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(54) **THERMAL TRANSFER APPARATUS AND METHOD THEREFOR**

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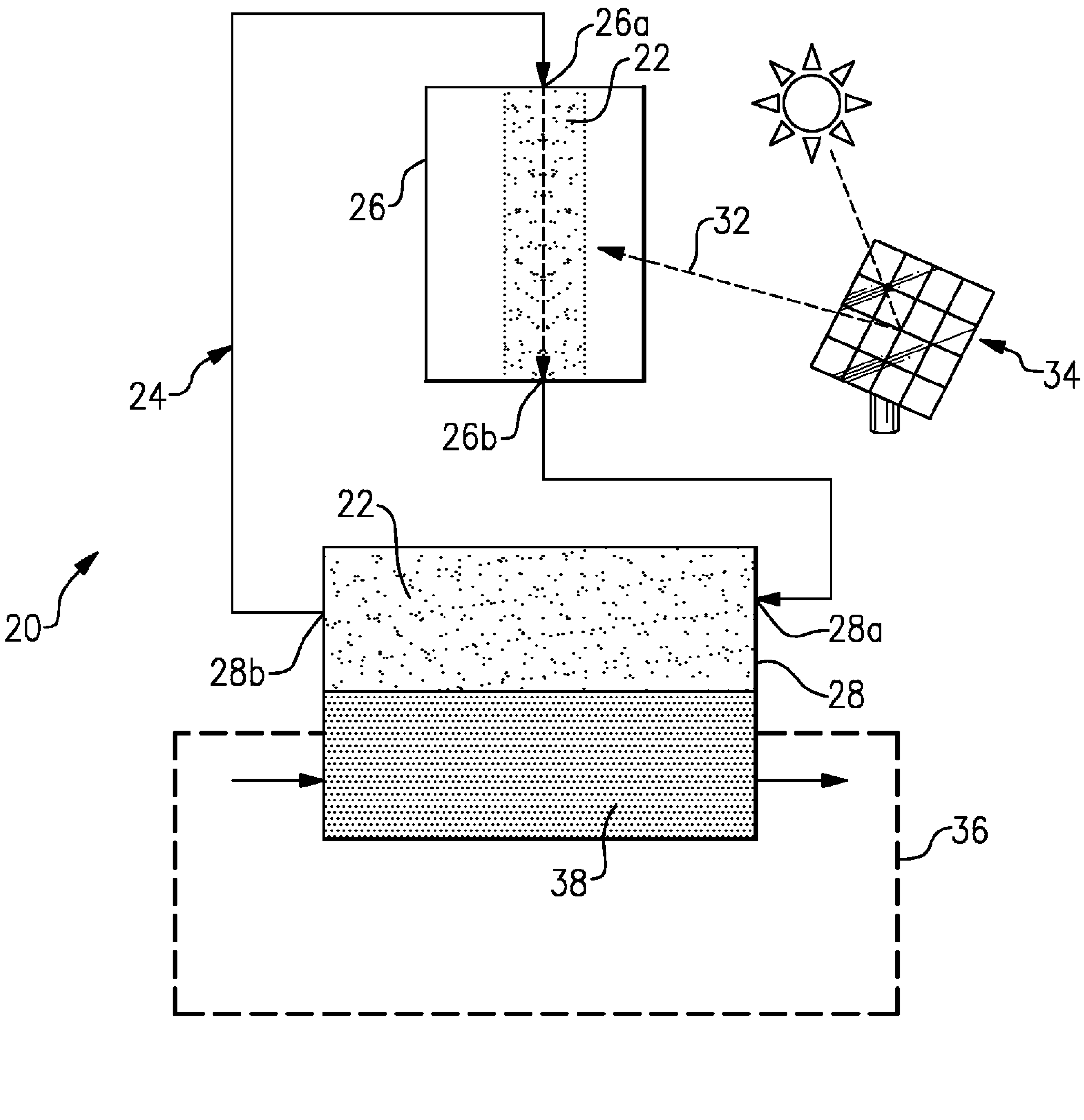
(57) **ABSTRACT**

An apparatus includes a closed loop circuit that has a concentrated solar receiver and a particulate thermal transfer media moveable through the closed loop circuit. The particulate thermal transfer media has a melting temperature of greater than 600° C./1112° F. A heat exchanger is in communication with the particulate thermal transfer media.



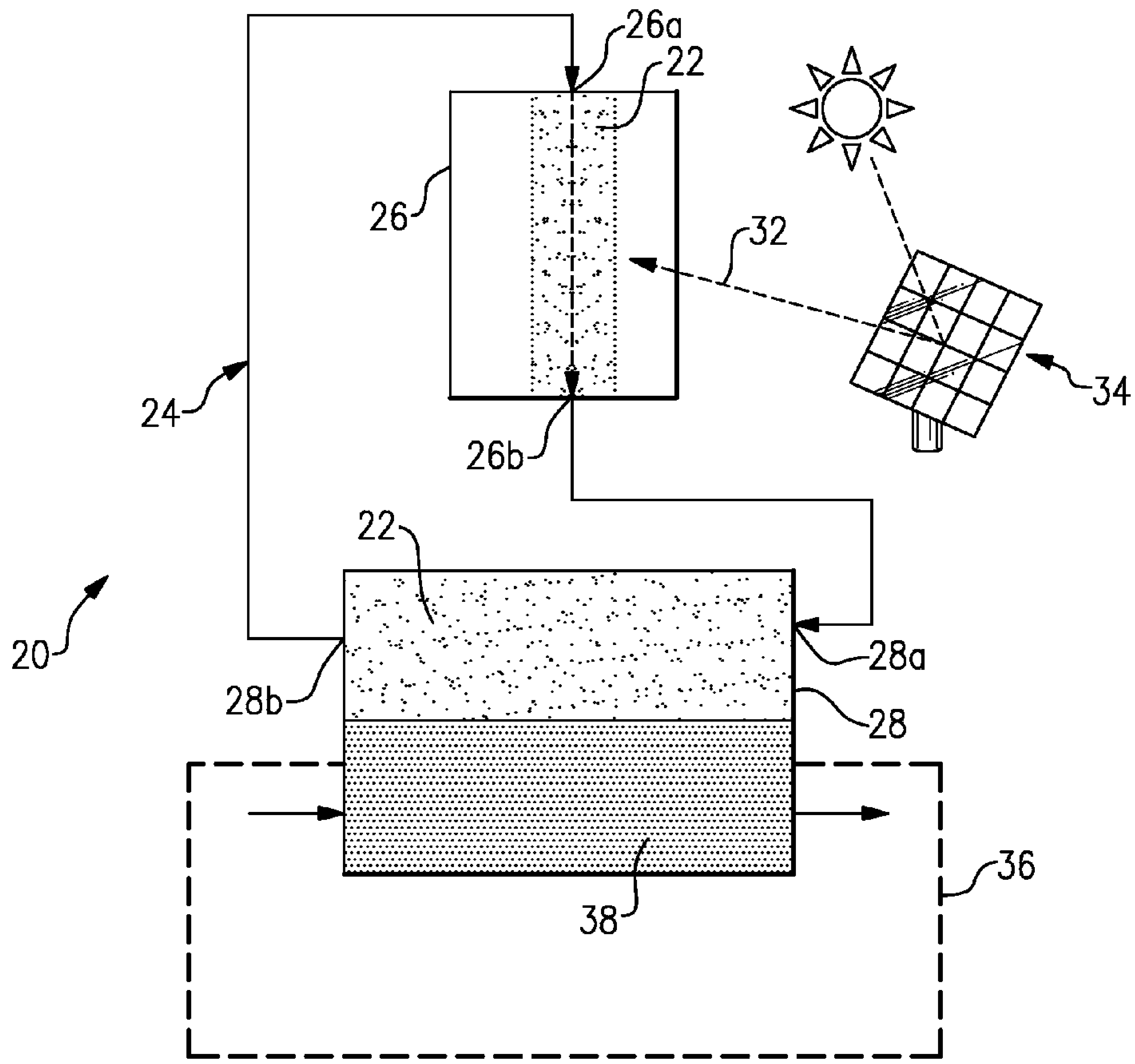


FIG.1

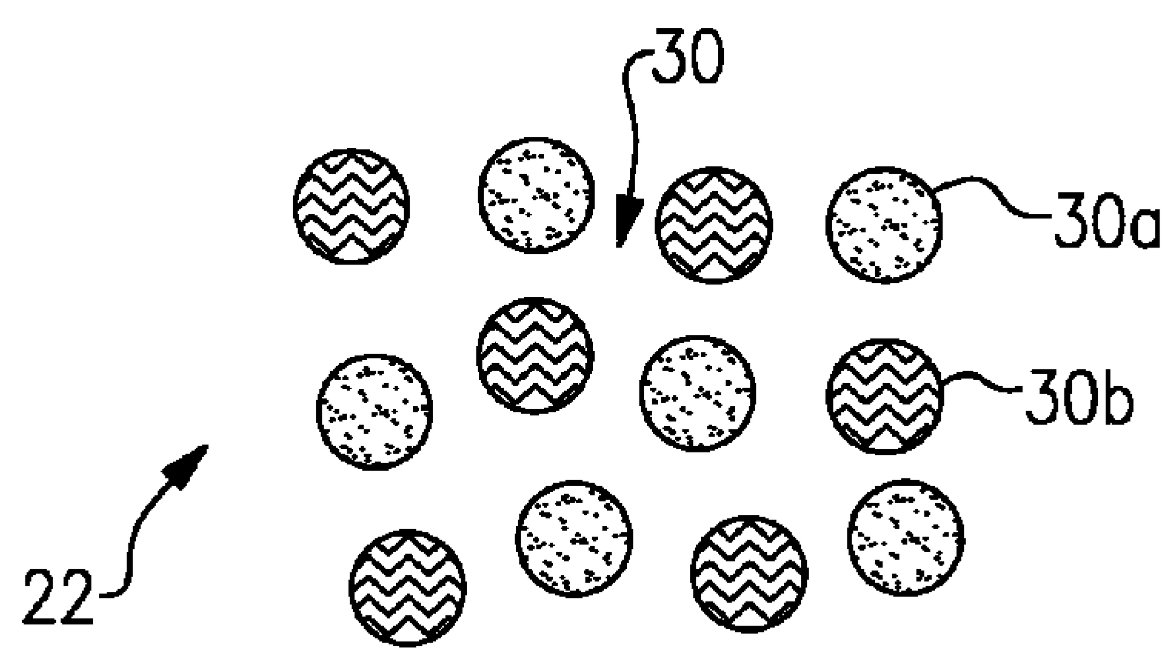


FIG.2

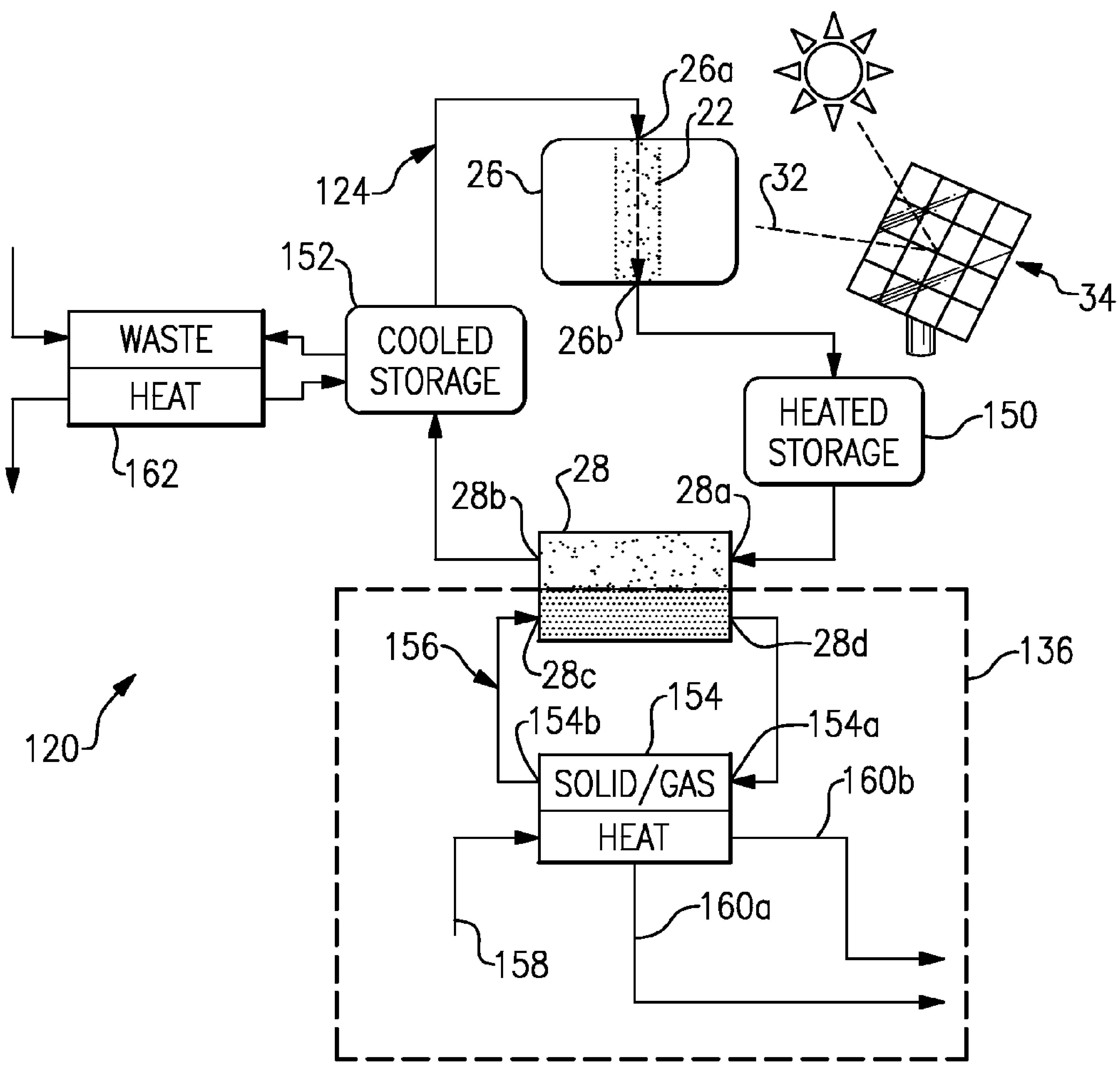

26a
22
26
124
32
152
34
WASTE
HEAT
COOLED
STORAGE
26b
HEATED
STORAGE
150
162
28b
28
28a
136
156
28c
28d
154
154b
154a
120
SOLID/GAS
HEAT
160b
160a
158

FIG.3

THERMAL TRANSFER APPARATUS AND METHOD THEREFOR

BACKGROUND

[0001] This disclosure relates to a thermal transfer system and, more particularly, to thermal transfer between a concentrated solar receiver and a heat exchanger.

[0002] A variety of different industrial products and processes utilize thermal energy to process raw materials and produce an end product. For example, in the cement industry, quick-lime is produced in a process known as chemical disassociation. When heated to a sufficient temperature, the chemical disassociation of quick-lime generates a solid oxide and a gaseous carbon dioxide. More recently, solar heating has been utilized to heat the quick-lime. However, one challenge in utilizing solar energy, or other sources of thermal energy, is that the availability of the solar energy varies over time.

SUMMARY

[0003] An apparatus according to an exemplary aspect of the disclosure includes a closed loop circuit that has a concentrated solar receiver and a particulate thermal transfer media moveable through the closed loop circuit. The particulate thermal transfer media has a melting temperature of greater than 600° C./1112° F. A heat exchanger is in communication with the particulate thermal transfer media.

[0004] In a further embodiment, the apparatus includes a storage vessel within the closed loop circuit between an outlet from the concentrated solar receiver and an inlet into the heat exchanger.

[0005] In a further embodiment of any of the foregoing examples, the apparatus includes a storage vessel within the closed loop circuit between an outlet of the heat exchanger and an inlet of the concentrated solar receiver.

[0006] In a further embodiment of any of the foregoing examples, the apparatus includes reactor vessel in thermal communication with the heat exchanger.

[0007] In a further embodiment of any of the foregoing examples, the particulate thermal transfer media includes bauxite.

[0008] In a further embodiment of any of the foregoing examples, the particulate thermal transfer media includes silicon carbide.

[0009] In a further embodiment of any of the foregoing examples, the particulate thermal transfer media includes silica.

[0010] In a further embodiment of any of the foregoing examples, the particulate thermal transfer media includes first particles having a first composition and second, different particles, having a second, different composition.

[0011] In a further embodiment of any of the foregoing examples, the particulate thermal transfer media includes particles, the particles, on average, having a size of greater than 1 micrometer.

[0012] A method for operating an apparatus according to an exemplary aspect of the disclosure includes moving a particulate thermal transfer media through a closed loop circuit into a concentrated solar receiver to absorb thermal energy into the particulate thermal transfer media, moving the particulate thermal transfer media from the concentrated solar receiver into a heat exchanger and heating a working fluid using the thermal energy extracted from the particulate thermal transfer media in the heat exchanger.

[0013] In a further embodiment, the method includes storing the particulate thermal transfer media in a storage vessel after absorbing the thermal energy in the concentrated solar receiver and, at a later time, moving the particulate thermal transfer media into the heat exchanger in response to a demand to heat the working fluid.

[0014] In a further embodiment of any of the foregoing examples, the method includes storing the particulate thermal transfer media in a storage vessel after extraction of the thermal energy from the particulate thermal transfer media in the heat exchanger and, at a later time, moving the particulate thermal transfer media into the concentrated solar receiver in response to an availability of thermal energy in the concentrated solar receiver.

[0015] In a further embodiment of any of the foregoing examples, the particulate thermal transfer media is selected from the group consisting of bauxite, silicon carbide, silica and combinations thereof.

[0016] In a further embodiment of any of the foregoing examples, the particulate thermal transfer media includes first particles having a first composition and second, different particles having a second, different composition.

[0017] In a further embodiment of any of the foregoing examples, the method includes circulating the working fluid through the heat exchanger to extract the thermal energy from the particulate thermal transfer media and heating a reactant material using the thermal energy in the working fluid to chemically disassociate the reactant material into a solid material and a gas material.

[0018] A method for operating an apparatus according to an exemplary aspect of the disclosure includes moving a particulate thermal transfer media through a closed loop circuit into a concentrated solar receiver to receive solar energy and absorb thermal energy from the solar energy into the particulate thermal transfer media, moving the particulate thermal transfer media from the concentrated solar receiver into a heat exchanger, circulating a working fluid through the heat exchanger to extract the thermal energy from the particulate thermal transfer media and heating a reactant material using the thermal energy in the working fluid to chemically disassociate the reactant material into a solid material and a gas material.

[0019] In a further embodiment of any of the foregoing examples, the method includes circulating the gas material from the chemical disassociation of the reactant material as the working fluid.

[0020] In a further embodiment of any of the foregoing examples, the reactant material includes a metal carbonate and the gas material is carbon dioxide.

[0021] In a further embodiment of any of the foregoing examples, the method includes removing the gas material to establish a steady state gas pressure.

[0022] In a further embodiment of any of the foregoing examples, the method includes heating the reactant material within a sealed volume.

[0023] In a further embodiment of any of the foregoing examples, the method includes storing the particulate thermal transfer media in a storage vessel after absorbing the thermal energy in the concentrated solar receiver and, at a later time, moving the particulate thermal transfer media into the heat exchanger in response to a demand to heat the working fluid.

[0024] In a further embodiment of any of the foregoing examples, the method includes storing the particulate thermal transfer media in a storage vessel after extraction of the thermal energy from the particulate thermal transfer media in the heat exchanger and, at a later time, moving the particulate thermal transfer media into the concentrated solar receiver in response to an availability of the solar energy in the concentrated solar receiver.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The various features and advantages of the present disclosure will become apparent to those skilled in the art from the following detailed description. The drawings that accompany the detailed description can be briefly described as follows.

[0026] FIG. **1** is a schematic illustration of a thermal transfer apparatus.

[0027] FIG. **2** illustrates particles of a particulate thermal transfer media.

[0028] FIG. **3** is a schematic illustration of another example thermal transfer apparatus.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0029] FIG. **1** schematically illustrates an apparatus **20**. As will be described herein, the apparatus **20** utilizes a particulate thermal transfer media **22** for thermal exchange and, optionally, thermal storage. The ability to store thermal energy allows time-shifting of the utilization of the thermal energy to overcome periods when a source of thermal energy, such as solar energy, is weak or unavailable. The particulate thermal transfer media **22** also permits tailoring thermal properties to enhance efficiency.

[0030] In this example, the apparatus **20** includes a closed loop circuit **24** through which the particulate thermal transfer media **22** circulates. A pump, conveyor, gravity or combinations thereof may be used to move the particulate thermal transfer media **22** in the closed loop circuit **24**. The term "closed loop" as used herein refers to the particulate thermal transfer media **22** being contained, with the exception of unintentional escape, within the closed loop circuit **24** for recirculation rather than consumption.

[0031] The closed loop circuit **24** includes a concentrated solar receiver **26** and is arranged such that the particulate thermal transfer media **22** is in communication with a heat exchanger **28**. The particulate thermal transfer media **22** is thus movable through the closed loop circuit **24** between the concentrated solar receiver **26** and the heat exchanger **28**. In this regard, the concentrated solar receiver **26** includes an inlet **26***a* through which the particulate thermal transfer media **22** is received and an outlet **26***b* through which the particulate thermal transfer media **22** is discharged from the concentrated solar receiver **26**. Similarly, the heat exchanger **28** includes an inlet **28***a* through which the thermal transfer media **22** is received and an outlet **28***b* through which the particulate thermal transfer media **22** is discharged. As an example, the heat exchanger **28** has a tube/plate configuration.

[0032] Referring also to FIG. **2**, the particulate thermal transfer media **22** has a melting temperature of greater than 600° C./1112° F. and includes particles **30** that are selected for good thermal absorbance and transfer. In one example, the particles **30** are made of inorganic material, such as ceramic material, that is chemically stable at elevated temperatures of approximately 900° C./1652° F. or higher in the environmental gas that the particulate thermal transfer media **22** is exposed to. For instance, the particulate thermal transfer media **22** may be exposed to air within the closed loop circuit **24** and/or in the concentrated solar receiver **26**, if the concentrated solar receiver **26** is open to the surrounding atmosphere. Additionally, the particles **30** have a relatively high thermal capacity and thermal absorbance for effective thermal storage and transfer within the apparatus **20**.

[0033] In a further example, the particles **30** are substantially spherical to facilitate flow through the closed loop circulation passage **24** and are made of at least one material having good high temperature chemical stability, good thermal capacity and good thermal absorbance. For example, the particles **30** are made of at least one of bauxite, silicon carbide and silica, which may be provided as sand.

[0034] In a further example, the particles **30**, on average, have a size of greater than 1 micrometer to facilitate flow through the closed loop circulation passage **24**. Additionally, the disclosed size of the particles **30** also facilitates flow through the concentrated solar receiver **26**. For example, if the concentrated solar receiver **26** is open to the surrounding environment, such as to enable solar energy to be received, gusts of wind may alter flow of the particles **30** in the thermal receiver **26**. To prevent or limit undesired escape of the particles **30**, the particles **30** are provided with the disclosed size to reduce the effects of the wind gusts.

[0035] In a further example, the particles **30** include first particles **30***a* and second, different particles **30***b*. The first particles **30***a* have a first composition and the second particles **30***b* have a second, different composition. As an example, the first particles **30***a* include one of bauxite, silicon carbide and silica, and the second particles **30***b* include a different one of bauxite, silicon carbide and silica. It is to be understood, however, that additional particles of other, different compositions may also be used.

[0036] The use of a hetero-compositional mix in the particulate thermal transfer media **22** allows the properties of the particulate thermal transfer media **22** to be tailored to meet design goals for thermal capacity, thermal absorbance, thermal transfer and flow of the particulate thermal transfer media **22** in the closed loop circuit **24**. For example, the first particles **30***a* are silicon carbide and the second particles **30***b* are bauxite. In a mixture in the particulate thermal transfer media **22**, the combination of silicon carbide and bauxite enhances bulk thermal capacity and bulk thermal transfer of the particulate thermal transfer media **22**. The bauxite has a relatively higher heat capacity than silicon carbide and the silicon carbide has a relatively higher thermal conductivity than the bauxite. Thus, in the mixture, the bauxite enhances thermal capacitance and the silicon carbide enhances heat transfer. In further examples, the compositions of the first particles **30***a* and the second particles **30***b* can also be selected to reduce expense of the particulate thermal transfer media **22** or tailor other properties, such as color, to enhance solar or thermal absorbance.

[0037] In this example, the apparatus **20** is a solar-based system with regard to the source of thermal energy. The apparatus **20** therefore enables the elimination of the use of fossil fuel as a thermal energy source. The concentrated solar receiver **26** is thus a receiver that is arranged to receive solar energy **32** directed from a solar concentrator **34**, such as one or more heliostats. The solar energy **32** is received into the concentrated solar receiver **26** through an opening or a window, and heats the particulate thermal transfer media **22**. In one example, the solar energy **32** directly impinges upon the particulate thermal transfer media **22** to heat the particulate thermal transfer media **22**.

[0038] Turning to the operation of the apparatus **20**, the particulate thermal transfer media **22** circulates through the closed loop circuit **24** between the concentrated solar receiver **26** and the heat exchanger **28**. The particulate thermal transfer media **22** is heated in the concentrated solar receiver **26** and then circulated into the heat exchanger **28** through the inlet **28***a*. The particulate thermal transfer media **22** may be continuously moved through the heat exchanger **28** or delivered as a "charge" that is held statically in the heat exchanger **28** for a period of time.

[0039] In this example, the heat exchanger **28** is in communication with a sub-system **36**. Within the sub-system **36**, a working fluid **38** circulates through the heat exchanger **28** to thereby absorb thermal energy from the heated particulate thermal transfer media **22**. By way of example, the sub-system **36** may be a reactor system that utilizes the thermal energy to drive a chemical reaction, a system based upon a super-critical carbon dioxide cycle, a Rankine steam cycle or a Brayton cycle. It is to be understood, however, that the sub-system **36** is not limited to any particular type of system.

[0040] As indicated above, the particulate thermal transfer media **22** can be tailored to enhance thermal transfer. As an example, the particulate thermal transfer media **22** includes the first particles **30***a* and the second particles **30***b* of different compositions, such as silicon carbide and bauxite, respectively. The first particles **30***a*, which have better thermal transfer properties, not only facilitate thermal exchange with the working fluid **38** but also facilitate thermal transfer from the second particles **30***b* by being in close proximity to the second particles **30***b* to remove thermal energy from the second particles **30***b* and provide a path of thermal transfer.

[0041] FIG. **3** schematically illustrates another example apparatus **120**. In this disclosure, like reference numerals designate like elements where appropriate and reference numerals with the addition of one-hundred designate modified elements that are understood to incorporate the same features and benefits of the corresponding elements. In this example, the apparatus **120** includes a first storage vessel **150** and a second storage vessel **152**.

[0042] The first storage vessel **150** is located within a closed loop circuit **124** between the outlet **26***b* of the concentrated solar receiver **26** and the inlet **28***a* of the heat exchanger **28**. Thus, the storage vessel **150** receives heated particulate thermal transfer media **22** from the concentrated solar receiver **26**.

[0043] The second storage vessel **152** is located within the closed loop circuit **124** between the outlet **28***b* of the heat exchanger **28** and the inlet **26***a* of the concentrated solar receiver **26**. Thus, the second storage vessel **152** receives relatively cool particulate thermal transfer media **22** from the heat exchanger **28**.

[0044] The apparatus **120** further includes a sub-system **136**. In this example, the sub-system **36** is a reactor system for utilizing the thermal energy from the particulate thermal transfer media **22** to drive a chemical reaction. The sub-system **136** includes a reactor vessel **154** that is in communication with the heat exchanger **28**. The reactor vessel **154** includes an inlet **154***a* in fluid-receiving communication with regard to the heat exchanger **28** and an outlet **154***b* in fluid-discharge communication with regard to the heat exchanger **28**. The heat exchanger **28** includes a second inlet **28***c* connected to the outlet **154***b* of the reactor vessel **154** and a second outlet **28***d* in communication with the inlet **154***a* of the reactor vessel **154**.

[0045] The reactor vessel **154** further includes a feed **158** for delivery of a reactant material into the reactor vessel **154**. Product lines **160***a* and **160***b* serve to transport reaction product materials, such as solid material and gaseous materials, respectively.

[0046] Turning to the operation of the apparatus **120**, the particulate thermal transfer media **22** circulates through the closed loop circuit **124** in a manner described above with reference to FIG. **1**. The heated particulate thermal transfer media **22** discharged from the concentrated solar receiver **26** is received into the first storage vessel **150**. If there is an immediate demand for thermal energy within the sub-system **136**, the particulate thermal transfer media **22** is responsively moved into the heat exchanger **28** for thermal transfer to a working fluid **138** circulating through a circulation loop **156**. Alternatively, if there is no immediate demand for thermal energy within the sub-system **136**, the heated particulate thermal transfer media **22** is stored in the storage vessel **150** until a later time at which there is a demand.

[0047] Because of the relatively high heat capacity of the particulate thermal transfer media **22**, the particulate thermal transfer media **22** retains the thermal energy absorbed from the thermal receiver **26**. Thus, the apparatus **120** permits a time-shifting of utilization of thermal solar energy with regard to the collection of the solar energy. That is, solar energy can be collected, as thermal energy, when available, such as when adequate sunshine is available, and immediately used or alternatively stored for a later time when there is a demand for such thermal energy.

[0048] After thermal exchange within the heat exchanger **28**, the particulate thermal transfer media **22** circulates to the second storage vessel **152**. If there is continued demand for thermal energy within the sub-system **136** and solar energy is available, the particulate thermal transfer media **22** is circulated from the second storage vessel **152** to the concentrated solar receiver **26** for another cycle of thermal absorbance and transfer. Alternatively, if there is no demand or if the solar energy is weak or unavailable, the particulate thermal transfer media **22** is stored within the second storage vessel **152** until a later time when there is demand and/or adequate solar energy availability.

[0049] The particulate thermal transfer media **22** that is discharged from the heat exchanger into the second storage vessel **152** may still include thermal energy that was not fully transferred to the working fluid **138** of the sub-system **136**. Optionally, the apparatus **120** includes an additional heat exchanger **162** through which the particulate thermal transfer media **22** can be circulated. The thermal energy absorbed from the particulate thermal transfer media **22** in the heat exchanger **162** may be utilized in another sub-system or within the apparatus **120**. As an example, the thermal energy absorbed from the particulate thermal transfer media **22** in the heat exchanger **162** may be used to preheat a reactant material before feeding the reactant material into the reactor vessel **154**. Alternatively, the thermal energy may be used in another process, such as a cement-producing process. Thus, the use and ability to store the particulate thermal transfer media **22** enables recovery of the thermal energy for other uses, which increases overall efficiency and reduces costs.

[0050] In a further example, the reactant material fed into the reactor vessel **154** is metal carbonate. The metal carbonate is either preheated using the thermal energy from the heat exchanger **162** or fed without preheating into the reactor vessel **154**. The reactor vessel **154** is used to chemically disassociate the metal carbonate into a constituent solid material and gas material. For metal carbonates, the gas material is carbon dioxide and the solid material is metal oxide.

[0051] As an example, an initial charge of the working fluid **138**, such as carbon dioxide, may be provided within the reactor vessel **154**. The working fluid **138** circulates in the circulation loop **156** through the heat exchanger **28** to receive thermal energy from the particulate thermal transfer media **22**. The heated working fluid **138** circulates back into the reactor vessel **154** and heats the metal carbonate material therein. The heat transfer that occurs in the apparatus **120** is thus double-indirect in that the thermal energy is transferred in two working materials, the particulate thermal transfer media **22** and the working fluid **138**, before being delivered to a target, reactant material.

[0052] The heating of the metal carbonate drives the disassociation reaction to thereby generate additional carbon dioxide. The generated carbon dioxide is then used as additional working fluid **138** and circulates in the circulation loop **156** to the heat exchanger **28** for further heating to further drive the chemical disassociation reaction. As more carbon dioxide is produced in the chemical disassociation, carbon dioxide may be removed through product line **160*b*** to establish a steady state carbon dioxide partial pressure within the reactor vessel **154**. The solid metal oxide produced may be removed from the reactor vessel **154** during or after the process through product line **160*a***.

[0053] The use of the particulate thermal transfer media **22** allows time-shifting between thermal solar energy collection and use in the reaction process within the sub-system **136**. That is, the apparatus **120** can be utilized to collect thermal energy in response to availability of solar energy and store the thermal energy within the first storage vessel **150** until a time at which there is a demand for the thermal energy within the sub-system **136**. Thus, even at times when solar energy is weak or unavailable, the heated particulate thermal transfer media **22** may be circulated from the first storage vessel **150** through the heat exchanger **28** to thereby heat the working fluid **138** and drive the reaction within the reactor vessel **154**.

[0054] Further, the use of the particulate thermal transfer media **22** enables indirect heating of the metal carbonate in the sub-system **136**, which limits exposure of tars or other impurity substances present in the metal carbonate to the sub-system **136** without fouling other components in the apparatus **120**. Additionally, the indirect heating enables the particulate thermal transfer media **22** to be tailored for efficient thermal capacitance and absorbance of solar energy. In comparison, the efficiency for direct heating of metal carbonate or other reactant material is limited by the thermal capacitance and absorbance properties inherent in the reactant material.

[0055] In a further example, the reactor vessel **154** and circulation loop **156** are sealed such that the generated gas remains within the volume of these components. The generated gas is thus sequestered and may be selectively removed through product line **160*b*** for further use in a downstream process or for economic purposes. The sequestering of the generated gas, such as carbon dioxide, also prevents discharge into the atmosphere which, in the cement industry, represents a substantial reduction in carbon dioxide emissions and potentially avoids penalties for such emissions. Further, the sealing of the reactor vessel **154** and circulation loop **156** also limits or prevents contamination of the product solid materials and gas materials, which adds economic value. In another example, the gas that is removed from the reactor vessel **154** has a relatively high temperature and is used to preheat the reactant material that is fed into the reactor vessel **154**.

[0056] Although a combination of features is shown in the illustrated examples, not all of them need to be combined to realize the benefits of various embodiments of this disclosure. In other words, a system designed according to an embodiment of this disclosure will not necessarily include all of the features shown in any one of the Figures or all of the portions schematically shown in the Figures. Moreover, selected features of one example embodiment may be combined with selected features of other example embodiments.

[0057] The preceding description is exemplary rather than limiting in nature. Variations and modifications to the disclosed examples may become apparent to those skilled in the art that do not necessarily depart from the essence of this disclosure. The scope of legal protection given to this disclosure can only be determined by studying the following claims.

What is claimed is:

1. An apparatus comprising:

a closed loop circuit including a concentrated solar receiver and a particulate thermal transfer media moveable through the closed loop circuit, the particulate thermal transfer media having a melting temperature of greater than 600°C./1112° F.; and

a heat exchanger in communication with the particulate thermal transfer media.

2. The apparatus as recited in claim **1**, further including a storage vessel within the closed loop circuit between an outlet from the concentrated solar receiver and an inlet into the heat exchanger.

3. The apparatus as recited in claim **1**, further including a storage vessel within the closed loop circuit between an outlet of the heat exchanger and an inlet of the concentrated solar receiver.

4. The apparatus as recited in claim **1**, further including a reactor vessel in thermal communication with the heat exchanger.

5. The apparatus as recited in claim **1**, wherein the particulate thermal transfer media includes bauxite.

6. The apparatus as recited in claim **1**, wherein the particulate thermal transfer media includes silicon carbide.

7. The apparatus as recited in claim **1**, wherein the particulate thermal transfer media includes silica.

8. The apparatus as recited in claim **1**, wherein the particulate thermal transfer media includes first particles having a first composition and second, different particles, having a second, different composition.

9. The apparatus as recited in claim **1**, wherein the particulate thermal transfer media includes particles, the particles, on average, having a size of greater than 1 micrometer.

10. A method for operating an apparatus, the method comprising:

moving a particulate thermal transfer media through a closed loop circuit into a concentrated solar receiver to absorb thermal energy into the particulate thermal transfer media;

moving the particulate thermal transfer media from the concentrated solar receiver into a heat exchanger; and

heating a working fluid using the thermal energy extracted from the particulate thermal transfer media in the heat exchanger.

11. The method as recited in claim **10**, further including storing the particulate thermal transfer media in a storage vessel after absorbing the thermal energy in the concentrated solar receiver and, at a later time, moving the particulate thermal transfer media into the heat exchanger in response to a demand to heat the working fluid.

12. The method as recited in claim **10**, further including storing the particulate thermal transfer media in a storage vessel after extraction of the thermal energy from the particulate thermal transfer media in the heat exchanger and, at a later time, moving the particulate thermal transfer media into the concentrated solar receiver in response to an availability of thermal energy in the concentrated solar receiver.

13. The method as recited in claim **10**, wherein the particulate thermal transfer media is selected from the group consisting of bauxite, silicon carbide, silica and combinations thereof.

14. The method as recited in claim **10**, wherein the particulate thermal transfer media includes first particles having a first composition and second, different particles having a second, different composition.

15. The method as recited in claim **10**, further including circulating the working fluid through the heat exchanger to extract the thermal energy from the particulate thermal transfer media and heating a reactant material using the thermal energy in the working fluid to chemically disassociate the reactant material into a solid material and a gas material.

16. A method for operating an apparatus, the method comprising:

moving a particulate thermal transfer media through a closed loop circuit into a concentrated solar receiver to receive solar energy and absorb thermal energy from the solar energy into the particulate thermal transfer media;

moving the particulate thermal transfer media from the concentrated solar receiver into a heat exchanger;

circulating a working fluid through the heat exchanger to extract the thermal energy from the particulate thermal transfer media; and

heating a reactant material using the thermal energy in the working fluid to chemically disassociate the reactant material into a solid material and a gas material.

17. The method as recited in claim **16**, further including circulating the gas material from the chemical disassociation of the reactant material as the working fluid.

18. The method as recited in claim **16**, wherein the reactant material includes a metal carbonate and the gas material is carbon dioxide.

19. The method as recited in claim **16**, further including removing the gas material to establish a steady state gas pressure.

20. The method as recited in claim **16**, further including heating the reactant material within a sealed volume.

21. The method as recited in claim **16**, further including storing the particulate thermal transfer media in a storage vessel after absorbing the thermal energy in the concentrated solar receiver and, at a later time, moving the particulate thermal transfer media into the heat exchanger in response to a demand to heat the working fluid.

22. The method as recited in claim **16**, further including storing the particulate thermal transfer media in a storage vessel after extraction of the thermal energy from the particulate thermal transfer media in the heat exchanger and, at a later time, moving the particulate thermal transfer media into the concentrated solar receiver in response to an availability of the solar energy in the concentrated solar receiver.

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