hydrocarbons (IH) to polyalphaolefins (PAO), and cycloparaffinic oils (CP). The hydrocarbon oils are summarized below (Table 1).

25 Table 1 – Hydrocarbon Fluids

ID	Base Fluid Type	KV40 ¹ (m ² /s)	Flash Point ² (°C)	Pour Point (°C)
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HC1	PAO	4.9	154	-78
HC2	PAO	8.2	182	-45
HC4	CP	2.7		-21
HC5	IH	2.9	103	< -57
HC6	PAO	13.6	234	-75
HC7	PAO	17.2	208	-78
HC8	PAO	18.3	227	-66
HC9	PAO	25.1	248	<-57
HC10	n-dodecane	1.5	90	-9
HC11	IH	3.6	115	<-57
HC12	PAO	47.1	258	-57
HC13	IH	9.7	202	-45

1. Carried out according to ASTM D445_40
2. Carried out according to ASTM D92
3. Carried out according to ASTM D97

- 5 **[0093]** Various oxygenates were evaluated, including esters, ethers, polyethers, and hydrocarbyl alcohols. The oxygenates are summarized below (Table 2).

Table 2 – Oxygenates Fluids

ID	Base Fluid Type	KV25 ¹ (m ² /s)	KV40 ² (m ² /s)	SG25 ³ (g/ml)	Dielectric Constant	Pour point ⁴ (°C)	Flash point ⁵ (°C)
OX1	Diisooctyl adipate (GDHIOAD)	14	9.0	0.92	3.4	-65	204

OX2	Neopentanoic acid isodecylester	4.3	3.0	0.85	3.56	-57	120
OX3	Diethylene glycol dibutylether	2.1	1.6	0.87	4.26	< -57	113
OX4	Di-tridecyl adipate (EDAD)		26.5			-60	235
OX5	Dihexyl ether		1.5			-45	103
OX6	Dioctyl ether		2.9			-7	160
OX7	C8&C10, 3-methylbutyl ester		2.4			-45	124
OX8	Propylene Glycol Dicaprylate		6.4			-36	203
OX9	Hexyl Isobutyrate	1.5	1.2	0.7		-90	85
OX10	2-ethylhexyl caprate		3.2			-75	165
OX11 ⁶	Propylene oxide trimer		3.5			-81	160
OX12 ⁷	Ethylene oxide trimer		3.84			-30	151
OX13 ⁸	Ethylene oxide trimer		7.08			-66	191
OX14 ⁹	Mixed trimer/tetramer of Ethylene oxide		6.74			-18	194
OX15 ¹⁰	Propylene oxide dimer		1.88				120
OX16 ¹¹	Oleate ester of ethylene oxide trimer		12.81			-27	253

1. Carried out according to ASTM D445_25
2. Carried out according to ASTM D445_40
3. Carried out according to ASTM D854
4. Carried out according to ASTM D5950 or D97
5. Carried out according to ASTM D92
6. 1-(2-(2-butoxypropoxy)propoxy)propan-2-yl acetate
7. 5,8,11,14-tetraoxaicosane
8. 2-(2-(2-(hexyloxy)ethoxy)ethoxy)ethyl 3,5,5-trimethylhexanoate
9. 7,10,13,16,19-pentaoxaheptacosane
10. 1-((1-((1-butoxypropan-2-yl)oxy)propan-2-yl)oxy)butane
11. 2-(2-(2-(hexyloxy)ethoxy)ethoxy)ethyl oleate

[0094] Fully formulated fluids were prepared from hydrocarbon oil, oxygenate, and optionally other performance additives. Formulations for evaluation are summarized below (Table 3).

5 Table 3 – Thermal Fluid Compositions¹

	EX1	EX2	EX3	EX4	EX5	EX6	EX7	EX8	EX9	EX10
HC1				70	75					90
HC2	33.3	30				90		30	30	
HC4				10						
HC5										
HC7			85							
HC8	66.7	60						60	55	
HC9							81			
HC10										
HC11										
HC12							10			
OX1		10	10	10		10		10		
OX4							9			
OX5										
OX6			5	10	15				3	
OX7										
OX8					10				12	
OX10										10
Additives ²	0	0.4	0.4	0.6	0.7	0.4	0.6	0.6	0.7	0.7

1. Base fluid concentrations are normalized to 100% treat. Additive concentrations are top treats to fluid compositions

2. Includes additives for improving foam inhibition, lubricity, surfactancy, and corrosion control which do not materially impact thermal properties

Testing

- 5 **[0095]** Fluid mixtures were evaluated for viscosity, electrical conductivity, flash point, and their ability to absorb and disperse heat. Testing included, in addition to kinematic viscosity (according to ASTM D445) and flash point (ASTM D92), heat capacity at 40°C was measured via differential scanning calorimetry (DSC), thermal conductivity at 50°C (ASTM D7896), and dielectric strength (ASTM D1816). Testing is summarized in
- 10 Table 4.

Table 4 – Thermal Testing

Examples	KV100 (m ² /s)	KV40 (m ² /s)	Flash Point (°C)	Specific Heat at 40°C (J/g-K)	Thermal Conductivity at 50°C (W/m-K)	Specific Gravity at 25°C (g/mL)	Dielectric Strength (kV)
HC1	1.67	4.93	154	1.983	0.131	0.7906	N/A
HC2	2.39	8.16	181	1.935	0.135	0.7998	15.6
HC7	3.9	17.1	208	1.945	0.138	0.81179	N/A
EX1	3.42	13.8	209	2.017	0.141	0.80873	N/A
EX2	3.11	12.0	202	1.856	0.139	0.81803	N/A
EX3	3.34	13.4	204	1.897	0.140	0.8214	51.2
EX4	1.60	4.56	151	1.932	0.128	0.80485	40.6
EX5	1.60	4.56	154	N/A	N/A	N/A	N/A
EX6	2.37	8.0	184	2.044	0.134	0.81049	54.3
EX7	5.37	26.2	251	1.941	0.144	0.82582	61
EX8	3.27	32.7	205	1.973	0.138	0.8188	39.3
EX9	3.01	11.3	202	N/A	N/A	N/A	N/A

EX10	1.63	4.76	147	2.051	0.131	0.79719	49.1
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[0096] The results show that the fluids of the invention provide acceptable removal of heat, at useful kinematic viscosities, while introducing insignificant conductivity compared, for example, to water.

- 5 **[0097]** Additional examples were prepared for determination of convective heat transfer coefficient (HTC) (Table 5).

Table 5 – Thermal Fluid Compositions for HTC Determination¹

	EX11	EX12	EX13
HC1	63	52	
HC11		24	
HC13			90
OX6	25	12	
OX7		12	
OX8			10
Hydrocarbyl Monoester	12		
Additives ²	0.6	0.6	0.7

1. Base fluid concentrations are normalized to 100% treat. Additive concentrations are top treats to fluid compositions

2. Includes additives for improving foam inhibition, lubricity, surfactancy, and corrosion control which do not materially impact thermal properties

10

[0098] Samples were also tested to determine the convective heat transfer coefficient “ h ,” of the sample fluid through a pipe having a specified wall area (“ A_{wall} ”). Higher heat transfer coefficients are considered the better performing fluid. The testing included

pumping the sample fluid through the pipe with a constant pump speed (“S”). The temperature of the fluid at the pipe inlet was also controlled by heat exchanger to a set inlet temperature, which in these tests was 35 degrees Celsius. The pipe wall was heated with constant power (“P”) with a direct current power supply. The wall temperature (“ T_{wall} ”) was measured using a thermocouple. A thermocouple was placed in the fluid flow and co-located near the point of the wall temperature measurement to measure the fluid temperature (“ T_{fluid} ”). After steady-state is reached, data is collected and averaged over 60 seconds. The convective heat transfer coefficient is calculated with Equation X.

Equation X

10

$$q'' = h * (T_{wall} - T_{fluid})$$

[0099] In Equation X, q'' is the heat flux calculated from the power supply input as well as the heated area of the pipe according to Equation Y.

Equation Y

15

$$q'' = P/A_{wall}$$

[0100] Using Equations X and Y, heat transfer coefficients were calculated for the sample fluids in the table below (Table 6).

Table 6 – Heat Transfer Coefficient Determination

Sample	Pump Speed (RPM)	Pump Power (W)	A_{wall} (m ²)	P (W)	T_{wall} (°C)	T_{fluid} (°C)	h (W/m ² C)
HC1	1140	66.53	5238.4	25.00	66.46	35.07	152.05
EX5	1140	66.68	5238.4	25.00	62.59	36.24	181.12
EX11	1140	65.76	5238.4	25.00	61.37	35.87	187.24
EX12	1140	66.12	5238.4	25.00	60.54	36.23	196.34
HC13	3060	265.67	5238.4	25.00	50.56	35.68	320.69
EX13	3060	277.99	5238.4	25.00	48.58	35.97	378.50

20

[0101] As the data demonstrates, compositions containing both hydrocarbon base fluid and oxygenate demonstrate significant increase in convective heat transfer coefficient (h) at constant pump speed.

[0102] A series of immersion coolants are prepared by addition of oxygenate fluids and nanoparticle additives to hydrocarbon fluid (Table A).

Table A – Hydrocarbon Fluid Example

	FEX1
Isoparaffin hydrocarbon ¹	72
Dodecane	27.2
Additives ²	0.8

1. Kinematic viscosity at 40 °C of 2.9 m²/s

2. Includes additives for improving foam inhibition, lubricity, surfactancy, and corrosion control which do not materially impact thermal properties

10

[0103] Formulated fluids are evaluated for their viscometric properties as well as the stability and dispersion of the particulate additive (Table B).

Table B – Formulated Heat Transfer Fluids¹

	EX31	EX32	EX33	EX34	EX35
FEX1	45.6	46.9	45.6	45.6	45.6
Diethyl ether	27.7	27.7	27.7	27.7	27.7
Polyether 1 ²				2.01	
Polyether 2 ³					2.01
Alkylbenzene sulfonic acid			2.01		
Magnesium oxide ⁴	20	20	20	20	20
Surfactant ⁵	6.7	5.4	4.69	4.69	4.69
Absolute viscosity at 25 °C (cP)	5.9	5.06	4.97	4.58	4.44
Mean particle size (μm)	126.0	0.159	2.215	0.143	0.140
Median particle size (μm)	90.4	0.123	0.133	0.135	0.131

15

1. Treat rates are oil free, unless otherwise indicated

2. Ether terminated polyether, (n-C₆H₁₃-O)-(CH₂CH₂O)_x-(n-C₄H₉); x = 1 to 7; x_{ave} = 3.5

3. Ester terminated polyether, (n-C₆H₁₃-O)-(CH₂CH₂O)_x-((C=O)-CH₃); x = 1 to 7; x_{ave} = 4

20

4. 3-8 micron solid

5. Poly(12-hydroxystearic acid) (Mn 1000)

[0104] The data demonstrates that inclusion of a polyether oxygenate improves the dispersion of the nanoparticles, as evidenced by the particle size distribution, and results in reduced viscosity of the resulting heat transfer fluid.

[0105] Each of the documents referred to above is incorporated herein by reference, including any prior applications, whether or not specifically listed above, from which priority is claimed. The mention of any document is not an admission that such document qualifies as prior art or constitutes the general knowledge of the skilled person in any jurisdiction. Except in the Examples, or where otherwise explicitly indicated, all numerical quantities in this description specifying amounts of materials, reaction conditions, molecular weights, number of carbon atoms, and the like, are to be understood as modified by the word "about." It is to be understood that the upper and lower amount, range, and ratio limits set forth herein may be independently combined. Similarly, the ranges and amounts for each element of the invention can be used together with ranges or amounts for any of the other elements.

[0106] As used herein, the transitional term "comprising," which is synonymous with "including," "containing," or "characterized by," is inclusive or open-ended and does not exclude additional, un-recited elements or method steps. However, in each recitation of "comprising" herein, it is intended that the term also encompass, as alternative embodiments, the phrases "consisting essentially of" and "consisting of," where "consisting of" excludes any element or step not specified and "consisting essentially of" permits the inclusion of additional un-recited elements or steps that do not materially affect the essential or basic and novel characteristics of the composition or method under consideration.

[0107] While certain representative embodiments and details have been shown for the purpose of illustrating the subject invention, it will be apparent to those skilled in this art that various changes and modifications can be made therein without departing

from the scope of the subject invention. In this regard, the scope of the invention is to be limited only by the following claims.

[0108] A heat transfer fluid comprising a mixture of hydrocarbon oil and oxygenate.

[0109] The heat transfer fluid of any previous sentence, wherein the heat transfer fluid is substantially free, or free, of cyclic structures. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid comprises an isoparaffinic oil containing at least one saturated hydrocarbon compound having from 8 to 50 carbon atoms. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid comprises an isoparaffinic oil containing at least one saturated hydrocarbon compound having at least 10 carbon atoms. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid comprises an isoparaffinic oil containing at least one saturated hydrocarbon compound having at least 12 carbon atoms. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid comprises an isoparaffinic oil containing at least one saturated hydrocarbon compound having from 14 to 34 carbon atoms. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid comprises an isoparaffinic oil having at least one hydrocarbyl branch, and has a single continuous carbon chain of no more than 24 carbon atoms. The heat transfer fluid of any previous sentence, wherein the at least one saturated hydrocarbon compound contains at least 10 carbon atoms and at least one hydrocarbyl branch, and has a single continuous carbon chain of no more than 24 carbon atoms. The heat transfer fluid of any previous sentence, wherein the at least one saturated hydrocarbon compound comprises a branched acyclic compound with a molecular weight of 140 g/mol to 550 g/mol. The heat transfer fluid of any previous sentence, wherein the at least one saturated hydrocarbon compound comprises a branched acyclic compound with a molecular weight of 160 g/mol to 480 g/mol.

[0110] The heat transfer fluid of any previous sentence, wherein the heat transfer fluid comprises, consists essentially of, consists of, a natural hydrocarbon oil. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid comprises, consists essentially of, consists of, a synthetic hydrocarbon oil. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid comprises, consists essentially of, consists of, an hydrocarbon

oil derived from petroleum or equivalent raw materials. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid comprises, consists essentially of, consists of, an hydrocarbon oil derived from natural sources. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid comprises, consists essentially of, consists of, an isoparaffinic oil derived from triglycerides. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin of number average molecular weight of from 140 to 5000 as measured by gel permeation chromatography with polystyrene standard. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin of number average molecular weight of from 200 to 4750 as measured by gel permeation chromatography with polystyrene standard. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin of number average molecular weight of from 250 to 4500 as measured by gel permeation chromatography with polystyrene standard. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin of number average molecular weight of from 500 to 4500 as measured by gel permeation chromatography with polystyrene standard. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin of number average molecular weight of from 750 to 4000 as measured by gel permeation chromatography with polystyrene standard. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin polymerized from a C2-C24 olefin or mixture thereof. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin polymerized from a C3-C24 olefin or mixture thereof. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin polymerized from a C4-C24 olefin or mixture thereof. The heat transfer fluid of

any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin polymerized from a C5-C20 olefin or mixture thereof. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin polymerized from a C6-C18 olefin or mixture thereof. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin polymerized from a C8-C14 olefin or mixture thereof. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of, a polyalphaolefin polymerized from a C8-C12 olefin or mixture thereof. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a propylene polymer. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of an isobutene polymer. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a 1-butene polymer. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of an isoprene polymer. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a 1,3-butadiene polymer. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyisobutylene polymer.

[0111] The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyisobutylene polymer having a number average molecular weight from 140 to 5000. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyisobutylene polymer having a number average molecular weight of from 200 to 4500. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyisobutylene polymer having a number average molecular weight of from 250 to 4000.

The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyisobutylene polymer having a number average molecular weight of from 300 to 3500. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyisobutylene polymer having a number average molecular weight of from 350 to 3000. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyisobutylene polymer having a number average molecular weight of from 400 to 2500 as measured by gel permeation chromatography with a polystyrene standard

10 **[0112]** The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from C4-C24 α -olefin or mixture thereof. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-pentene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-hexene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-heptene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-octene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-nonene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-decene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-decene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-undecene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-dodecene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-tridecene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-tetradecene. The composition of any sentence of

any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-pentadecene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-hexadecene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-heptadecene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-octadecene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-nonadecene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-eicosene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-heneicosene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-docosene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-tricosene. The composition of any sentence of any previous paragraph, wherein the at least one branched polyolefin polymer is polymerized from 1-tetracosene.

[0113] The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a 1000 to 5000 Mn polydecene polymer as measured by gel permeation chromatography with a polystyrene standard. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a 1250 to 4750 Mn polydecene polymer as measured by gel permeation chromatography with a polystyrene standard. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a 1500 to 4500 Mn polydecene polymer as measured by gel permeation chromatography with a polystyrene standard. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a 2000 to 4250 Mn polydecene polymer as measured by gel permeation chromatography with a polystyrene standard. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists

essentially of, consists of a 2500 to 4000 Mn polydecene polymer as measured by gel permeation chromatography with a polystyrene standard.

[0114] The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyalphaolefin comprising a mixture of any of the polymers in the preceding sentences. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists a polyalphaolefin of mixtures of C6 and C8 α -olefins. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyalphaolefin of mixtures of C6 and C10 α -olefin. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyalphaolefin of mixtures of C6 and C12 α -olefin. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyalphaolefin of mixtures of C6 and C14 α -olefin. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyalphaolefin of mixtures of C6 and C16 α -olefin. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyalphaolefin of mixtures of C6, C8 and C10 α -olefin. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyalphaolefin of mixtures of C6, C8 and C12 α -olefin. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyalphaolefin of mixtures of C6, C8 and C14 α -olefin. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyalphaolefin of mixtures of C6, C8 and C16 α -olefin. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyalphaolefin of mixtures of C8 and C10 α -olefin. The heat transfer fluid of any previous sentence, wherein the isoparaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyalphaolefin of mixtures

of C8 and C12 α -olefin. The heat transfer fluid of any previous sentence, wherein the isopara-
affinic oil of the heat transfer fluid comprises, consists essentially of, consists of a polyal-
phaolefin of mixtures of C8 and C14 α -olefin. The heat transfer fluid of any previous sentence,
wherein the isoparaaffinic oil of the heat transfer fluid comprises, consists essentially of, con-
5 sists of a polyal-phaolefin of mixtures of C8 and C16 α -olefin. The heat transfer fluid of any
previous sentence, wherein the isoparaaffinic oil of the heat transfer fluid comprises, consists
essentially of, consists of a polyal-phaolefin of mixtures of C8, C10 and C12 α -olefin. The heat
transfer fluid of any previous sentence, wherein the isoparaaffinic oil of the heat transfer fluid
comprises, consists essentially of, consists of a polyal-phaolefin of mixtures of C8, C10 and
10 C14 α -olefin. The heat transfer fluid of any previous sentence, wherein the isoparaaffinic oil of
the heat transfer fluid comprises, consists essentially of, consists of a polyal-phaolefin of mix-
tures of C8, C10 and C16 α -olefin. The heat transfer fluid of any previous sentence, wherein
the isoparaaffinic oil of the heat transfer fluid comprises, consists essentially of, consists of a
polyal-phaolefin of mixtures of C10 and C12 α -olefin. The heat transfer fluid of any previous
15 sentence, wherein the isoparaaffinic oil of the heat transfer fluid comprises, consists essentially
of, consists of a polyal-phaolefin of mixtures of C10 and C14 α -olefin. The heat transfer fluid
of any previous sentence, wherein the isoparaaffinic oil of the heat transfer fluid comprises,
consists essentially of, consists of a polyal-phaolefin of mixtures of C10 and C16 α -olefin. The
heat transfer fluid of any previous sentence, wherein the isoparaaffinic oil of the heat transfer
20 fluid comprises, consists essentially of, consists of a polyal-phaolefin of mixtures of C10, C12
and C14 α -olefin. The heat transfer fluid of any previous sentence, wherein the isoparaaffinic
oil of the heat transfer fluid comprises, consists essentially of, consists of a polyal-phaolefin of
mixtures of C10, C12 and C16 α -olefin.

[0115] The heat transfer fluid of any previous sentence, wherein the oxygenate
25 comprises a hydrocarbon having at least 1 aprotic or protic oxygen for every 6 carbon
atoms. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises
a hydrocarbon having at least 1 aprotic or protic oxygen for every 7 carbon atoms. The
heat transfer fluid of any previous sentence, wherein the oxygenate comprises a hydro-
carbon having at least 1 aprotic or protic oxygen for every 8 carbon atoms. The heat

transfer fluid of any previous sentence, wherein the oxygenate comprises a hydrocarbon having at least 1 aprotic or protic oxygen for every 12 carbon atoms. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises a hydrocarbon having at least 1 aprotic or protic oxygen for every 16 carbon atoms. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises a hydrocarbon having at least 1 aprotic or protic oxygen for every 20 carbon atoms.

[0116] The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of, alcohol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of, ester oil. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of, ether oil.

[0117] The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of monohydric alcohols. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of ethanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of methanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of propylene alcohol derivatives. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of n-butanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of tert-butanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of isopropyl alcohol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of isomers of pentanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of isomers hexanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of isomers heptanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of isomers octanol. The heat transfer fluid of any previous sentence, wherein the

oxygenate comprises, consists essentially of, consists of isomers decanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of isomers dodecanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of isomers tetradecanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of isomers hexadecanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of branched alcohols. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of 2-ethylhexanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of iso-octanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of iso-decanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of isododecanol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of polyols. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of propylene glycol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of ethylene glycol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of 1,4-butanediol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of pentaerythritol. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of trimethylolpropane.

[0118] The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of methyl tertiary butyl ether (MTBE). The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of tertiary amyl methyl ether (TAME). The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of ethyl tertiary butyl ether (ETBE). The heat transfer fluid of any previous sentence,

wherein the oxygenate comprises, consists essentially of, consists of tertiary amyl ethyl ether (TAEE). The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of tert-hexyl methyl ether (THEME). The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists
5 essentially of, consists of diisopropyl ether. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of polyether. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of diethylene glycol dibutyl ether. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists
10 of low molecular weight oligomers of polyalkylene glycols. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of polyethylene glycol (PEG). The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of polypropylene glycol (PPG).

[0119] The heat transfer fluid of any previous sentence, wherein the oxygenate
15 comprises, consists essentially of, consists of esters of monocarboxylic acids with monohydric alcohols. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of di-esters of diols with monocarboxylic acids. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of di-esters of dicarboxylic acids with monohydric alcohols. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises,
20 consists essentially of, consists of polyol esters of monocarboxylic acids. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of polyesters of monohydric alcohols with polycarboxylic acids. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of esters of monocarboxylic acid or dicarboxylic acids with monohydric alcohols. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of dibutyl adipate. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of di(2-ethylhexyl) sebacate. The heat transfer fluid of any previous sentence, wherein
25

the oxygenate comprises, consists essentially of, consists of di-n-hexyl fumarate. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of dioctyl sebacate. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of diisooctyl azelate. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of diisodecyl azelate. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of dioctyl phthalate. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of didecyl phthalate. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of dieicosyl sebacate. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of 2-ethylhexyl diester of linoleic acid dimer. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of the complex ester formed by reacting one mole of sebacic acid with two moles of tetraethylene glycol and two moles of 2-ethylhexanoic acid. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of esters made from C₅ to C₁₂ monocarboxylic acids and polyols and polyol ethers. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of esters of hydroxy-substituted carboxylic acids in combination with monohydric alcohols. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of fatty acid triglycerides. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of hydrolyzed or partially hydrolyzed triglycerides. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of transesterified triglyceride esters. The heat transfer fluid of any previous sentence, wherein the oxygenate comprises, consists essentially of, consists of fatty acid methyl ester (or FAME).

[0120] The heat transfer fluid of any previous sentence, wherein the oxygenate is present at from about 1 to about 45 wt.%. The heat transfer fluid of any previous sentence,

wherein the oxygenate is present at from about 1.5 to about 40 wt.%. The heat transfer fluid of any previous sentence, wherein the oxygenate is present at about 2 to about 35 wt.%. The heat transfer fluid of any previous sentence, wherein the oxygenate is present at from about 2.5 to about 30 wt.%. The heat transfer fluid of any previous sentence, wherein the oxygenate is present at about 3 to about 25 wt.%. The heat transfer fluid of any previous sentence, wherein the oxygenate is present at from 1 to about 20 wt.%. The heat transfer fluid of any previous sentence, wherein the oxygenate is present at from about 1.5 to about 19 wt.%. The heat transfer fluid of any previous sentence, wherein the oxygenate is present at about 2 to about 18 wt.%. The heat transfer fluid of any previous sentence, wherein the oxygenate is present at from about 2.5 to about 17 wt.%. The heat transfer fluid of any previous sentence, wherein the oxygenate is present at about 3 to about 16 wt.%.

[0121] The heat transfer fluid of any previous sentence, having a kinematic viscosity measured at 100°C of 0.7 to 7.0 cSt as measured according to ASTM D445_100.

[0122] The heat transfer fluid of any previous sentence wherein the heat transfer fluid has a flash point of at least at least 50 °C as measured according to ASTM D56. The heat transfer fluid of any previous sentence wherein the heat transfer fluid has a flash point of at least at least 93 °C as measured according to ASTM D56. The heat transfer fluid of any previous sentence wherein the heat transfer fluid has a flash point of at least at least 110 °C as measured according to ASTM D56. The heat transfer fluid of any previous sentence wherein the heat transfer fluid has a flash point of at least at least 150 °C as measured according to ASTM D56. The heat transfer fluid of any previous sentence wherein the heat transfer fluid has a flash point of at least at least 200 °C as measured according to ASTM D56. The heat transfer fluid of any previous sentence wherein the heat transfer fluid has a flash point of at least at least 250 °C as measured according to ASTM D56.

[0123] The heat transfer fluid of any previous sentence, wherein the heat transfer fluid has a pour point of at least -5 °C as measured according to ASTM D5985. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid has a pour point of at least -40 °C as measured according to ASTM D5985. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid has a pour point of at least -36 °C as measured according to

ASTM D5985. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid has a pour point of at least -20 °C as measured according to ASTM D5985.

[0124] The heat transfer fluid of any previous sentence, wherein the heat transfer fluid has a dielectric constant of 5.0 or lower as measured according to ASTM D924. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid has a dielectric constant of 4.5 or lower as measured according to ASTM D924. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid has a dielectric constant of 4.0 or lower as measured according to ASTM D924. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid has a dielectric constant of 3.0 or lower as measured according to ASTM D924. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid has a dielectric constant of 2.5 or lower as measured according to ASTM D924. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid has a dielectric constant of 2.3 or lower as measured according to ASTM D924. The heat transfer fluid of any previous sentence, wherein the heat transfer fluid has a dielectric constant of 1.9 or lower as measured according to ASTM D924.

[0125] The heat transfer fluid of any previous sentence, further comprising heat transfer additives.

[0126] The heat transfer fluid of any previous sentence, further comprising a metal or non-metal particle.

[0127] The heat transfer fluid of any previous sentence, wherein the oxygenate comprises or consists of polyethers and the metal or non-metal particle comprises or consists of a metal particle.

[0128] The heat transfer fluid of any previous sentence, wherein the polyether comprises alkylene oxide polymers and oligomers containing 1 to 20 repeat units. The heat transfer fluid of any previous sentence, wherein the polyether comprises alkylene oxide polymers and oligomers containing 2 to 10 repeat units. The heat transfer fluid of any previous sentence, wherein the polyether comprises alkylene oxide polymers and oligomers containing 2 to 5 repeat units of ethylene oxide. The heat transfer fluid of any previous sentence, wherein the

polyether comprises alkylene oxide polymers and oligomers containing 2 to 5 repeat units of propylene oxide. The heat transfer fluid of any previous sentence, wherein the polyether comprises alkylene oxide polymers and oligomers containing 2 to 5 repeat units of n-butylene oxide. The heat transfer fluid of any previous sentence, wherein the polyether comprises

5 5,8,11,14-tetraoxaicosane; 1-(2-(2-butoxypropoxy)propoxy)propan-2-yl acetate; 2-(2-(2-(hexyloxy)ethoxy)ethoxy)ethyl oleate; 1-((1-((1-butoxypropan-2-yl)oxy)propan-2-yl)oxy)butane; 7,10,13,16,19-pentaoxaheptacosane; 2-(2-(2-(hexyloxy)ethoxy)ethoxy)ethyl 3,5,5-trimethylhexanoate; and combinations thereof.

[0129] The heat transfer fluid of any previous sentence wherein the metal particle

10 comprises alkaline earth metal. The heat transfer fluid of any previous sentence wherein the metal particle comprises magnesium. The heat transfer fluid of any previous sentence wherein the metal particle comprises calcium. The heat transfer fluid of any previous sentence wherein the metal particle comprises strontium. The heat transfer fluid of any previous sentence wherein the metal particle comprises barium.

15 **[0130]** The heat transfer fluid of any previous sentence wherein the metal particle comprises transition metal. The heat transfer fluid of any previous sentence wherein the metal particle comprises lanthanide metal. The heat transfer fluid of any previous sentence wherein the metal particle comprises actinide series metal. The heat transfer fluid of any previous sentence wherein the metal particle comprises post-transition metal. The

20 heat transfer fluid of any previous sentence wherein the metal particle comprises metalloid.

[0131] The heat transfer fluid of any previous sentence wherein the metal particle comprises iron oxide (e.g., Fe_2O_3 , Fe_3O_4). The heat transfer fluid of any previous sentence wherein the metal particle comprises cobalt oxide (e.g., CoO). The heat transfer

25 fluid of any previous sentence wherein the metal particle comprises zinc oxide (e.g., ZnO). The heat transfer fluid of any previous sentence wherein the metal particle comprises cerium oxide (e.g., CeO_2). The heat transfer fluid of any previous sentence wherein the metal particle comprises titanium oxide (e.g., TiO_2). The heat transfer fluid of any previous sentence wherein the metal particle comprises Boron Oxide (e.g., B_2O_3).

The heat transfer fluid of any previous sentence wherein the metal particle comprises Aluminum Oxide (e.g., Al_2O_3). The heat transfer fluid of any previous sentence wherein the metal particle comprises Magnesium oxide (e.g., MgO). The heat transfer fluid of any previous sentence wherein the metal particle comprises Tungsten oxide (e.g., W_2O_3 , WO_2 , WO_3 , W_2O_5).

[0132] The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of a battery. The method and/or system of the previous sentence wherein the electrical componentry comprises multiple battery cells stacked relative to one another to construct a battery module. The method and/or system of the previous sentence, wherein the battery operates an electric vehicle. The method and/or system of the previous sentence, wherein the electric vehicle comprises, consists essentially of, consists of an electric car. The method and/or system of the previous sentence, wherein the electric vehicle comprises, consists essentially of, consists of a truck. The method and/or system of the previous sentence, wherein the electric vehicle comprises, consists essentially of, consists of an electrified mass transit vehicle. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of aircraft electronics. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of computer electronics such as computer servers. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of invertors. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of DC to DC convertors. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of chargers. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of electric motors. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of electric motor controllers. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of microprocessors. The method and/or system of the previous paragraph, wherein the electrical

componentry comprises, consists essentially of, consists of uninterruptable power supplies (UPSs). The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of power electronics. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of IGBTs. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of SCRs. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of thyristers. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of capacitors.

10 The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of diodes. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of transistors. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of rectifiers. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of DC to AC invertors. The method and/or system of any previous sentence wherein the method and/or system further comprises operating the electrical componentry in charging operations. The method and/or system of any previous sentence wherein the method and/or system further comprises operating the electrical componentry in discharging operations.

20 The method and/or system of any previous sentence wherein the step of removing heat comprises removing heat transferred into the electrical componentry as a result of extreme ambient conditions. The method and/or system of any previous sentence wherein the heat transfer fluid enables the charging of the battery module to at least 75% of the total battery capacity restored in a time period of less than 15 minutes. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of fuel cells. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of solar cells. The method and/or system of the previous paragraph, wherein the electrical componentry comprises, consists essentially of, consists of solar panels. The method and/or system of the previous para-

- graph, wherein the electrical componentry comprises, consists essentially of, consists of photovoltaic cells. The method and/or system of the previous paragraph, wherein the electrical vehicle further comprises, consists essentially of, consists of an internal combustion engine. The method and/or system of any previous sentence wherein removing heat from said electrical componentry comprises, consists essentially of, or consists of situating the electrical componentry in a bath to be in direct fluid communication with the heat transfer fluid and circulating the heat transfer fluid through a heat transfer system. The method and/or system of any previous sentence, wherein the bath of the heat transfer system is in fluid communication with a heat transfer fluid reservoir and a heat exchanger.
- 5
- 10 **[0133]** A method of improving dispersancy of metal particles in a heat transfer fluid comprising preparing a fluid according to any previous sentence.

What is claimed is:

1. A heat transfer fluid comprising a mixture of hydrocarbon oil and oxygenate.
2. The heat transfer fluid of claim 1, wherein the hydrocarbon oil is substantially free, or
5 free, of cyclic structures.
3. The heat transfer fluid of any previous claim, wherein the hydrocarbon oil comprises isoparaffinic oil containing at least one saturated hydrocarbon compound having from 8 to 50 carbon atoms.
4. The heat transfer fluid of claim 3, wherein the at least one saturated hydrocarbon com-
10 pound contains at least 10 carbon atoms and at least one hydrocarbyl branch, and has a single continuous carbon chain of no more than 24 carbon atoms.
5. The heat transfer fluid of claim 3, wherein the at least one saturated hydrocarbon com-
pound comprises a branched acyclic compound with a molecular weight of 140 g/mol to 550 g/mol.
- 15 6. The heat transfer fluid of any previous claim, comprising from 1 to 45 wt.% of the oxygenate.
7. The heat transfer fluid of any previous claim, comprising from 1 to 20 wt.% of the oxygenate.
8. The heat transfer fluid of any previous claim, wherein the oxygenate agent comprises
20 an organic oxygenate.
9. The heat transfer fluid of claim 8 wherein the oxygenate comprises alcohol, ester, ether, polyether, or a mixture thereof.
10. The heat transfer fluid of any previous claim, having a kinematic viscosity measured at 100°C of 0.7 to 7.0 cSt as measured according to ASTM D445_100.
- 25 11. The heat transfer fluid of any previous claim, having a flash point of at least 50 °C as measured according to ASTM D56.

12. The heat transfer fluid of any previous claim, having a pour point of at least -5 °C as measured according to ASTM D5985.
13. The heat transfer fluid of any previous claim, having a dielectric constant of 5.0 or lower as measured according to ASTM D924.
- 5 14. The heat transfer fluid of any previous claim, further comprising heat transfer additives.
15. The heat transfer fluid of any previous claim, further comprising metal or non-metal particles or combinations thereof.
- 10 16. A method of cooling electrical componentry comprising immersing the electrical componentry in a bath comprising a heat transfer fluid of any previous claim, and operating the electrical componentry.
17. The method of claim 15, wherein the electrical componentry comprises a battery.
18. The method of claim 16, wherein the battery operates an electric vehicle.
- 15 19. The method of claim 15, wherein the electrical componentry comprises at least one of aircraft electronics, computer electronics, invertors, DC to DC convertors, AC to DC convertors, chargers, invertors, electric motors, and electric motor controllers.
20. The method of any of claims 15 to 18,
21. The method of claim 16, where the electrical componentry comprises a computer electronics.
- 20 22. An immersion coolant system for an electric vehicle comprising a battery pack situated in a bath, wherein the bath is in fluid communication with a heat transfer fluid reservoir comprising the heat transfer fluid of any of claims 1 to 14.