

HEAT-TRANSFER FLUIDS FOR INDIRECT LIQUID COOLING SYSTEMS

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DESCRIPTION**FIELD OF THE INVENTION**

The present application relates to the use of a heat-transfer fluid based on an aliphatic diester for the indirect cooling of electronic components.

BACKGROUND

Nowadays, heat dissipation is a relevant topic in the design and operation of electronic devices, especially for devices which comprise densely packaged electronic circuit components and in particular semi-conductor type circuit components such as integrated circuit components. Heat dissipation is a serious issue for example in modern server farms as well as in telecommunication centres and datacentres, where the large number of hard disks, microprocessors or central processing units (CPU) and the continuous increase of their processing and storage power renders heat dissipation a crucial factor for the prevention of overheating of such electronic components, which may lead to failure and irreparable damages to them.

In the field of design and operation of electronic devices, it is therefore strongly felt the need of identifying and developing new and improved cooling systems.

Today, there are different cooling systems which employ various techniques to transfer heat away from electronic components for maintaining their suitable operating temperature; they may be classified based on the type of heat-transfer fluid and on the basis of whether the heat-transfer occurs with a direct or indirect contact of the heat-transfer with the electronic component.

Indirect cooling systems are designed to dissipate the heat generated by the electronic components without letting the heat-transfer fluid come into direct contact with such components. Depending on the physical state and type of the heat-transfer fluid and on the mechanism of heat dissipation, common types of indirect cooling systems are:

- air cooling systems: this type of cooling systems is the most widely used method for indirect cooling of electronic components. It utilizes fans and heat sinks to dissipate heat. Fans, either active (powered) or passive (relying on natural convection),

enhance the airflow around the heat sink, improving heat dissipation. Air cooling systems are relatively simple, cost-effective, and suitable for many applications. However, their effectiveness may be limited in high-power or densely packed systems.

- phase-change cooling systems: they involve the use of refrigerants that change state from liquid to gas and back again. The cooling process starts with the refrigerant absorbing heat from the electronic components, causing it to evaporate into a gas. The gaseous refrigerant is then condensed back into a liquid by a heat exchanger, releasing the absorbed heat. The liquid refrigerant then flows back to the components, repeating the cycle.
- liquid cooling systems: liquid cooling systems use a heat-transfer fluid in liquid state to transfer heat away from electronic components. This method is more efficient than air cooling systems and it is less expensive and requires less complex systems than phase-change cooling systems .

Typically, indirect liquid cooling systems include a cooling loop for circulating the heat-transfer fluid, a pump system to circulate the heat-transfer fluid throughout the cooling loop, a thermally conductive element coupled to the electronic component to absorb the heat from the same and to transfer said heat to the heat-transfer fluid, a heat exchanger for dissipating the heat absorbed by the heat-transfer fluid and cool the same, and optionally a reservoir to contain the heat-transfer fluid. In these systems, the heat-transfer fluid is pumped by the pump system through the cooling loop, it enters into thermal contact with the thermally conductive element and in such a way it absorbs the heat from the same. It is thereby dissipating the heat generated by the electronic component, and the heat-exchange fluid is then cooled by the heat exchanger before being recirculated in the loop or is stored when cooled in the reservoir before being subsequently recirculated in the loop.

The heat-transfer fluid used in liquid cooling systems plays therefore a crucial role for heat dissipation and for the performance of the system itself, in view of its rheological and fluid dynamic properties, its thermal and chemical stability properties, as well as its thermal capacity properties. Today, known fluids for indirect liquid cooling are water and specialized fluids, among which those containing PFAS (per- and polyfluorinated substances) have found wide application.

SUMMARY OF INVENTION

The Applicant noted, however, that even if water is a common choice due to its excellent thermal properties and availability, it requires the implementation of complex and expensive purification systems for overcoming the risks of corrosion and of fouling that may lead to breakdowns and damages of the cooling system and of the electronic components. At the same time, water has a limited working temperature window and this further limits the cooling efficiency of the systems using it.

The Applicant also noted that even if specialized fluids such as those containing PFAS have enhanced properties, such as higher boiling points or better corrosion resistance allowing their use in specialized applications, these compounds have recently shown technical and application limitations.

PFAS, indeed, tend to have a high volatility and this results in a partial loss of these fluids due to their evaporation when exposed to high temperature components. This high volatility and partial loss of PFAS requires their refilling into the heat exchange system, at the same time increasing the exposition to said fluids for operators.

At the same time, PFAS have also raised relevant concerns for their environmental impact, rendering particularly critical their use and requiring also the adoption of complex and expensive containment systems for avoiding any spread and/or contact with the external environment during operation, transport, maintenance operations of the systems and devices using them.

An object of the present invention is therefore to provide a new heat-transfer fluid capable of overcoming the functional and environmental limits of the heat-transfer fluids currently employed in indirect liquid cooling systems of electronic components and the Applicant surprisingly found out that a heat-transfer fluid based on a specific class of aliphatic diesters may effectively be used for such purpose.

Particularly, the present invention relates, in a first aspect, to the use of a heat-transfer fluid comprising at least one diester of at least one C₂-C₉ aliphatic diol with at least one linear or branched C₂-C₇ aliphatic monocarboxylic acid, for cooling an electronic component with an indirect liquid cooling system.

Surprisingly, the Applicant has indeed found out that such diesters show suitable rheological and fluid dynamic properties, thermal and chemical stability properties, as well as thermal

capacity properties rendering the same effectively suitable for use in indirect liquid cooling systems for dissipating the heat generated by an electronic component.

Advantageously, said diesters may also offer a more environmentally sustainable solution to PFAS-based specialized fluids, rendering the operation, transport and maintenance operations of the cooling system, less critical.

Notably, said diesters offer excellent alternatives to PFAS-based fluids, particularly due to their remarkable low dynamic viscosity at extremely low temperatures. This exceptional property enables efficient pumpability and circulation of heat transfer fluids even in the harshest cold environments. Moreover, these esters boast a high flash point and low volatility, ensuring both safety and effective cooling of electronics at elevated temperatures. Their unique combination of low viscosity, high flash point, and low volatility make these diesters ideal choices for various types of indirect electronic cooling systems, providing efficient thermal management for a range of electronic devices., offering reliable and efficient heat transfer capabilities while prioritizing safety and performance.

These fluids, with their low viscosity, facilitate the effective transfer of heat away from electronic components in indirect cooling systems of different types. The high flash point and low volatility of these esters ensure at the same time safe operation and minimize the risk of fire or failure also in such systems.

For example, such diesters can be used as working fluids in heat pipes or in narrow channels or conduits, which are widely employed for indirect cooling electronic devices. These diesters enable efficient heat transfer in such conditions, allowing heat to be absorbed from the source and dissipated at the sink. The low viscosity of the fluids at the working temperature ensures optimal circulation through narrow channels or conduits and so even with a limited contact time and heat transfer surface area, enhancing the overall cooling performance.

This is a remarkably stringent requirement for viscosity in contrast with direct cooling system, particularly those using immersion baths, where the heat transfer fluid is not forced through narrow spaces and where the contact time and heat transfer surface area are greater than in indirect cooling systems.

In indirect cooling systems with closed-loops, such diesters may therefore advantageously serve as the heat transfer fluids circulating through a closed-loop system. As these fluids have low dynamic viscosity at the working temperature, they can easily flow through narrow

channels and intricate cooling structures, efficiently carrying heat away from electronic components. The high flash point and low volatility enhance the safety and reliability of the cooling system.

Said diesters can therefore also effectively be used in cold plate cooling systems, where they may advantageously flow through metal plates in direct contact with electronic components. The low viscosity of these fluids allows for efficient heat transfer, enabling effective cooling of high-power electronic devices. The high flash point and low volatility of the esters ensure safe operation and minimize the risk of fluid leakage or system damage.

In this way, a more efficient and safe use of electronic devices mounting electronic components can be achieved by improving their thermal management and avoiding or at least remarkably reducing overheating phenomena of electronic components mounted therein, which may lead to failure and irreparable damages of the same.

In addition, their low viscosity at low temperature allows to set and use a high and constant difference of temperature between the hot electronic component and the heat transfer fluid, making the heat exchange more effective and rapid. Maintaining a temperature as constant as possible, avoiding thermal changes or eliminating them as quickly as possible, is in fact a fundamental requirement for the cooling of electronic components and in particular those based on semiconductors.

In a further aspect, the present invention relates also to a method for cooling an electronic component with an indirect liquid cooling system, wherein said liquid cooling system comprises a heat-transfer fluid as defined in the first aspect of the invention.

In a still further aspect, the present invention relates also to an electronic device comprising: at least one electronic component; and

at least one indirect liquid cooling system apt to cool said electronic component and comprising at least one heat-transfer fluid as defined in the first aspect of the invention.

The advantages of the method and of the electronic device according to these aspects of the present invention have been already disclosed in relation to the use according to the first aspect of the present invention and are not herewith repeated.

DETAILED DESCRIPTION OF INVENTION

The present invention relates, in a first aspect, to the use of a heat-transfer fluid comprising at least one diester of at least one C₂-C₉ aliphatic diol with at least one linear or branched

C₂-C₇ aliphatic monocarboxylic acid, for cooling an electronic component with an indirect liquid cooling system.

Surprisingly, the Applicant has indeed found out that such diesters show suitable rheological and fluid dynamic properties, thermal and chemical stability properties, thermal capacity properties rendering the same effectively suitable for use in indirect liquid cooling systems for dissipating the heat generated by an electronic component.

Within the framework of the present description and in the subsequent claims, except where otherwise indicated, all the numerical entities expressing amounts, parameters, percentages, and so forth, are to be understood as being preceded in all instances by the term "about". As used herein, the term "about" will be understood by persons of ordinary skill in the art and will vary to some extent on the context in which it is used. As used herein when referring to a measurable value such as an amount, a temporal duration, and the like, the term "about" is meant to encompass variations of $\pm 20\%$ or $\pm 10\%$, including $\pm 5\%$, $\pm 1\%$, and $\pm 0.1\%$ from the specified value, as such variations are appropriate to perform the disclosed methods.

Also, all ranges of numerical entities include all the possible combinations of the maximum and minimum values and include all the possible intermediate ranges, in addition to those specifically indicated herein below.

Unless defined otherwise, all technical and scientific terms used herein generally have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

As used herein, the articles "a" and "an" refer to one or to more than one (i.e. to at least one) of the grammatical object of the article. By way of example, "an element" means one element or more than one element.

As used herein, with the expression "indirect liquid cooling system" is meant a cooling system wherein the heat-transfer fluid is (or is kept) in liquid state, or predominantly in liquid state, during the operation of the system and wherein said heat-transfer fluid does not come into direct contact with the component that has to be cooled- while being apt to cool the same. In particular, when referred to an electronic component, an indirect liquid cooling system is a cooling system wherein the heat-transfer fluid does not come into direct contact with such electronic components, for example by interposition of a different element thermally coupled with the electronic component and made of a thermally conductive

material, such as copper or other metals, that is interposed between the electronic components and the heat-transfer fluid. This thermally conductive element prevents the direct contact of the fluid with the electronic component and has the function of transferring the heat. In indirect cooling systems such different elements interposed between the electronic components and the heat-transfer fluid may have different shapes and configurations (heat sinks, a wall in a tube, or a plate) depending on the design of the system.

In indirect cooling heat transfer involves both conduction and convection, as the fluid exchanges heat with a material thermally coupled with the component to be cooled and the heat exchange is predominantly influenced by the difference of temperature between the component to be cooled and the heat transfer fluid.

The present invention may present in one or more of the above aspects one or more of the characteristics disclosed hereinafter.

According to the present invention, the heat-transfer fluid comprises at least one diester of at least one C₂-C₉ aliphatic diol with at least one linear or branched C₂-C₇ aliphatic monocarboxylic acid.

Preferably, said C₂-C₉ aliphatic diol is selected from the group consisting of: ethylene glycol, 1,2-propanediol, 1,3-propanediol, 1,4-butanediol, 1,3-butanediol, di-ethylene glycol, tri-ethylene glycol, di-propylene glycol, neopentyl glycol, 2-methyl-1,3-propanediol, 1,5-pentanediol, 1,6-hexanediol, 3-methyl-1,5-pentanediol, 2-butyl-2-ethyl-1,3-propanediol, 2,2,4-trimethyl-1,3-pentanediol and mixtures thereof.

Preferably, the aliphatic diol of the diester according to the invention is a C₃-C₆ aliphatic diol, more preferably selected from the group consisting of: 1,3-propanediol, 1,4-butanediol, 1,3-butanediol, di-ethylene glycol, tri-ethylene glycol, di-propylene glycol, neopentyl glycol, 2-methyl-1,3-propanediol, 1,5-pentanediol, 1,6-hexanediol, 3-methyl-1,5-pentanediol and mixtures thereof. Even more preferably, the aliphatic diol of the diester according to the invention is a C₃-C₅ aliphatic diol, still even more preferably selected from the group consisting of: 1,3-propanediol, 1,4-butanediol, 1,3-butanediol, di-ethylene glycol, neopentyl glycol, 2-methyl-1,3-propanediol, 1,5-pentanediol, and mixtures thereof.

In a preferred embodiment, the aliphatic diol of the diester according to the invention is selected from the group consisting of 1,2-propanediol, 1,3-propanediol, neopentyl glycol,

and mixtures thereof, preferably selected from the group consisting of 1,2-propanediol, 1,3-propanediol and mixtures thereof.

In an embodiment of the invention, the linear or branched C₂-C₇ aliphatic monocarboxylic acid of the diester according to the invention is a C₃-C₅ aliphatic monocarboxylic acid, more preferably selected from the group consisting of: propanoic acid, butyric acid, isobutyric acid, 2-methylbutyric acid, 3-methylbutyric acid, valeric acid, and mixtures thereof; more preferably is selected from the group consisting of: 2-methylbutyric acid, 3-methylbutyric acid, valeric acid, and mixtures thereof.

In another embodiment of the invention, the linear or branched C₂-C₇ aliphatic monocarboxylic acid of the diester according to the invention is a C₅-C₇ aliphatic monocarboxylic acid; preferably in such embodiment at least one of the monocarboxylic acids of the diester according to the invention is a C₅ acid. More preferably in such embodiment the aliphatic monocarboxylic acid of the diester according to the invention is a C₅ acid, optimally valeric acid.

In a preferred embodiment of the present invention, said diester is selected from the group consisting of: neopentyl glycol divalate, 1,2-propanediyl divalate, 1,3-propanediyl divalate, 2-methyl-1,3-propanediyl divalate, and mixtures thereof, more preferably 1,2-propanediyl divalate, 1,3-propanediyl divalate, and mixtures thereof.

Diols, monocarboxylic acids, and diesters as above defined have indeed surprisingly shown a combination of properties, such as a low dynamic viscosity at temperatures up to – 55 °C combined with a flash point higher than 125 °C, and a high volume resistivity, rendering them particularly suitable and operatively efficient in indirect electronic cooling systems in a broad temperature range window from - 55 °C to 125 °C, and so particularly efficient as components of heat-transfer fluids for indirect liquid cooling systems of electronic components.

In addition to the diester, the heat-transfer fluid according to the invention may advantageously contain one or more other components, among which for example a synthetic or natural ester, a mineral oil, a polyether such as a polyalkylene glycol, a polyolefin, an additive.

In an embodiment, the heat-transfer fluid according to the invention comprises at least one diester as defined above and at least one monoester of at least one C₆-C₁₂ aliphatic mono-

alcohol with at least one linear or branched C₂-C₁₂ aliphatic monocarboxylic acid, for example a monoester such as 2-propylheptanyl valerate, 2-ethylhexanyl heptanoate.

Preferably, the heat-transfer fluid according to the invention comprises at least one additive selected from the group consisting of: an antioxidant, a pour-point-depressant additive, an antifoam, an anticorrosion agent, a viscosity modifier, a wear-resistance and/or extreme-pressure additive, a friction modifier, a detergent, a dispersant, and mixtures thereof.

Advantageously, the heat-transfer fluid according to the invention shows one or more of the following features:

- a dynamic viscosity at – 30 °C of less than 50 mPa*s;
- a flash point higher than 125 °C;
- a volume resistivity at 25 °C higher than 0.1 tera ohm-centimeter (TΩ*cm).

Additionally, the heat-transfer fluid according to the invention shows suitable heat capacity and thermal conductivity properties for cooling electronic components.

Preferably, the heat-transfer fluid according to the present invention is in liquid state during the operation of the indirect liquid cooling system.

In the indirect liquid cooling system according to the invention, the heat-transfer fluid has the function of dissipating the heat generated by an electronic component, which may be advantageously mounted in an electronic device.

In indirect cooling heat transfer involves both conduction and convection, as the fluid exchanges heat with a material thermally coupled with the component to be cooled and the heat exchange is predominantly influenced by the difference of temperature between the component to be cooled and the heat transfer fluid. Another well-known factor influencing the heat exchange is the quantity of the heat exchange fluid used, which in turn is limited by the design of the cooling system.

Thanks to the advantageous properties of the heat transfer fluid according to the present invention, the indirect liquid cooling system is not particularly limited and may be any type of indirect liquid cooling system known to the skilled person in the relevant technical field for indirectly cooling an electronic component.

Preferably, the indirect liquid cooling system according to the present invention comprises at least one thermally conductive element thermally coupled to said electronic component,

and said thermally conductive element is apt to transfer heat from said electronic component to said heat-transfer fluid. More preferably, said thermally conductive element is selected from the group consisting of: a wall, a layer, a heat sink, a cold plate, a heat pipe, and a vapour chamber.

Preferably, said indirect liquid cooling system comprises:

- a liquid cooling loop apt to circulate said heat-transfer fluid;
- a pump apt to pump said heat-transfer fluid throughout said liquid cooling loop;
- an heat exchanger apt to cool said heat-transfer fluid; and
- optionally, a reservoir apt to contain said heat-transfer fluid.

According to the present invention, the electronic component may be any type of electronic component apt to generate heat when in use and that needs to be therefore cooled, or that may undergo to failure and irreparable damages following an overheating.

Preferably, said electronic component is selected from the group consisting of: a microprocessor, a semiconductor wafer, a power control semiconductor, an electrochemical cell, an electrical distribution switch gear, a power transformer, a circuit board, a multi-chip module, an hard disk, a central processing unit, a packaged or unpackaged semiconductor device, a fuel cell, a laser, and a semiconductor integrated circuit.

More preferably, said electronic component is selected from the group consisting of: a microprocessor, a semiconductor wafer, a power control semiconductor, a circuit board, a multi-chip module, an hard disk, a central processing unit, a packaged or unpackaged semiconductor device, and a semiconductor integrated circuit.

Preferably, said electronic component is mounted in an electronic device.

According to the present invention, the electronic device may be any type of electronic device mounting an electronic component, and it is not particularly limited. Preferably, said electronic device is selected from the group consisting of: a computer, a server, a server farm, a telecommunication centre, and a datacentre.

Thanks to the properties of the heat-transfer fluid according to the present invention, a more efficient and safe cooling method of electronic components can be achieved by improving their thermal management and avoiding or remarkably reducing overheating phenomena, which may lead to failure and irreparable damages.

In a further aspect, therefore, the present invention relates also to a method for cooling an electronic component with an indirect liquid cooling system, wherein said liquid cooling system comprises a heat-transfer fluid comprising at least one diester of at least one C₂-C₉ aliphatic diol with at least one linear or branched C₂-C₇ aliphatic monocarboxylic acid, as above defined in the first aspect of the invention.

Advantages and preferred features of this method have been already defined above with respect to the first aspect of the invention, and are therefore not herewith repeated.

In the method according to this aspect of the invention, an heat-transfer fluid as defined in the first aspect of the invention is used. Preferred features of this heat-transfer fluid have been therefore already defined above with respect to the same component in the first aspect of the invention, and are therefore not herewith repeated.

Preferred features of the indirect liquid cooling system and of the electronic component of the method according to the present invention have also been already defined above with respect to the same components in the first aspect of the invention, and are therefore not herewith repeated.

Preferably, the method for cooling an electronic component according to the present invention comprises the step of: transferring heat from said electronic component to said heat-transfer fluid.

In a preferred embodiment, when in the method according to the present invention the indirect liquid cooling system comprises at least one thermally conductive element thermally coupled to said electronic component, in said step of transferring heat said thermally conductive materials is apt to transfer heat from said electronic component to said heat-transfer fluid.

Thanks to the use of the heat-transfer fluid comprising the diesters as above defined in an indirect liquid cooling system for cooling an electronic component, a more efficient and safe use of electronic devices mounting them can be achieved, by improving their thermal management and avoiding or remarkably reducing overheating phenomena, which may lead to failure and irreparable damages.

In a further aspect, the present invention therefore relates also to an electronic device comprising:

at least one electronic component; and

at least one indirect liquid cooling system apt to cool said electronic component and comprising at least one heat-transfer fluid comprising at least one diester of a C₂-C₉ aliphatic diol with at least one linear or branched C₂-C₇ aliphatic monocarboxylic acid, as above defined in the first aspect of the invention.

The advantages and preferred features of the electronic device according to the present invention have been disclosed in relation to the use and method according to the other aspects of the present invention and are not herewith repeated.

In the device according to this aspect of the invention, an heat-transfer fluid and an indirect liquid cooling system as defined in the other aspects of the invention is used. Preferred features of this heat-transfer fluid and indirect liquid cooling system have been therefore already defined above with respect to the same components in the other aspects of the invention, and are therefore not herewith repeated.

Preferably, the electronic device according to this aspect of the invention is selected from the group consisting of: a computer, a server, a server farm, a telecommunication centre, and a datacentre.

Preferably, in the device according to this aspect of the invention the electronic component of the device according to this aspect of the invention is selected from the group consisting of: a microprocessor, a semiconductor wafer, a power control semiconductor, an electrochemical cell, an electrical distribution switch gear, a power transformer, a circuit board, a multi-chip module, an hard disk, a central processing unit, a packaged or unpackaged semiconductor device, a fuel cell, a laser, and a semiconductor integrated circuit.

More preferably, said electronic component is selected from the group consisting of: a microprocessor, a semiconductor wafer, a power control semiconductor, a circuit board, a multi-chip module, an hard disk, a central processing unit, a packaged or unpackaged semiconductor device, and a semiconductor integrated circuit.

In a further aspect, the present invention relates also to a heat transfer fluid for cooling an electronic component, comprising at least one diester of a C₂-C₉ aliphatic diol with at least one linear or branched C₂-C₇ aliphatic monocarboxylic acid and at least one an additive selected from the group consisting of: an antioxidant, a pour-point-depressant additive, an antifoam, an anticorrosion agent, a viscosity modifier, a wear-resistance and/or extreme-pressure additive, a friction modifier, a detergent, a dispersant, and mixtures thereof.

The advantages and preferred features of the heat transfer fluid according to the present invention have been disclosed in relation to the use and method according to the other aspects of the present invention and are not herewith repeated.

Preferred features of the heat-transfer fluid according to this further aspect of the invention have been therefore already defined above with respect to the same component in the first aspect of the invention, and are therefore not herewith repeated.

Further features and advantages of the invention will appear more clearly from the following description of some preferred embodiments thereof, made hereinafter by way of the following non-limiting examples.

EXPERIMENTAL PART

Example 1 – preparation of neopentyl glycol divalerate

400 g (3.84 moles) of neopentyl glycol were charged in a multi neck reaction flask equipped with anchor stirrer, Vigreux column, condenser and distillate vessel. 980 g (9.6 moles) of valeric acid and 3 g of sodium hypophosphite monohydrate were added to the flask. The stirring was started and the system was purged with nitrogen, then the temperature was raised up to the boiling of the reaction mixture. The reaction was then left to run until a quantity of water corresponding to 100 % of the stoichiometric amount for a 100% esterification yield was evaporated. After that, the unreacted valeric acid was removed by vacuum distillation, until an acid value of less than 5 mg KOH/g was obtained. A sodium hydroxide aqueous solution at 4 wt% in stoichiometric excess with respect to the quantity needed to neutralize said acid value was added to the esterified product and stirred for 30 minutes; the organic phase was then separated from the aqueous phase, then washed with water, and then dried under vacuum and filtered.

Example 2 – preparation of 1,2-propanediyl divalerate

Example 1 was repeated, using 292.18 g (3.84 moles) of 1,2-propanediol instead of 400 g of neopentyl glycol, and obtaining at the end of the valeric acid removal an acid value of 5 mgKOH/g.

Example 3 – preparation of 1,3-propanediyl divalerate

Example 1 was repeated, using 292.184 g (3.84 moles) of 1,3-propanediol instead of 400 g of neopentyl glycol, and obtaining at the end of the valeric acid removal an acid value of 5 mgKOH/g.

Example 4 – preparation of 2-methyl-1,3-propanediyl divalerate

Example 1 was repeated, using 346 g (3.84 moles) of 2-methyl-1,3-propanediol instead of 400 g of neopentyl glycol, and obtaining at the end of the valeric acid removal an acid value of 5 mgKOH/g.

Example 5 - characterization of the diesters

The diesters obtained according to examples 1 - 4 were characterized in terms of dynamic viscosity at – 30 °C according to ISO 3219, flash point according to ASTM D7094-04, pour point according to ASTM D5950, and volume resistivity at 25 °C according to ASTM D1169. The results are reported in Table 1 below.

Table 1

	Ex. 1	Ex. 2	Ex. 3	Ex. 4
Dynamic viscosity (mPa*s) at - 30 °C	40	24	25	36
Flash point (°C)	154	130	145	145
Pour point (°C)	-93	-96	-66	-96
Volume resistivity (TΩ*cm) at 25 °C	2.0	0.69	0.97	0.89

Example 6 - characterization of the diesters

The diesters obtained according to examples 1 - 4 were characterized in terms of thermal conductivity, thermal diffusivity and specific heat.

The analysis were performed with transient hot wire method, according to ASTM D7896-19. The test equipment was Thermtest THW-L2; thermal conductivity and diffusivity were measured at 40°C whereas the specific heat was calculated as: $C_p \text{ at } 40\text{ °C} = \text{Thermal conductivity at } 40\text{ °C} / (\text{Thermal diffusivity at } 40\text{ °C} * \text{Density at } 40\text{ °C})$

The results are reported in Table 2 below.

Table 2

	Ex 1	Ex 2	Ex 3	Ex 4
Thermal conductivity (W/m*K) at 40°C	0.1449	0.1360	0.1449	0.1387
Thermal diffusivity (mm ² /s) at 40°C	0.0675	0.0631	0.0651	0.0638
Specific heat (J/g*K) at 40°C	2.31	2.15	2.23	2.18

Based on the comprehensive characterization of the developed and characterized diesters for indirect cooling of the examples above, it is evident that these fluids present highly promising attributes as alternative solutions to PFAS-based fluids. The diesters exhibit remarkable features such as low viscosity at ultra-low temperatures, ensuring efficient flow and circulation even in demanding cooling applications. Additionally, their high flash point enhances safety measures, reducing the risk of potential fire hazards.

Moreover, the diesters demonstrate excellent volume resistivity and permittivity, guaranteeing optimal electrical insulation properties. Furthermore, their exceptional thermal conductivity and heat transfer capacity enable efficient dissipation of heat, contributing to enhanced performance and reliability of electronic systems. Considering these advantageous characteristics, the diesters represent highly favourable substitutes to PFAS fluids in the realm of electronic cooling applications.

In summary, the diesters offer a more sustainable and environmentally friendly option compared to PFAS fluids, particularly in terms of greenhouse gas emissions. Their superior characteristics, coupled with reduced environmental impact, make them highly favourable alternatives for cooling electronics.

CLAIMS

1. Use of a heat-transfer fluid comprising at least one diester of at least one C₂-C₉ aliphatic diol with at least one linear or branched C₂-C₇ aliphatic monocarboxylic acid, for cooling an electronic component with an indirect liquid cooling system.
2. The use according to claim 1, wherein in said heat-transfer fluid said C₂-C₉ aliphatic diol of said diester is selected from the group consisting of: ethylene glycol, 1,2- propanediol, 1,3- propanediol, 1,4-butanediol, 1,3-butanediol, di-ethylene glycol, tri-ethylene glycol, di-propylene glycol, neopentyl glycol, 2-methyl-1,3-propanediol, 1,5-pentanediol, 1,6-hexanediol, 3-methyl-1,5-pentanediol, 2-butyl-2-ethyl-1,3-propanediol, 2,2,4-trimethyl-1,3-pentanediol and mixtures thereof.
3. The use according to claim 1 or 2, wherein in said heat-transfer fluid said aliphatic diol of the diester is a C₃-C₆ aliphatic diol.
4. The use according to claim 3, wherein in said heat-transfer fluid said aliphatic diol of said diester is a C₃-C₅ aliphatic diol.
5. The use according to any one of claims from 1 to 4, wherein in said heat-transfer fluid said monocarboxylic acid of said diester is a C₃-C₅ aliphatic monocarboxylic acid.
6. The use according to any one of claims from 1 to 4, wherein in said heat-transfer fluid said monocarboxylic acid of said diester is a C₅-C₇ aliphatic monocarboxylic acid.
7. The use according to any one of claims from 1 to 6, wherein in said heat-transfer fluid said diester is selected from the group consisting of: neopentyl glycol divalate, 1,2-propanediyl divalate, 1,3-propanediyl divalate, 2-methyl-1,3-propanediyl divalate and mixtures thereof.
8. The use according to any one of claims from 1 to 7, wherein said indirect liquid cooling system comprises at least one thermally conductive element thermally coupled to said electronic component, wherein said thermally conductive element is apt to transfer heat from said electronic component to said heat-transfer fluid.
9. The use according to claim 8, wherein said thermally conductive element is selected from the group consisting of: a wall, a layer, a heat sink, a cold plate, a heat pipe, and a vapour chamber.
10. The use according to any one of claims from 1 to 9, wherein said indirect liquid cooling system comprises:

a liquid cooling loop apt to circulate said heat-transfer fluid;
a pump apt to pump said heat-transfer fluid throughout said liquid cooling loop;
a heat exchanger apt to cool said heat-transfer fluid; and
optionally, a reservoir apt to contain said heat-transfer fluid.

11. The use according to any one of claims from 1 to 10, wherein said electronic component is selected from the group consisting of: a microprocessor, a semiconductor wafer, a power control semiconductor, an electrochemical cell, an electrical distribution switch gear, a power transformer, a circuit board, a multi-chip module, an hard disk, a central processing unit, a packaged or unpackaged semiconductor device, a fuel cell, a laser, and a semiconductor integrated circuit.

12. The use according to any one of claims from 1 to 11, wherein said electronic component is mounted in an electronic device.

13. The use according to claim 12, wherein said electronic device is selected from the group consisting of: a computer, a server, a server farm, a telecommunication centre, and a datacentre.

14. A method for cooling an electronic component with an indirect liquid cooling system, wherein said liquid cooling system comprises a heat-transfer fluid comprising at least one diester of at least one C₂-C₉ aliphatic diol with at least one linear or branched C₂-C₇ aliphatic monocarboxylic acid.

15. The method according to claim 14, wherein said method comprises the step of: transferring heat from said electronic component to said heat-transfer fluid.

16. The method according to claim 14 or 15, wherein said heat-transfer fluid is a heat-transfer fluid according to any claims from 1 to 7.

17. The method according to any one of claims from 14 to 16, wherein said indirect liquid cooling system is an indirect liquid cooling system according to any claims from 8 to 10.

18. The method according to claim 17, wherein said indirect liquid cooling system comprises at least one thermally conductive element thermally coupled to said electronic component, and wherein in said step of transferring heat said thermally conductive materials is apt to transfer heat from said electronic component to said heat-transfer fluid.

19. The method according to any one of claims from 14 to 18, wherein said electronic component is an electronic component according to any one of claims from 11 to 12.

20. An electronic device comprising:
at least one electronic component; and
at least one indirect liquid cooling system apt to cool said electronic component and comprising at least one heat-transfer fluid comprising at least one diester of a C₂-C₉ aliphatic diol with at least one linear or branched C₂-C₇ aliphatic monocarboxylic acid.
21. The electronic device according to claim 20, wherein said heat-transfer fluid is an heat-transfer fluid according to any claims from 1 to 7.
22. The electronic device according to claim 20 or 21, wherein said indirect liquid cooling system is an indirect liquid cooling system according to any claims from 8 to 10.
23. The electronic device according to any one of claims from 20 to 22, wherein said electronic device is selected from the group consisting of: a computer, a server, a server farm, a telecommunication centre, and a datacentre.
24. The electronic device according to any one of claims from 20 to 23, wherein said electronic component is an electronic component is selected from the group consisting of: a microprocessor, a semiconductor wafer, a power control semiconductor, an electrochemical cell, an electrical distribution switch gear, a power transformer, a circuit board, a multi-chip module, an hard disk, a central processing unit, a packaged or unpackaged semiconductor device, a fuel cell, a laser, and a semiconductor integrated circuit.
25. A heat transfer fluid for cooling an electronic component, comprising at least one diester of a C₂-C₉ aliphatic diol with at least one linear or branched C₂-C₇ aliphatic monocarboxylic acid and at least one an additive selected from the group consisting of: an antioxidant, a pour-point-depressant additive, an antifoam, an anticorrosion agent, a viscosity modifier, a wear-resistance and/or extreme-pressure additive, a friction modifier, a detergent, a dispersant, and mixtures thereof.