(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
29 December 2011 (29.12.2011)

PCT

(10) International Publication Number
WO 2011/163039 A2

(51) International Patent Classification:
F03G 7/00 (2006.01) *F03G 7/06* (2006.01)

(21) International Application Number:
PCT/US2011/040606

(22) International Filing Date:
16 June 2011 (16.06.2011)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/357,136 22 June 2010 (22.06.2010) US

(71) Applicant *(for all designated States except US)*: **SAINT-GOBAIN CERAMICS & PLASTICS, INC.** [US/US]; One New Bond Street, P O Box 15138, Worcester, Massachusetts 01615-0138 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **SHERMAN, Daniel, C.** [US/US]; 1583 Amboy, Hudson, Ohio 44236 (US). **WARNER, Dean, A.** [US/US]; 1156 Windward Lane, Kent, Ohio 44240 (US).

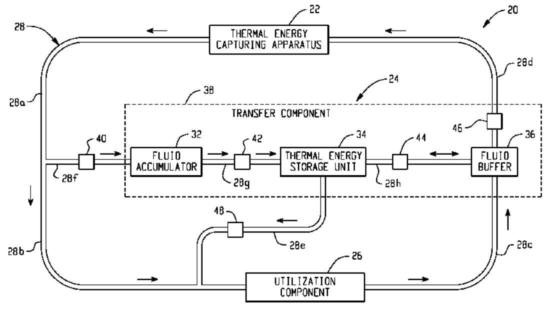
(74) Agent: **FRASER, Stewart Allan**; Saint-Gobain NorPro, 3840 Fishcreek Road, Stow, Ohio 44224 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) **Title**: THERMAL ENERGY UTILIZATION SYSTEM AND PROCESS FOR OPERATION OF THE SAME



22 APPAREIL DE CAPTURE D'ENERGIE THERMIQUE
24 ELEMENT DE TRANSFERT
32 ACCUMULATEUR DE FLUIDE
34 UNITE DE STOCKAGE D'ENERGIE THERMIQUE
36 FLUIDE TAMPON
26 ELEMENT D'UTILISATION

Figure

(57) **Abstract**: A thermal energy storage system including a thermal energy capturing apparatus connected to a thermal energy transfer component and a thermal energy utilization component is disclosed. The thermal energy transfer component includes a fluid accumulator connected in series to a thermal energy storage unit and a fluid buffer. A process for utilizing thermal energy is also disclosed.

WO 2011/163039 A2

THERMAL ENERGY UTILIZATION SYSTEM AND PROCESS FOR OPERATION OF THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 61/357,136 filed June 22, 2010.

BACKGROUND OF THE INVENTION

A wide variety of heat transfer processes are known in the patent literature and are used in many commercial operations. One example is a regenerative thermal oxidizer which recovers heat from a portion of a manufacturing process and then uses the recovered heat to preheat waste streams of effluents prior to their combustion. Another example of a process that utilizes heat transfer equipment is a solar powered space heater which uses heat from the sun to warm air which is then used in residential and commercial environments. Another example of a process in which heat transfer may be used is a solar powered generating station which captures and uses heat to produce electricity. Examples of patents and published patent applications that disclose capturing solar energy and using it to produce electricity include US 4,286,141 and WO 2008/108870.

SUMMARY

Embodiments of the present invention enable the efficient transfer of heat to and from heat transfer media in a thermal energy storage unit while reducing the amount of equipment and process steps to complete the capture, storage and ultimate use of the heat.

In one embodiment, the present invention includes a thermal energy utilization system comprising a thermal energy capturing apparatus connected to a thermal energy transfer component and a thermal energy utilization component. The thermal energy transfer component comprises a fluid accumulator connected in series to a thermal energy storage unit and a fluid buffer.

Another embodiment relates to a process that may include the following steps. Capturing thermal energy in a heat transfer fluid flowing through a thermal energy capturing apparatus connected, via a fluid distribution system, to a thermal energy transfer component and a thermal energy utilization component. The thermal energy transfer component comprises a fluid accumulator connected in series to a thermal energy storage unit and a fluid buffer. Transferring the fluid from the energy capturing apparatus to the fluid accumulator. Conveying the fluid from the accumulator to the thermal energy storage unit. Conveying the fluid from the thermal energy storage unit to the buffer and from the buffer to the thermal energy capturing apparatus. Conveying the fluid to the thermal energy utilization component.

BRIEF DESCRIPTION OF THE DRAWINGS

The Figure is a schematic representation of a thermal energy utilization system of an embodiment.

DETAILED DESCRIPTION

Thermal energy utilization systems that absorb thermal energy at a variable rate but use the energy at a constant rate are inherently faced with the problems of how to efficiently (1) store excess energy generated during periods of peak energy absorption and then (2) recover and use the energy during periods of low energy absorption. Some commercially available heat transfer processes have attempted to solve these problems by using a heat sink reservoir containing heat transfer media. Upon contact with a heat transfer fluid the media absorbs the thermal energy therefrom. As the heat transfer fluid enters the reservoir, the temperature and rate of flow of the fluid into the reservoir are allowed to vary in direct response to the temperature fluctuations and variable rate at which the thermal energy is received. Unfortunately, heat absorption media absorb and release heat most efficiently when the temperature of the fluid and the rate of flow of the fluid onto the media are constant and optimized. Fluctuations in the temperature of the fluid may decrease the efficiency of the thermal transfer process. Similarly, variations in the rate of flow of the fluid onto the media may also decrease the efficiency of the thermal transfer process. For example, if the rate of flow is too high, the efficiency of the thermal transfer process may decrease. As will be disclosed below, the inventors of this application have discovered how to substantially improve the efficiency of the thermal transfer process in a thermal energy utilization system that may use a reservoir of heat transfer media to store excess thermal energy which the system receives at a variable rate of flow and variable temperature and subsequently may utilize at a constant rate of flow and constant temperature.

The following phrases are defined for use herein. The phrase “transferring a fluid” denotes a process step in which the fluid is moved at a variable rate of flow for a specified period of time. The phrase “conveying a fluid” denotes a process step that in which the fluid may be moved at either a variable or a constant rate of flow for a specified period of time. Conveying a fluid may be used to mean moving fluid at a variable rate of flow, a constant rate of flow or a combination of a variable rate for a first period of time and a fixed rate of flow for a second period of time. A fluid having a “constant rate of flow” is a fluid that flows within plus or minus five percent of the fluid’s nominal rate of flow for a specified of time. A fluid having a “constant temperature” is a fluid whose temperature over a specified period of time is within plus or minus five percent of the fluid’s nominal temperature during the same period of time.

Referring now to the Figure, there is shown a schematic representation of an embodiment of a thermal energy utilization system 20 that includes thermal energy capturing apparatus 22, thermal energy transfer component 24 and thermal energy utilization component 26. Capturing apparatus 22 is connected to transfer component 24 and utilization component 26 by fluid distribution system 28 which includes pipes 28a, 28b, 28c, 28d, 28e, 28f, 28g and 28h. Transfer component 24 includes fluid accumulator 32, thermal energy storage unit 34 and fluid buffer 36. Within transfer component 24, which is delineated by dotted line 38, fluid accumulator 32 is connected in series to thermal energy storage unit 34 and fluid buffer 36. As used herein, fluid accumulator 32 may also be described as a prestorage fluid reservoir and fluid buffer 36 may also be described as a post-storage fluid reservoir. The fluid accumulator acts as a fluid reservoir before the heat in the fluid is conveyed to the thermal energy storage unit and the fluid buffer acts as a fluid reservoir after the fluid is conveyed from the thermal energy storage unit.

In this embodiment, flowing through the thermal energy utilization system is a heat transfer fluid which could be a liquid, such as an oil, that is stable at high temperatures such as 300°C and higher. One of more pumps, not shown in the Figure, may be used to force the fluid through the fluid distribution system and the apparatus and components connected thereto. With regard to pumping a fluid through the system, fluid distribution system 28 may include a first controller 40, a second controller 42, a third controller 44, a fourth controller 46 and a fifth controller 48. First controller 40 may control fluid flow between capturing apparatus 22 and fluid accumulator 32. Second controller 42 may control fluid flow between fluid accumulator 32 and thermal energy storage unit 34. Third controller 44 may control fluid flow between thermal energy storage unit 34 and fluid buffer 36. Fourth controller 46 may control fluid flow between fluid buffer 36 and thermal energy capturing apparatus 22. Fifth controller 48 may control fluid flow between thermal energy storage unit 34 and utilization component 26. The first, second, third, fourth and fifth fluid flow controllers may be a combination of pumps, valves, switches, piping, sensors, etc that cooperate to move fluid as desired between two locations in the thermal energy storage system.

First controller 40 may use input received from the capturing apparatus to determine the rate and duration of fluid flow from the capturing apparatus to the fluid accumulator. The rate of fluid flow from the thermal energy capturing apparatus may be varied as needed to accommodate changes in the rate the thermal energy is captured by the capturing apparatus. For example, if the capturing apparatus is a solar collector and, due to full exposure to the sun, the collector is receiving large quantities of thermal energy, then the rate at which first controller 40 allows the fluid to flow to the fluid accumulator may be relatively high. If the capturing apparatus is receiving little thermal energy because the capturing apparatus has been shielded from the sun by clouds, then the rate at which first controller 40 allows fluid to flow to the fluid accumulator may be lower. In contrast to first controller 40, second controller 42, uses input received from fluid accumulator 32 to determine the frequency at which a known quantity of fluid is conveyed to the thermal energy storage unit. In one embodiment, the rate at which fluid is conveyed from the accumulator to the thermal energy storage unit may vary. In another embodiment, the rate at which fluid is conveyed from the accumulator to the thermal energy storage unit is constant. Disposing fluid to and through the thermal energy storage unit at a fixed rate and temperature may allow the thermal energy storage unit to operate at a desirably high thermal transfer efficiency. Because the first, second, third, fourth and fifth controllers are independently controllable, the system can be operated so that fluid can be: (1) transferred at an optimum and variable rate from the capturing apparatus to the fluid accumulator; (2) conveyed from the fluid accumulator to the thermal energy storage unit; (3) conveyed to the fluid buffer and (4) conveyed from the thermal energy storage unit to the thermal energy utilization component. As explained above, transferring fluid at a variable rate through the thermal energy storage unit may be feasible but disposing fluid at a constant rate may benefit the efficiency of the thermal transfer process that occurs within the thermal energy storage unit.

Fluid accumulator 32 may include upper and lower volumetric level indicators which provide input to second controller 42 concerning the ability or inability of the thermal energy storage unit to receive heated transfer fluid from the accumulator. In this embodiment, as fluid flows from the capturing apparatus into the accumulator, the level of fluid rises until the upper volumetric level indicator is activated. Upon activation, the upper level indicator may cause the conveyance of a fixed quantity of the fluid from the accumulator to the thermal energy storage unit. The fluid may be conveyed at a variable rate or at a constant rate. The rate may be measured as liters per second. The fluid may also be conveyed for a fixed period of time, such as five minutes, thereby regulating the volumetric quantity of fluid conveyed. If each conveyance of fluid from the accumulator to the thermal energy storage unit is essentially identical in quantity to every other conveyance of fluid, then each conveyance may be referred to herein as an aliquot. While conveying aliquots of fluid is consistent with operating the accumulator by allowing the fluid to begin flowing from the accumulator when the upper volumetric level indicator is activated and stopping the flow of fluid when the drop in the level of fluid triggers the lower volumetric level indicator, conveying the fluid in aliquots may be optional.

In contrast to accumulator 32, fluid buffer 36 receives fluid that has been cooled by passing the fluid through the thermal energy storage unit or the thermal energy storage utilization component. The cooled fluid may flow into the buffer at a variable rate of flow and at a variable temperature. Furthermore, cooled fluid may be transferred from the buffer to the thermal energy capturing apparatus at a variable rate of flow and at a variable temperature.

Thermal energy storage unit 34 may include sensible heat transfer media such as a plurality of ceramic heat transfer elements as disclosed in US 6,889,963 and/or latent heat transfer elements as disclosed in US 4,504,402. The elements may be randomly oriented and stacked upon one another thereby forming a bed of heat transfer elements. Alternately, instead of using relatively small, randomly oriented heat transfer elements, larger packing elements known as monoliths may be stacked to align passageways therethrough. Furthermore, the storage unit may include a single vessel containing a single bed of heat transfer elements and described herein as having a single storage zone or the storage unit may contain a plurality of vessels and be described herein as having a plurality of thermal energy storage zones. Each zone may have similar or dissimilar characteristics such as volume, shape, thermal capacity, pressure drop, etc.

Thermal energy capturing apparatus 22 represents any apparatus that functions as a source of thermal energy by generating or receiving thermal energy at a variable rate. Examples of apparatuses that may receive thermal energy at a variable rate include solar collectors such as concentrated solar collectors, tower solar collectors and flat plate solar collectors. Other examples include processes that may generate heat sporadically such as nuclear reactors and geothermal heat pumps.

Thermal energy utilization component 26 represents any component that uses thermal energy from the heat transfer fluid to perform a useful function such as heating water to generate steam which is used to drive a turbine that produces electricity. Another example is a thermal oxidizer which uses heat from the fluid to preheat an industrial waste stream prior to combustion of the waste.

The advantages of using an embodiment of the thermal energy utilization system disclosed herein may be illustrated in the following description of a hypothetical scenario. In an embodiment in which the thermal energy capturing apparatus is a concentrated solar collector that has been exposed to full sun (i.e. maximum solar gain) for several hours and the thermal energy utilization component is a steam driven turbine that generates electricity, the system could function as follows. Transfer fluid could be made to flow through the capturing apparatus at a sufficient rate of flow, which could be varied as needed, to heat the fluid to an optimum temperature defined herein as T_1. A first portion of the heated fluid exiting the solar collector could be made to flow directly to the turbine where the heat would be extracted, thereby reducing the temperature of the fluid to temperature T_2, and used to produce steam. Simultaneously, a second portion of the heated fluid flowing from the solar collector could be made to flow into the accumulator. When a sufficient quantity of heated fluid had accumulated in the accumulator, the second controller could convey heated fluid to the thermal energy storage unit where the fluid could contact the heat transfer media and heat could be absorbed from the fluid thereby cooling the fluid to a lower temperature defined herein as T_3. In one embodiment, the second controller could convey heated fluid at a constant rate of flow and constant temperature to the thermal energy storage unit. The fluid's temperature and rate of flow could be selected to facilitate the transfer of heat to the heat transfer media at a desired and predetermined thermal transfer efficiency. The cooled fluid from the turbine, having a temperature T_2, and the cooled fluid from the thermal energy storage unit, having a temperature T_3, could be transferred to the buffer. The temperature of the fluid in the buffer would rise or fall depending on the temperatures (i.e. T_2 and T_3) and the relative rates of flow of the incoming fluids. In response to the solar collector's continued capture of thermal energy from the full sun, cooled fluid in the buffer could be transferred to the solar collector where the fluid could be reheated and made to flow to the accumulator and turbine. After the solar collector has transferred thermal energy to the thermal energy storage unit for several hours and the solar collector is no longer capturing thermal energy, heated fluid in the thermal energy storage unit could be conveyed to the turbine. Heated fluid from the thermal energy storage unit and heated fluid from the thermal energy capturing apparatus may simultaneously flow to the utilization component. When the thermal energy capturing apparatus is not able to supply any heated fluid, then all of the heated fluid supplied to the utilization component may flow solely from the thermal energy storage unit. The rate of flow of the heated fluid from the thermal energy storage unit to the turbine is selected to facilitate the transfer of heat at a desired and predetermined thermal transfer efficiency. Unlike thermal energy utilization systems that use a single vessel to accumulate and store thermal energy, thereby allowing the efficiency of the thermal transfer process to rise and fall in response to non-optimum rates of fluid flow, embodiments of a thermal energy storage system of this invention can stabilize and improve the efficiency of the thermal transfer process within the thermal energy storage unit.

The above description is considered that of particular embodiments only. Modifications of the invention will occur to those skilled in the art and to those who make or use the invention. Therefore, it is understood that the embodiments shown in the drawings and described above are merely for illustrative purposes and are not intended to limit the scope of the invention, which is defined by the following claims as interpreted according to the principles of patent law.

CLAIMS

What is claimed is:

1. A thermal energy utilization system, comprising: a thermal energy capturing apparatus connected to a thermal energy transfer component and a thermal energy utilization component, wherein said thermal energy transfer component comprises a fluid accumulator connected in series to a thermal energy storage unit and a fluid buffer.

2. The thermal energy utilization system of claim 1 further comprising a fluid distribution system which connects said thermal energy capturing apparatus to said thermal energy transfer component and said thermal energy utilization component.

3. The thermal energy utilization system of claim 2 further comprising a heat transfer fluid disposed within said fluid distribution system, said apparatus and said components.

4. The thermal energy utilization system of claim 3 wherein said heat transfer fluid is a liquid.

5. The thermal energy utilization system of claim 2 wherein said fluid distribution system comprises a first controller, which controls fluid flow between said thermal energy capturing apparatus and said fluid accumulator, and a second controller which controls fluid flow between said accumulator and said thermal energy storage unit, wherein said first controller and said second controller are independently controllable.

6. The thermal energy utilization system of claim 2 wherein said fluid accumulator comprises upper and lower volumetric level indicators.

7. The thermal energy utilization system of claim 5 wherein said fluid distribution system comprises a third controller which controls fluid flow between said thermal energy storage unit and said fluid buffer.

8. The thermal energy utilization system of claim 7 wherein said fluid distribution system further comprises a fourth controller which controls fluid flow between said fluid buffer and said thermal energy capturing apparatus .

9. The thermal energy utilization system of claim 8 wherein said fluid distribution system further comprises a fifth controller which controls fluid flow between said thermal energy storage unit and said utilization component.

10. The thermal energy utilization system of claim 1 wherein said thermal energy storage unit comprises heat transfer media.

11. The thermal energy utilization system of claim 10 wherein said heat transfer media comprises a plurality of heat transfer elements.

12. The thermal energy utilization system of claim 11 wherein said heat transfer elements are randomly oriented.

13. The thermal energy utilization system of claim 1 wherein said thermal energy storage unit comprises a single thermal energy storage zone.

14. The thermal energy utilization system of claim 1 wherein said thermal energy storage unit comprises a plurality of thermal energy storage zones.

15. The thermal energy utilization system of claim 14 wherein said plurality of thermal energy storage zones are connected to each other in series.

16. The thermal energy utilization system of claim 1 wherein said thermal energy capturing apparatus is selected from the group consisting of a solar collector, nuclear reactor and geothermal heat pump.

17. The thermal energy utilization system of claim 1 wherein said thermal energy utilization component is selected from the group consisting of a turbine and a thermal oxidizer.

18. A process for utilizing thermal energy, comprising the steps of:

(a) capturing thermal energy in a heat transfer fluid flowing through a thermal energy capturing apparatus connected, via a fluid distribution system, to a thermal energy transfer component and a thermal energy utilization component, wherein said thermal energy transfer component comprises a fluid accumulator connected in series to a thermal energy storage unit and a fluid buffer;

(b) transferring said fluid from said energy capturing apparatus to said fluid accumulator;

(c) conveying said fluid from said accumulator to said thermal energy storage unit;

(d) conveying said fluid from said thermal energy storage unit to said buffer and from said buffer to said thermal energy capturing apparatus; and

(e) conveying said fluid to said thermal energy utilization component.

19. The process of claim 18, wherein said fluid in step (e) flows simultaneously from said thermal energy capturing apparatus and said thermal energy storage unit to said thermal energy utilization component.

20. The process of claim 18, wherein said fluid in step (e) flows solely from said thermal energy storage unit to said thermal energy utilization component.

21. The process of claim 18, wherein said fluid in step (c) is conveyed at a constant temperature.

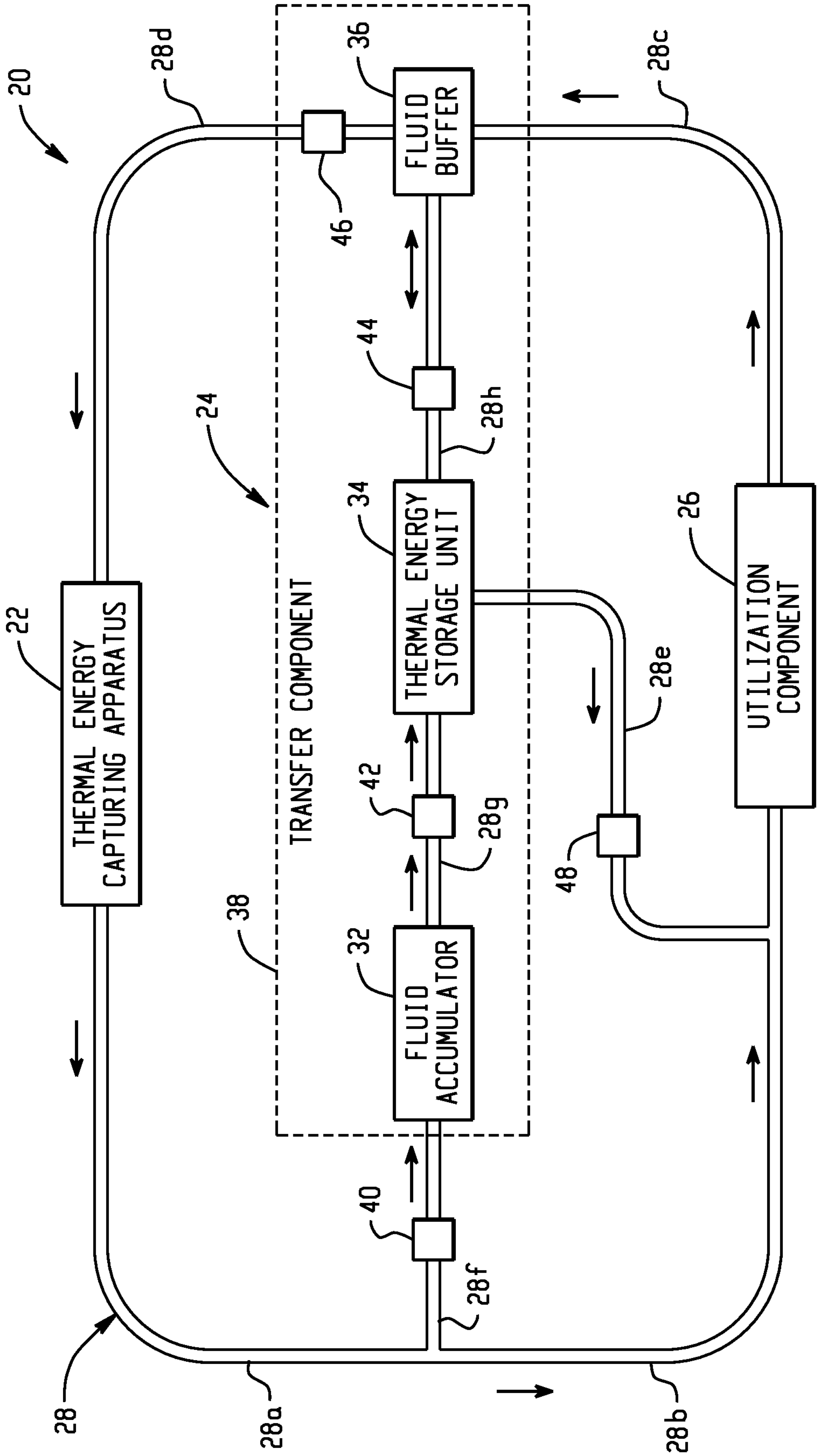
22. The process of claim 18, wherein said fluid in step (c) is conveyed at a constant rate of flow.

23. The process of claim 18, wherein said fluid in step (c) is conveyed in aliquots.

24. The process of claim 18, further comprises the step of transferring fluid from said thermal energy utilization component to said fluid buffer.

25. The process of claim 18, wherein said fluid in step (b) is transferred at a constant temperature.

26. The process of claim 18, wherein said fluid in step (e) is conveyed at a constant temperature.


20
22
THERMAL ENERGY CAPTURING APPARATUS
24
TRANSFER COMPONENT
38
32
FLUID ACCUMULATOR
34
THERMAL ENERGY STORAGE UNIT
36
FLUID BUFFER
26
UTILIZATION COMPONENT
40
42
44
46
48
28
28a
28b
28c
28d
28e
28f
28g
28h

Figure