A Working Fluid

Field of the Invention

The present invention relates to a working fluid. More specifically the present invention relates to a working fluid for use in a heat transfer system, for example of the type used to transfer heat in a heat engine, heating system or a closed circuit heat transfer system.

Background to the Invention

Working fluids may be gasses or liquids and are used to transport energy or to drive or actuate machinery. A working fluid is a liquid or gas that absorbs or transmits energy; working fluids may be used to transfer thermal energy from a first location to a second location, and/or may be used to actuate or drive a machine.

Energy is typically imparted to a working fluid by heating the working fluid (for example, by passing it through a heat exchanger or a solar thermal panel) or by compressing the working fluid.

Energy may be extracted from a working fluid in the form of heat (for example, by passing the working fluid through a heat exchanger) or by using the working fluid to produce mechanical work in an engine, for example, to drive a turbine or an expander.

In working fluids which receive heat from, or deliver heat to other elements via heat exchangers, it is advantageous for the working fluid to have a high thermal conductivity so as to increase the rate of heat transfer (heat flux) between the working fluid and the other elements with which they are in thermal contact. This allows energy to be transferred more rapidly to and from the working fluid.

In addition to the thermal conductivity, there are a number of other properties of a heat transferring working fluid that need to be considered when designing a specific type of heat engine or application. These include: the specific heat capacity of the working fluid, the viscosity of the working fluid and the density of the working fluid. It is desirable to be able to vary these variables. They are also required in order to calculate the Reynolds number of a working fluid, within a specific flow regime and in different types of heat exchanger, in order to determine to what extent these affect the rate and nature of transfer of heat to or from the working fluid.

An object of the present invention is to provide a working fluid with a greater thermal conductivity.

Another object of the present invention is to provide a method of increasing the thermal conductivity of a working fluid.

A further object of the present invention is to provide an improved working fluid with improved heat transfer capability.

A yet further object of the present invention is to provide a method of increasing the specific heat capacity of a working fluid. In this sense therefore the working fluid is able to produce a greater net work output per cycle.

Another object is to provide a system for manufacturing the improved working fluid with improved heat transfer capability.

A yet further object of the present invention is to provide a method of increasing the specific heat capacity of a working fluid.

Statement of the Invention

According to a first aspect of the invention there is provided a working fluid comprising a plurality of nano-particles comprising nano-particles of silicon (Si), of boron carbine (B_4C), of boron nitride (BN), of beryllium oxide (BeO), of graphene, of aluminium nitride (AlN), of silicon carbide (SiC), or of titanium dioxide (TIO_2) suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether.

Suspending particles within a working fluid, which themselves have a higher thermal conductivity than the fluid, has been found to increase the thermal conductivity of a working fluid. Such a mixture is hereinafter referred to as a nano-fluid. Nano-fluids are fluids which include suspended nano-particles intended to vary one or more physical characteristic of the fluid. Suspending nano-particles within a fluid has been found to increase the thermal conductivity of the fluid without significant clogging of conduits.

Nano-particles are typically particles with dimensions greater than 1nm and typically less than 100nm; although in some embodiments, particles with dimensions in the range 1nm to 500nm may be mixed with a fluid. Typically, a characteristic dimension may be length, width, height or diameter of a nano-particle.

Alternatively, nano-particles may be spherical, tubular or fibrous with one or two characteristic dimensions of less than 100nm.

A suspension material may be used to suspend nano-particles within a base fluid in order to increase the thermal conductivity of the fluid so as to increase the specific heat capacity of the fluid.

Increasing the thermal conductivity of a working fluid tends to increase the rate at which heat is transferred to or from the working fluid, for example in use, in a heat exchanger or a solar thermal panel. Therefore, working fluids comprising suspended nano-particles (so called nano-fluids) to transfer heat or drive a machine are more efficient than existing working fluids. Working fluids with higher specific heat capacities (due to the presence of the nano-particles) tend to undergo greater increases and rates of increase in temperature than other working fluids when the same amount of heat is transferred to the working fluid. These characteristics ensure that the nano-fluids comprising nano-particles allow the energy to be more rapidly transferred from the working fluid at a subsequent heat exchanger due to an increased temperature differential between the working fluid and the element to which heat is transferred from the fluid.

Use of certain types of nano-particle has been found to decrease the specific heat capacity of the fluid which may decrease the rate at which energy is transferred to the working fluid. As such the temperature differential between the working fluid and the source of energy decreases more rapidly as the working fluid is heated. However this may be compensated by maintaining the temperature differential between the working fluid and the heat source, for example, by pumping the working fluid more rapidly through a heat exchanger.

The use of nano-particles (as opposed to millimetre or micrometre scale particles) to improve the thermal characteristics of the working fluid may be advantageous as it reduces the risks of clogging of, or abrasion to the conduits through which the working fluid is passing. Additionally, suspended nano-particles may be used to alter the viscosity of the working fluid.

A system for manufacturing a nano-fluid including a plurality of hoppers each containing at least one type of nano-particle; a reservoir containing a base fluid; control means associated with valves on the hoppers and a valve on the reservoir which valves are operable to dispense a user defined volume of working fluid and user defined amounts of nano-particles into a mixer tank; a mixer for mixing the nano-particles with the base fluid in the mixer tank to produce a nano-fluid; and a dispenser for dispensing the nano-fluid into storage containers.

Suspending particles within the working fluid has been found to increase the thermal heat transfer characteristics of the nano-fluid. Nano-fluids are fluids which include suspended nano-particles intended to vary one or more physical characteristic of the fluid. The nano-particles are ideally mixed so that they are suspended in the base fluid in a colloidal suspension.

In preferred embodiments, the materials from which the nano-particles are formed, ideally has a greater thermal conductivity than the base fluid.

The plurality of nano-particles may comprise nano-particles of metal and/or metal oxide and/or metal nitride and/or metal silicide and/or metal carbide.

Ideally nano-particles include: boron carbine (B_4C), nano-particles of boron nitride (BN), nano-particles of beryllium oxide (BeO), nano-particles of magnesium oxide (MgO), nano-particles of graphite, nano-particles of silicon (Si), nano-particles of aluminium nitride (AlN), nano-particles of silicon carbide (SiC), nano-particles of aluminium oxide (Al_2O_3), nano-particles of titanium dioxide (TIO_2), nano-particles of silicon dioxide (SiO_2), nano-particles of copper (II) oxide (CuO), or any combination thereof.

Optionally the nano-particles include a graphene and/or reduced graphene mixture.

In some embodiments a characteristic dimension (length or diameter) of the nano-particles is preferably smaller than 100nm, preferably smaller than 75nm, more preferably smaller than 50nm, and most preferably smaller than 25nm. Alternatively, or additionally, the nano-particles may have dimensions less than 90nm, less than 70nm, less than 45nm, or less than 20nm.

In some embodiments, the nano-particles may have dimensions greater than 5nm, greater than 10nm, or greater than 15nm.

The base liquid comprises at least one hydro-fluoro-ether and may comprise at least 50% hydro-fluoro-ethers by volume. The base liquid comprises at least one type of HFE-7000 hydro-fluoro-ether and ideally the liquid comprises at least 50% HFE-7000 hydro-fluoro-ethers by volume.

The volumetric concentration of the nano-particles within the working fluid may be greater than 1%; it may be greater than 2%; it may be greater than 3%; it may be greater than 4%; it may be greater than 5%; it may be greater than 6%; it may be greater than 7%, or it may be less than 8%.

It is further appreciated that according to another aspect the invention also extends to a method of operating the aforementioned system for manufacturing a nano-fluid.

Preferred embodiments of the invention will now be described by way of examples only and with reference to the Figures, in which:

Brief Description of the Figures

Figure 1 is a table showing the increase in the heat transfer coefficient ($W/(m^2K)$ of a working fluid when different nano-particles are added at different volumetric concentrations;

Figure 2 is a table showing the power of a system performing an organic Rankine cycle when using different working fluids;

Figure 3 is a diagram illustrating key steps in the production of a working fluid with different nano-particles; and

Figure 4 is a basic functional diagram of a production plant for manufacturing working fluid with a range of different nano-particles.

Detailed Description of the Figures

Figure 1 is a table illustrating the percentage differences between the mean heat transfer coefficients of a HFE-7000 based working fluid and thirty-six different working nano-fluids, each of which comprises nano-particles of one of twelve different chemicals added to the HFE-7000 based working fluid at one of three different volumetric concentrations.

The thirty-six different basic working fluids are described, twenty-four of these being separate example embodiments of the invention. A particularly preferred embodiment may be derived, for example by coating some of the nano-particles with graphene. A refinement of these additional variations may be obtained by coating nano-particles with a monolayer coating of graphene on nano-particles.

The twelve different chemicals from which the nano-particles comprised by the thirty-six working nano-fluids are formed are: boron carbine (B_4C), boron nitride (BN), beryllium oxide (BeO), magnesium oxide (MgO), graphite, graphene (reduced graphene), silicon (Si), aluminium nitride (AlN), silicon carbide (SiC), aluminium oxide (Al_2O_3), titanium dioxide (TIO_2), silicon dioxide (SiO_2), and copper (II) oxide (CuO).

The three different volumetric concentrations of the nano-particles within the working fluid being 1%, 4%, and 6%.

The mean heat transfer coefficients of the HFE-7000 working fluid and the thirty-six working nano-fluids are measured when conducting heat in flows with Reynolds Number of around 1200.

The nano-particles of the thirty-six examples of working nano-fluids have dimensions of approximately 45nm.

All thirty-six of the working nano-fluids have greater mean thermal conductivities than the HFE-7000 working fluid with no suspended nano-particles present.

Figure 2 is a table illustrating the power output of as system performing an organic Rankine cycle between a solar thermal panel and an expander, when using thirteen different working fluids.

The thirteen working fluids are: pure HFE-7000, a nano-fluid comprising nano-particles of boron carbine (B_4C) suspended in HFE-7000, a nano-fluid comprising nano-particles of boron nitride (BN) suspended in HFE-7000, a nano-fluid comprising nano-particles of beryllium oxide (BeO) suspended in HFE-7000, a nano-fluid comprising nano-particles of magnesium oxide (MgO) suspended in HFE-7000, a nano-fluid comprising nano-particles of graphite suspended in HFE-7000, a nano-fluid comprising nano-particles of silicon (Si) suspended in HFE-7000, a nano-fluid comprising nano-particles of aluminium nitride (AlN) suspended in HFE-7000, a nano-fluid comprising nano-particles of silicon carbide (SiC) suspended in HFE-7000, a nano-fluid comprising nano-particles of aluminium oxide (Al_2O_3) suspended in HFE-7000, a nano-fluid comprising nano-particles of titanium dioxide (TIO_2) suspended in HFE-7000, a nano-fluid comprising nano-particles of silicon dioxide (SiO_2) suspended in HFE-7000, and a nano-fluid comprising nano-particles of copper (II) oxide (CuO) suspended in HFE-7000.

The nano-particles of the twelve working nano-fluids having dimensions of approximately 45nm and volumetric concentrations within the working nano-fluids of 4%.

The system passes the working fluids through a solar thermal panel, upon which radiation of intensity 800 W/m^2 is incident. The working fluids are then passed through positive displacement expander where mechanical work is extracted from the working fluid. The working fluid then passes through a heat exchanger to a reservoir from which it is pumped back through the solar thermal panel. The pressure ratio of the system being 5.

An example working fluid comprises 94% by volume HFE-7000, 6% by volume nano-particles of titanium dioxide (TiO_2) with dimensions greater than 40nm and less than 50nm.

The invention may be included in heat transfer systems for use for example in buildings and/or vehicles in which heat needs to be transferred to cooler zones or from hotter zones. Examples of systems include: air-condoning units, combined heat and power units and blowers, for example for warming cabs in vehicles or rooms.   The improved heat transfer efficiency of the working fluid enables heat energy to be transferred more efficiently (quicker and with less pumping power) than was previously the case and so provides for lighter and more compact heat transfer systems.

Figure 3 illustrates key steps in the manufacture of a working fluid with different nano-particles. Figure 4 is a basic functional diagram of a production plant for manufacturing working fluid with a range of different nano-particles and shows in diagrammatical form key stages in production.

The invention has been described by way of example only and it will be appreciated that variation may be made to the embodiments described above without departing from the scope of the claims.

Claims

1. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of silicon (Si).

2. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of boron carbide (B_4C).

3. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of boron nitride (BN).

4. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of beryllium oxide (BeO).

5. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of graphene.

6. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of aluminium nitride (AlN).

7. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of silicon carbide (SiC).

~~8. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of titanium dioxide (TIO_2).~~

~~9.~~8. A working fluid according to any preceding claim wherein the nano-particles are suspended in the base fluid in a colloidal suspension.

~~10.~~9. A working fluid according to any preceding claim wherein the plurality of nano-particles further comprises nano-particles of boron carbine (B_4C), nano-particles of boron nitride (BN), nano-particles of beryllium oxide (BeO), nano-particles of magnesium oxide (MgO), nano-particles of graphite, nano-particles of silicon (Si), nano-particles of aluminium nitride (AlN), nano-particles of silicon carbide (SiC), nano-particles of aluminium oxide (Al_2O_3), nano-particles of titanium dioxide (TIO_2), nano-particles of silicon dioxide (SiO_2), nano-particles of copper (II) oxide (CuO), or any combination thereof.

~~11.~~10. A working fluid according to any ~~preceding~~ of claims 1 or 3 to 7 wherein the plurality of nano-particles further comprises nano-particles of boron carbide (B_4C).

~~12.~~11. A working fluid according to any of~~preceding~~ claims 1 or 2 or 4 to 7 wherein the plurality of nano-particles further comprises nano-particles of boron nitride (BN).

~~13.~~12. A working fluid according to any of~~preceding~~ claims 1, 2 or 3 or 5 to 7 wherein the plurality of nano-particles further comprises nano-particles of beryllium oxide (BeO).

~~14.~~13. A working fluid according to any ~~preceding~~ of claims 1 to 7 wherein the plurality of nano-particles further comprises nano-particles of magnesium oxide (MgO).

~~15.~~14. A working fluid according to any ~~preceding~~ of claims 1 to 4 or 6 or 7 wherein the plurality of nano-particles further comprises nano-particles of graphite or graphene.

~~16.~~15. A working fluid according to any of~~preceding~~ claims 1 to 6 wherein the plurality of nano-particles further comprises nano-particles of silicon (Si).

~~17.~~16. A working fluid according to any ~~preceding~~ of claims 1 to 7 wherein the plurality of nano-particles further comprises nano-particles of aluminium nitride (AlN).

~~18.~~17. A working fluid according to any ~~preceding~~ of claims 1 to 7 wherein the plurality of nano-particles further comprises nano-particles of silicon carbide (SiC).

~~19.~~18. A working fluid according to any ~~preceding~~ of claims 1 to 7 wherein the plurality of nano-particles further comprises nano-particles of aluminium oxide (Al_2O_3).

~~20.~~19. A working fluid according to any ~~preceding~~ of claims 1 to 7 wherein the plurality of nano-particles further comprises nano-particles of titanium dioxide (TiO_2).

~~21.~~20. A working fluid according to any ~~preceding~~ of claims 1 to 7 wherein the plurality of nano-particles further comprises nano-particles of silicon dioxide (SiO_2).

~~22.~~21. A working fluid according to any ~~preceding~~ of claims 1 to 7 wherein the plurality of nano-particles further comprises nano-particles of copper (II) oxide (CuO).

~~23.~~22. A working fluid according to any preceding claim wherein nano-particles have at least two characteristic dimensions less than 100nm.

~~24.~~23. A working fluid according to any preceding claim wherein nano-particles have dimensions less than 100nm.

~~25.~~24. A working fluid according to any preceding claim wherein nano-particles have at least two dimensions less than 75nm.

~~26.~~25. A working fluid according to any preceding claim wherein nano-particles have dimensions less than 75nm.

~~27.~~26. A working fluid according to any preceding claim wherein nano-particles have at least two dimensions less than 50nm.

~~28.~~27. A working fluid according to any preceding claim wherein nano-particles have dimensions less than 50nm.

~~29.~~28. A working fluid according to any preceding claim wherein nano-particles have at least two dimensions less than 25nm.

~~30.~~29. A working fluid according to any preceding claim wherein nano-particles have dimensions less than 25nm.

~~31.~~30. A working fluid according to any preceding claim wherein the nano-particles have dimensions greater than 5nm.

~~32.~~31. A working fluid according to any preceding claim wherein the nano-particles have dimensions greater than 10nm.

~~33.~~32. A working fluid according to any preceding claim wherein the nano-particles have dimensions greater than 15nm.

~~34.~~33. A working fluid according to any preceding claim wherein the base fluid is at least 50% hydro-fluoro-ethers by volume.

~~35.~~34. A working fluid according to any preceding claim wherein the base fluid is at least 50% HFE-7000 hydro-fluoro-ether by volume.

~~36.~~35. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 1%.

~~37.~~36. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 2%.

~~38.~~37. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 3%.

~~39.~~38. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 4%.

~~40.~~39. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 5%.

~~41.~~40. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 6%.

~~42.~~41. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 7%.

~~43.~~42. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within the working fluid is less than 8%.

~~44.~~43. A working fluid according to any of claims 1 to 40~~1~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 7%.

~~45.~~44. A working fluid according to any of claims 1 to 39~~40~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 6%.

~~46.~~45. A working fluid according to any of claims 1 to 38~~9~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 5%.

~~47.~~46. A working fluid according to any of claims 1 to 37~~8~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 4%.

~~48.~~47. A working fluid according to any of claims 1 to 36~~7~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 3%.

~~49.~~48. A working fluid according to any of claims 1 to 35~~6~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 2%.

~~50.~~49. A working fluid according to any of claims 1 to 34~~5~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 1%.

~~51.~~50. A working fluid according to any preceding claim wherein the heat transfer property of the base fluid which is improved is the heat transfer coefficient (h).

~~52.~~51. A system for manufacturing a working fluid according to any of claims 1 to 50~~1~~ including a plurality of hoppers each containing at least one type of nano-particle; a reservoir containing the at least one base fluid; control means associated with valves on the hoppers and a valve on the reservoir, the valves are operable to dispense a user defined volume of base fluid and user defined amounts of nano-particles into a mixer tank; a mixer for mixing the nano-particles with the base fluid in the mixer tank to produce a nano-fluid; and a dispenser for dispensing the working fluid into storage containers.

~~53.~~52. A system according to claim 51~~2~~ wherein the mixer is operative to mix the nano-particles and the at least one base fluid until the nano-particles are suspended in the base fluid in a colloidal suspension.

~~54.~~53. A method of operating the system for manufacturing a working fluid according to either claim 51~~2~~ or 523.

Abstract

The present invention relates to a working fluid. More specifically the present invention relates to a working fluid for use in a heat transfer system, for example of the type used to transfer heat in a heat engine.

Working fluids require good heat transfer properties (thermal conductivity and specific heat capacity) so that they can absorb and release large amounts of energy quickly.

The invention describes a working fluid comprising a plurality of nano-particles suspended in a base fluid so as to improve a heat transfer property of the base fluid. Ideally the nano-particles are suspended in the base fluid in a colloidal suspension.

A system for manufacturing a nano-fluid is also described. The system includes a plurality of hoppers for containing types of nano-particle and a reservoir that contains a base fluid. A control means controls valves on the hoppers and on the reservoir in order to dispense working fluid and defined amounts of nano-particles into a mixer tank. A mixer mixes the nano-particles with the base fluid to produce a nano-fluid which is in colloidal suspension in the working fluid.

(Figure 4)

A Working Fluid

Field of the Invention

The present invention relates to a working fluid. More specifically the present invention relates to a working fluid for use in a heat transfer system, for example of the type used to transfer heat in a heat engine, heating system or a closed circuit heat transfer system.

Background to the Invention

Working fluids may be gasses or liquids and are used to transport energy or to drive or actuate machinery. A working fluid is a liquid or gas that absorbs or transmits energy; working fluids may be used to transfer thermal energy from a first location to a second location, and/or may be used to actuate or drive a machine.

Energy is typically imparted to a working fluid by heating the working fluid (for example, by passing it through a heat exchanger or a solar thermal panel) or by compressing the working fluid.

Energy may be extracted from a working fluid in the form of heat (for example, by passing the working fluid through a heat exchanger) or by using the working fluid to produce mechanical work in an engine, for example, to drive a turbine or an expander.

In working fluids which receive heat from, or deliver heat to other elements via heat exchangers, it is advantageous for the working fluid to have a high thermal conductivity so as to increase the rate of heat transfer (heat flux) between the working fluid and the other elements with which they are in thermal contact. This allows energy to be transferred more rapidly to and from the working fluid.

In addition to the thermal conductivity, there are a number of other properties of a heat transferring working fluid that need to be considered when designing a specific type of heat engine or application. These include: the specific heat capacity of the working fluid, the viscosity of the working fluid and the density of the working fluid. It is desirable to be able to vary these variables. They are also required in order to calculate the Reynolds number of a working fluid, within a specific flow regime and in different types of heat exchanger, in order to determine to what extent these affect the rate and nature of transfer of heat to or from the working fluid.

An object of the present invention is to provide a working fluid with a greater thermal conductivity.

Another object of the present invention is to provide a method of increasing the thermal conductivity of a working fluid.

A further object of the present invention is to provide an improved working fluid with improved heat transfer capability.

A yet further object of the present invention is to provide a method of increasing the specific heat capacity of a working fluid. In this sense therefore the working fluid is able to produce a greater net work output per cycle.

Another object is to provide a system for manufacturing the improved working fluid with improved heat transfer capability.

A yet further object of the present invention is to provide a method of increasing the specific heat capacity of a working fluid.

Statement of the Invention

According to a first aspect of the invention there is provided a working fluid comprising a plurality of nano-particles comprising nano-particles of silicon (Si), of boron carbine (B_4C), of boron nitride (BN), of beryllium oxide (BeO), of graphene, of aluminium nitride (AlN), of silicon carbide (SiC), or of titanium dioxide (TIO_2) suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether.

Suspending particles within a working fluid, which themselves have a higher thermal conductivity than the fluid, has been found to increase the thermal conductivity of a working fluid. Such a mixture is hereinafter referred to as a nano-fluid. Nano-fluids are fluids which include suspended nano-particles intended to vary one or more physical characteristic of the fluid. Suspending nano-particles within a fluid has been found to increase the thermal conductivity of the fluid without significant clogging of conduits.

Nano-particles are typically particles with dimensions greater than 1nm and typically less than 100nm; although in some embodiments, particles with dimensions in the range 1nm to 500nm may be mixed with a fluid. Typically, a characteristic dimension may be length, width, height or diameter of a nano-particle.

Alternatively, nano-particles may be spherical, tubular or fibrous with one or two characteristic dimensions of less than 100nm.

A suspension material may be used to suspend nano-particles within a base fluid in order to increase the thermal conductivity of the fluid so as to increase the specific heat capacity of the fluid.

Increasing the thermal conductivity of a working fluid tends to increase the rate at which heat is transferred to or from the working fluid, for example in use, in a heat exchanger or a solar thermal panel. Therefore, working fluids comprising suspended nano-particles (so called nano-fluids) to transfer heat or drive a machine are more efficient than existing working fluids. Working fluids with higher specific heat capacities (due to the presence of the nano-particles) tend to undergo greater increases and rates of increase in temperature than other working fluids when the same amount of heat is transferred to the working fluid. These characteristics ensure that the nano-fluids comprising nano-particles allow the energy to be more rapidly transferred from the working fluid at a subsequent heat exchanger due to an increased temperature differential between the working fluid and the element to which heat is transferred from the fluid.

Use of certain types of nano-particle has been found to decrease the specific heat capacity of the fluid which may decrease the rate at which energy is transferred to the working fluid. As such the temperature differential between the working fluid and the source of energy decreases more rapidly as the working fluid is heated. However this may be compensated by maintaining the temperature differential between the working fluid and the heat source, for example, by pumping the working fluid more rapidly through a heat exchanger.

The use of nano-particles (as opposed to millimetre or micrometre scale particles) to improve the thermal characteristics of the working fluid may be advantageous as it reduces the risks of clogging of, or abrasion to the conduits through which the working fluid is passing. Additionally, suspended nano-particles may be used to alter the viscosity of the working fluid.

A system for manufacturing a nano-fluid including a plurality of hoppers each containing at least one type of nano-particle; a reservoir containing a base fluid; control means associated with valves on the hoppers and a valve on the reservoir which valves are operable to dispense a user defined volume of working fluid and user defined amounts of nano-particles into a mixer tank; a mixer for mixing the nano-particles with the base fluid in the mixer tank to produce a nano-fluid; and a dispenser for dispensing the nano-fluid into storage containers.

Suspending particles within the working fluid has been found to increase the thermal heat transfer characteristics of the nano-fluid. Nano-fluids are fluids which include suspended nano-particles intended to vary one or more physical characteristic of the fluid. The nano-particles are ideally mixed so that they are suspended in the base fluid in a colloidal suspension.

In preferred embodiments, the materials from which the nano-particles are formed, ideally has a greater thermal conductivity than the base fluid.

The plurality of nano-particles ~~may be – or~~ may comprise ~~–~~nano-particles of metal and/or metal oxide and/or metal nitride and/or metal silicide and/or metal carbide.

Ideally nano-particles include: boron carbine (B_4C), nano-particles of boron nitride (BN), nano-particles of beryllium oxide (BeO), nano-particles of magnesium oxide (MgO), nano-particles of graphite, nano-particles of silicon (Si), nano-particles of aluminium nitride (AlN), nano-particles of silicon carbide (SiC), nano-particles of aluminium oxide (Al_2O_3), nano-particles of titanium dioxide (TIO_2), nano-particles of silicon dioxide (SiO_2), nano-particles of copper (II) oxide (CuO), or any combination thereof.

Optionally the nano-particles include a graphene and/or reduced graphene mixture.

In some embodiments a characteristic dimension (length or diameter) of the nano-particles is preferably smaller than 100nm, preferably smaller than 75nm, more preferably smaller than 50nm, and most preferably smaller than 25nm. Alternatively, or additionally, the nano-particles may have dimensions less than 90nm, less than 70nm, less than 45nm, or less than 20nm.

In some embodiments, the nano-particles may have dimensions greater than 5nm, greater than 10nm, or greater than 15nm.

The base liquid comprises at least one hydro-fluoro-ether and may comprise at least 50% hydro-fluoro-ethers by volume. The base liquid ~~may~~ comprises at least one type of HFE-7000 hydro-fluoro-ether and ideally the liquid comprises at least 50% HFE-7000 hydro-fluoro-ethers by volume.

The volumetric concentration of the nano-particles within the working fluid may be greater than 1%; it may be greater than 2%; it may be greater than 3%; it may be greater than 4%; it may be greater than 5%; it may be greater than 6%; it may be greater than 7%, or it may be less than 8%.

It is further appreciated that according to another aspect the invention also extends to a method of operating the aforementioned system for manufacturing a nano-fluid.

Preferred embodiments of the invention will now be described by way of examples only and with reference to the Figures, in which:

Brief Description of the Figures

Figure 1 is a table showing the increase in the heat transfer coefficient (W/(m^{2}K) of a working fluid when different nano-particles are added at different volumetric concentrations;

Figure 2 is a table showing the power of a system performing an organic Rankine cycle when using different working fluids;

Figure 3 is a diagram illustrating key steps in the production of a working fluid with different nano-particles; and

Figure 4 is a basic functional diagram of a production plant for manufacturing working fluid with a range of different nano-particles.

Detailed Description of the Figures

Figure 1 is a table illustrating the percentage differences between the mean heat transfer coefficients of a HFE-7000 based working fluid and thirty-six different working nano-fluids, each of which comprises nano-particles of one of twelve different chemicals added to the HFE-7000 based working fluid at one of three different volumetric concentrations.

The thirty-six different basic working fluids~~,~~ are described, twenty-four of these being separate example embodiments of the invention. A particularly preferred embodiment may be derived, for example by coating some of the nano-particles with graphene. A refinement of these additional variations may be obtained by coating nano-particles with a monolayer coating of graphene on nano-particles.

The twelve different chemicals from which the nano-particles comprised by the thirty-six working nano-fluids are formed are: boron carbine (B_4C), boron nitride (BN), beryllium oxide (BeO), magnesium oxide (MgO), graphite, graphene (reduced graphene), silicon (Si), aluminium nitride (AlN), silicon carbide (SiC), aluminium oxide (Al_2O_3), titanium dioxide (TIO_2), silicon dioxide (SiO_2), and copper (II) oxide (CuO).

The three different volumetric concentrations of the nano-particles within the working fluid being 1%, 4%, and 6%.

The mean heat transfer coefficients of the HFE-7000 working fluid and the thirty-six working nano-fluids are measured when conducting heat in flows with Reynolds Number of around 1200.

The nano-particles of the thirty-six examples of working nano-fluids have dimensions of approximately 45nm.

All thirty-six of the working nano-fluids have greater mean thermal conductivities than the HFE-7000 working fluid with no suspended nano-particles present.

Figure 2 is a table illustrating the power output of as system performing an organic Rankine cycle between a solar thermal panel and an expander, when using thirteen different working fluids.

The thirteen working fluids are: pure HFE-7000, a nano-fluid comprising nano-particles of boron carbine (B_4C) suspended in HFE-7000, a nano-fluid comprising nano-particles of boron nitride (BN) suspended in HFE-7000, a nano-fluid comprising nano-particles of beryllium oxide (BeO) suspended in HFE-7000, a nano-fluid comprising nano-particles of magnesium oxide (MgO) suspended in HFE-7000, a nano-fluid comprising nano-particles of graphite suspended in HFE-7000, a nano-fluid comprising nano-particles of silicon (Si) suspended in HFE-7000, a nano-fluid comprising nano-particles of aluminium nitride (AlN) suspended in HFE-7000, a nano-fluid comprising nano-particles of silicon carbide (SiC) suspended in HFE-7000, a nano-fluid comprising nano-particles of aluminium oxide (Al_2O_3) suspended in HFE-7000, a nano-fluid comprising nano-particles of titanium dioxide (TIO_2) suspended in HFE-7000, a nano-fluid comprising nano-particles of silicon dioxide (SiO_2) suspended in HFE-7000, and a nano-fluid comprising nano-particles of copper (II) oxide (CuO) suspended in HFE-7000.

The nano-particles of the twelve working nano-fluids having dimensions of approximately 45nm and volumetric concentrations within the working nano-fluids of 4%.

The system passes the working fluids through a solar thermal panel, upon which radiation of intensity 800 W/m^2 is incident. The working fluids are then passed through positive displacement expander where mechanical work is extracted from the working fluid. The working fluid then passes through a heat exchanger to a reservoir from which it is pumped back through the solar thermal panel. The pressure ratio of the system being 5.

An ~~In a preferred~~ example ~~embodiment of the invention the~~ working fluid comprises 94% by volume HFE-7000, 6% by volume nano-particles of titanium dioxide (TiO_2) with dimensions greater than 40nm and less than 50nm.

The invention may be included in heat transfer systems for use for example in buildings and/or vehicles in which heat needs to be transferred to cooler zones ~~-~~or from hotter zones. Examples of systems include: air-condoning units, combined heat and power units and blowers, for example for warming cabs in vehicles or rooms.   The improved heat transfer efficiency of the working fluid enables heat energy to be transferred more efficiently (quicker and with less pumping power) than was previously the case and so provides for lighter and more compact heat transfer systems.

Figure 3 illustrates key steps in the manufacture of a working fluid with different nano-particles. Figure 4 is a basic functional diagram of a production plant for manufacturing working fluid with a range of different nano-particles and shows in diagrammatical form key stages in production~~-~~.

The invention has been described by way of example only and it will be appreciated that variation may be made to the embodiments described above without departing from the scope of the claims.

Claims

1. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of silicon (Si).

2. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of boron carbide (B_4C).

3. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of boron nitride (BN).

4. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of beryllium oxide (BeO).

5. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of graphene.

6. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of aluminium nitride (AlN).

7. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of silicon carbide (SiC).

~~1.~~8. A working fluid comprising a plurality of nano-particles suspended in at least one hydro-fluoro-ether base fluid which comprises HFE-7000 hydro-fluoro-ether; wherein the nano-particles comprise nano-particles of titanium dioxide (TIO_2).

~~2.~~9. A working fluid according to any preceding claim ~~claim 1~~ wherein the nano-particles are suspended in the base fluid in a colloidal suspension.

~~3.~~10. A working fluid according to any preceding claim ~~claim 1 or claim 2~~ wherein the plurality of nano-particles comprise nano-particles of boron carbine (B_4C), nano-particles of boron nitride (BN), nano-particles of beryllium oxide (BeO), nano-particles of magnesium oxide (MgO), nano-particles of graphite, nano-particles of silicon (Si), nano-particles of aluminium nitride (AlN), nano-particles of silicon carbide (SiC), nano-particles of aluminium oxide (Al_2O_3), nano-particles of titanium dioxide (TIO_2), nano-particles of silicon dioxide (SiO_2), nano-particles of copper (II) oxide (CuO), or any combination thereof.

~~4.~~11. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of boron carbide (B_4C).

~~5.~~12. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of boron nitride (BN).

~~6.~~13. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of beryllium oxide (BeO).

~~7.~~14. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of magnesium oxide (MgO).

~~8.~~15. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of graphite or graphene.

~~9.~~16. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of silicon (Si).

~~10.~~17. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of aluminium nitride (AlN).

~~11.~~18. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of silicon carbide (SiC).

~~12.~~19. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of aluminium oxide (Al_2O_3).

~~13.~~20. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of titanium dioxide (TiO_2).

~~14.~~21. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of silicon dioxide (SiO_2).

~~15.~~22. A working fluid according to any preceding claim wherein the plurality of nano-particles comprises nano-particles of copper (II) oxide (CuO).

~~16.~~23. A working fluid according to any preceding claim wherein nano-particles have at least two characteristic dimensions less than 100nm.

~~17.~~24. A working fluid according to any preceding claim wherein nano-particles have dimensions less than 100nm.

~~18.~~25. A working fluid according to any preceding claim wherein nano-particles have at least two dimensions less than 75nm.

~~19.~~26. A working fluid according to any preceding claim wherein nano-particles have dimensions less than 75nm.

~~20.~~27. A working fluid according to any preceding claim wherein nano-particles have at least two dimensions less than 50nm.

~~21.~~28. A working fluid according to any preceding claim wherein nano-particles have dimensions less than 50nm.

~~22.~~29. A working fluid according to any preceding claim wherein nano-particles have at least two dimensions less than 25nm.

~~23.~~30. A working fluid according to any preceding claim wherein nano-particles have dimensions less than 25nm.

~~24.~~31. A working fluid according to any preceding claim wherein the nano-particles have dimensions greater than 5nm.

~~25.~~32. A working fluid according to any preceding claim wherein the nano-particles have dimensions greater than 10nm.

~~26.~~33. A working fluid according to any preceding claim wherein the nano-particles have dimensions greater than 15nm.

~~27.~~34. A working fluid according to any preceding claim wherein the base fluid is at least 50% hydro-fluoro-ethers by volume.

~~28. A working fluid according to any preceding claim wherein the base fluid comprises HFE-7000 hydro-fluoro-ether.~~

~~29.~~35. A working fluid according to any preceding claim wherein the base fluid is at least 50% HFE-7000 hydro-fluoro-ether by volume.

~~30.~~36. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 1%.

~~31.~~37. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 2%.

~~32.~~38. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 3%.

~~33.~~39. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 4%.

~~34.~~40. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 5%.

~~35.~~41. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 6%.

~~36.~~42. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within working fluid is greater than 7%.

~~37.~~43. A working fluid according to any preceding claim wherein the volumetric concentration of the nano-particles within the working fluid is less than 8%.

~~38.~~44. A working fluid according to any of claims 1 to 41 ~~35~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 7%.

~~39.~~45. A working fluid according to any of claims 1 to 40 ~~34~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 6%.

~~40.~~46. A working fluid according to any of claims 1 to 39 ~~33~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 5%.

~~41.~~47. A working fluid according to any of claims 1 to 38 ~~32~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 4%.

~~42.~~48. A working fluid according to any of claims 1 to 37 ~~31~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 3%.

~~43.~~49. A working fluid according to any of claims 1 to 36 ~~30~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 2%.

~~44.~~50. A working fluid according to any of claims 1 to 35 ~~29~~ wherein the volumetric concentration of the nano-particles within the working fluid is less than 1%.

~~45.~~51. A working fluid according to any preceding claim wherein the heat transfer property of the base fluid which is improved is the heat transfer coefficient (h).

~~46.~~52. A system for manufacturing a working fluid according to any of claims 1 to 51 ~~45~~ including a plurality of hoppers each containing at least one type of nano-particle; a reservoir containing the at least one base fluid; control means associated with valves on the hoppers and a valve on the reservoir, the valves are operable to dispense a user defined volume of base fluid and user defined amounts of nano-particles into a mixer tank; a mixer for mixing the nano-particles with the base fluid in the mixer tank to produce a nano-fluid; and a dispenser for dispensing the working fluid into storage containers.

~~47.~~53. A system according to claim 52 ~~46~~ wherein the mixer is operative to mix the nano-particles and the at least one base fluid until the nano-particles are suspended in the base fluid in a colloidal suspension.

~~48.~~54. A method of operating the system for manufacturing a working fluid according to either claim 52 ~~46~~ or 53. ~~47.~~

Abstract

The present invention relates to a working fluid. More specifically the present invention relates to a working fluid for use in a heat transfer system, for example of the type used to transfer heat in a heat engine.

Working fluids require good heat transfer properties (thermal conductivity and specific heat capacity) so that they can absorb and release large amounts of energy quickly.

The invention describes a working fluid comprising a plurality of nano-particles suspended in a base fluid so as to improve a heat transfer property of the base fluid. Ideally the nano-particles are suspended in the base fluid in a colloidal suspension.

A system for manufacturing a nano-fluid is also described. The system includes a plurality of hoppers for containing types of nano-particle and a reservoir that contains a base fluid. A control means controls valves on the hoppers and on the reservoir in order to dispense working fluid and defined amounts of nano-particles into a mixer tank. A mixer mixes the nano-particles with the base fluid to produce a nano-fluid which is in colloidal suspension in the working fluid.

(Figure 4)