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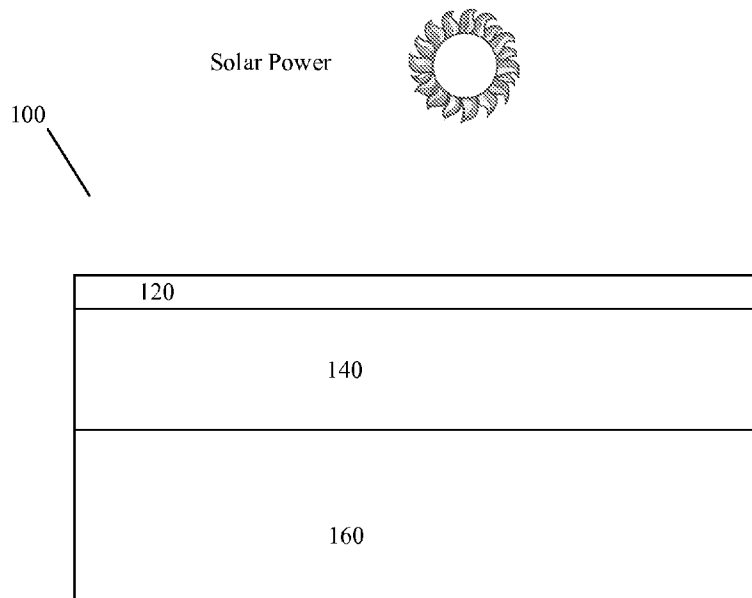
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(54) Title: IONIC LIQUID SOLAR PONDS

FIG. 1



[Continued on next page]



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(57) Abstract: A solar pond includes a upper convection zone including an ionic liquid; a non-convection zone; and a lower convection zone. The ionic liquid may be an imidazolium salt, an ammonium salt, a pyridinium salt, a piperidium salt, or a phosphonium salt.

IONIC LIQUID SOLAR PONDS

TECHNOLOGY

[0001] This technology is generally related to the use of ionic liquids in solar ponds.

BACKGROUND

[0002] Solar ponds are used for collection and storage of solar energy. The energy can be extracted from the solar ponds for any suitable thermal application. In general, a solar pond has a structure of three or more layers of different density liquids. Typically, salts such as magnesium chloride, sodium chloride or sodium nitrate are dissolved in water in a concentration from 20% to 30% in the bottom layer, and the top layer is void, or nearly void of such salts. The top, *i.e.* least dense, layer is termed the upper convection zone (UCZ), with the middle zone being termed the non-convection zone (NCZ), and the lower, *i.e.* most dense, layer being termed the lower convection zone (LCZ).

[0003] The salinity of the UCZ is typically very close to that of fresh water. In the NCZ, the salinity increases with the depth, with the salinity of the upper part of the NCZ being close to that of fresh water, and that of the lower part being close to that in the LCZ. There is little or no natural thermal convection in the NCZ, hence the name, “non-convection zone.” However, solar radiation is able to penetrate this zone and increase the temperature of the solar pond as a function of the depth. The LCZ is the most dense layer and has a high density of salt. The LCZ layer acts as an energy storage. Maintenance of the temperature gradient in the NCZ is essential for the efficient use of solar ponds.

[0004] There are at least two major problems leading to the poor thermal efficiency of solar ponds. One of them relates to the stability of the salt gradient, and, the other, to the thickness of the upper convection zone. Generally, the upper convection zone is a thick layer to prevent water evaporation since the stability of the salt gradient is important for the thermal performance of the solar pond. However, a thicker UCZ may limit the solar energy reaching the LCZ.

SUMMARY

[0005] In one aspect, a solar pond is provided including an upper convection zone that includes an ionic liquid; a non-convection zone; and a lower convection zone. In some embodiments, the ionic liquid has a density that is less than a density of the non-convection zone and the lower convection zone, at an operating temperature of the upper convection zone of the solar pond. In other embodiments, the ionic liquid has a density that is greater than a density of the non-convection zone, at an operating temperature of the upper convection zone of the solar pond, where the surface tension of the non-convection zone is sufficient to retain the ionic liquid as the upper convection zone. In some embodiments, the density of the ionic liquid is from 0.80 g/ml to 1.25 g/ml, and the operating temperature of the upper convection zone is from about 0°C to about 100°C.

[0006] In some embodiments, the ionic liquid includes an imidazolium ion, an ammonium ion, a pyrrolidinium ion, a pyridinium ion, a piperidinium ion, or a phosphonium ion. In other embodiments, the ionic liquid is a liquid at the operating temperature of the upper convection zone of the solar pond. In other embodiments, the ionic liquid is stable to IR, UV, and/or visible radiation for extended periods. In some embodiments, the ionic liquid is stable to IR, UV, and/or visible radiation for up to 6 months. In other embodiments, the ionic liquid is stable to IR, UV, and/or visible radiation for 6 months or longer. In yet other embodiments, the ionic liquid is stable to IR, UV, and/or visible radiation for from 6 months to 2 years. In some embodiments, the upper convection zone is from 0.1% to 10% of a total depth of the solar pond.

[0007] In some embodiments, the non-convection zone is an aqueous salt solution. In some embodiments, the lower convection zone includes an aqueous salt solution, that is of a higher concentration than the non-convection zone. In such embodiments, the aqueous salt solutions include sodium chloride, potassium chloride, magnesium chloride, calcium chloride, sodium nitrate, potassium nitrate, ammonium nitrate, sodium sulfate, sodium carbonate, sodium bicarbonate, disodium phosphate, borax, and diammonium phosphate.

[0008] In another aspect, a solar pond upper convection zone includes an ionic liquid.

[0009] In another aspect, a geothermal system includes a solar pond including an upper convection zone including an ionic liquid.

BRIEF DESCRIPTION OF THE DRAWING

[0010] FIG. 1 is a schematic drawing of a solar pond, according to one embodiment.

DESCRIPTION

[0011] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here. The present technology is also illustrated by the examples herein, which should not be construed as limiting in any way.

[0012] In one aspect, a solar pond is provided in which the UCZ includes an ionic liquid. In some embodiments the ionic liquid is non-volatile at atmospheric pressure and at a temperature of about 100°C. The zero, or near zero, evaporation of ionic liquids allows their application as a thin upper convection zone, which acts as a cap on the solar pond, preventing or diminishing evaporation of the water from the NCZ and LCZ, thereby maintaining a steady salt gradient in the system. This can improve the thermal performance of the solar pond in comparison to purely aqueous-based ponds.

[0013] An illustration of an ionic liquid solar pond design is schematically shown in FIG. 1. Ionic liquids are used as the UCZ (120), while the NCZ (140) and the LCZ (160) are aqueous salt solutions as are known in conventional solar ponds. Since there is a density gradient which increases from the top to the bottom layers, the layers tend not to mix to the extent that they maintain their separate identities. As a result, the ionic solar pond may simply be prepared by carefully layering the NCZ atop the LCZ and the UCZ atop the NCZ. Because of their zero or near zero evaporation pressure, ionic liquids act as a cover for the non-convection zone below it. Therefore, the water evaporation is decreased

or avoided and the salt gradient remains more stable and consistent than in a conventional solar pond. Therefore thermal performance variations of the solar pond caused by fluctuations of the salt gradient of the non-convection zone will be reduced or eliminated. Also because of its diminished evaporation, the thickness of the ionic liquid containing upper convection zone can be very thin, so that the solar energy can be effectively transferred to the energy storage zone, with a minimum of losses due to absorption by the ionic liquid.

[0014] Ionic liquids are typically non-flammable, or are flame retardants, and have a high heat capacity of fusion. Consequently, the ionic liquid upper convection zone may improve the stability and the energy harvesting of the solar pond.

[0015] Ionic liquids useful as the upper convection zone of solar ponds may be selected based on a variety of physical characteristics including but not limited to their stability to the sun's radiation; fluidity within the operating temperature of the solar pond; ability to remain the surface layer of the solar pond; and relative immiscibility with water.

[0016] For example, the ionic liquid for use as an UCZ in a solar pond is stable to the sun's radiation for the period of time it is used in the solar pond. When exposed to the sun in a solar pond, such ionic liquids are stable, *e.g.*, for 1- 12 hours, 1-7 days, 1- 4 weeks, 1- 6 months, 6 months to 2 years, or longer than 6 months. In some embodiments, the ionic liquid is stable to infra-red, visible, and/or UV radiation for these periods of time. In some embodiments, the ionic liquid absorbs 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, or 90% of UV radiation in the 400 nm - 800 nm, 300 nm – 400 nm, or the 150 nm - 300 nm region, and the rest is allowed to pass through the UCZ to the NCL or LCZ. In other embodiments, the ionic liquid absorbs 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, or 90% of infra-red radiation, and the rest is allowed to pass through the UCZ to the NCZ or LCZ. The UV and IR absorption properties of the ionic liquids can be easily determined by methods well-known to the skilled artisan, for example simply by using UV- or IR-absorption spectrometers.

[0017] It is desirable that the ionic liquid exists in the fluid state when used in a solar pond to harvest solar energy. If the UCZ is a liquid, the transfer of energy via the UCZ to the NCZ may be supported by the convection within the UCZ. Generally the LCZ

and the NCZ are also fluids. The LCZ of the a solar pond relies on fluid movement in that zone to absorb and transfer heat within the pond. For mass balance and salinity balance in the pond, the NCZ of the solar pond is also typically a liquid.

[0018] The ionic liquid will have a density so that the UCZ including the ionic liquid is maintained as a cap on the solar pond. This may be accomplished in at least two ways. First, the density of the ionic liquid may be lower than that of the least dense portion of the NCZ. Thus, based upon density alone, the ionic liquid will remain as the top layer and maintain its position as a cap on the solar pond. Second, the density of the ionic liquid may be slightly greater than the least dense portion of the NCZ; however, in such situations, the UCZ layer may have to be sufficiently thin that the surface tension of the NCZ is sufficient to retain the ionic liquid as a UCZ and not allow it to sink into the solar pond. If the density of the ionic liquid is much larger than that of the least dense portion of the NCZ, the ionic liquid may not be retained as a surface cap. The temperature of the UCZ may also impact its density. The ionic liquid should not be miscible with water solutions.

[0019] Accordingly, in some embodiments, the ionic liquid has a density that is less than a density of the non-convection zone and the lower convection zone, at an operating temperature of the upper convection zone of the solar pond. In other embodiments, the density of the ionic liquid is from 0.80 g/ml to 1.25 g/ml, and the operating temperature of the upper convection zone is from about 0°C to about 100°C. As used herein, the term about as applied to the temperature is a value that takes into account the phenomena of freezing point depression and boiling point elevation. When a solute such as a salt is dissolved in water, it may have a freezing point that is less than that of pure water (*i.e.* 0°C), or it may have a boiling point that is higher than that of pure water (*i.e.* 100°C). Therefore, where the saline solutions of the NCZ or the LCZ have freezing points lower than that of pure water, the operating temperature is from a temperature that is about equal to the temperature of the freezing point depressed saline solution to a temperature that is about equal to the temperature of the boiling point elevated saline solution. Or, in other words, from about 0°C to about 100°C. If the temperature goes beyond the boiling point of the boiling point elevated saline solution, the solar pond will be disrupted. If the temperature is below the freezing point, there may not be efficient heat convection.

[0020] It is also desirable that the ionic liquid is not miscible with aqueous salt solutions that form the NCZ layer or in some instances with water to the extent that it is not dispersed upon contact with the NCZ. This way, the water in the NCZ or the LCZ layers may not solubilize the ionic liquid and disperse it throughout the solar pond.

[0021] There are a large number of known ionic liquids that may be included in the UCZ of a solar pond. For example, some ionic liquids generally include imidazolium ions, ammonium ions (including tetraalkylammonium ions), pyrrolidinium ions, pyridinium ions, piperidinium ions, or phosphonium ions. A large number of ionic liquids and their properties have been reviewed by Handy (*Current Organic Chemistry* (2005) 9, 959-988), which may be used in accordance with the present technology. Illustrative examples ionic liquids include alkyl imidazolium salts, such as, but not limited to,:

- 3-methyl-1-(propan-2-ol)-imidazolium hexafluorophosphate;
- 3-methyl-1-(propan-2-ol)-imidazolium chloride;
- 3-methyl-1-(propan-2-ol)-imidazolium nitrate;
- 3-methyl-1-(ethoxyethoxy)-imidazolium hexafluorophosphate;
- 3-hexyl-1-(2-diethylphosphonato-ethyl)-imidazolium tetrafluoroborate;
- 3-hexyl-1-(3-diethylphosphonato-propyl)-imidazolium tetrafluoroborate;
- 3-octyl-1-(2-diethylphosphonato-ethyl)-imidazolium tetrafluoroborate;
- 3-methyl-1-butyl-imidazolium tetrafluoroborate;
- 3-methyl-1-butyl-imidazolium chloride;
- 3-methyl-1-butyl-imidazolium octyl sulfate;
- 3-methyl-1-butyl-imidazolium fluorohydrogenate;
- 3-methyl-1-ethyl-imidazolium tricyanomethane;
- 3-methyl-1-ethyl-imidazolium fluorohydrogenate;
- 3-methyl-1-ethyl-imidazolium carborane;
- 3-methyl-1-ethyl-imidazolium methylcarborane;
- 3-methyl-1-ethyl-imidazolium ethylcarborane;
- 3-methyl-1-methyl-imidazolium fluorohydrogenate;
- 3-methyl-1-propyl-imidazolium fluorohydrogenate;
- 3-methyl-1-pentyl-imidazolium fluorohydrogenate;
- 3-methyl-1-hexyl-imidazolium fluorohydrogenate;

3-methyl-1-hexyl-imidazolium chloride;
3-methyl-1-octyl-imidazolium chloride;
3-methyl-1-octyl-imidazolium tetrafluoroborate;
3-methyl-1-methyl-imidazolium tetrafluoroborate;
3-methyl-2-ethyl-1-methyl-imidazolium carborate;
octylimidazolium salicylate;
nonylimidazolium salicylate;
dodecylimidazolium salicylate; or
(butyoxymethyl)imidazolium salicylate.

[0022] Other illustrative examples of ionic liquids include ammonium salts such as, but not limited to:

tetraethylammonium tributyoctylborate;
tetraethylammonium acetate;
hexyl-triethyl-ammonium hexyl-triethylborate;
hexyl-triethyl-ammonium tributyoctylborate;
tetrapropylammonium tripropylhexylborate;
tetrabutylammonium tributylhexylborate;
hexyl-tri-butylammonium tributylhexylborate;
hexyl-tri-butylammonium bis-trifluoromethanesulfonamide;
heptyl-tri-butylammonium bis-trifluoromethanesulfonamide;
tetrapentylammonium bis-trifluoromethanesulfonamide;
octyl-tri-butylammonium bis-trifluoromethanesulfonamide;
octyl-tri-butylammonium trifluoromethylsulfonate;
tetrahexylammonium bis-trifluoromethanesulfonamide;
tetrahexylammonium tributylhexylborate;
tetraheptylammonium bis-trifluoromethanesulfonamide;
tetraoctylammonium bis-trifluoromethanesulfonamide; or
tetradodecylammonium bis-trifluoromethanesulfonamide.

[0023] Yet other illustrative examples of ionic liquids include pyrrolidinium salts such as, but not limited to:

N-methyl-N-propylpyrrolidine dicyanimide;

N-methyl-N-butylpyrrolidine dicyanimide; or
N-methyl-N-hexylpyrrolidine dicyanimide.

[0024] Yet other illustrative examples of ionic liquids include bis-aminomethylene-ammonium salts such as, but not limited to:

[bis-(N-butyl-N-ethyl-amino)-methylene]-dimethyl-ammonium tetrafluoroborate;
[bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium tetrafluoroborate;
[bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium hexafluorophosphate;
[bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium chloride;
[bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium bis-trifluoromethanesulfonamide;
[bis-(N-octyl-N-octyl-amino)-methylene]-dimethyl-ammonium tetrafluoroborate;
[bis-(N-octyl-N-octyl-amino)-methylene]-dimethyl-ammonium hexafluorophosphate; or
[bis-(N-octyl-N-octyl-amino)-methylene]-dimethyl-ammonium chloride.

[0025] Yet other illustrative examples of ionic liquids include phosphonium salts such as, but not limited to:

methyl-tripropylphosphonium tosylate;
methyl-tri-(iso-butyl)phosphonium tosylate;
methyl-tri-(tert-butyl)phosphonium tosylate;
methyl-di-(iso-butyl)-octylphosphonium tosylate;
methyl-di-(iso-butyl)-tetradecylphosphonium tosylate;
tetradecyl-tri-(hexyl)-phosphonium bromide;
tetradecyl-tri-(hexyl)-phosphonium tetrafluoroborate; or
tetradecyl-tri-(hexyl)-phosphonium hexafluorophosphate.

[0026] As will be understood, the density of the ionic liquids may vary as a function of both the cationic part (*i.e.* the imidazolium, ammonium, phosphonium, pyridinium,

pyrrolidinium, etc) and the anionic part (*i.e.* the salicylate, tetrafluoroborate, other borates, carborane, tosylate, etc.). The structure-density variations of various ionic liquids and variations of their other properties relative to their structure are well known. See, *e.g.*, Zhang *et al.*, J. Phys. Chem. Ref. Data, Vol. 35, No. 4, 2006 (incorporated herein by reference).

[0027] As noted above, the non-convection zone and the lower convection zone are aqueous salt solutions. These zones form a vertical salinity gradient, in which lower salinity solutions float on top of higher salinity solutions. Thus, near the interface between the ionic liquid and the NCZ, the salinity of the aqueous phase is lowest and near the bottom of the LCZ, the salinity is highest. Because of the higher salinity of the LCZ, solar radiation is more efficiently absorbed, thereby heating the water. According to various embodiments, the solutions included in the NCZ and the LCZ may use a variety of salt including, but not limited to, sodium chloride, potassium chloride, magnesium chloride, calcium chloride, sodium nitrate, potassium nitrate, ammonium nitrate, sodium sulfate, sodium carbonate, sodium bicarbonate, disodium phosphate, borax, and diammonium phosphate, and other fertilizer salts.

[0028] The various layers may be of various thickness, as long as their relative layered structure and function remains intact. According to some embodiments, the UCZ is from 0.1% to 10% of a total depth of the solar pond; the NCZ is from 1% to 50% of a total depth of the solar pond; and the LCZ is from 10% to 90% of a total depth of the solar pond..

[0029] Solar ponds including an ionic liquid may be used in a variety of thermal applications. For example, geothermal systems which extract energy from the ground or water for use in heating, may advantageously use such solar ponds. Other uses include electricity production, for example as produced by Rankine engines.

EQUIVALENTS

[0030] While certain embodiments have been illustrated and described, it should be understood that changes and modifications can be made therein in accordance with ordinary

skill in the art without departing from the technology in its broader aspects as defined in the following claims.

[0031] All publications, patent applications, issued patents, and other documents referred to in this specification are herein incorporated by reference as if each individual publication, patent application, issued patent, or other document was specifically and individually indicated to be incorporated by reference in its entirety. Definitions that are contained in text incorporated by reference are excluded to the extent that they contradict definitions in this disclosure.

[0032] The present disclosure is not to be limited in terms of the particular embodiments described in this application. Many modifications and variations can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. Functionally equivalent methods and compositions within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods, reagents, compounds compositions or biological systems, which can of course vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

[0033] The embodiments, illustratively described herein may suitably be practiced in the absence of any element or elements, limitation or limitations, not specifically disclosed herein. Thus, for example, the terms “comprising,” “including,” “containing,” etc. shall be read expansively and without limitation. Additionally, the terms and expressions employed herein have been used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the claimed technology. Additionally, the phrase “consisting essentially of” will be understood to include those elements specifically recited and those additional elements that do not materially affect the

basic and novel characteristics of the claimed technology. The phrase “consisting of” excludes any element not specified.

[0034] In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

[0035] As will be understood by one skilled in the art, for any and all purposes, particularly in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, *etc.* As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third and upper third, *etc.* As will also be understood by one skilled in the art all language such as “up to,” “at least,” “greater than,” “less than,” and the like, include the number recited and refer to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member.

[0036] Other embodiments are set forth in the following claims.

WHAT IS CLAIMED IS:

1. A solar pond comprising:
 - a upper convection zone comprising an ionic liquid;
 - a non-convection zone; and
 - a lower convection zone.
2. The solar pond of Claim 1, wherein the ionic liquid has a density that is less than a density of the non-convection zone and the lower convection zone, at an operating temperature of the upper convection zone of the solar pond.
3. The solar pond of Claim 2, wherein the density of the ionic liquid is from 0.80 g/ml to 1.25 g/ml, and the operating temperature of the upper convection zone is from about 0°C to about 100°C.
4. The solar pond of Claim 1, 2, or 3, wherein the ionic liquid comprises an imidazolium ion, an ammonium ion, a pyridinium ion, a piperidinium ion, or a phosphonium ion.
5. The solar pond of any one of Claims 1-4, wherein the ionic liquid comprises 4-(2-hydroxy-propyl)-1-methyl-4H-imidazolium hexafluorophosphate; 3-methyl-1-(propan-2-ol)-imidazolium hexafluorophosphate; 3-methyl-1-(propan-2-ol)-imidazolium chloride; 3-methyl-1-(propan-2-ol)-imidazolium nitrate; 3-methyl-1-(ethoxyethoxy)-imidazolium hexafluorophosphate; 3-hexyl-1-(2-diethylphosphonato-ethyl)-imidazolium tetrafluoroborate; 3-hexyl-1-(3-diethylphosphonato-propyl)-imidazolium tetrafluoroborate; 3-octyl-1-(2-diethylphosphonato-ethyl)-imidazolium tetrafluoroborate; 3-methyl-1-butyl-imidazolium tetrafluoroborate; 3-methyl-1-butyl-imidazolium chloride; 3-methyl-1-butyl-imidazolium octyl sulfate; 3-methyl-1-butyl-imidazolium fluorohydrogenate; 3-methyl-1-ethyl-imidazolium tricyanomethane; 3-methyl-1-ethyl-imidazolium fluorohydrogenate; 3-methyl-1-ethyl-imidazolium carborane; 3-methyl-1-ethyl-imidazolium methylcarborane; 3-methyl-1-ethyl-imidazolium ethylcarborane; 3-methyl-1-methyl-imidazolium fluorohydrogenate; 3-methyl-1-propyl-imidazolium fluorohydrogenate; 3-methyl-1-pentyl-imidazolium fluorohydrogenate; 3-methyl-1-

hexyl-imidazolium fluorohydrogenate; 3-methyl-1-hexyl-imidazolium chloride; 3-methyl-1-octyl-imidazolium chloride; 3-methyl-1-octyl-imidazolium tetrafluoroborate; 3-methyl-1-methyl-imidazolium tetrafluoroborate; 3-methyl-2-ethyl-1-methyl-imidazolium carborate; tetraethylammonium tributyoctylborate; tetraethylammonium acetate; hexyl-triethyl-ammonium hexyl-triethylborate; hexyl-triethyl-ammonium tributyoctylborate; tetrapropylammonium tripropylhexylborate; tetrabutylammonium tributylhexylborate; hexyl-tri-butylammonium tributylhexylborate; hexyl-tri-butylammonium bis-trifluoromethanesulfonamide; heptyl-tri-butylammonium bis-trifluoromethanesulfonamide; tetrapentylammonium bis-trifluoromethanesulfonamide; octyl-tri-butylammonium bis-trifluoromethanesulfonamide; octyl-tri-butylammonium trifluoromethylsulfonate; tetrahexylammonium bis-trifluoromethanesulfonamide; tetrahexylammonium tributylhexylborate; tetraheptylammonium bis-trifluoromethanesulfonamide; tetraoctylammonium bis-trifluoromethanesulfonamide; tetradodecylammonium bis-trifluoromethanesulfonamide; N-methyl-N-propylpyrrolidine dicyanimide; N-methyl-N-butylpyrrolidine dicyanimide; N-methyl-N-hexylpyrrolidine dicyanimide; [bis-(N-butyl-N-ethyl-amino)-methylene]-dimethyl-ammonium tetrafluoroborate; [bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium tetrafluoroborate; [bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium hexafluorophosphate; [bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium chloride; [bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium bis-trifluoromethanesulfonamide; [bis-(N-octyl-N-octyl-amino)-methylene]-dimethyl-ammonium tetrafluoroborate; [bis-(N-octyl-N-octyl-amino)-methylene]-dimethyl-ammonium hexafluorophosphate; [bis-(N-octyl-N-octyl-amino)-methylene]-dimethyl-ammonium chloride; methyl-tripropylphosphonium tosylate; methyl-tri-(iso-butyl)phosphonium tosylate; methyl-tri-(tert-butyl)phosphonium tosylate; methyl-di-(iso-butyl)-octylphosphonium tosylate; methyl-di-(iso-butyl)-tetradecylphosphonium tosylate; tetradecyl-tri-(hexyl)-phosphonium bromide; tetradecyl-tri-(hexyl)-phosphonium tetrafluoroborate; tetradecyl-tri-(hexyl)-phosphonium hexafluorophosphate; octylimidazolium salicylate; nonylimidazolium salicylate; dodecylimidazolium salicylate; or (butyoxymethyl)imidazolium salicylate.

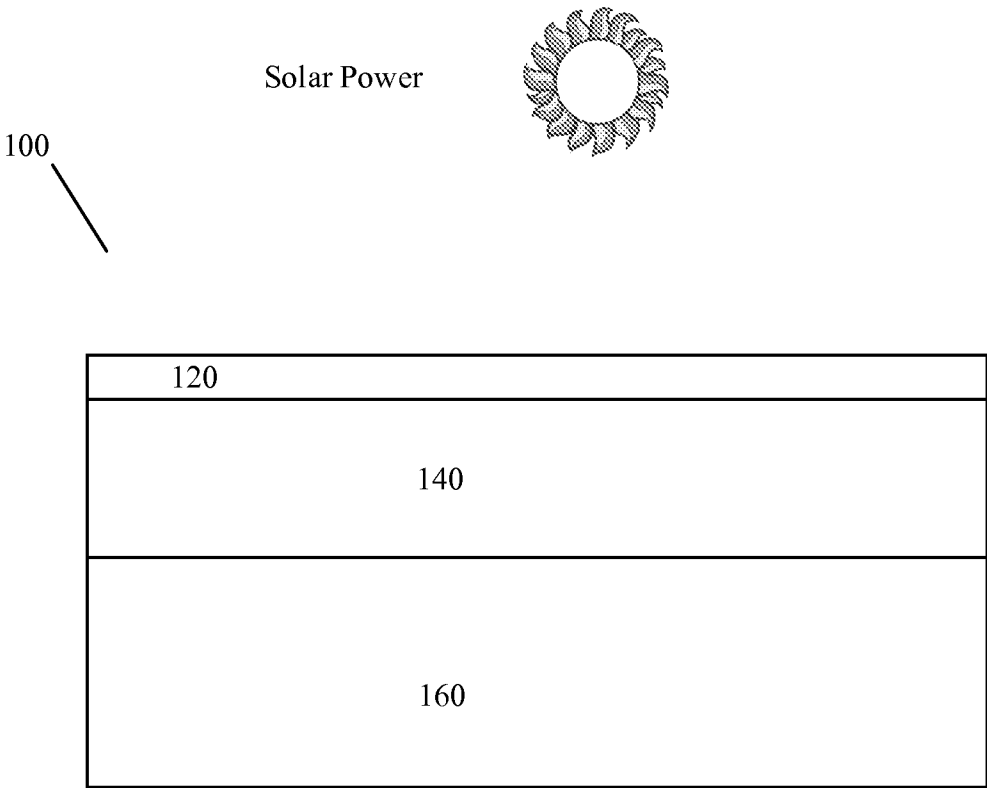
6. The solar pond of any one of Claims 2-5, wherein the ionic liquid is a liquid at the operating temperature of the upper convection zone of the solar pond.
7. The solar pond of Claim 6, wherein the operating temperature is from about 0°C to about 100°C.
8. The solar pond of any one of Claims 1-7, wherein the ionic liquid is stable to electromagnetic radiation.
9. The solar pond of Claim 8, wherein the electromagnetic radiation is ultra-violet radiation.
10. The solar pond of any one of Claims 1-9, wherein the upper convection zone comprises from 0.1% to 10% of a total depth of the solar pond.
11. The solar pond of any one of Claims 1-10, wherein the non-convection zone comprises an aqueous salt solution.
12. The solar pond of any one of Claims 1-11, wherein the non-convention zone comprises from 1% to 50% of a total depth of the solar pond.
13. The solar pond of any one of Claims 1-12, wherein the lower convection zone comprises an aqueous salt solution, that is of a higher concentration than the non-convention zone.
14. The solar pond of Claim 13, wherein the aqueous salt solution comprises sodium chloride, potassium chloride, magnesium chloride, calcium chloride, sodium nitrate, potassium nitrate, ammonium nitrate, sodium sulfate, sodium carbonate, sodium bicarbonate, disodium phosphate, borax, or diammonium phosphate.
15. The solar pond of any one of Claims 1-14, wherein the upper convection zone comprises from 0.1% to 10% of a total depth of the solar pond.
16. A solar pond upper convection zone comprising an ionic liquid.

17. The solar pond upper convection zone of Claim 16, wherein a density of the ionic liquid is from 0.80 to 1.25 g/ml, and an operating temperature of the upper convection zone from about 0°C to about 100°C.
18. The solar pond upper convection zone of Claim 16 or 17, wherein the ionic liquid comprises an imidazolium ion, an ammonium ion, a pyridinium ion, a piperidium ion, or a phosphonium ion.
19. The solar pond upper convection zone of Claim 16, 17, or 18, wherein the ionic liquid comprises 4-(2-hydroxy-propyl)-1-methyl-4H-imidazolium hexafluorophosphate; 3-methyl-1-(propan-2-ol)-imidazolium hexafluorophosphate; 3-methyl-1-(propan-2-ol)-imidazolium chloride; 3-methyl-1-(propan-2-ol)-imidazolium nitrate; 3-methyl-1-(ethoxyethoxy)-imidazolium hexafluorophosphate; 3-hexyl-1-(2-diethylphosphonato-ethyl)-imidazolium tetrafluoroborate; 3-hexyl-1-(3-diethylphosphonato-propyl)-imidazolium tetrafluoroborate; 3-octyl-1-(2-diethylphosphonato-ethyl)-imidazolium tetrafluoroborate; 3-methyl-1-butyl-imidazolium tetrafluoroborate; 3-methyl-1-butyl-imidazolium chloride; 3-methyl-1-butyl-imidazolium octyl sulfate; 3-methyl-1-butyl-imidazolium fluorohydrogenate; 3-methyl-1-ethyl-imidazolium tricyanomethane; 3-methyl-1-ethyl-imidazolium fluorohydrogenate; 3-methyl-1-ethyl-imidazolium carborane; 3-methyl-1-ethyl-imidazolium methylcarborane; 3-methyl-1-ethyl-imidazolium ethylcarborane; 3-methyl-1-methyl-imidazolium fluorohydrogenate; 3-methyl-1-propyl-imidazolium fluorohydrogenate; 3-methyl-1-pentyl-imidazolium fluorohydrogenate; 3-methyl-1-hexyl-imidazolium fluorohydrogenate; 3-methyl-1-hexyl-imidazolium chloride; 3-methyl-1-octyl-imidazolium chloride; 3-methyl-1-octyl-imidazolium tetrafluoroborate; 3-methyl-1-methyl-imidazolium tetrafluoroborate; 3-methyl-2-ethyl-1-methyl-imidazolium carborate; tetraethylammonium tributyoctylborate; tetraethylammonium acetate; hexyl-triethyl-ammonium hexyl-triethylborate; hexyl-triethyl-ammonium tributyoctylborate; tetrapropylammonium tripropylhexylborate; tetrabutylammonium tributylhexylborate; hexyl-tri-butylammonium tributylhexylborate; hexyl-tri-butylammonium bis-trifluoromethanesulfonamide; heptyl-tri-butylammonium bis-trifluoromethanesulfonamide; tetrapentylammonium bis-trifluoromethanesulfonamide; octyl-tri-butylammonium bis-

trifluoromethanesulfonamide; octyl-tri-butylammonium trifluoromethylsulfonate; tetrahexylammonium bis-trifluoromethanesulfonamide; tetrahexylammonium tributylhexylborate; tetraheptylammonium bis-trifluoromethanesulfonamide; tetraoctylammonium bis-trifluoromethanesulfonamide; tetradodecylammonium bis-trifluoromethanesulfonamide; N-methyl-N-propylpyrrolidine dicyanamide; N-methyl-N-butylpyrrolidine dicyanamide; N-methyl-N-hexylpyrrolidine dicyanamide; [bis-(N-butyl-N-ethyl-amino)-methylene]-dimethyl-ammonium tetrafluoroborate; [bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium tetrafluoroborate; [bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium hexafluorophosphate; [bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium chloride; [bis-(N-hexyl-N-hexyl-amino)-methylene]-dimethyl-ammonium bis-trifluoromethanesulfonamide; [bis-(N-octyl-N-octyl-amino)-methylene]-dimethyl-ammonium tetrafluoroborate; [bis-(N-octyl-N-octyl-amino)-methylene]-dimethyl-ammonium hexafluorophosphate; [bis-(N-octyl-N-octyl-amino)-methylene]-dimethyl-ammonium chloride; methyl-tripropylphosphonium tosylate; methyl-tri-(iso-butyl)phosphonium tosylate; methyl-tri-(tert-butyl)phosphonium tosylate; methyl-di-(iso-butyl)-octylphosphonium tosylate; methyl-di-(iso-butyl)-tetradecylphosphonium tosylate; tetradecyl-tri-(hexyl)-phosphonium bromide; tetradecyl-tri-(hexyl)-phosphonium tetrafluoroborate; tetradecyl-tri-(hexyl)-phosphonium hexafluorophosphate; octylimidazolium salicylate; nonylimidazolium salicylate; dodecylimidazolium salicylate; or (butyoxymethyl)imidazolium salicylate.

20. A geothermal system comprising a solar pond comprising an upper convection zone comprising an ionic liquid.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2011/023317

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

F24J 2/42 (2006.01)

F24J 2/04 (2006.01)

F24J 3/08 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Epodoc & WPI: IPC⁸: (F24J 2/42 or F24J 2/04 or F24J 3/08 or Ecla: F24J 2/04B16B) and ionic or (imidazolium or ammonium or pyridinium or piperidium or phosphonium)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5220792 A (Doron et al) 22 June 1993 Column 2 line 64 to column 5 line 24, Claims and Drawings	
A	Patent Abstracts of Japan JP 63-210562 A (Toshiba Corp) 1 September 1988 Abstract	
A	Patent Abstracts of Japan JP 62-218766 A (Toshiba Corp) 26 September 1987 Abstract	



Further documents are listed in the continuation of Box C



See patent family annex

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search
08 March 2011

Date of mailing of the international search report

15 MAR 2011

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2011/023317

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
US	5220792	AR	244856	AU	14003/92	AU	26472/88
		CN	1070982	IL	88572	IL	101193
		IL	102787	IN	171035	MX	9204428
		NZ	243573	TR	26435	US	4894993
		US	5148677	US	5404937	US	5582690
JP	63210562	NONE					
JP	62218766	NONE					
Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.							
END OF ANNEX							