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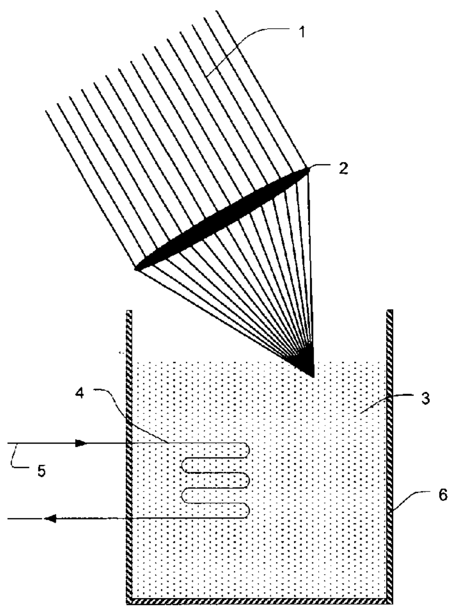

Fig. 1

(57) Abstract: System for thermal energy storage from solar radiation comprising a concentrator of solar rays (2), a bed of solid particles (3) in relative continuous and casual movement functioning as storage means of the thermal energy and a device of heat exchange (4) between said solid particles (3) and a fluid (5) which carries out a thermo-dynamic cycle. In presence of the direct solar radiation (1), the concentrator of solar rays (2) directs the solar radiation in an area inside the bed of solid particles (3) increasing directly and uniformly the temperature of the storage means without requiring intermediate heat exchanges. The stored thermal energy can be transferred in a second moment to the fluid which carries out the thermo-dynamic cycle. The movement of the particles can be obtained by means of the fluidization or by means of mechanical or acoustic devices, while the concentration of the solar radiation can occur by means of a Fresnel lens.

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THERMAL ENERGY STORAGE SYSTEM BY DIRECT SOLAR RADIATION

Object of the present invention is a system for thermal energy storage from solar radiation apt to store thermal energy efficiently and to transfer simply and efficiently, even in different times, heat to a fluid which carries out a thermo-dynamic cycle to generate electric energy.

Recently, owing to the progressive increase in fossil fuels cost, to their inevitable depletion and to the environmental damage linked to their consumption, great attention has been given to the research aimed at the solar energy exploitation, in its different and various applications, as valid alternative energy source. Solar energy is in fact the cleanest and most available energy form, besides being potentially unlimited.

However solar energy has drawbacks linked to the continuity of usage, and can be simply exploited for the production of electric energy only as integrative source to lower the running costs in plants powered by fossil fuels or biomasses. In this kind of applications, the direct part of the solar radiation is exploited to provide, by means of a thermo-vector fluid, only a portion of the heat required for the entire power cycle.

If it is intended that the continuity of operation would be provided by the sole energy contained in the solar radiation, it is necessary to adopt a system for thermal energy storage able to limit the short lasting transients linked to the solar radiation irregularity and, more generally, to separate temporarily the collection moment from the usage one. A system for thermal energy storage from solar radiation is generally made up of a means able to concentrate the solar radiation and to transfer it to a second means able to store the heat contained therein and to give such heat to a fluid for following usage.

The highest temperature reachable by the fluid heated by the storage system influences the yield reachable by the thermo-dynamic cycle. The possibility that the operating fluid reaches the nearest temperature to the highest reachable one by concentrating the solar radiation, reducing the inevitable losses, is therefore one of the most important features of such storage systems.

In the state of art, some applications are known wherein the thermal energy contained in the solar radiation is stored according to the above-described general principles.

In the thermo-dynamic solar plants with thermal storage it is generally possible to distinguish two operating fluids: the thermo-vector fluid which receives the heat from the concentration system and defines the storage peculiarity with its chemical-physical features; the process fluid which receives the heat from the thermo-vector fluid in an exchanger and carries out the thermo-dynamic or power cycle.

The thermo-vector fluids used in plants which have exceeded a considerable number of operating hours are two: the synthetic/mineral oils and the mixtures of sodium and potassium fused salts. Both the fluids, which operate at the operating temperature at the liquid state, have shown a series of problems and limits of usage: the synthetic/mineral oils can be used up to the highest temperature of about 400°C, thus limiting the above-described power cycle yield; in addition they are expensive and in case of losses, they are simply flammable and dangerous for the environment.

The sodium and potassium fused salts allow to operate at maximum temperatures of about 550°C (not more owing to the dissociation), but the mixtures of these salts cannot be cautiously cooled under 290°C, as they crystallize at 238°C and solidify at 221°C, thus imposing a series of technological measures aimed at avoiding possible solidifications during night and in the starting steps of the plant.

Some applications are known, which solve the disadvantages linked to the usage of oils or salts mixtures as storage systems.

The international patent WO 2008/154455 relates to a granular means for heat storage and apparatuses for heat storage systems. The patent describes various heat storage systems, their method of usage and the plants for the production of vapor and energy which use them. It is described a solar energy concentration system, comprising a field of reflecting mirrors or Fresnel lens which heats a fluid, which in turn heats the heat storage system made up of granular inert material. The heat storage system is able to give, in a second moment, the heat to the fluid which carries out the thermo-dynamic cycle. Further it is claimed the method for using such storage system which provides to direct the heat source on one or more ducts in which the fluid flows, which later gives the heat to the storage means.

The patent WO 2008/108870 filed on 12/09/2008 relates to a "Solar energy plant and a method and/or system for energy storage in a concentration solar plant".

It is described a concentrator of solar radiation, a heat storage system and a plant for the production of energy connected by means of pipes which convey a gas under pressure. The heat storage system is made up of tanks full of a solid means resistant to high temperatures, in spheres with diameter between 5 and 10 mm. When the solar radiation exceeds the plant energy demand, the hot gases coming from the manifold pass in these tanks where they heat the solid means contained therein. When the energy demand is greater than the available solar radiation, the tanks where the heat is stored are crossed by cold gases coming from the plant, to extract the stored heat. Also in the system according to this patent, the direct solar radiation increases the temperature of a compressed gas flow, which in turn increases the temperature of the single solid particles constituting the storage means. These latter can transfer the stored thermal energy to the fluid carrying out the thermo-dynamic cycle in a second moment.

There exist other applications wherein the solar energy is stored and exploited in different ways and for different usage; in the French patent FR 2356094 there are described improvements of systems for solar energy storage which use an organic liquid as storage means. In the American patent n° 4153047 it is described a heat storage system in which a solar concentrator heats a circulating fluid in a first circuit which heats in turn the granular material contained inside a tank. A fluid circulating in a second circuit which is provided with exchange surfaces inside the granular means contained in the tank allows to extract totally independently the stored heat. The American patent n° 4286141 relates to a method for heat storage using a bed of anhydrous sodium sulfate gravel. In this document it is described a heat storage method inside a bed of granular material in which a fluid circulates which is heated outside the gravel bed when this one has to store heat. In a second moment, the heat can be released by the bed of granular material to the fluid. In the American patent n° 4081024 there are described an apparatus and a method for air conditioning the environments of a thermal storage in form of granular solid which is crossed alternatively by air heated by solar panels or by cold air which is intended to be heated.

In the American patent n° 4405010 it is described and claimed a heat storage system made up of an insulated tank full of alternate layers of materials with different thermal conductivity. Also in this case, the granular material functioning as heat tank is heated by thermal exchange with a fluid passed inside a solar manifold, and cooled down by means of a second fluid which is then used in the energy production process.

The applications known according to the state of the art are limited in that the thermal energy contained in the solar radiation is subdued to a double thermal exchange prior it is possible to use it for the production of electric energy, thus limiting the maximum temperature reachable by the fluid which carries out the power cycle. Moreover, according to some applications, potentially dangerous or polluting storage fluids or means are used.

Object of the present invention is to solve the above-cited problems and disadvantages and to provide a new system for thermal energy storage from solar radiation which reduces the losses of energy linked to the thermal exchanges and which uses only materials and fluids totally environmentally compatible.

These and other advantages will be highlighted in the following description, referring to the drawings attached:

Figure 1 shows generally schematically the elements of a storage system according to the invention;

Figure 2 shows schematically the storage system in which the concentrator acts indirectly on the solid fluidized particles of the bed;

Figure 3 shows schematically the storage system in which a Fresnel lens acts directly on the solid fluidized particles of the bed;

Figure 4 shows schematically the storage system usable for the production of electric energy;

Figure 5 shows schematically the solar plant made up of a series of storage systems according to the invention, integrated with other devices which use different forms of energy, integrative or substitutive for the solar one.

Figure 1 shows a preferred embodiment of the storage system according to the present invention, comprising a bed of perfectly mixed particles (3) inside a generic containment structure (6); a concentration system (2) of solar rays (1); a generic device for thermal exchange (4), in which the fluid (5), which carries out the thermo-dynamic cycle, flows. The thermal energy coming from solar radiation is stored directly in the particles constituting the bed (3) and not in a substance at liquid state as a fused salt or oil, and however without requiring to interpose an intermediate fluid between the solar radiation and the storage means. The particles nature determines the maximum operating temperature of the system: the advantages of such a storage system are clear as, by using a very common material as quartz it is possible to reach temperatures even higher than 1000°C without impairing the characteristics of state and time. Obviously, problems of agglomeration of the particles with high and low operating temperatures do not occur: the particles are not flammable and dangerous for the environment as it occurs for the fused salts and oils. In order to guarantee uniform temperature conditions in the whole mass interested in the thermal storage, it is necessary that the bed of particles is in continuous re-mixing above all in the concentration area, where very high and dependent from the concentration system used, temperatures are reached: such a condition is defined by perfectly mixed bed.

In figure 2, it is shown an embodiment of the storage system according to the invention in which the conditions of perfect mixing are attained by fluidizing the solid particles (3) with a gas or vapor, as it occurs in fluid bed systems whose characteristics and performance are well known in the different industrial embodiments. A fluid bed of solid particles is characterized by a very high thermal inertia, a constant temperature in the whole mass and by very high coefficients of thermal exchange with the immersed surfaces in the dense phase. Figure 2 shows that the fluidizing of the particles occurs by introducing the fluid (9) across the duct (12) in the distributing area (10), delimited by the bottom of the container (6) and by a perforated plate (11); after crossing with suitable speed the bed of particles, when reached the freeboard (13), the fluid (9) abandons the system, insulated from outside by means of the covering (8), across the duct (14). The thermal energy stored by the fluidized particles (3) is transferred to the fluid (5) by means of the exchanger (4). The described embodiment is intended to be an example and does not limit the application; in fact although the fluid distribution is shown by adopting a perforated distributor (11), many other kinds of distributors can be used for this function, as for example sintered plates or ceramics and/or distributing nozzles in the most different configurations. Every kind has however the only aim to distribute the flow of fluid used in the best and simplest possible form. The same considerations are valid for the container (6); according to a preferred embodiment of the present invention this is made of high temperatures resistant-steel, it is insulated to limit its dispersions and it is cylindrically shaped, but different materials and sections can be used without departing from the scope of the present invention.

In addition, it is convenient to precise that the continuous and causal re-mixing of the solid particles can be obtained not only by means of the fluidization of the same by means of a gas or vapor, but only by using mechanical devices for mixing or by generating acoustic waves. Such systems can be used alone or in combination to improve the mixing of the solid particles the most. The generation of the acoustic waves can be efficiently obtained by using an amplifier, a generator of signal and a loudspeaker and it is used to obtain the continuous re-mixing of solid particles with particular features, maybe contemporaneously with the fluidization obtained as above-described.

According to figure 2, the solar rays (1), concentrated across the device (2), do not hit directly the particles thus causing the progressive heating of the whole mass, but a device (7) which, while heating itself, transmits in turn the heat to the mass of the perfectly mixed bed (3) by direct contact with the particles constituting it. Such heating is of the indirect kind and the device (7) can be as a way of example but not in a limiting way, a simple material with good characteristics of thermal conductivity or a more complex system as, for example, a heat pipe. In figure 2, the fluid (5) which carries out the thermo-dynamic cycle and the fluid (9) which carries out the fluidization, are different in nature and naturally separated. It is known that in the systems with fluid bed, the temperature of the fluid abandoning the dense phase is practically identical to the one of the bed and so, the fluid (9) going out from the duct (14) is at the same temperature of the bed (3): since, at least theoretically, it is an energy which would go lost, it is desirable its regeneration with exchange devices, not represented in figure 2, which are inserted between the fluid (9) going out from the duct (14) and the same fluid entering the duct (12). Generally, and only as a way of example, the temperature level reachable with a system as represented in figure 2 could allow to carry out a Stirling cycle where the gases of the thermodynamic cycle (5), usually hydrogen and helium under high pressure, are heated by means of the exchange surfaces (4) immersed in the dense phase of the perfectly mixed bed (3).

In figure 3, the storage system object of the invention is characterized by provision of a Fresnel lens (19), which acts directly on the particles of the fluidized bed by means of a window of material transparent to the solar radiation (18), in place of the generic concentration system;

according to the diagram, the perfect mixing of the solid particles (3) is obtained by introducing the fluid (9) across the duct (12), or the fluid (5) across the duct (15); in this latter a part of the fluid (5), normally used to carry out the thermo-dynamic cycle, is bled while outgoing from the exchanger (4) and used for the fluidization. Depending on the used operating conditions, the fluid (9) or the fluid (5) can outgo from the duct (14): although the opening of the valve (17) provides normally the closing of the valve (16), the possibilities of mixing the two fluids are not excluded *a priori*. It is extremely clear that, by adopting a fluid for the fluidization which coincides with the one carrying out the thermo-dynamic cycle, significant energy regeneration is possible. Only as a way of example, providing a Fresnel lens realized in a plastic material as for example polymethylmetacrylate (PMMA) has considerable advantages: the optimum optical properties, the low costs and the great production rates today reachable among the others.

In figures 2 and 3 it is also evident another advantage of the invention; since the storage system increases the temperature of the particles only during the insolation times, it is possible, in its absence, to block completely the fluidization and to avoid the losses of heat linked therewith. Such an advantage can be exploited only during the step of reaching the fixed temperature for the storage and the proceeding of the thermo-dynamic cycle, in which step the heat exchange (4) is not active; the system stores energy during the insolation by fluidizing the particles and maintains the temperature level reached, without fluidization, during the times when the thermal charge lacks. The blocking of the fluidization or however of the mixing can be obviously carried out not only by night but also during the interruptions of the insolation for the temporary passage of clouds and variable weather; as a consequence, each possible case of thermal shock occurring in the other storage systems are warded off. In figure 4, only as a way of example but in a not limiting way, it is shown a different embodiment according to the invention; the fluid which carries out the operating cycle is water, in form of overheated vapor, which expands in the turbine (21) to generate power. The overheated vapor is generated inside the exchange surface (4), immersed in the

dense phase of the bed of perfectly mixed solid particles, contained inside a fluidization column (24). A condenser (22) and a water pump (23) complete the classical scheme of a Rankine cycle. In the scheme, part of the overheated vapor (5) outgoing from the exchanger (4) is withdrawn and used, by means of the opening of the valve (26) for the fluidization of the column: the vapor, outgoing from the freeboard, goes again in the circuit between the condenser (22) and the turbine (21).
In the initial steps, when the system has not reached the sufficient temperature and the heat exchanges are reduced, the opening of the valve (27) allows to inlet fluid (5) from other plant or application. Figure 4 shows another advantage of the storage system according to the invention deriving from the usage of the vapor as process and fluidization fluid: the thermal storage, carried out by using the fluidized solid particles, lies physically on the same concentration area and it is the vapor, which, also at a considerable distance, reaches the usage area. It is also clear the reduced environmental impact of a storage system realized like that, where the fluidization column (24) and each vapor and water lines which reach the

same can be arranged under the earth, and so can be invisible. Figure 5 represents only as a way of example and in a not limiting way, a diagram in which many storage systems as in figure 4, numbered (28) to (37) are part of an unique plant for energy production together with the vapor generators (38) and (39) connected to processes which use substitutive forms of energy for the solar one, as for example the one contained in the biomasses or fossil fuels. The fluid (5) circulated by the pump (23) crosses each storage system, the ones connected in series as well as those connected in parallel in an absolutely generic way, generating vapor usable in the turbine (21). In the diagram, the plants have generally different power and dimensions and can function with their own inner exchanger with water or vapor depending on their arrangement. What is represented is naturally a so-called hybrid system in which, when active, part of the whole power is generated by traditional systems and part by the storage systems of the solar radiation: in the limit cases they would function in an exclusive way or the plants (38) and (39) for total absence of solar radiation, or the storage systems (28) to (37) in particular situations of insolation. In addition, even if not represented in the figures, many storage systems could be excluded with suitable by-passes of the vapor line (5), thus realizing operating and maintenance flexibility.

A clear advantage of the embodiment of the device according to the present invention represented in figure 5 is that the system has neither lower limits for the condensation temperature, nor upper limits for the storage temperature: the result is a significant increase in the whole yield with similar other conditions with respect to the applications using only oils and fused salts.

CLAIMS

1. System for thermal energy storage from solar radiation comprising at least a concentrator of solar rays (2), a bed of solid particles (3) in a relative continuous and casual movement functioning as storage means of the thermal energy and a device of heat exchange (4) between said solid particles (3) and a fluid (5) which carries out a thermo-dynamic cycle characterized in that in presence of the direct solar radiation (1), said concentrator of solar rays (2) directs the solar radiation in an area inside said bed of solid particles (3) increasing directly and uniformly the temperature of the storage means without requiring intermediate heat exchanges and in that said system allows, also in different times, by means of said device of heat exchange (4), the transferring of the thermal energy, stored in said bed of solid particles (3), to the fluid (5) which carries out the thermo-dynamic cycle.

2. System according to claim 1, characterized in that the relative continuous and casual movement of the solid particles is obtained by means of the fluidization of the same with a gas or vapor.

3. System according to claim 2, characterized in that the fluid (5) which carries out the thermodynamic cycle is of the same nature of the one which fluidizes the bed of solid particles.

4. System according to claim 3, characterized in that said fluid is water vapor.

5. System according to claim 1, characterized in that the relative continuous and casual movement is obtained by using mechanical or electromechanical or acoustic devices, alone or in combination between each other.

6. System according to claim 2, characterized in that the relative continuous and casual movement of the particles can be obtained by the fluidization of the same by means of a gas or vapor in combination with the usage of mechanical and/or electromechanical and/or acoustic devices.

7. System according to any one of the preceding claims, characterized in that the concentrator of solar rays (2) is made up of a Fresnel lens.

8. System according to any one of the preceding claims, characterized in that the heating of the bed of solid particles (3) in relative continuous and casual movement can occur by directing the solar radiation (1) by means of said concentrator

(2) directly on a solid device (7) interposed between the bed of solid particles (3) and the concentrator of solar rays (2), in contact with the perfectly mixed solid particles.

9. System according to any one of the preceding claims, realized using solid particles of every form, nature and dimension and fluids of different nature and features relating to both the thermo-dynamic cycle and the fluidization process.

10. Plant for the production of electric energy from solar radiation characterized in that it provides the usage of one o more storage systems of solar energy according to the preceding claims, if necessary integrated with other generators of energy from different sources, connected in series or in parallel between each other by commonly using the fluid which carries out the thermo-dynamic cycle.

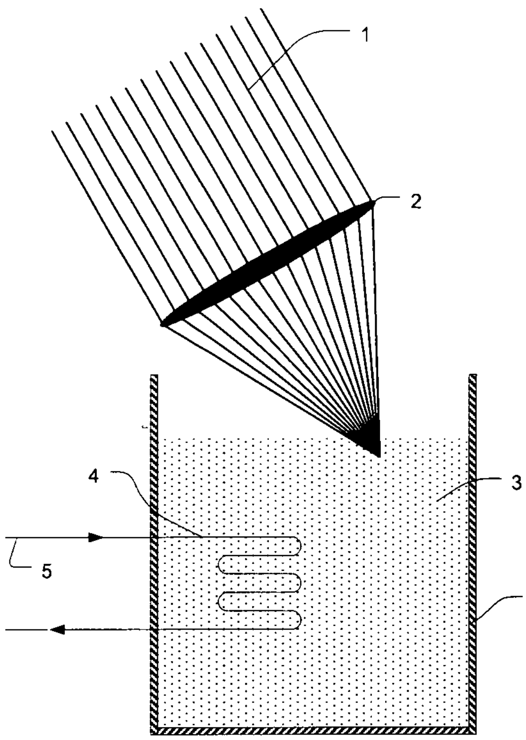

Fig. 1

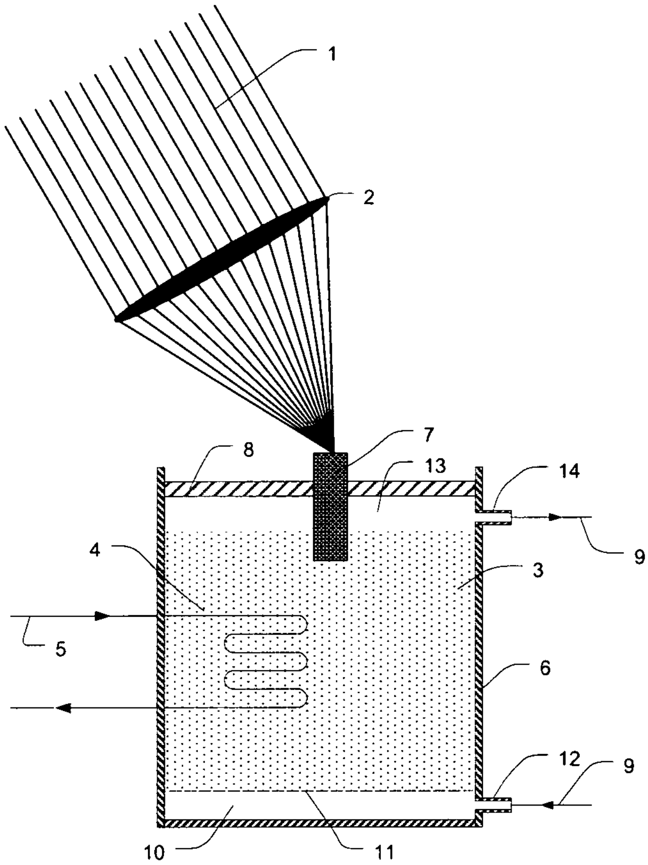

Fig. 2

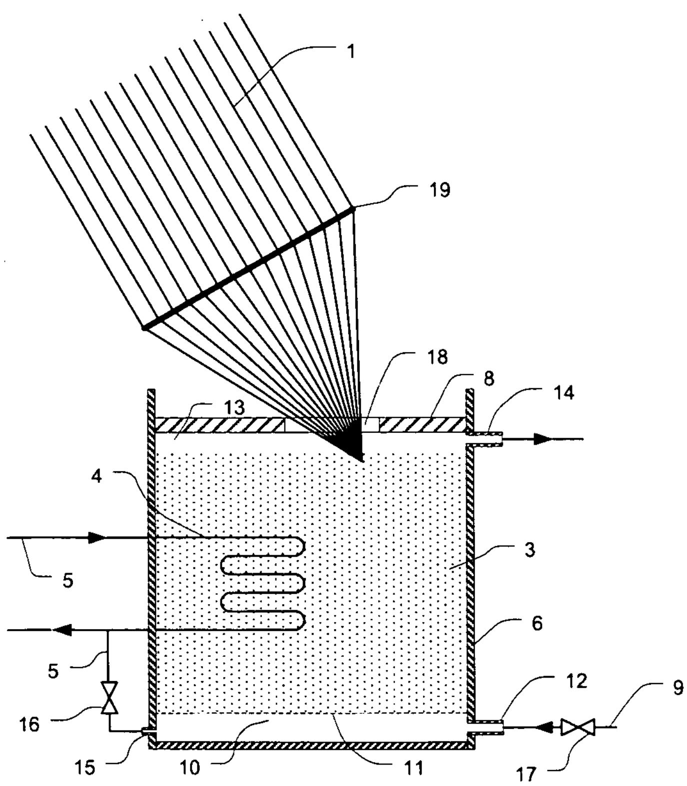

Fig. 3

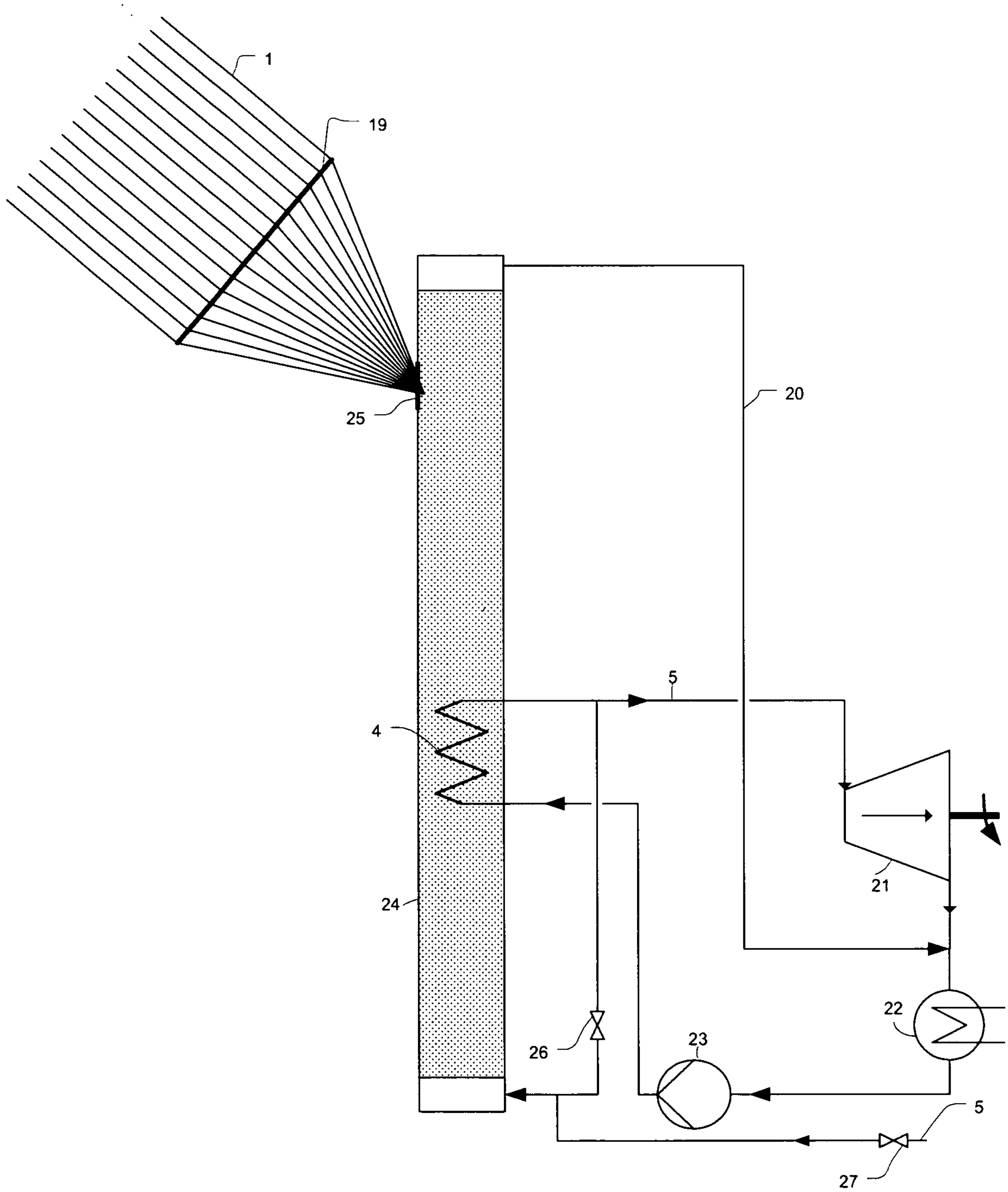

Fig. 4

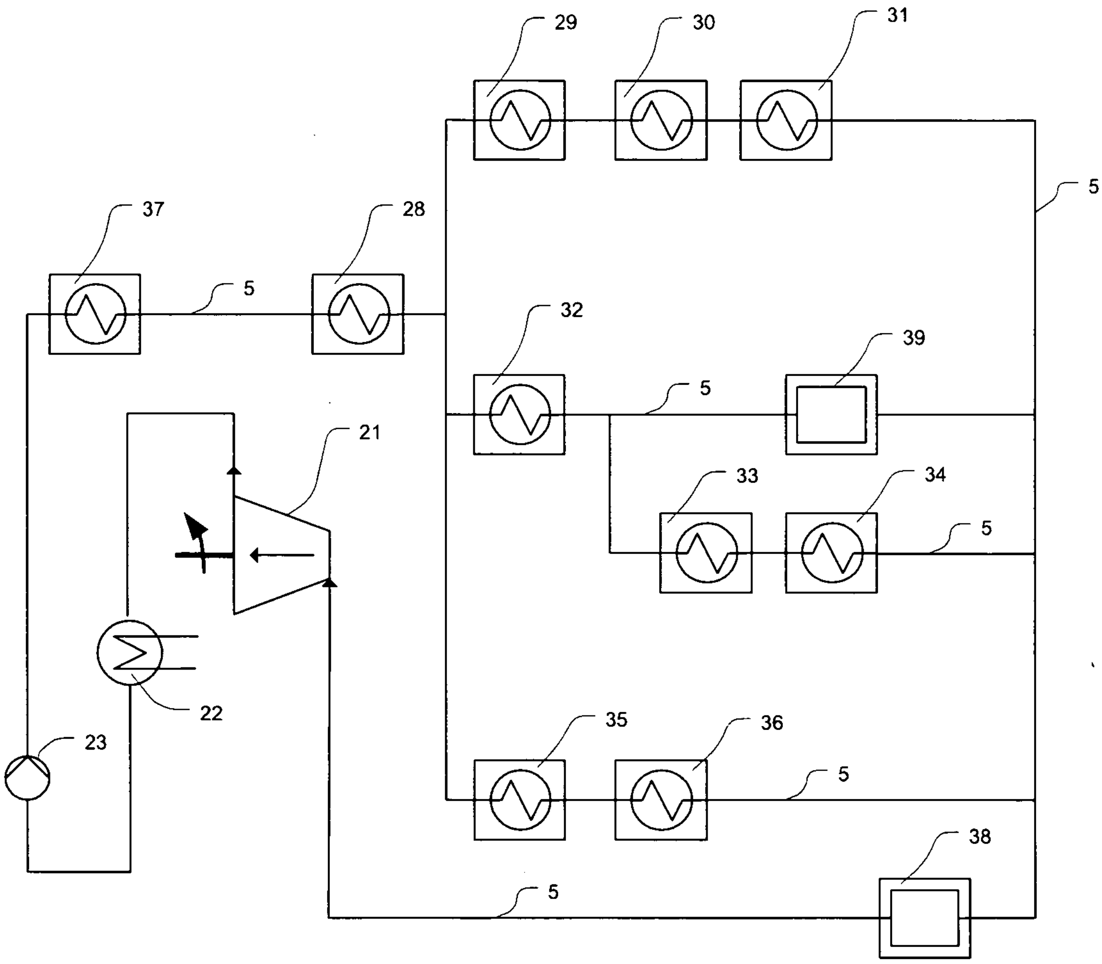

Fig. 5