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# (54) AN ENERGY TRANSFER SYSTEM, A METHOD OF MANUFACTURING THEREOF, AND A METHOD OF INCREASING A THERMAL STABILITY OF A WORKING FLUID THEREIN

(57) The invention relates to an energy transfer system comprising a thermal circuit with a working fluid configured to perform a thermodynamic cycle and/or an energy transfer process, the thermal circuit comprising a piping system for conveying the working fluid, and at least one energy transfer device, wherein the energy transfer device is configured to transfer a portion of energy from one part of the thermal circuit to another part of the thermal circuit, and wherein at least a portion of the thermal circuit comprises a coating layer on surfaces in contact with the working fluid, wherein the coating layer includes an inert material that is inert with respect to the working fluid during operation and that maintains structural integrity at a temperature above 550 K, and wherein the inert material, when in a pure state/form, has a thermal conductivity above 50 W/mK at room temperature.

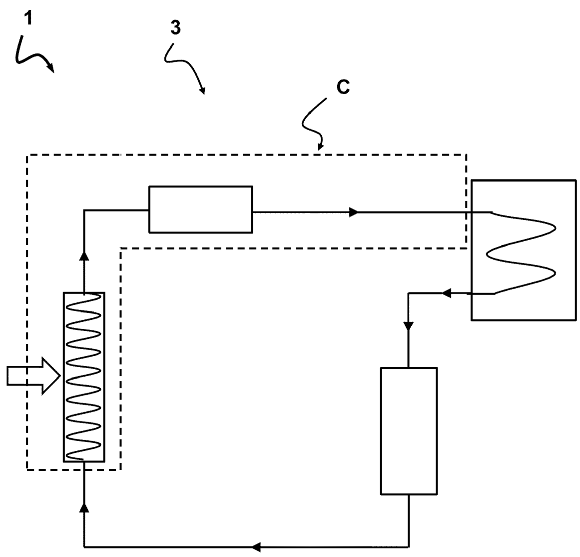


FIG 3

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## Description

FIELD OF THE INVENTION

**[0001]** The invention relates to an energy transfer system comprising a thermal circuit with a working fluid configured to perform a thermodynamic cycle and/or an energy transfer process. Furthermore, the invention relates to a method of manufacturing an energy transfer system. Additionally, the invention relates to a method of increasing a thermal stability limit temperature of a working fluid in an energy transfer system.

BACKGROUND TO THE INVENTION

**[0002]** Energy transfer systems are well known and widely used in various applications. Typically, a working fluid, possibly including a heat transfer fluid, is used in a thermal circuit configured for carrying out a thermodynamic cycle and/or an energy transfer process. For example, various thermal conversion systems make use of organic fluids as heat transfer medium or working fluid to realize a thermodynamic cycle. Exemplary applications are heat pumps, thermal oil baths, concentrated solar collectors, and Organic Rankine Cycle (ORC) electric generators.

**[0003]** However, the performance of an energy transfer systems is often limited by the thermal stability of the working fluid (e.g. organic fluid) they adopt when characterized by relatively high operating temperatures. More particularly, above a certain temperature threshold, the organic molecules may start to decompose by breaking down into smaller compounds and the properties of the original organic fluid may be lost. This can result in significant drops in the performance of the energy transfer systems or even its failure over time. Additionally, such detrimental effects may also result in an environmental or safety hazard. The organic compounds resulting from the decomposition process may, for example, be toxic and/or lead to the formation of a solid layer within piping and heat exchangers, which reduces heat transfer or even clogs the flow passages. In order to effectively prevent this, organic fluids have always to be operated at temperatures below their thermal stability limit, with a consequent limitation on the maximum performance of the application.

**[0004]** In many cases, the thermal stability of organic fluids currently employed in high temperatures applications does not exceed 400 - 425 °C for stainless steel as containment material. For instance, the maximum operating temperature of thermal oils of industrial heaters and solar parabolic troughs may be at most 425 °C for stainless steel as containment material. Similarly, the maximum temperature of state-of-the-art high-temperature ORC systems may be bound to the same limit. The fluids showing the best thermal stability, such as benzene and toluene, are, however, highly toxic and flammable. For this reason, the maximum operating temperature of ORC units is in practice typically around 300 °C for stainless steel as containment material.

**[0005]** The use of mixtures may increase the thermal stability of organic heat transfer media/working fluids. The idea is that a blend of organic fluids may exhibit, at the same temperature level, a lower decomposition rate than that of the single pure fluids of the mixture. However, the use of such mixtures may only allow a limited increase of the thermal stability limit temperature of a working fluid in an energy transfer system.

**[0006]** There is a strong desire to improve the performance of energy transfer systems in a reliable way.

SUMMARY OF THE INVENTION

**[0007]** It is an object of the invention to provide for a method and a system that obviates at least one of the above mentioned drawbacks.

**[0008]** Additionally or alternatively, it is an object of the invention to improve the performance of energy transfer systems.

**[0009]** Additionally or alternatively, it is an object of the invention to improve the reliability and/or reduce maintenance costs for energy transfer systems.

**[0010]** Additionally or alternatively, it is an object of the invention to improve the design of energy transfer systems.

**[0011]** Additionally or alternatively, it is an object of the invention to increase the thermal stability limit temperature of a working fluid in an energy transfer system.

**[0012]** Additionally or alternatively, it is an object of the invention to increase the achievable efficiency in energy transfer systems.

**[0013]** Thereto, the invention provides for an energy transfer system comprising a thermal circuit with a working fluid configured to perform a thermodynamic cycle and/or an energy transfer process, the thermal circuit comprising a piping system for conveying the working fluid, and at least one energy transfer device, wherein the energy transfer device is configured to transfer a portion of energy from one part of the thermal circuit to another part of the thermal circuit, and wherein at least a portion of the thermal circuit comprises a coating layer on surfaces in contact with the working fluid, wherein the coating layer includes an inert material that is inert with respect to the working fluid during operation and that maintains structural integrity at a temperature above 550 K, and wherein the inert material has, when in pure state/form, a thermal conductivity above 50 W/mK at room temperature.

**[0014]** The performance of the energy transfer system is often limited by the stability limit temperature of the working fluid. The temperature at which the working fluid can be used within the thermal circuit of the energy transfer system depends on its stability limit temperature. The temperature of the working fluid in the thermal circuit is kept below its thermal stability temperature in order to prevent detrimental effects such as fluid decomposition.

In this way, the frequency in which the working fluid has to be replaced by new working fluid may be reduced. For example, a periodic replacement of the working fluid may be delayed, or even prevented.

**[0015]** The present invention presents the advantage that due to the presence of the coating layer, the working fluid can be effectively used at higher temperatures in the vicinity of or above its thermal stability limit temperature, for instance, when used with stainless steel, in at least some parts of the thermal circuit in which the coating layer is provided at the contact surface between a solid material and the working fluid. In this way, the performance of the energy transfer system can be effectively increased. Advantageously, a more cost-effective solution can be obtained. Additionally or alternatively, the energy transfer system may require less maintenance.

**[0016]** The coating layer may provide an inert surface in contact with the working fluid, resulting in a higher thermal stability for said working fluid. The material properties of the coating layer are selected such that the stability limit temperature of the working fluid can be increased. As a result, the design of the energy transfer system can be improved.

**[0017]** Optionally, the coating layer is provided for preventing deterioration and/or degradation of the working fluid at higher temperatures in the vicinity or above the thermal stability limit temperature when in contact with stainless steel in the thermal circuit. For example, the coating layer may be a carbon based layer with a particular nanostructure which can effectively increase the stability of the working fluid at higher temperatures.

**[0018]** Optionally, the coating layer is only applied on surfaces in contact with the working fluid at or approximate locations in the thermal circuit at which high temperature heat transfer occurs.

**[0019]** Optionally, the energy transfer system is configured to have the working fluid heated to a temperature above its thermal stability limit temperature for the material of the surface which is coated by the coating layer. For example, the one or more surfaces being coated by the coating layer may be made of stainless steel. Hence, in these cases, the energy transfer system may be configured to heat the working fluid to an increased temperature which is above its thermal stability limit temperature for stainless steel as uncoated containment material. Advantageously, the system can effectively increase the thermal stability limit of the working fluid.

**[0020]** It will be appreciated that the piping system may include pipes, conduits, channels, holes and/or other components, such as reservoirs, pumps, etc. for conveying the working fluid. In some examples, one or more (inner) surfaces of the piping system are coated with the inert material.

**[0021]** Optionally, the inert material has a damage temperature above 620 K, preferably above 670 K, even more preferably above 690 K.

**[0022]** The damage temperature is the temperature at which the mechanical properties of the coating and its structural integrity start to degrade. In this way, the coating layer may be effectively used for increasing the thermal stability limit temperature of the working fluid in the thermal circuit of the energy transfer system. As a result, the achievable efficiency in the energy transfer system can be improved.

**[0023]** Optionally, the coating layer comprises silicon carbide as coating material. Optionally, the coating material (in a pure state/form) has a thermal conductivity of 60 to 120 at ambient temperature.

**[0024]** Optionally, the inert material, when in a pure state/form, has a thermal conductivity above 1000 W/mK at room temperature. Such relatively high thermal conductivity of the inert material may be beneficial.

**[0025]** Optionally, the inert material in a pure state/form has a thermal conductivity in a range of 1000 to 5000 W/mK at room temperature.

**[0026]** It is preferred that the inert material has a high thermal conductivity. Such high thermal conductivity in combination with its inert properties can result in a higher thermal stability limit temperature of the working fluid, thereby enabling an enhancement of the performance and/or efficiency of the energy transfer system, without causing a decrease in the heat transfer properties of the heat transfer equipment.

**[0027]** Optionally, the inert material is graphene or contains graphene.

**[0028]** The graphene coating layer has excellent properties for increasing the thermal stability of the working fluid. It can be used to locally increase the thermal stability of the working fluid in the thermal circuit, preferably at the higher temperature parts of said thermal circuit. For example, the graphene coating layer may be applied locally on surfaces in contact with the working fluid near and/or inside the heat exchangers (e.g. at heat exchangers and approximate tubing). Graphene can enable a wide surface functional coating. Furthermore, a graphene coating layer is stable and is not consumed during operation due to its inert properties. Additionally, it has advantageous mechanical properties, such that breaking (cf. brittleness) can be prevented. Hence, the coating layer can retain its structural integrity for a relatively long period of time, even under harsh circumstances. Moreover, graphene has excellent heat transfer properties and is a great thermal conductor. It can be used at high temperatures. Additionally, the graphene coating layer may provide additional benefits, such as, smoothness of coating, non-stickiness of coating, anti-corrosive properties of coating, etc.

**[0029]** Optionally, the coating layer is applied locally only in one or more parts of the thermal circuit.

**[0030]** The energy transfer system may have the coating layer around some or all of the components in the thermal circuit that are in direct contact with the working fluid. In some examples, only a subset of components in the thermal circuit are provided with the coating layer. Only parts of the thermal circuit where it is necessary to increase the thermal stability limit of the working fluid may be coated with the coating layer. Advantageously, in this way, the manufacturing costs may be significantly reduced.

**[0031]** Optionally, at least a subset of pipes of the piping system of the thermal circuit, where in contact with the working fluid, are coated with the coating layer.

**[0032]** Graphene can have a very high thermal conductivity. However, lower conductivity graphene material may also be used. The actual thermal conductivity may depend on the coating thickness and the employed deposition process.

**[0033]** Optionally, the inert material in a pure state/form has a thermal conductivity in above that of a material of the surface on which it is applied. In some examples, the inert material has a thermal stability above that of stainless steel.

**[0034]** Optionally, the heat transfer circuit of the energy transfer system comprises a first portion and a second portion, wherein the first portion is configured to convey the working fluid in a first temperature range, and wherein the second portion is configured to convey the working fluid in a second temperature range, wherein the first temperature range is below 550 K, preferably below 520 K, and wherein the second temperature range is above 570 K, preferably above 600 K, and wherein only surfaces in contact with working fluid in the second portion of the heat transfer circuit are coated with the coating layer.

**[0035]** In some examples, only parts of the thermal circuit are coated with the coating layer. For example, for a solar power plant system (e.g. solar collector system), the coating layer may be provided on surfaces in contact with the fluid being at higher temperatures. For example in a solar power plant, the higher temperature part where the coating may be applied includes the heat exchangers used to transfer the thermal energy from the thermal fluid (e.g. thermal oil) of the solar collectors to the power cycle, and the solar collector piping (e.g. made of stainless steel). Another exemplary applications are ORC power units. In this case, the high temperature part that may be coated comprises the heat exchangers and the piping that goes to the turbine, In some examples, at least a part of the surfaces of the turbine which are in contact with the working fluid can also be coated with the coating layer. It is not needed to coat the lower temperature parts of the thermal circuit, which can result in a more cost-effective solution.

**[0036]** No coating may be provided on a power cycle side where the working fluid is steam. Hence, the coating may be applied in parts of the thermal circuit where it can be used for increasing the thermal stability of the working fluid(s). In this way, a cost-effective solution can be obtained for increasing the efficiency.

**[0037]** Optionally, the second temperature range is between 570 K to 870 K, preferably 600 K to 820 K.

**[0038]** In this way, the coating layer is only applied selectively in parts of the thermal circuit which require an increase of the thermal stability limit temperature of the working fluid. The lower temperature part of the thermal circuit may not require such coating, since the working fluid will not degrade and/or deteriorate at those temperatures.

**[0039]** Optionally, the coating layer forms a smooth surface, preferably having a thickness in a range of 1 to 2000 micrometer, more preferably in a range of 10 micrometer to 2000 micrometer, even more preferably in range of 15 micrometer to 1000 micrometer, most preferably in a range of 30 micrometer to 500 micrometer.

**[0040]** Optionally, the coating layer is formed by a plurality of layers applied on top of each other (cf. laminated layers). The coating layer may thus be a group of multiple layers of inert material.

**[0041]** Optionally, the coating layer is applied by spraying. For example, a graphene coating may be applied over a surface by means of a spraying unit, such as for instance a spray gun. The graphene layer may provide sufficient stability under several thermal dilation cycles.

**[0042]** Optionally, the working fluid is non-corrosive.

**[0043]** The fluid at higher temperatures in the thermal circuit (e.g. above 300 degrees Celsius, for example above 400 degrees Celsius) may not pose significant corrosive issues. Often, the working fluid in energy transfer systems (e.g. heat exchange systems) are non-corrosive. For example, working fluids in organic Rankine cycle systems, heat pumps, thermal oil baths, solar collectors, may be non-corrosive with respect to the surfaces in contact with said working fluid.

**[0044]** Optionally, the working fluid is an organic liquid.

**[0045]** A working fluid having to operate at temperatures below its thermal stability limit temperature may imply a limitation on the performance of the energy transfer system. This thermal stability limit temperature may be limited for organic fluids. For example, the efficiency of ORC energy transfer systems may be a function of the maximum temperature of the thermodynamic cycle and/or the energy transfer process, in analogy with Carnot cycle efficiency.

**[0046]** Preferred working fluids for heat transfer processes have a high heat capacity and a high boiling point to enable efficient heat transfer by an amount of fluid as small as possible, and to minimise the risk to vaporisation at high temperatures. The heat capacity denotes the amount of heat a working fluid can hold per unit change in its temperature.

**[0047]** Examples of working fluids suitable for use with this invention include mineral oils, silicone-based fluids, natural organic hydrocarbons or synthetic organic hydrocarbons, organic blends, glycols,

**[0048]** Other working fluids are also envisaged.

**[0049]** Optionally, the coating layer forms a smooth film with a surface roughness, for example in a range of about 0.1 micrometer to 5 micrometer.

**[0050]** The coating layer may be a smooth surface providing limited flow resistance for the working fluid being guided in the thermal circuit.

**[0051]** Optionally, the heat transfer system is a thermal oil system, a geothermal loop or a concentrated solar collector system, or a thermal conversion system such as an organic Rankine cycle electrical generator, or a heat pump system.

**[0052]** Optionally, one or more surfaces coated with the coating layer are made of stainless steel.

**[0053]** The thermal stability of the working fluid may be related to the material which the fluid is in contact with. The thermal stability limit temperature values are typically given for working fluids used with stainless steel as containment material. For example, if carbon steel is used in place of stainless steel the maximum operating temperature of the working fluid (cf. thermal stability limit temperature) drops significantly. Conversely, a high thermal stability limit temperature may be obtained when platinum material is used. However, platinum is too expensive for use in the energy transfer systems. Advantageously, the method according to the invention provides for a cost-effective solution for obtaining a high thermal stability limit temperature. Stainless steel can be used which is coated by the coating layer for significantly increasing the thermal stability limit temperature. Advantageously, the coating layer provides an inert material in contact with the fluid thereby improving the thermal stability.

**[0054]** According to an aspect, the invention relates to a method of manufacturing an energy transfer system, the method comprising: providing a thermal circuit with a working fluid configured to perform a thermodynamic cycle and/or an energy transfer process, the thermal circuit provided with a piping system for conveying the working fluid and at least one energy transfer device, wherein the energy transfer device is configured to transfer a portion of energy from one part of the thermal circuit to another part of the thermal circuit; and providing at least a portion of the thermal circuit with a coating layer on surfaces in contact with the working fluid, wherein the coating layer includes inert material that is inert with respect to the working fluid during operation and which maintains structural integrity at a temperature above 550 K, and wherein the inert material in a pure state/form has a thermal conductivity above 50 W/mK at room temperature.

**[0055]** The coating layer may effectively increase the thermal stability of the working fluid in the thermal circuit of the energy transfer system. The thermal stability may be influenced by the material with which the working fluid is in contact with. In some examples, the solid material with which the working fluid is in contact with is stainless steel (e.g. parts of the devices, tubing, valves, etc. For example, stainless steel is often used in Rankine cycle power application, solid collectors, etc. It has adequate properties and is relatively cheap. The commercially available working fluids are often heated to a maximum temperature of 440 degrees Celsius for retaining stability and/or prevent degradation (e.g. thermal decomposition, chemical reactions). For example, thermal oil in solar collectors are heated up to 420 degrees Celsius. Advantageously, by means of the method according to the disclosure, the working temperature can be heated to a higher temperature whilst keeping said stability and/or prevent degradation. As a result, the performance of the energy transfer systems can be effectively improved.

**[0056]** According to an aspect, the invention relates to a method of increasing a thermal stability limit temperature of a working fluid in an energy transfer system, the method including coating one or more surfaces in contact with the working fluid with a coating layer, wherein the coating layer includes an inert material which maintains structural integrity at a temperature above 550 K, and wherein the inert material in a pure state/form has a thermal conductivity above 50 W/mK at room temperature.

**[0057]** The higher thermal stability that the coating layer (e.g. graphene coating layer) provides, can effectively allow an increase in the maximum operating temperature in parts of the energy transfer system, such as to avoid detrimental effects such as decomposition and/or degradation of the working fluid. For example, the maximum operating temperature of solar collectors, ORC systems, etc. can be increased in an efficient and cost-effective manner, thus leading to a significant increase in conversion efficiency of such energy transfer systems.

**[0058]** According to an aspect, the invention provides for a method of arranging the energy transfer system according to the disclosure.

**[0059]** It will be appreciated that any of the aspects, features and options described in view of the system apply equally to the method of manufacturing and the described method of increasing a thermal stability limit temperature of a working fluid in an energy transfer system. It will also be clear that any one or more of the above aspects, features and options can be combined.

## BRIEF DESCRIPTION OF THE DRAWING

**[0060]** The invention will further be elucidated on the basis of exemplary embodiments which are represented in a drawing. The exemplary embodiments are given by way of non-limitative illustration. It is noted that the figures are only schematic representations of embodiments of the invention that are given by way of non-limiting example.

**[0061]** In the drawing:

Fig. 1 shows a schematic diagram of an embodiment of an energy transfer system;

Fig. 2 shows a schematic diagram of an embodiment of an energy transfer system; and

Fig. 3 shows a schematic diagram of an embodiment of an energy transfer system.

## DETAILED DESCRIPTION

**[0062]** Fig. 1 shows a schematic diagram of an embodiment of an energy transfer system 1. The energy transfer system 1 comprises a thermal circuit 3 with a working fluid configured to perform a thermodynamic cycle and/or an energy transfer process The thermal circuit 3 comprises a piping system 5 for conveying the working fluid between components 7 in the thermal circuit 3. The thermal circuit 3 includes at least one energy transfer device, wherein the energy transfer device is configured to transfer a portion of energy from one part of the thermal circuit 3 to another part of the thermal circuit. In this example, the thermal circuit is arranged in a loop, wherein the working fluid is conveyed along the multiple components 5 and the piping system 5. At least a portion of the thermal circuit 3, for instance at least a portion of the piping system 5 and/or at least a portion of the components 5, comprises a coating layer on surfaces in contact with the working fluid, wherein the coating layer includes an inert material that is inert with respect to the working fluid during operation and that maintains structural integrity at a temperature above 550 K, and wherein the inert material in a pure state/form has a thermal conductivity above 50 W/mK at room temperature. Advantageously, by means of the coating layer, the thermal stability limit temperature of the working fluid of the energy transfer system can be increased, and thereby the overall thermal efficiency of the energy transfer system can be effectively improved.

**[0063]** The coating layer is inert and has good thermal properties (i.e. good thermal conductor). The coating layer can operate at relatively high temperatures, such as 570 K or more.

**[0064]** Advantageously, graphene can be applied as a coating. The graphene coating layer does not become brittle at temperatures at which the heat exchangers are used. Furthermore, the mechanical properties of the graphene coating layer does not degrade at higher temperatures in parts of the thermal circuit.

**[0065]** Advantageously, at least a portion of the contact surfaces in contact with the working fluid is coated with a graphene coating, which can permit using the energy transfer system at a higher temperature than hitherto possible. In this way, the performance of the energy transfer system can be significantly improved.

**[0066]** In some examples, the energy transfer system is an organic Rankine cycle (ORC) system. Such a system may be used for power production from low to medium temperature heat sources in the range of 80 to 350 °C and for small-medium power capacity applications at any temperature level. The ORC system may allow for exploitation of low-grade heat that otherwise would be wasted.

**[0067]** Various other types of energy transfer systems may also be used. For example, the energy transfer system may be a large scale solar power system.

**[0068]** For example, the maximum temperature in concentrated solar power plants adopting parabolic trough is bound to the thermal stability limit of the thermal oil used in the collectors. In the case the power cycle of the plant is a steam power cycle, it results that the efficiency of the steam power cycle of these plants is about one-third lower than that of a state-of-the-art steam cycle. The system according to the disclosure provides a gain in the thermal stability of the working fluid and can then lead to an improvement in thermodynamic efficiency.

**[0069]** In some examples, the working fluid is non-corrosive. A non-corrosive working fluid may not result in a corrosion problem within the thermal circuit 3. In some examples, the energy transfer system 1 is a thermal conversion system. Such thermal conversion system may use non-corrosive working fluids.

**[0070]** Fig. 2 shows a schematic diagram of an embodiment of an energy transfer system 1. In this example, the energy transfer system 1 is an organic Rankine cycle (ORC) system. The ORC system 1 uses an organic, fluid with a molecular weight higher than steam. The organic fluid allows heat to be recovered from lower temperature heat sources than conventional water-steam cycles. The low temperature heat can be converted into useful work, which is further converted into electricity by a generator.

**[0071]** The exemplary ORC generating system 1 comprises a thermal circuit 3 including an evaporator 9, an ORC expander 11 and a generator 13. In this exemplary arrangement, the expander 11 and generator 13 are one unit. Furthermore, the thermal circuit 3 includes a condenser 15 and additional auxiliary equipment, such as a reservoir 17, a pump 19. In operation, the heat source 21 transfers thermal energy into the ORC system. The evaporator 9 vaporizes the organic working fluid previously pressurized by the pump of the thermal circuit 3. The pressurized organic fluid enters the expander 11, where expansion of the fluid drives a turbine to generate electrical power in the generator 13. The working fluid then is condensed through the condenser 15 back to the liquid phase and is further fed back into the system, through the reservoir 17 and the pump 19, to repeat the closed-loop cycle. The various components in the thermal circuit are connected by means of a tubing system 5 having pipes through which the working fluid is conveyed. Other variant arrangements are also possible. At least a portion of the thermal circuit 3 is provided with a coating layer on surfaces in contact with the working fluid, wherein the coating layer includes an inert material that is inert with respect to the working fluid during operation and that maintains structural integrity at a temperature above 550 K, and wherein the inert material in a pure state/form has a thermal conductivity above 50 W/mK at room temperature. The coating layer may be in direct contact with the working fluid (e.g. including a heat transfer fluid in the thermal circuit). The use of the coating layer enables heating the working fluid to higher temperatures, whilst retaining the thermal stability of the working fluid. In this way, the thermal efficiency of the energy transfer system 1 can be higher.

**[0072]** A material that may allow for higher thermal stability limits of the working fluid, such as for instance organic fluids, is graphene. Additionally, the graphene coating layer may provide for an extremely good heat transfer properties.

**[0073]** It will be appreciated that various other energy transfer systems 1 may be used. For example, in some examples, the coating layer is applied in a solar collector piping. In some examples, the coating layer is applied in the piping of the high-temperature components of ORC systems. In some examples, the coating layer is applied on one or more surfaces of components of the energy transfer system, such as for example turbines, heat exchanger unit, etc. The coating layer may be selectively applied on surfaces of the thermal circuit 3 in contact with the working fluid, for preventing deterioration and/or degradation of said working fluid at higher temperatures.

**[0074]** Fig. 3 shows a schematic diagram of an embodiment of an energy transfer system 1, which is similar to the exemplary system 1 shown in fig. 2. In this example, the coating layer is applied locally only in one or more parts of the thermal circuit 3, indicated by C.

**[0075]** The heat transfer circuit 3 of the energy transfer system 1 comprises a first portion and a second portion C, wherein the first portion is configured to convey the working fluid in a first temperature range, and wherein the second portion is configured to convey the working fluid in a second temperature range. The first temperature range is below 500 K, preferably below 450 K, and the second temperature range is above 520 K, preferably above 550 K. Only surfaces in contact with working fluid in the second portion C of the heat transfer circuit are coated with the coating layer. In this way, a distinction is made between higher temperature parts of the thermal circuit 3 (cf. 'C') and lower temperature parts of the thermal circuit 3. Only surfaces in contact with the working fluid at the higher temperature parts of the thermal circuit 3 are coated for achieving a higher thermal stability limit temperature of the working fluid in an energy transfer system 1. In some examples, the second temperature is in a range between 500 K to 870 K, preferably 550 K to 820 K.

**[0076]** In the drawings, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components.

**[0077]** "Optional" or "optionally" means that the subsequently described event or circumstance may or may not occur, and that the description includes instances where said event or circumstance occurs and instances where it does not.

**[0078]** As used in the claims, unless otherwise specified, the use of the ordinal adjectives "first", "second", "third", etc., to describe a common element, merely indicate that different instances of like elements are being referred to, and are not intended to imply that the elements so described must be in a given sequence, either temporally, spatially, in ranking, or in any other manner.

**[0079]** Whereas the terms "one or more" or "at least one", such as one or more or at least one member(s) of a group of members, is clear per se, by means of further exemplification, the term encompasses inter alia a reference to any one of said members, or to any two or more of said members, such as, e.g., any 3, .4, 5, >6 or >7 etc. of said members, and up to all said members.

**[0080]** As used herein in the specification and claims, including as used in the examples and unless otherwise expressly specified, all numbers may be read as if prefaced by the word "about" or "approximately," even if the term does not expressly appear. The phrase "about" or "approximately" may be used when describing magnitude and/or position to indicate that the value and/or position described is within a reasonable expected range of values and/or positions. For example, a numeric value may have a value that is +/-0.1% of the stated value (or range of values), +/-1% of the stated value (or range of values), +/-2% of the stated value (or range of values), +/-5% of the stated value (or range of values), +/-10% of the stated value (or range of values), etc. Any numerical range recited herein is intended to include all sub-ranges subsumed therein.

**[0081]** Herein, the invention is described with reference to specific examples of embodiments of the invention. It will, however, be evident that various modifications, variations, alternatives and changes may be made therein, without departing from the essence of the invention. For the purpose of clarity and a concise description features are described herein as part of the same or separate embodiments, however, alternative embodiments having combinations of all or some of the features described in these separate embodiments are also envisaged and understood to fall within the framework of the invention as outlined by the claims. The specifications, figures and examples are, accordingly, to be regarded in an illustrative sense rather than in a restrictive sense. The invention is intended to embrace all alternatives, modifications and variations which fall within the scope of the appended claims. Further, many of the elements that are described are functional entities that may be implemented as discrete or distributed components or in conjunction with other components, in any suitable combination and location.

**[0082]** In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word 'comprising' does not exclude the presence of other features or steps than those listed in a claim. Furthermore, the words 'a' and 'an' shall not be construed as limited to 'only one', but instead are used to mean 'at least one', and do not exclude a plurality. The mere fact that certain measures are recited in mutually different claims does not indicate that a combination of these measures cannot be used to an advantage.

## Claims

1. An energy transfer system comprising a thermal circuit with a working fluid configured to perform a thermodynamic cycle and/or an energy transfer process, the thermal circuit comprising a piping system for conveying the working fluid, and at least one energy transfer device, wherein the energy transfer device is configured to transfer a portion of energy from one

part of the thermal circuit to another part of the thermal circuit, and wherein at least a portion of the thermal circuit comprises a coating layer on surfaces in contact with the working fluid, wherein the coating layer includes an inert material that is inert with respect to the working fluid during operation and that maintains structural integrity at a temperature above 550 K, and wherein the inert material in a pure state/form has a thermal conductivity above 50 W/mK at room temperature.

**2.** The energy transfer system according to claim 1, wherein the inert material has a damage temperature above 620 K, preferably above 670 K, more preferably above 690 K.

**3.** The energy transfer system according to claim 1 or 2, wherein the inert material in a pure state/form has a thermal conductivity in a range of 500 to 5000 W/mK at room temperature.

**4.** The energy transfer system according to any one of the preceding claims, wherein the inert material is graphene or contains graphene.

**5.** The energy transfer system according to any one of the preceding claims, wherein the coating layer is applied locally only in one or more parts of the thermal circuit.

**6.** The energy transfer system according to any one of the preceding claims, wherein the heat transfer circuit of the energy transfer system comprises a first portion and a second portion, wherein the first portion is configured to convey the working fluid in a first temperature range, and wherein the second portion is configured to convey the working fluid in a second temperature range, wherein the first temperature range is below 550 K, preferably below 520 K, and wherein the second temperature range is above 570 K, preferably above 600 K, and wherein only surfaces in contact with working fluid in the second portion of the heat transfer circuit are coated with the coating layer.

**7.** The energy transfer system according to claim 6, wherein the second temperature range is between 570 K to 870 K, preferably 600 K to 820 K.

**8.** The energy transfer system according to any one of the preceding claims, wherein the coating layer forms a smooth surface, preferably having a thickness in a range of 1 to 2000 micrometer, more preferably in a range of 10 micrometer to 2000 micrometer, eve more preferably in range of 15 micrometer to 1000 micrometer, most preferably in a range of 30 micrometer to 500 micrometer.

**9.** The energy transfer system according to any one of the preceding claims, wherein the working fluid is non-corrosive.

**10.** The energy transfer system according to any one of the preceding claims, wherein the working fluid is an organic liquid.

**11.** The energy transfer system according to any one of the preceding claims, wherein the coating layer forms a smooth film with a surface roughness in a range of about 0.1 micrometer to 5 micrometer.

**12.** The energy transfer system according to any one of the preceding claims, wherein the heat transfer system is a thermal oil system, a geothermal loop or a concentrated solar collector system, a thermal conversion system such as an organic Rankine cycle electrical generator, or a heat pump system.

**13.** The energy transfer system according to any one of the preceding claims, wherein the one or more surfaces coated with the coating layer are made of stainless steel.

**14.** A method of manufacturing an energy transfer system, the method comprising:

providing a thermal circuit with a working fluid configured to perform a thermodynamic cycle and/or an energy transfer process, the thermal circuit provided with a piping system for conveying the working fluid and at least one energy transfer device, wherein the energy transfer device is configured to transfer a portion of energy from one part of the thermal circuit to another part of the thermal circuit; and

providing at least a portion of the thermal circuit with a coating layer on surfaces in contact with the working fluid, wherein the coating layer includes inert material that is inert with respect to the working fluid during operation and which maintains structural integrity at a temperature above 550 K, and wherein the inert material when in a pure state/form has a thermal conductivity above 50 W/mK at room temperature.

**15.** A method of increasing a thermal stability limit temperature of a working fluid in an energy transfer system, the method including coating one or more surfaces in contact with the working fluid with a coating layer, wherein the coating layer includes an inert material which maintains structural integrity at a temperature above 550 K, and wherein the inert material when in a pure state/form has a thermal conductivity above 50 W/mK at room temperature.

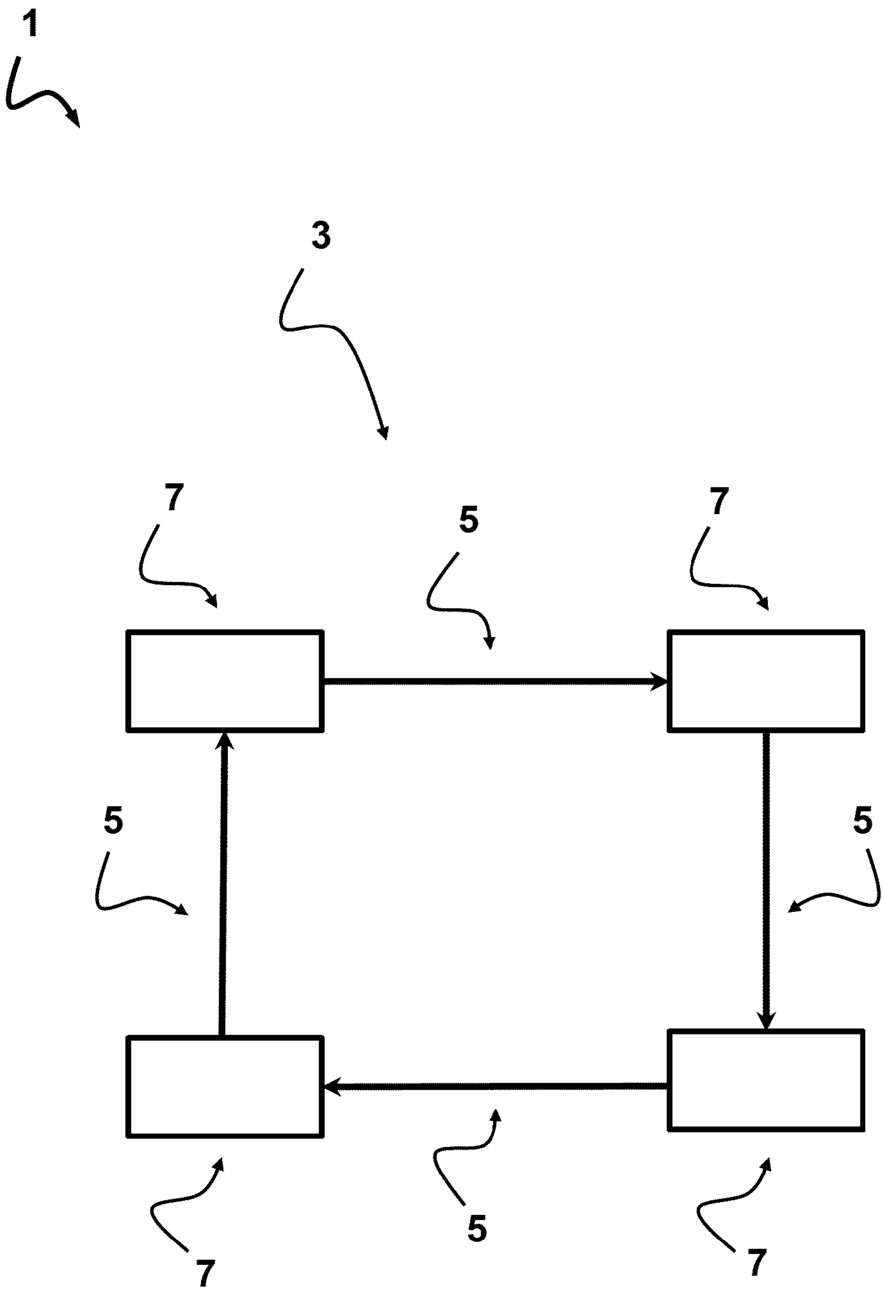


FIG 1

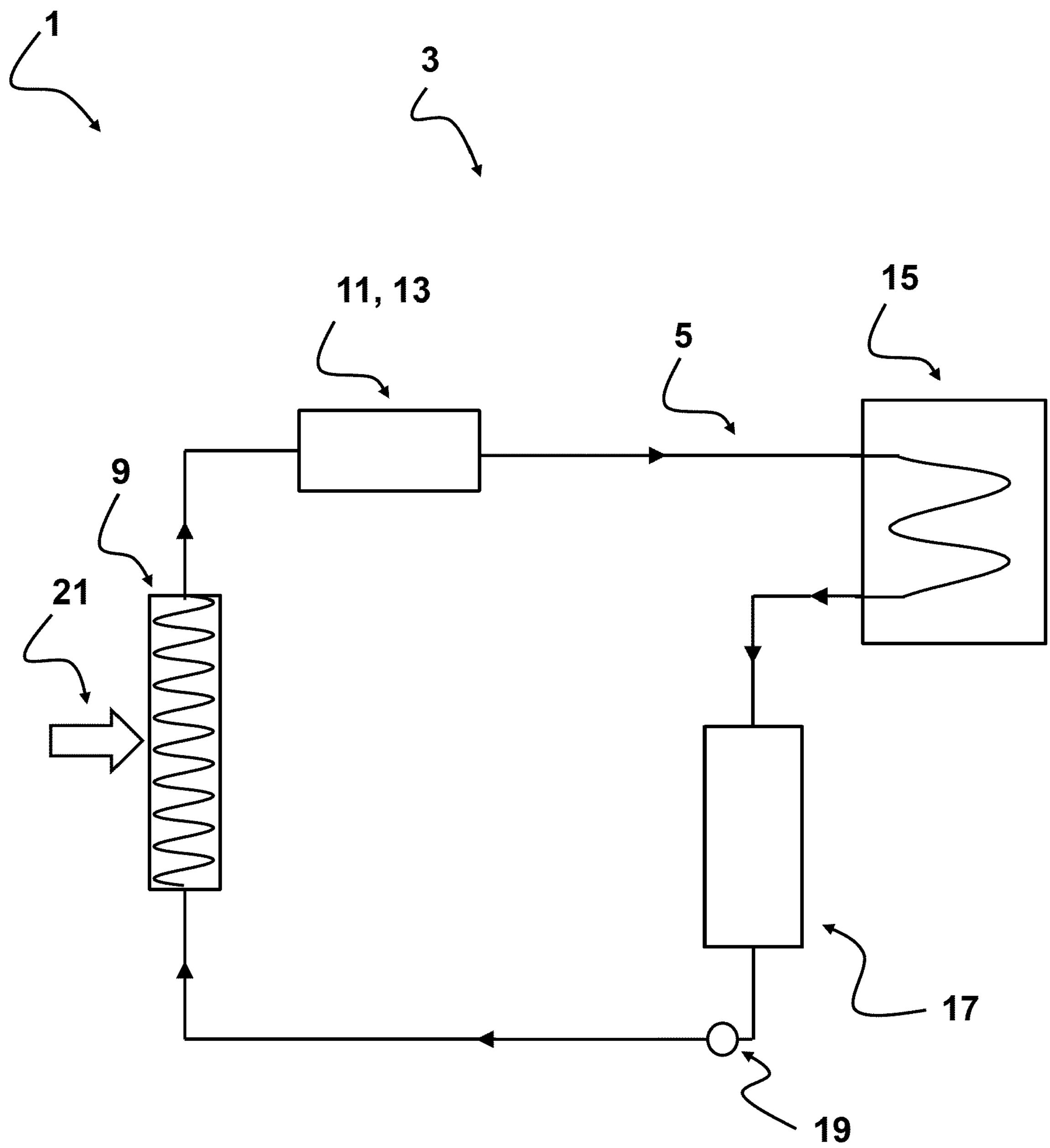


FIG 2

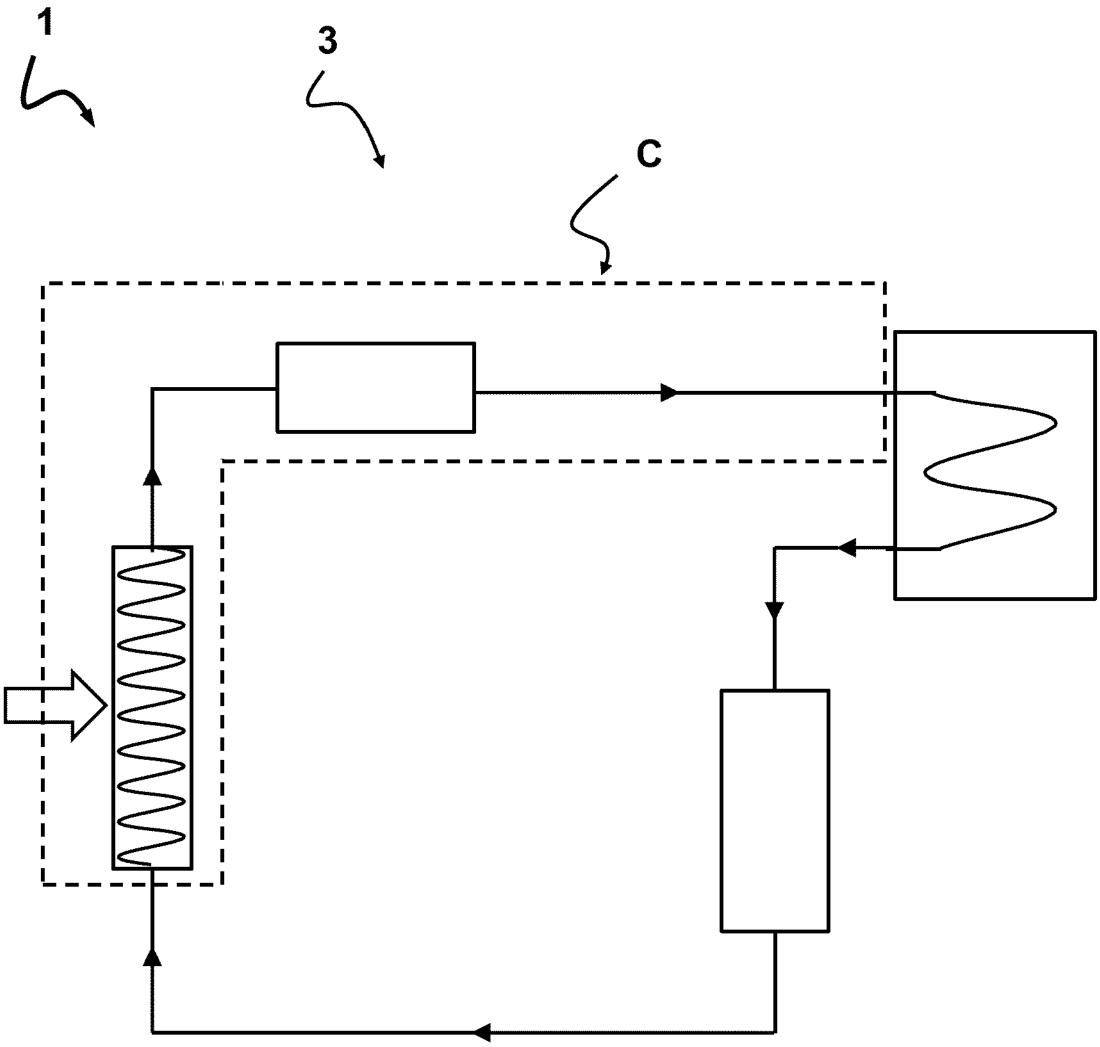


FIG 3

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# EUROPEAN SEARCH REPORT

Application Number
EP 21 21 5727

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| Place of search | Date of completion of the search | Examiner |
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