another material, for example a storage heating system. The tubing can be maintained within the panel within an evacuated or near-evacuated chamber formed for example using a sealed chamber with a glass surface. The vacuum or semi-vacuum reduces loss of heat from the working fluid back to the atmosphere.

For thermal solar systems that simply convert incident radiation into a heated fluid, efficiencies can theoretically be high, but the efficiency of these systems is limited by factors such as the reflection and/or transmission of solar energy from the absorbing surface and any covering protective layer, such as a glass layer. The efficiency of these systems is also limited by the capacity of the absorbing surface to absorb the incoming radiation, which varies with the temperature difference between the solar panel and its surroundings. Typical efficiencies for flat-plate solar thermal systems are around 50-60%.

The invention is defined in the independent claims. Some optional features of the invention are defined in the dependent claims.

According to one exemplary technique, there is provided a solar energy system for heating a target fluid using incident solar radiation, the system comprising:

a protective upper layer;
a target fluid layer comprising the target fluid;
a light transmissive inter-fluidic dividing layer;
a working fluid layer comprising a working fluid; and
a lower retaining layer.

The system provides a solar energy system in which a higher proportion of the energy in the incident radiation is absorbed into the target fluid. In particular, by arranging both the target fluid and the working fluid as layers in the system, for example in a panel, both fluids can be used to absorb incident solar radiation. This can increase efficiency since the target fluid can absorb as much energy as it can directly without requiring heat exchange with another medium. However, the working fluid can be designed to absorb radiation at wavelengths at which the target fluid has poor absorption, hence capturing more of the incident energy in total.

While the order of the layers presented above is preferable for most embodiments, the claimed system is not limited to a particular ordering of the layers. The target fluid may be provided in a layer above or below the working fluid. The arrangement of layers depends on the different wavelength ranges in which each of the fluid absorbs radiation.

In one embodiment, the transfer of energy between the working fluid and the target fluid predominantly comprises radiant transfer.

According to another exemplary technique, there is provided a high shear mixing system for dispersing nanoparticles in a dispersion medium, to manufacture a working fluid for a solar energy system, comprising:

a surface for receiving the dispersion medium and the nanoparticles;

a blade; and

means for mounting the blade wherein the means for mounting is arranged at a predetermined distance from the surface; and

means for moving the blade across the surface.

By moving the blade across the surface, a large force can be applied to the nanoparticles to mix them evenly into the dispersion medium. The blade can be pressed against the surface, causing the blade to bend and exert a force on the surface. When the blade is dragged through the mixture of dispersion medium and nanoparticles, the force exerted on the blade is transmitted to the mixture, mixing it. Due to the blade pressing against the surface, only a small amount of the mixed dispersion medium and nanoparticles passes under the blade, and forms a thin layer on the surface, while the remainder of the mixture is pushed ahead of the blade as it moves over the surface.

Optionally, the predetermined distance between the means for mounting the blade and the surface in the high shear mixing system is adjustable. The distance between the means for mounting the blade and the surface determines the thickness of the layer left behind, as the blade moves across the surface. In a first example, when the blade does not touch the surface, the thickness of the layer may be determined by the distance between the lower edge of the blade and the surface. In a second example, when the blade does touch the surface, reducing the distance between the means for mounting the blade and the surface applies pressure to the blade, and causes it to bend. When the blade is moved across the surface in this situation, the bending of the blade exerts a force on the mixture, and a thin layer of the mixture is able to pass under the blade. The closer the means for mounting the blade is to the surface, the more force is exerted, and the thinner the layer of mixture which is formed behind the blade as it moves. Thus moving the means for mounting the blade

closer to the surface in this example allows a very thin layer to be accurately and reproducibly produced and therefore provides a well-mixed layer of dispersion medium and nanoparticles.

In this example, the blade may be made from any suitable material, with the material selected so that its springiness provides the desired layer thickness. While metal blades may be used, it has been found that small impurities of metal can greatly diminish the effectiveness of carbon nanoparticles in absorbing incident radiation. Therefore, when the high shear mixing system is used to manufacture a working fluid comprising carbon nanoparticles, for example for use in the solar energy systems and solar panels described herein, it is preferable to use a non-metallic blade, for example made from plastic or rubber materials.

Optionally, the means for moving the blade rotates the blade in the plane of the surface. By arranging the means for moving the blade to move in a rotational manner, the blade is able to pass over the surface many times in a single pass. This means that there can be a constant stream of the mixture of dispersion medium and nanoparticles passing under the blade. The blade can be moved in this rotational manner for a long time. For example, rotating the blade at 100rpm for one week gives a little over one million rotations. This large number of rotations means that it is overwhelmingly likely, statistically speaking, that every nanoparticle has passed under the blade, and correspondingly that the result is a fluid in which the nanoparticles are highly dispersed in the dispersion medium.

According to a further exemplary technique, there is provided a method of manufacturing a working fluid for a solar energy system comprising:

providing a plurality of nanoparticles;

providing a dispersion medium having a viscosity of greater than 500cP, preferably greater than 800cP;

dispersing the nanoparticles within the dispersion medium in a high shear mixing system.

The use of a high shear mixing system together with a dispersion medium of sufficient viscosity to retain the particles in suspension once they have been mixed can enable the working fluid to be manufactured without the use of additional chemicals or additives.

Optionally, the method further includes mixing or coating the plurality of nanoparticles with a surfactant prior to dispersing the nanoparticles within the dispersion medium. In some embodiments, the nanoparticles may already be mixed or coated with a surfactant as a result of the method of manufacturing the nanoparticles themselves. Retaining any remaining surfactant on the nanoparticles can assist in the dispersion of the nanoparticles within the dispersion medium.

The method of manufacturing a working fluid may make use of the high shear mixing system described above, and the mixing process may further include the steps of:

placing the dispersion medium and the nanoparticles on the surface; and

dragging the blade across the surface. Optionally, the blade is dragged across the surface a plurality of times, for example many tens of thousands of times. As discussed above, the use of this mixing system provides high shear mixing, with reliable control of the shear forces. Allowing the blade to pass across the surface multiple times results in an extremely well mixed working fluid.

There is also described herein a working fluid for a solar energy system, wherein the working fluid comprises a colloid comprising:

a dispersion medium having a viscosity of greater than 1cP, preferably greater than 300cP; and

a dispersion phase, wherein the dispersion phase comprises carbon nanoparticles; wherein the dispersion phase is dispersed within the dispersion medium using a high shear mixing system.

According to a further exemplary technique, there is provided a fluid for absorbing incident radiation in a solar energy system, wherein the fluid comprises a colloid comprising:

a dispersion medium having a viscosity of greater than 800cP and less than 1200cP;

a dispersion phase of nanoparticles.

In one embodiment, the dispersion phase is dispersed within the dispersion medium using a high shear mixing system.

Preferably, the nanoparticles comprise carbon nanoparticles.

The following features apply equally to the preceding exemplary method and system aspects.

Optionally, the fluid further comprises a surfactant, and the carbon nanoparticles may be mixed with the surfactant prior to dispersion within the dispersion medium.

In one embodiment, the dispersion medium comprises water and a high viscosity fluid for thickening the dispersion medium, optionally a lecithin. Alternatively, the dispersion medium comprises oil, optionally castor bean oil.

Optionally, the working fluid further comprises a wax for increasing the viscosity of the dispersion medium, optionally the wax comprising carnauba wax.

Optionally, the carbon nanoparticles comprise at least 3% by weight, preferably at least 5% by weight, further preferably at least 6% by weight of the working fluid.

Optionally, the carbon nanoparticles comprise less than 10% by weight, preferably less than 8% by weight, further preferably less than 7% by weight of the working fluid.

An amount of around 6.6% by weight of the carbon nanoparticles within the fluid has been found to provide a good absorption of the incident radiation.

The carbon nanoparticles may comprise many different shapes and dimensions of nanoparticles, however, the nanoparticles preferably comprise tube-shaped carbon nanoparticles, optionally the nanoparticles comprise at least 25% tube-shaped carbon nanoparticles, preferably at least 50%. The tube-shaped nanoparticles may be carbon nanotubes, or may comprise graphene sheets rolled into tube shapes. Such rolled tubes are encompassed within the definition of carbon nanotubes as used herein. The properties of carbon nanotubes have been found to enable good absorption of the incident radiation.

Optionally, the working fluid further comprises a high transmissivity material, optionally comprising a material with a transmissivity greater than 70%.

The high transmissivity material may comprise a material with a high refractive index, optionally with a refractive index greater than 1.4.

Suitable high transmissivity materials include CaF_2 and SiO_2.

The working fluid may comprise the high transmissivity material in a ratio of less than 0.1% by weight of the high transmissivity material to the nanoparticles. Hence the high transmissivity material is present only in small proportions in relation to the nanoparticles or the dispersion medium.

According to a further exemplary technique, there is provided herein an impedance matching layer for electromagnetic radiation, the impedance matching layer comprising:

a first composite having a first impedance to the transmission of electromagnetic radiation;

a second composite having a second impedance to the transmission of electromagnetic radiation, different to the first impedance;

wherein each composite comprises a carrier material and a dopant, the carrier material and the dopant having different impedances to the transmission of electromagnetic radiation;

wherein the first composite comprises a first proportion of the dopant in relation to the carrier material to provide the composite having the first impedance to the transmission of electromagnetic radiation; and

wherein the second composite comprises a second proportion of the dopant in relation to the carrier material to provide the composite having the second impedance to the transmission of electromagnetic radiation.

Hence by using a carrier material and a dopant in varying proportions, composites of different impedance can be formed and these composites can be used to create an impedance matching layer for electromagnetic radiation. The impedance matching layer is therefore formed having a profile with an impedance to electromagnetic radiation that varies through the thickness of the layer, hence enabling incoming electromagnetic radiation to transition more efficiently and with reduced reflection losses from a material on one side of the matching layer to a material on the other side of the matching layer.

Optionally, λ corresponds to a frequency of between 6 x 10^{14} Hz and 1 x 10^{15} Hz. This corresponds to the region of maximum power delivered to the earth's surface by the sun, and roughly spans the near ultraviolet to the green part of the spectrum.

According to another exemplary technique, there is provided a solar panel for heating a target fluid using incident solar radiation, the solar panel comprising:

three major edges arranged so that the solar panel can be inscribed in a triangle with each major edge of the panel lying along at least a portion of a side of the triangle;

a cavity for retaining the target fluid; and

an inlet and an outlet for the target fluid, for exchanging the target fluid with adjacent solar panels.

By making solar panels in a shape which is based on the triangle, it is possible to tile large areas, since triangles tessellate. In this context, the three major edges of the panel are the three longest edges. For example, when the edges of the panel lie along the whole length of the sides of the triangle, the panel itself will also be triangular, and therefore have only three edges. In this case, these three edges correspond to the full lengths of the major edges.

In other embodiments, the major edges of the panel lie along only a portion of the triangle. In this case, the major edges are joined together by minor edges, and the shape of the panel may be that of a truncated triangle with the corners removed, which can also be thought of as an irregular hexagon.

The solar panel may comprise the inlet and outlet being located adjacent to a corner of the triangle. While other shapes also tessellate (squares, rectangles, hexagons etc.), a further advantage of triangle-based shapes is that a large number of connections can be made between adjacent triangles when the inlet and outlet are located adjacent to the corner of the triangle. For example, comparing triangles to other shapes which tessellate, a hexagon can connect to at most 6 adjacent hexagons, squares or rectangles can connect to up to 8 adjacent squares or rectangles, but triangles are able to connect to up to 12 adjacent shapes. Therefore, when triangle-based shapes are used, the target fluid can flow out of one panel to a large number of neighbouring panels, thus providing a flexible network.

Optionally, the working fluid is a fluid for absorbing incident solar radiation as described above.

According to a further exemplary technique, there is provided a network of solar panels for heating a target fluid using incident solar radiation, the network comprising:

a first solar panel; and

a second solar panel; wherein

the first and second solar panels each include a cavity for retaining a target fluid, and the first and second solar panels are coupled together to allow the target fluid to flow between them; and

further comprising means for selectively enabling fluid flow into each panel.

When fluid flow is selectively enabled into the panels, the flow can be directed around the network. For example, the flow may be directed based on how hot each panel is. When a panel is cooler, for example because it is in the shade, target fluid is not sent to that panel, as it would not be able to contribute to the heating of the target fluid. The efficiency of the network is therefore improved by avoiding cooler panels.

Preferably, flow through an array of solar panels is controlled by restricting or enabling the inflow of fluid into a panel. However, the outflow of fluid from a panel is not restricted.

The solar panels forming part of the network are preferably the solar panels described above.

Optionally, the solar panels in the network are arranged adjacent to one another, coupled along one of their major edges. As described above, connecting the solar panels together along their major edges means that the panels meet at their corners (or minor edges). This provides each panel with up to 12 adjacent panels to exchange target fluid with, and provides a flexible network.

The solar panels in the network may be joined together adjustably and/or flexibly so that the distance and/or angle between adjacent panels is variable. This allows the panels to be

mounted on surfaces with complex underlying geometry, since the network can flex to fit the panels to the underlying surface.

Optionally, each panel has an inlet and an outlet coupled to an adjacent panel, and the flow of target fluid is controlled by selectively opening or closing inlets.

Optionally the target fluid can flow in either direction between adjacent panels.

The flow of target fluid around the network is controlled by valves configured to open above a first predetermined temperature, and close below a second predetermined temperature. A suitable switching temperature may be 60°C as this is a temperature high enough to kill most water-borne pathogens. Thus, allowing water to flow into panels which are at around 60°C, and preventing flow into those below this temperature can help to ensure that all water in the system is sanitised.

The valves in the network may comprise a physical valve, arranged to change shape and/or size in response to temperature. For example, the physical valve may be a diaphragm having a dome-shaped body, configured to invert itself in response to stresses generated by thermal expansion or contraction of the diaphragm. Arranging the valves to operate in this way means that there need not be complex control systems in place. Instead, bypassing of cooler panels is an inherent feature of the system.

According to a further exemplary technique, there is provided a diaphragm for use in a temperature controlled valve, comprising a dome-shaped body, configured to invert itself at a predetermined temperature in response to stresses generated by thermal expansion or contraction of the diaphragm. Such a diaphragm is cheap and easy to produce.

The temperature at which the diaphragm inverts itself may be determined by the geometry or materials of the diaphragm. This allows a variety of different diaphragms to be produced, depending on the intended use.

Optionally, the diaphragm is made of a plastics material, for example the diaphragm is made in part from polyvinylidene fluoride (PVDF) or polypropylene. The diaphragm may

be made from more than one material, each material having a different coefficient of thermal expansion. Plastics are cheap, readily available, and easy to shape.

The diaphragm may have a thickness which varies across the diaphragm. This provides a manner in which the temperature at which the diaphragm inverts itself can be set during production.

It will be appreciated that exemplary techniques of the disclosure described above may be implemented alone or in conjunction with other aspects. Preferred features of one aspect may be applied to other aspects. Apparatus for implementing the methods described and methods of operating the apparatus described are also provided. There are also provided computer programs, computer program products and computer-readable media comprising instructions for operating apparatus for manufacturing and controlling the systems described herein.

Embodiments of the apparatus and methods described herein will now be described in more detail with reference to the drawings in which:

Fig. 1 is a schematic diagram of a solar thermal system according to one embodiment;

Fig. 2 is a schematic diagram of a solar thermal system according to a further embodiment;

Fig. 3 is a plan view of a solar panel according to an embodiment;

Figs. 4A and 4B are plan views of a network of solar panels according to an embodiment;

Figs. 5A and 5B are plan views of solar panels according to another embodiment;

Fig. 6 is a schematic diagram of a high shear mixer;

Figs. 7A and 7B are schematic views of high shear mixers according to yet another embodiment;

Fig.8 illustrates a step in the manufacture of an impedance matching layer according to one embodiment;

Fig. 9 illustrates an impedance matching layer according to one embodiment;

Fig. 10 illustrates a calendering process in the manufacture of an impedance matching layer according to one embodiment;

Fig. 11A is a schematic illustration of a diaphragm according to one embodiment; and

Figs. 11B and 11C provide a schematic illustration of the diaphragm of fig. 11A in use as a valve in a pipe.

Claims

1. A solar energy system for heating a target fluid using incident solar radiation, the system comprising:

a protective upper layer;

a target fluid layer comprising the target fluid;

an inter-fluidic dividing layer;

a working fluid layer comprising the working fluid; and

a lower retaining layer;

wherein the inter-fluidic dividing layer enables transmission of the incident solar radiation to the working fluid, such that both the target fluid and the working fluid absorb the incident solar radiation; and

both the target fluid and the working fluid comprise liquids.

2. The system according to claim 1 further comprising means for circulating the target fluid through the target fluid layer of the system.

3. The system according to claim 1 or 2 wherein the target fluid and the working fluid are arranged such that incoming solar radiation passes through the target fluid prior to passing into the working fluid.

4. The system according to any preceding claim wherein the target fluid comprises water.

5. The system according to any preceding claim wherein the working fluid comprises oil.

6. The system according to any preceding claim wherein the working fluid comprises a colloid comprising a dispersed phase of nanoparticles.

7. The system according to claim 6 where the nanoparticles comprise carbon nanoparticles.

8. The system according to claim 6 or 7 wherein the colloid comprises a dispersion medium comprising oil.

9. The system according to claim 6 or 7 wherein the colloid comprises a dispersion medium comprising water.

10. The system according to claim 8 or 9 wherein the dispersion medium further comprises a high viscosity fluid for thickening the dispersion medium.

11. The system according to any preceding claim wherein the absorbance of the incident radiation in the working fluid is greater than the absorbance of the incident radiation in the target fluid for at least a portion of the spectrum of the incident solar radiation.

12. The system according to claim 11 wherein the portion of the spectrum comprises visible wavelengths.

13. The system according to any preceding claim wherein the working fluid emits absorbed radiation at infrared wavelengths.

14. The system according to any preceding claim further comprising an upper insulating layer.

15. The system according to any preceding claim wherein the lower retaining layer comprises a reflective layer for reflecting radiation back through the overlying layers.

16. The system according to any preceding claim wherein the transfer of energy between the working fluid and the target fluid predominantly comprises radiant transfer.