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Lowenstein

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(54) **SOLAR ENERGY COLLECTION**

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PCT Pub. Date: **Apr. 8, 2010**

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F24J 2/24 (2006.01)

(52) **U.S. Cl.**
USPC **126/636**; 126/652; 126/663; 126/635; 126/676

(58) **Field of Classification Search**
USPC 123/636, 652, 663, 635, 676, 655, 123/670, 672; 165/142, 143, 144
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,018,215	A	4/1977	Pei	
4,262,658	A	4/1981	Frissora	
4,320,743	A	3/1982	Allen	
2003/0037907	A1 *	2/2003	Lee	165/104.19

OTHER PUBLICATIONS

International Search Report dated Jan. 10, 2010.

* cited by examiner

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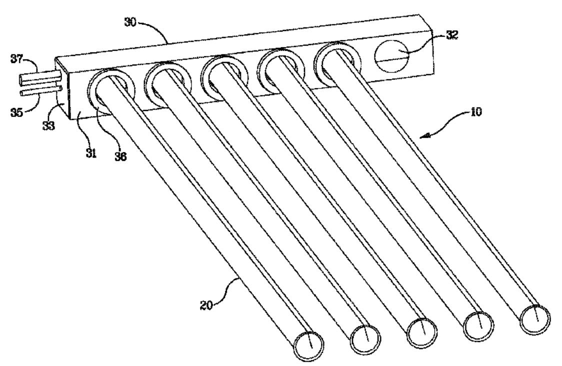
(57) **ABSTRACT**

A solar collector apparatus with Dewar-type evacuated tubes results in the more efficient collection of solar radiation by, for example, maintaining the level of a volatile liquid flowing into the solar collector so that no more than 80% of the volume of an inner cylinder of a collection tube is filled with liquid and a corresponding manifold collects the vapor produced when heat is transferred from the surface of the inner glass cylinder that absorbs solar radiation to the volatile liquid. The aforementioned apparatus may likewise be used to heat a liquid within an absorber tube, the liquid having a volatile and a non-volatile component. As heat is transferred to the liquid, a fraction of the volatile component is converted to vapor, leaving the liquid more concentrated in the non-volatile component.

22 Claims, 9 Drawing Sheets



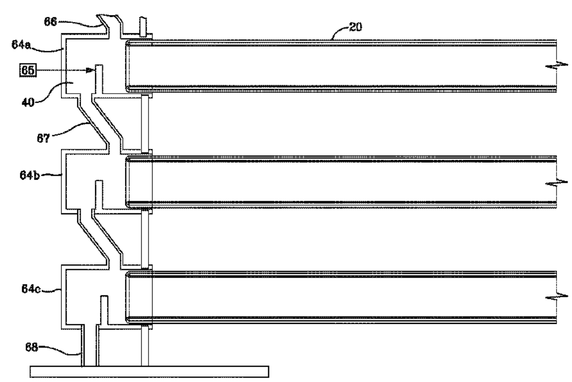
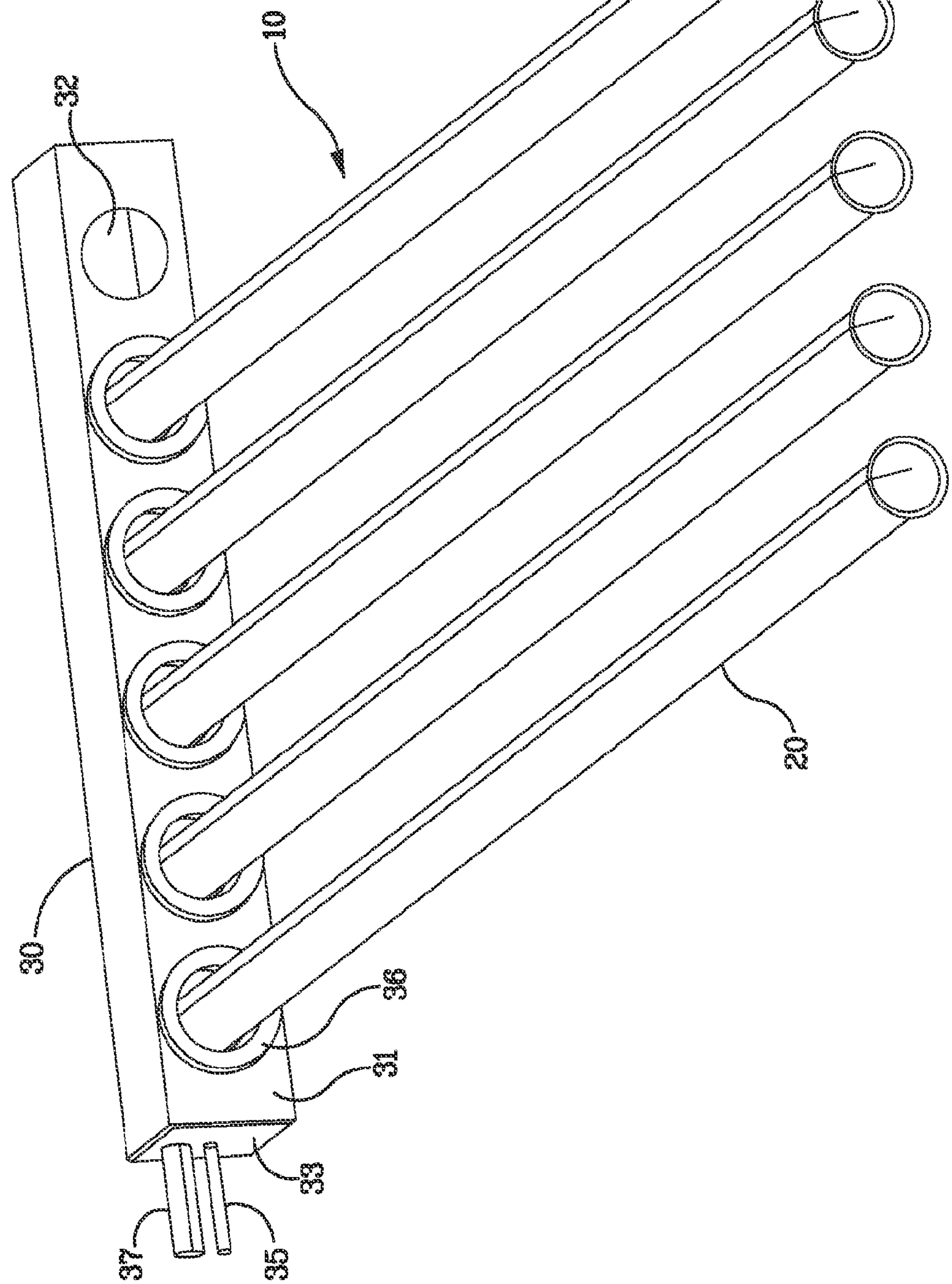


FIG. 1



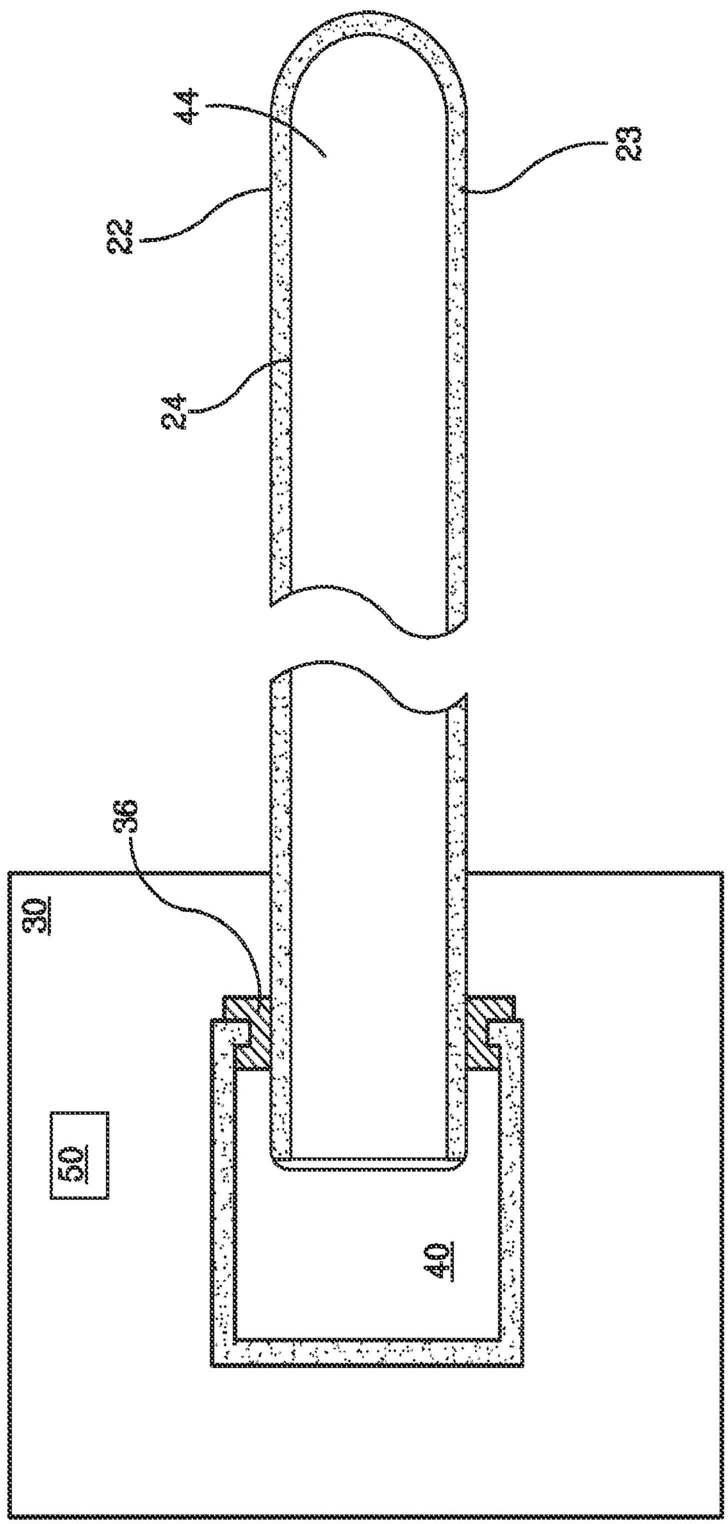


FIG. 2

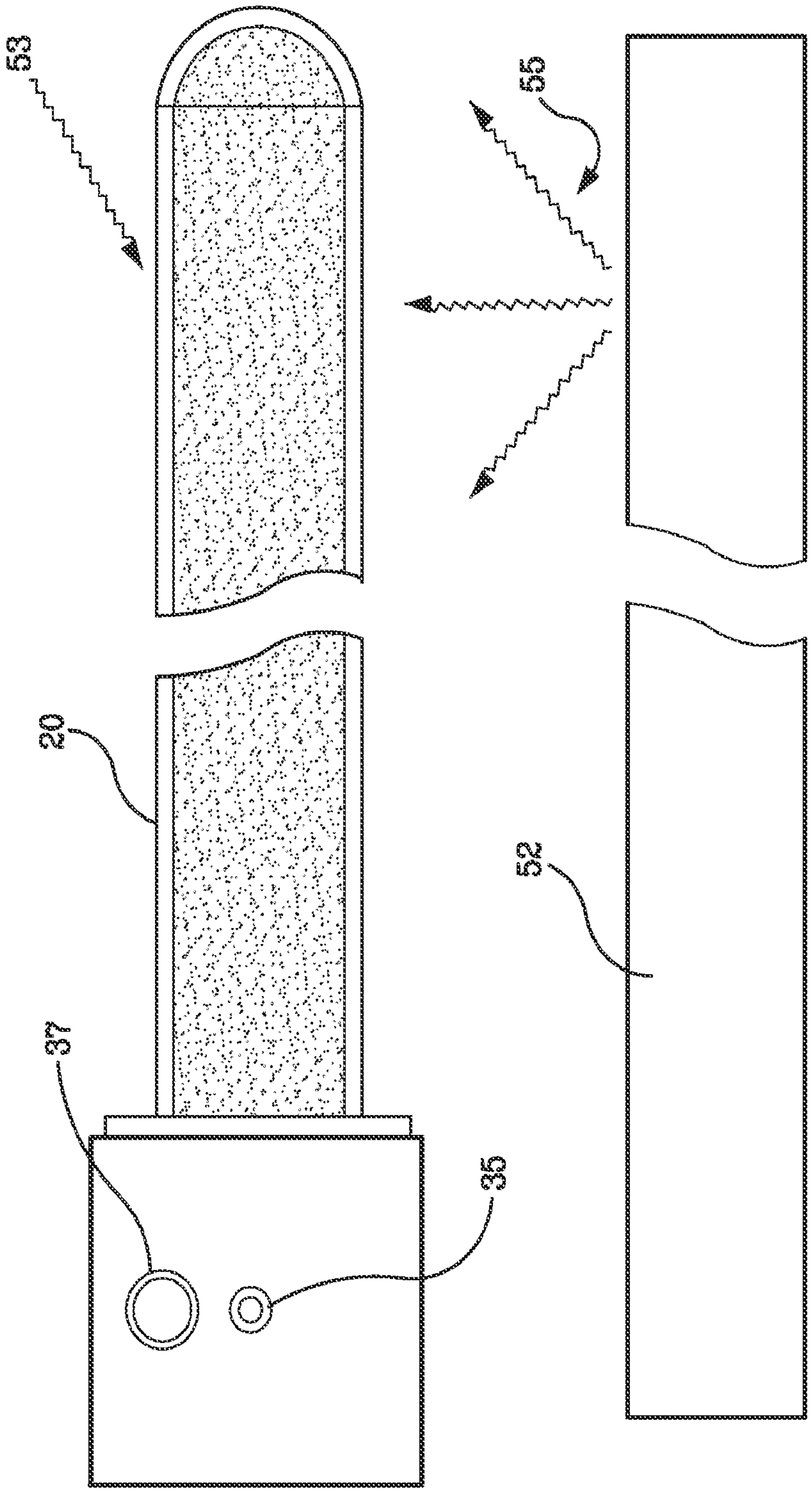


FIG. 3

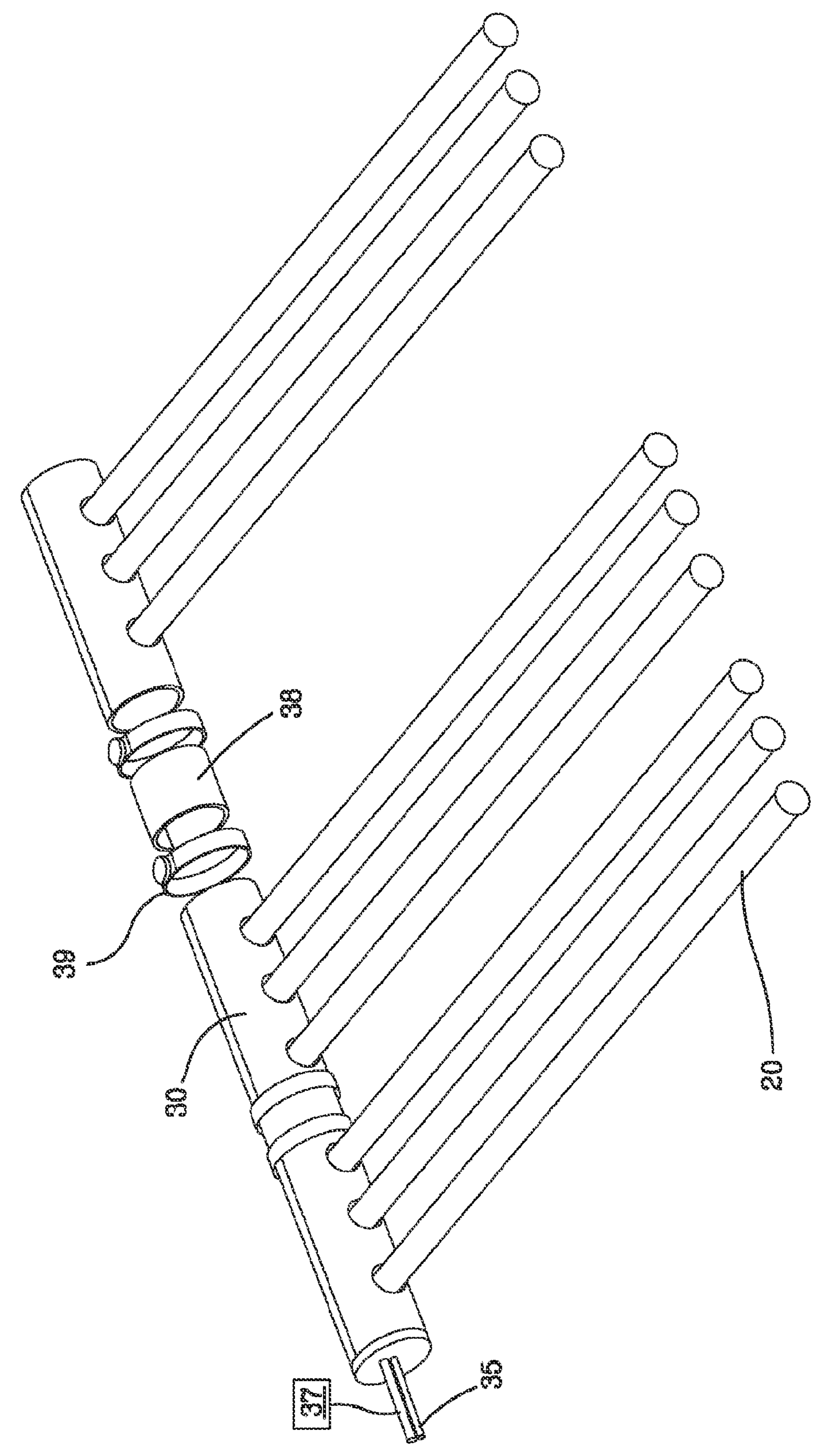


FIG. 4

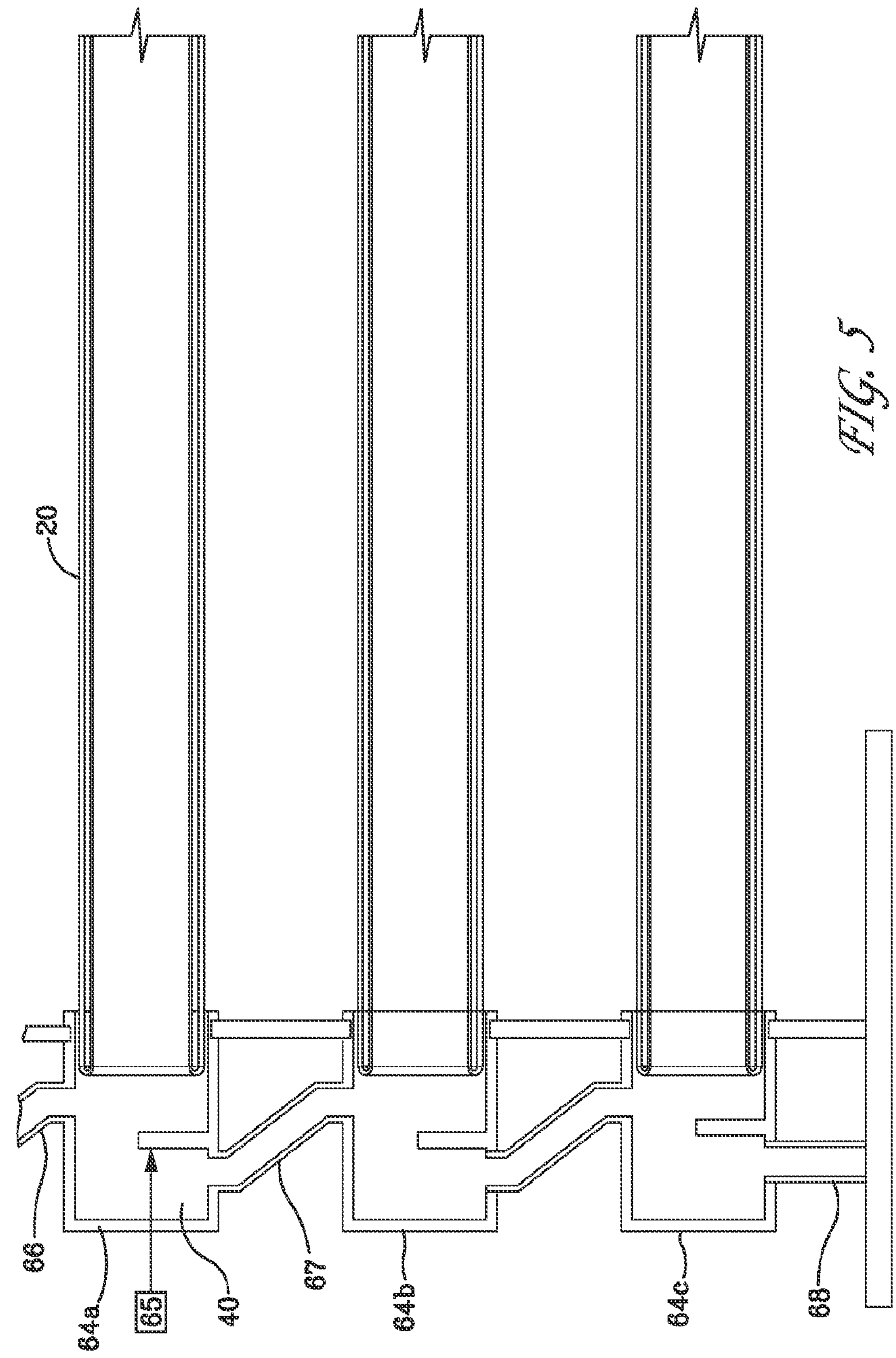


FIG. 5

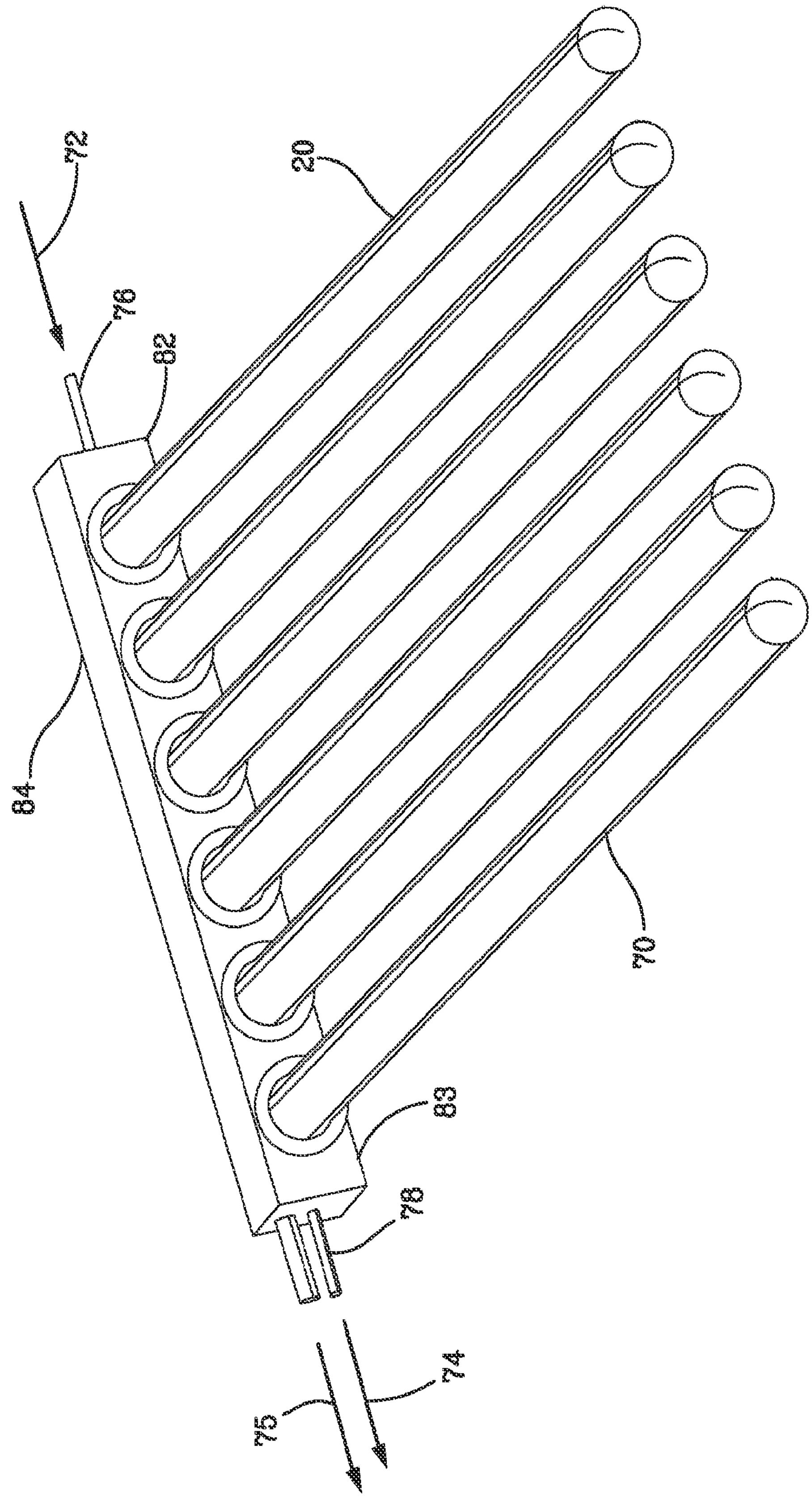


FIG. 6

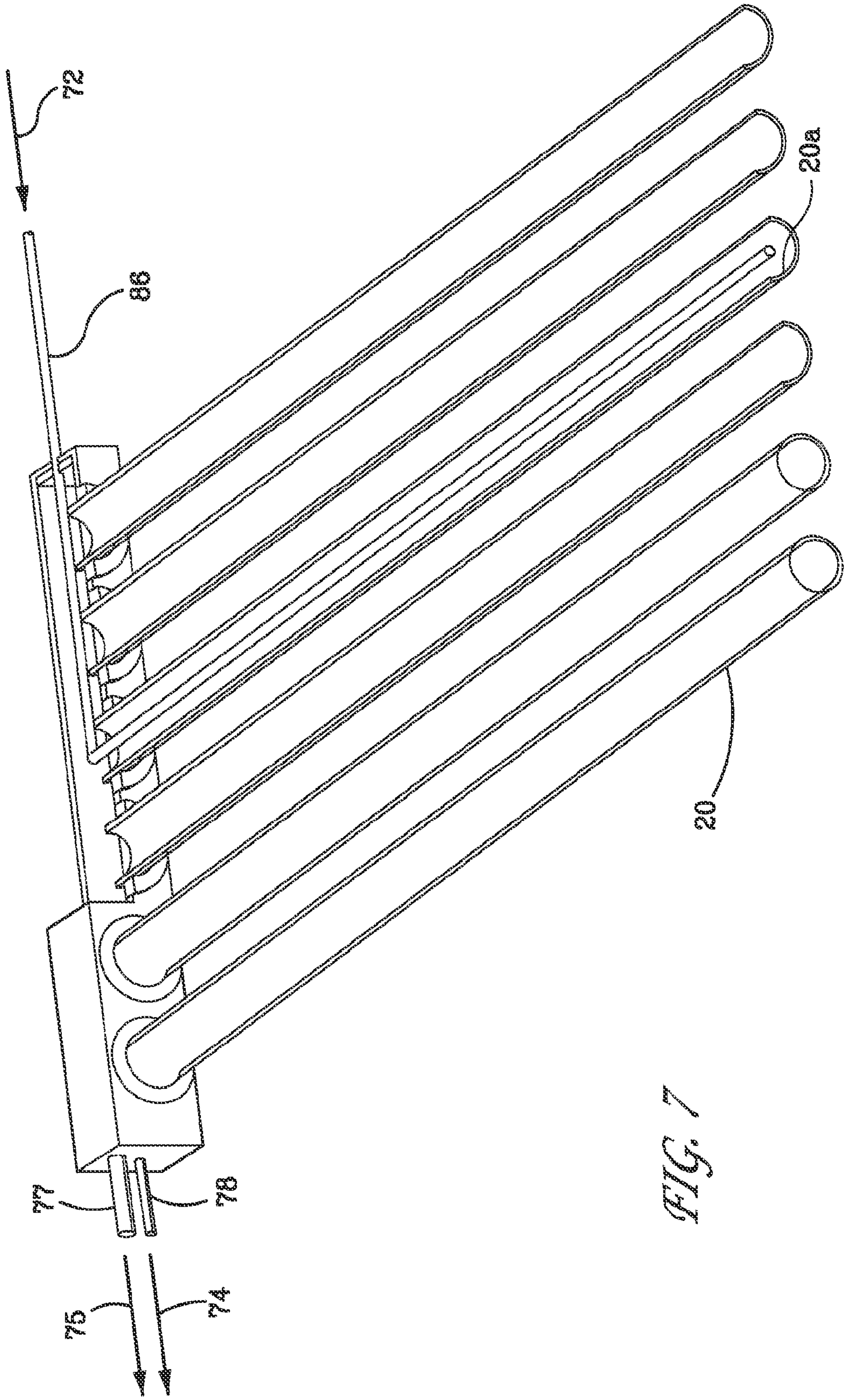


FIG. 7

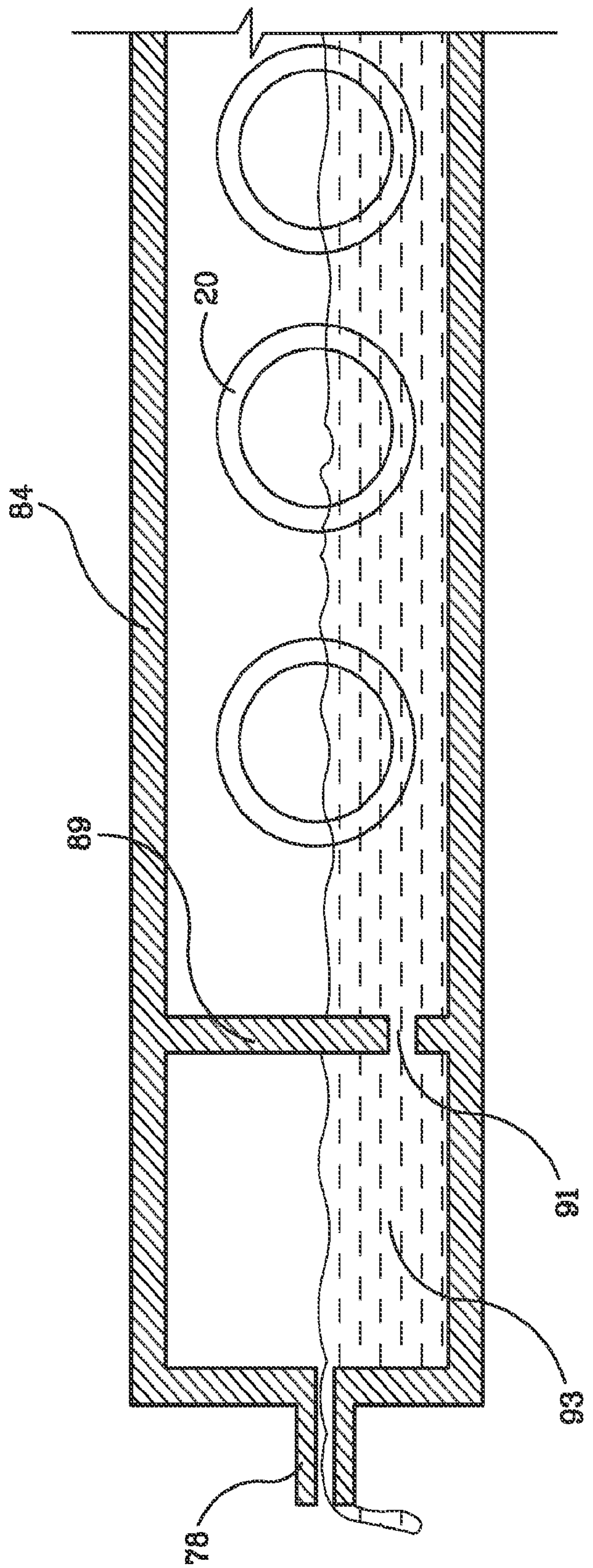


FIG. 8

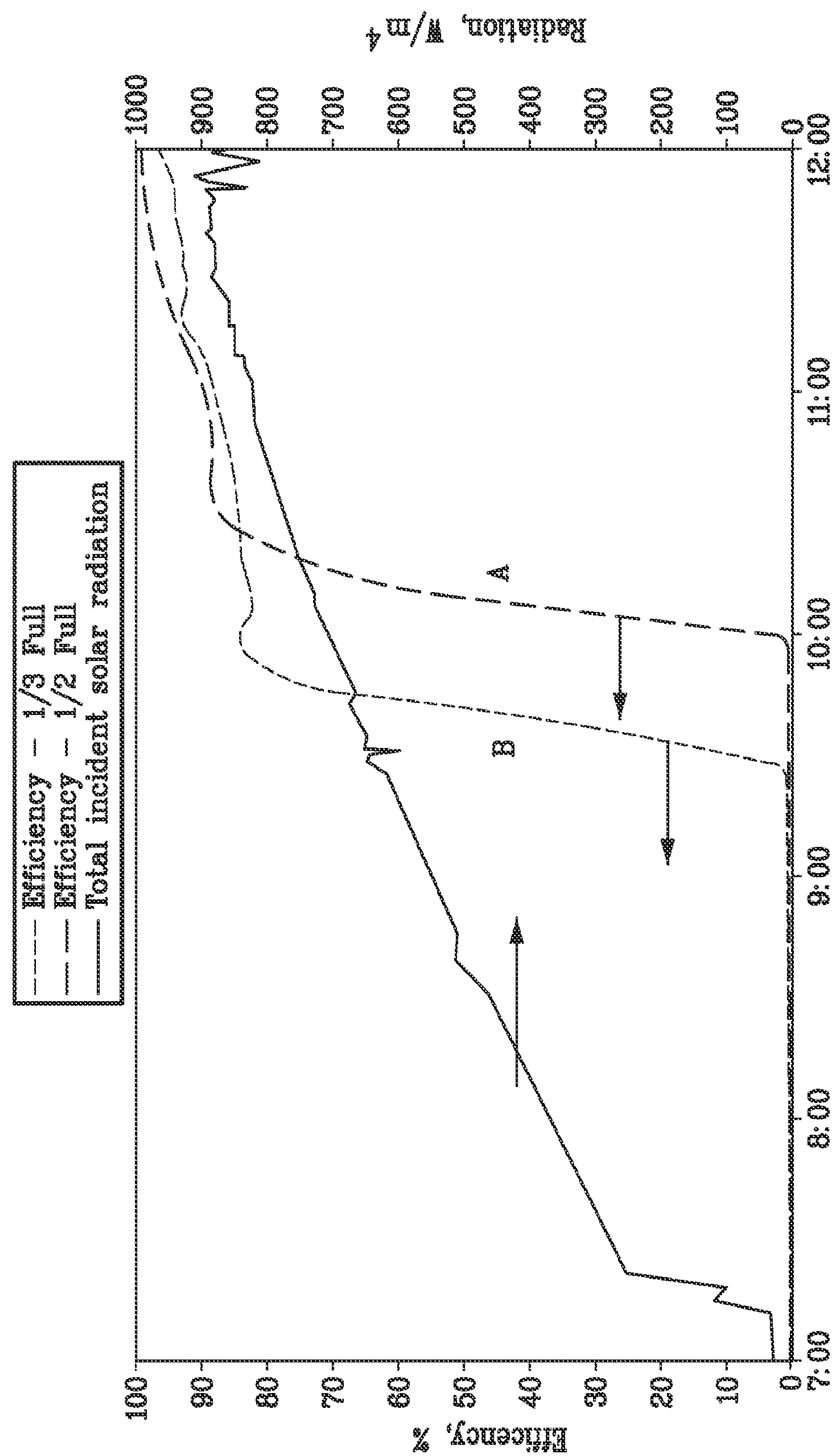

Efficiency – 1/3 Full
Efficiency – 1/2 Full
Total incident solar radiation
Radiation, W/m²
Efficiency, %
A
B
7:00
8:00
9:00
10:00
11:00
12:00
0
10
20
30
40
50
60
70
80
90
100
100
200
300
400
500
600
700
800
900
1000

FIG. 9

SOLAR ENERGY COLLECTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally concerns solar energy collection. More specifically, the present invention concerns increasing the efficiency of a tubular solar collector apparatus.

2. Description of the Related Art

The application of solar energy to heating generally requires a collector that efficiently absorbs solar radiation. The collector transfers the radiated energy to a fluid, which transports the energy to a final application in the form of heat. This final application may include a domestic water or space heating apparatus. An effective collector must absorb a high percentage of incident solar radiation, while losing only a small amount of the absorbed energy to the ambient through either heat conduction or radiation.

Solar collectors including two concentric glass tubes with an evacuated space there between have generally been recognized as an effective configuration for absorbing a high percentage of incident radiation and minimizing heat loss by conduction. A solar collector configured in such a manner is similar to the configuration of a Dewar flask, which may be used as an insulated storage vessel, and are sometimes appropriately referred to as Dewar-type evacuated-tube collectors. The need to minimize radiation heat loss has been addressed by coating the vacuum-side of the inner glass tube with a selective surface that has a high absorptivity for visible radiation and low emissivity for infrared radiation.

The primary developmental effort relating to evacuated tube solar concerns removal of the thermal energy absorbed by the elongated glass tubes. One method of removing the thermal energy from the elongated inner glass tube of evacuated tube solar collectors is to circulate water or other working fluid into and out of the interior of the glass tube. The working fluid circulated through the glass tube absorbs the solar energy and carries that energy to a location where the energy can be stored or put to practical use. An alternative methodology circulates the water or working fluid through the elongated glass tube via pipes or circulation tubes positioned inside the glass tube so that the water or other working fluid does not actually come in contact with the glass tube.

A further technique uses heat pipes to transfer the absorbed solar energy to a working fluid medium that functions as a heat sink. The heat sink "stores" the collected thermal energy and/or transfers the energy to a location where the stored energy can be put to practical use. In such an embodiment, the heat pipe may include an evaporator portion that absorbs the solar energy and causes a volatile thermal transfer fluid in the heat pipe—not the working fluid medium—to vaporize. The vapor pressure drives the vapor toward the cooler condenser section of the heat pipe, which is placed in contact with the working fluid medium or heat sink.

The thermal energy absorbed from the sun in the evaporator portion is conducted from the vapor of the thermal transfer fluid inside the heat pipe to the working fluid or heat sink outside the heat pipe by way of the condenser. The lower temperature of the thermal transfer fluid vapor, which is due to conduction of the heat from the vapor to the working fluid, results in condensation of the thermal transfer fluid in the heat pipe. The condensed thermal transfer fluid then flows from the condenser portion back to the evaporator portion of the heat pipe where solar energy is absorbed to continue the cycle.

An additional method for transferring heat out of a Dewar-type evacuated-tube solar collector involves absorbed solar energy boiling water within the collector. The steam generated from the boiling water transports heat out of the collector through a process called vapor-phase pumping. A solar collector utilizing vapor-phase-pumping involves a tubular absorber filled almost to the top with a heating liquid, such as water, to provide a relatively small vapor-phase zone at the upper end of the absorber; a boiler mounted at a higher elevation than the solar collector; a tube through which liquid flows from the boiler into the tubular absorber and that extends into the interior of the tubular absorber for substantially the full length of the absorber; and a tube that connects the upper vapor-phase zone in the boiler with the vapor-phase zone in the tubular absorber. Extracting heat from an evacuated-tube solar collection using vapor-phase-pumping is easier than with a heat pipe and also avoids the need for a mechanical pump.

It has generally been viewed as disadvantageous not to fill the tubular absorbers such that the top half is in contact with the liquid. Vapor-phase pumping devices have intentionally avoided such a configuration by filling the inner absorber cylinder with liquid or converting the inner absorber cylinder into a heat pipe. Another option has involved inserting a separate heat pipe or U-tube into the inner absorber cylinder and using a metal, thermally conductive fin to thermally couple the evaporator of the heat pipe or the U-tube to the inner absorber cylinder.

The vapor-phase-pumping arrangement described above, however, has several limitations. By operating with the tubular absorber filled almost to the top, the hot fluid within the tubular absorber stores a significant amount of thermal energy. Most of this thermal energy will be lost to the ambient during the night. Furthermore, if the fluid within the tubular absorber is water, the absorber is likely to be damaged by freezing in cold climates since water expands when it freezes. If the vapor that is produced within the absorber is to flow to the boiler without interfering with the in-flowing liquid, an inlet tube that extends into the absorber must be used. This tube, which is often metallic as to withstand possible stagnation conditions within the evacuated-tube collector, increases the cost for the solar collector, especially for more expensive metals such as copper.

SUMMARY OF THE CLAIMED INVENTION

A first claimed embodiment sets forth an apparatus for converting liquid to vapor. The apparatus includes a tubular solar collector having a transparent outer cylinder with one closed end and a concentric inner cylinder with one closed end. The inner cylinder includes a surface coating that absorbs solar radiation. The longitudinal axes of both cylinders are substantially horizontal and the inner cylinder is oriented within the outer cylinder so that the closed ends of the two cylinders are proximate to each other whereby an evacuated space is formed between the two cylinders. The apparatus also includes a manifold that maintains the level of a volatile liquid flowing into the tubular solar collector so that no more than 80% of the volume of the inner cylinder is filled with liquid. The manifold also collects the vapor produced when heat is transferred from the surface of the inner glass cylinder that absorbs solar radiation to the volatile liquid.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates a perspective view of a multi-tube solar collector with tubes in the same horizontal plane.

FIG. **2** illustrates a longitudinal sectional view through one horizontal tube of the multi-tube solar collector of FIG. **1**.

FIG. **3** illustrates a side view of the multi-tube solar collector of FIG. **1** including a reflecting back plane.

FIG. **4** illustrates a perspective view of a multi-tube solar collector composed of three separate manifold-tube sub-assemblies.

FIG. **5** is a longitudinal sectional view through the end-caps and horizontal tubes of a multi-tube solar collector for which the horizontal tubes lie in a plane that is not horizontal.

FIG. **6** is a perspective view of a multi-tube solar collector with horizontal tubes used to evaporate a volatile component of a multi-component liquid.

FIG. **7** illustrates a cut-away perspective view of a multi-tube solar collector with horizontal tubes used to evaporate a volatile component of a multi-component liquid and including an internal artery to deliver the multi-component liquid to one of the tubes.

FIG. **8** illustrates a longitudinal sectional view through the center plane of a manifold that uses a partition with an orifice to allow concentrated liquid to be withdrawn from the manifold through an end wall fitting.

FIG. **9** illustrates performance data corresponding to a multi-tube solar collector that produces steam.

DETAILED DESCRIPTION

A solar collector apparatus with Dewar-type evacuated tubes is generally described. The tubes may be oriented essentially horizontally and partially filled with liquid unlike a prior art solar collection apparatus that operates with liquid filling the tube almost to the top. Instead, the tubes of embodiments of the present invention may be filled only partially with liquid so that the space for vapor above the liquid extends more than three-quarters the length of the tube. With the tubes oriented close to horizontal and partially filled with liquid, the vapor produced within the tube can leave the tube without interfering with the entering liquid. Such a configuration, specifically the relatively low amount of liquid within the tube, reduces the heat lost during the night and, in applications where the tubes are less than half filled with liquid, a liquid that expands during freezing can do so within the tube without creating high stresses that might damage the tube.

An embodiment of the invention as described herein may heat a liquid within an absorber tube, the liquid having a volatile and a non-volatile component. As heat is transferred to the liquid, a fraction of the volatile component is converted to vapor, leaving the liquid more concentrated in the non-volatile component. Both the vapor and the more concentrated liquid leave the absorber tube through its open end.

FIG. **1** illustrates a perspective view of a multi-tube solar collector **10** with tubes **20** in the same horizontal plane. Each of the tubes **20** of solar collector **10** may be of a Dewar-type evacuated tube configuration as is reflected in the context of FIG. **2**. FIG. **2** illustrates a longitudinal sectional view through one horizontal tube **20** of the multi-tube solar collector **10** of FIG. **1**. Each evacuated tube **20** has, as illustrated in FIG. **2**, an outer transparent cylinder **22** and an inner absorber cylinder **24**.

As shown in FIG. **1**, the open end of each evacuated tube **20** is inserted into a grommet **36** (also illustrated in FIG. **2**) that fits into a circular opening **32** in the sidewall **31** of a central manifold **30**. The central manifold **30** has a layer of insulation **50** (FIG. **2**) to reduce heat loss to the ambient. Insulation **50** is not shown in FIG. **1** so that the underlying features of the solar collector **10** may more easily be understood.

In FIGS. **1** and **2**, the manifold **30** has a square cross section, but may be circular, rectangular, or of any other shape that corresponds to the particular requirements of the application or associated manufacturing costs. The grommet **36** is preferably made from an elastomer that is compatible with liquid **40** that is being heated within the collector **10**. The grommet **36** is designed to form a fluid seal between the evacuated tube **20** and the manifold **30**.

Use of grommet **36** allows for damaged evacuated tubes **20** to be more easily replaced. Notwithstanding, grommet **36** may be interchangeable with other means to seal the evacuated tubes **20** in the manifold **30**. For example, the manifold **30** may be made from a material that creates a fluid seal when the evacuated tubes **20** are inserted into the circular openings **32**. Beads of sealant such as a silicone RTV can alternatively be laid around the joints between the evacuated tubes **20** and the manifold **30** to achieve the same sealing effect.

Liquid **40** enters the manifold **30** through an inlet fitting **35** (FIG. **1**), which may be located in an end wall **33** of the manifold **30**. The flow of liquid **40** may be controlled such that liquid **40** only partially fills the tubes **20**. With the tubes **20** horizontally configured, the vapor space **44** above the liquid will extend the entire length of each tube **20**. Though shown in FIGS. **1** and **2** as being round, the tubes **20** could be designed in other shapes including oval, pear, or reverse pear shaped, as well as other shapes that may be used to maximize solar energy collection or optimize fluid flow in the collector **10**.

While a preferred embodiment of collector **10** may implement the tubes **20** in a horizontal configuration, if the tubes **20** are arranged such that the open end is higher than the closed end, the length of the vapor space **44** might be less than the length of the tube **20**. The length of the vapor space **44** as a fraction of the length of the tube **20** may contribute to the efficient operation of solar collector **10**. For example, if liquid **40** is water, the collector **10** may be more vulnerable to damage by freezing as the amount of water (liquid **40**) in the tubes **20** increases. Heat loss at night may likewise increase as the amount of liquid **40** in the tubes **20** increases.

When tubes **20** are arranged such that the open end is lower than the closed end, the level of liquid **40** within the tube **20** may be such that liquid **40** does not extend the full length of the tube **20**. In such a configuration, the surface of the inner absorber cylinder **24** may be modified to act as a wick so that liquid is drawn by capillary forces either axially towards the closed end of the inner absorber cylinder **24** or circumferentially around the inner absorber cylinder. This wick can be of granulated glass particles that are bonded to the inner absorber cylinder like that illustrated in U.S. Pat. No. 4,474,170. Other refractory particles that can withstand high temperatures may be used such as sand or particles of aluminum oxide.

The wick can also be a thin woven or non-woven layer of glass fibers that are inserted into the inner absorber cylinder **24**. Other wicks are possible so long as they can be wetted by liquid **40** and do not degrade when exposed to the highest temperatures that could be produced within an evacuated-tube solar collector **10**. In one embodiment, a wick might draw liquid onto the hotter upper portion of the inner absorber cylinder **24** thereby improving performance of the solar collector **10**.

During the operation of solar collector **10**, solar radiation passes through the outer transparent glass cylinders **22** of the evacuated tubes **20** and impinges on the inner absorber cylinder **24**. The volume **23** between the outer glass cylinder **22** and the inner absorber cylinder **24** is evacuated to eliminate heat loss by conduction from the inner absorber cylinder to the surroundings.

The surface of the absorber cylinder **24** that faces the vacuum may have high absorptivity for solar radiation and low emissivity for infrared (i.e., thermal) radiation. The absorbtivity and emissivity of the absorber cylinder **24** may be controlled through a galvanically applied selective coating such as black chrome, black nickel, or aluminum oxide with nickel. A titanium-nitride-oxide layer may alternatively be applied via steam in a vacuum process. This titanium-nitride-oxide coating has low emission rates and can be produced by an emission-free, energy-efficient process.

The solar radiation that impinges on the absorber cylinder **24** is converted to thermal energy and raises the temperature of the upper portion of the absorber cylinder **24**. A combination of radiation from the inner wall of the absorber cylinder **24**, heat conduction, and heat convection transfers thermal energy from the absorber cylinder **24** to liquid **40** within the absorber cylinder **24**. If the incident solar radiation is sufficiently intense, liquid **40** will be heated to a temperature at which its vapor pressure is above the ambient pressure. At this temperature, the evolving vapor will flow out of the absorber cylinder **40** and into the manifold **30**. Said flow pushes out any air that might be in the cylinder. The vapor leaves the manifold **30** through the vapor outlet fitting **37**. The vapor can be used as a heat source for desiccant regeneration, water heating, space heating or similar operations.

FIG. **3** illustrates a side view of the multi-tube solar collector of FIG. **1** including a reflecting back plane. As shown in FIG. **3**, a reflecting surface **52** positioned below the tubes **20** can be used to increase the amount of solar radiation collected by each tube **20**. In FIG. **3**, the reflecting surface **52** is illustrated as flat and the incident solar radiation **53** that is not absorbed by the evacuated tube **20** reflects as diffuse radiation **55** upward towards the evacuated tubes **20**.

Reflecting surface **52** can also specularly reflect the solar radiation; surface **52** may thus have a compound parabolic shape. Other shapes may be implemented in the context of reflecting surface **52**. Alternatively, mirror image pairs of manifolds **30** can be interspersed to maximize the amount of surface areas available for solar absorption. This interleaved or interspersed tube arrangement would result in two parallel manifolds and a smaller space requirement for implementation. Such an arrangement may sacrifice some reflected energy potential provided by a mirror placed behind the tubes of the collector **10**.

In applications that require large amounts of thermal energy, it may not be practical to couple all the evacuated tubes **20** to a single manifold **30**. As shown in FIG. **4**, which illustrates a perspective view of a multi-tube solar collector composed of three separate manifold-tube sub-assemblies, coupling sleeves **38** can be used to join two or more manifolds **30** end-to-end so that they function as a single manifold. A toric joint **39**, sometimes referred to as a mechanical gasket or O-ring, may be utilized to properly seal manifolds **30** and coupling sleeves **38**. When multiple manifolds are joined together, end walls **33** may be applied only to the outer ends of the first and last manifold **30** in the series. Such end walls **33** may sealed with the manifold **30** using the aforementioned toric joint **39**.

The evacuated tubes **20** of the solar collector **10** illustrated in FIGS. **1** and **2** all lie in essentially the same flat, horizontal plane. With the evacuated tubes **20** all in the same horizontal plane and no obstructions to the flow of liquid between the evacuated tubes **20**, the level of liquid **40** will generally be the same in all the evacuated tubes **20**. In some embodiments, however, the evacuated tubes may lie in a plane that is not horizontal. FIG. **5** is just such an embodiment and illustrates a longitudinal sectional view through the end-caps and horizontal tubes of a multi-tube solar collector for which the horizontal tubes lie in a plane that is not horizontal. The embodiment illustrated in FIG. **5** will allow the solar collector **10** to operate with each tube **20** substantially horizontal but the tubes no longer lying in the same horizontal plane.

In FIG. **5**, a levelizing end cap **64** is added to the open end of each evacuated tube **20**. During the operation of the solar collector **10** of FIG. **5**, liquid **40** is pumped into the uppermost levelizing end cap ***64a*** through an inlet tube **66**. Upon reaching a predetermined level within the evacuated tube **20**, the liquid flows over weir **65**. The overflow liquid flows by gravity through transfer tube **67** and into the next lower levelizing end cap ***64b***. This cascading of liquid **40** continues to the lowest levelizing end cap ***64c***. From the lowest levelizing end cap ***64c***, liquid **40** flows out of the solar collector **10** via the outlet tube **68**. Liquid **40** that flows from outlet tube **68** can be re-circulated to inlet tube **66** using a pump (not shown). Aside from the use of levelizing end caps **64** and the possible recirculation of liquid **40**, the operation of the solar collector **10** as shown in FIG. **5** is substantially similar to that of the solar collector **10** of FIGS. **1** and **2**.

FIG. **6** is a perspective view of a multi-tube solar collector **70** with horizontal tubes used to evaporate a volatile component of a multi-component liquid. The solar collector **70** shown in FIG. **6** is used to partially separate a liquid mixture into a volatile component and a non-volatile component. Although not limited to this application, the solar collector **70** can be used to remove water (i.e., the volatile component) from an aqueous solution of an ionic salt such as calcium chloride (i.e., the non-volatile component).

Other ionic salts that are soluble in water include lithium chloride, calcium bromide, lithium bromide, sodium chloride, potassium sulfate, sodium sulfate, as well as solutions in which the vapor produced when the solution is heated has only one component (i.e., water in the case of an aqueous salt solution). The liquid mixture with the higher fraction of the non-volatile component will be called the concentrated liquid, and the liquid mixture with the lower fraction, the dilute liquid. Thus, dilute liquid **72** is supplied to the solar collector **70** and concentrated liquid **74** and vapor **75** are returned from the solar collector.

As the concentration of the non-volatile component increases and as its temperature decreases, the density of the liquid mixture may increase. In this context, consider an application where the dilute liquid **72** that is supplied to the solar collector **70** is heated to a sufficiently high temperature to ensure that its density is lower than that of the hot, concentrated liquid **74** that is returned from the solar collector. In this case, the inlet fitting **76** for the dilute liquid **72** may be located on the front end wall **82** of the central manifold **84** at an elevation that is close to the level of the liquid within the evacuated-tubes **20**. Such a configuration is illustrated in FIG. **6**.

The concentrated liquid **74** is withdrawn from the central manifold **84** through an outlet fitting **78** that may be located on the rear-end wall **83** at an elevation near the bottom of the central manifold **84** as is also illustrated in FIG. **6**. With this arrangement of inlet fitting **76** and outlet fitting **78**, the dilute liquid **72** will tend to spread out over the surface of the liquid within the solar collector **70** and be delivered to each evacuated tube **20** in a relatively uniform manner.

As the dilute liquid **72** is heated by the solar radiation that is absorbed by the evacuated tube **20**, some of the volatile component of dilute liquid **72** is converted to vapor. As this happens, the dilute liquid **72** becomes more concentrated and the density of dilute liquid **72** increases thereby causing dilute liquid **72** to sink to a lower level within the evacuated tube **20**. During the operation of the solar collector **70**, there may be a continuous flow of dilute liquid to the tubes and return of concentrated liquid from the tubes, the dilute liquid flowing above the concentrated liquid. The vapor **75** flows out of manifold **84** through vapor outlet fitting **77** that is located above the liquid level within the manifold as illustrated in FIG. **6**.

In some applications, it may be convenient to locate the inlet fitting **76** for the dilute liquid and the outlet fitting **78** for the concentrated liquid on the same end wall of the manifold **84**. In these applications, the inlet fitting **76** can be extended within the manifold so that the dilute liquid is delivered to a location within the manifold that is away from location where the concentrated liquid flows out of the manifold. This design would prevent "short-circuiting" of the weak liquid directly to the outlet fitting.

In some applications it may not be practical to preheat the dilute liquid **72** to a sufficiently high temperature to ensure that its density is lower than the concentrated liquid **74**. In these applications, an internal artery **86** can be added to the solar collector **70** as shown in FIG. **7**. FIG. **7** illustrates a cut-away perspective view of a multi-tube solar collector with horizontal tubes used to evaporate a volatile component of a multi-component liquid and including an internal artery to deliver the multi-component liquid to one of the tubes.

Internal artery **86** delivers the dilute liquid **72** to the closed end of one evacuated tube **20***a* of the many tubes **20** that are a party of solar collector **70**. The dilute liquid will be heated within this evacuated tube **20***a* to a temperature at which its density is less than that of the concentrated liquid **74**. The heated dilute liquid that leaves the evacuated tube **20***a* will then flow to the other evacuated tubes **20** along the surface of the liquid that fills these tubes **20**. Once the dilute liquid **72** has flowed to the other evacuated tubes **20**, the process of creating vapor and concentrated liquid within these tubes **20** will be the same as that described for the operation of the solar collector **70** in FIG. **6**.

Depending on the temperature of the dilute liquid **72** that is supplied to the solar collector **70**, it may be necessary to use more than one internal artery **86** and more than one evacuated tube **20***a* for preheating. The number of internal arteries **86** will nevertheless be less than the number of evacuated tubes **20**; this configuration remains a simplification over those prior designs that require one internal artery for each evacuated tube.

In the solar collector **70** illustrated in FIGS. **6** and **7**, if the diameter of the outlet fitting **78** is large and the concentrated liquid **74** freely flows out of the central manifold **84**, then the elevation of this fitting may set the level of the liquid within the manifold **84** and the evacuated tubes **20**. The denser concentrated liquid that is produced within the solar collector **70** will, however, flow below the less dense dilute liquid. As such, it may be preferable for the outlet fitting **78** to be located near the bottom of the central manifold **84** so that only the concentrated liquid is withdrawn from the manifold.

FIG. **8** illustrates a longitudinal sectional view through the center plane of a manifold that uses a partition with an orifice to allow concentrated liquid to be withdrawn from the manifold through an end wall fitting. As shown in FIG. **8**, a partition **89** with an orifice **91** near the bottom of the partition **89** can be used to form a pool **93** of liquid at the end of the central manifold **84**. The liquid that flows into this pool **93** through the orifice **91** will be concentrated liquid. The level of the liquid in the pool **93** will be nearly the same as the level of liquid within the remainder of the central manifold **84** and the evacuated tubes **20**. If the concentrated liquid freely flows out of the outlet fitting **78**, then the elevation of this fitting can be used to establish the level of liquid within the pool **93**, the remainder of the central manifold **84**, and the evacuated tubes **20**.

In the embodiments illustrated in FIGS. **1** through **8**, only the lower portion of the inner absorber cylinder **24** is wetted by liquid. A significant fraction of the solar radiation that impinges on the solar collector is absorbed by the upper portion of the inner absorber cylinder **24**, which faces the sky. This portion of the inner absorber cylinder is not wetted by liquid. Nor if there is a thermally conductive element within the evacuated tubes that would facilitate the transfer of heat from the hot, upper portion of the inner absorber cylinder **24** and the liquid **40** that is within the tube.

FIG. **9** illustrates performance data corresponding to a multi-tube solar collector that produces steam. The performance data of FIG. **9** corresponds, specifically, to a 24-tube solar collector implemented in the context of the embodiment illustrated in FIG. **3**. The diameter of the transparent outer cylinder of the evacuated tubes resulting in the data of FIG. **9** was 58 mm and the diameter of the inner absorber cylinder was 47 mm; the length of each tube was 1.8 m. The tubes were spaced apart along the central manifold so that the distance between their axial centerlines was equal to 94 mm. The backplane was a white, diffusely reflecting surface located 94 mm below the axial centerlines of the evacuated tubes. The 24-tube solar collector operated with water entering the collector at close to ambient temperature and pressure, and steam leaving the collector slightly superheated to approximately 105° C.

The curve labeled A in FIG. **9** shows the solar energy that was productively used to produce steam in the 24-tube solar collector expressed as a percentage of the non-reflected solar energy that was incident on the inner absorber cylinders of the collector when the tubes were approximately one-half full of water. The curve labeled B in FIG. **9** shows the performance of the collector when the tubes were approximately one-third full of water.

As shown in FIG. **9**, following an initial three-hour period of heating for the collector that was one-half full (i.e., Curve A) and a two and one-half hour period of heating for a collector that was one-third full (i.e., Curve B), both collectors produced steam at a rate that corresponds to approximately 80% to 100% of the non-reflected solar radiation incident on the inner absorber cylinders of the related tube. It should be noted that the tubes also receive reflected radiation from the backplane, so the 100% conversion rate does not imply that all the incident radiation is converted to steam. Otherwise, once at operating temperature, both collectors—regardless of fill levels—produce steam at about the same efficiency.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. The descriptions are not intended to limit the scope of the invention to the particular forms set forth herein. To the contrary, the present descriptions are intended to cover such alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims and otherwise appreciated by one of ordinary skill in the art. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments. For example, the solar absorber of the present invention can also be used to heat a multi-component liquid like glycol and water, thereby producing vapor that has a much higher fraction of water than the initial liquid. In such case the present invention could be used as the thermal source for a distillation column.

What is claimed is:

1. An apparatus that converts a liquid into vapor comprising:

one or more solar collectors each comprising:

a transparent outer cylinder having a closed end and an open end;

an inner cylinder having a closed end and an open end, the inner cylinder being concentric with and disposed within the transparent outer cylinder so that the closed end of the inner cylinder is located proximate the closed end of the transparent outer cylinder, an outer surface of the inner cylinder being made of a material that absorbs solar radiation to generate heat,

the longitudinal axes of the transparent outer cylinder and the inner cylinder being substantially horizontal; and

an enclosed and evacuated space formed between the transparent outer cylinder and the inner cylinder; and

a manifold engaged with the one or more solar collectors and that comprises one or more openings, each of the one or more openings being in communication with the open end of the inner cylinder of a respective one of the one or more solar collectors so that liquid supplied to the manifold is directed through the opening into the inner cylinder and vapor produced when the generated heat is transferred to the liquid is directed out of the inner cylinder through the opening, the manifold maintaining the level of the liquid flowing into the one or more solar collectors so that for each of the one or more solar collectors no more than 80% of the volume of the inner cylinder is filled with liquid.

2. The apparatus of claim 1, wherein, for each of the one or more solar collectors, the open ends of the transparent outer cylinder and the inner cylinder are inserted into a respective one of the one or more openings, and the manifold comprises a means for forming a fluid seal between the one or more solar collectors and the manifold.

3. The apparatus of claim 2, wherein the means for forming a fluid seal comprises one or more grommets.

4. The apparatus of claim 1, wherein the manifold further comprises one or more inlet openings that allow the liquid to enter the manifold and one or more first outlet openings that allow the vapor to exit the manifold.

5. The apparatus of claim 4, wherein the liquid has a volatile component and a non-volatile component so that when the volatile component is converted into a vapor, the concentration of the non-volatile component in the liquid increases, and the manifold further comprises one or more second outlet openings for the liquid with a higher concentration of the non-volatile component to flow out of the manifold.

6. The apparatus of claim 5, further comprising one or more internal arteries that transfer liquid from the one or more inlet openings to locations within at least one of the one or more of the solar collectors.

7. The apparatus of claim 5, wherein the liquid is an aqueous solution of an ionic salt, and water is the volatile component and the ionic salt is the non-volatile component.

8. The apparatus of claim 7, wherein the liquid flowing out of the one or more second outlet openings, which has a higher concentration of the non-volatile component ionic salt, is supplied to at least one of a liquid-desiccant air conditioner and a dehumidifier.

9. The apparatus of claim 1, wherein an inner surface of the inner cylinder is coated with a material that wicks the liquid at least one of axially along and circumferentially around the inner cylinder.

10. The apparatus of claim 9, wherein the material comprises granulated glass particles, aluminum oxide particles or woven or non-woven glass fibers.

11. The apparatus of claim 1, wherein the manifold further comprises insulation.

12. The apparatus of claim 1, wherein no more than 50% of the volume of the inner cylinder is filled with the liquid.

13. The apparatus of claim 1, wherein the manifold comprises one or more discrete segments, each of the one or more discrete segments comprising at least one of the one or more openings.

14. The apparatus of claim 1, wherein the longitudinal axes of the one or more solar collectors lie in substantially the same horizontal plane.

15. The apparatus of claim 1, further comprising a reflecting surface positioned so as to reflect the solar radiation towards the one or more solar collectors.

16. The apparatus of claim 1, wherein the longitudinal axes of the one or more solar collectors lie in a plane that is angled from a horizontal plane, each of the one or more solar collectors comprises a means for maintaining the level of the liquid flowing into the solar collector, and the apparatus further comprises one or more delivery tubes that supply the liquid to each solar collector.

17. The apparatus of claim 1, wherein the material that absorbs solar radiation is made of a coating comprising black chrome, black nickel, aluminum oxide with nickel or titanium-nitride-oxide.

18. The apparatus of claim 1, wherein the inner cylinder is made of glass.

19. The apparatus of claim 1, wherein the outer cylinder is made of glass.

20. A method of converting a liquid into a vapor comprising the steps of:

directing liquid into one or more solar collectors through a manifold that supports the one or more solar collectors, each of the one or more solar collectors comprising:

a transparent outer cylinder having a closed end and an open end;

an inner cylinder having a closed end and an open end, the inner cylinder being concentric with and disposed within the transparent outer cylinder so that the closed end of the inner cylinder is located proximate to the closed end of the transparent outer cylinder, a outer surface of the inner cylinder being made of a material that absorbs solar radiation to generate heat;

the longitudinal axes of the transparent outer cylinder and the inner cylinder being substantially horizontal; and

an enclosed and evacuated space formed between the transparent outer cylinder and the inner cylinder;

maintaining the level of the liquid directed into the one or more solar collectors so that for each of the one or more solar collectors no more than 80% of the volume of the inner cylinder is filled with liquid; and

collecting vapor produced when the heat generated in the inner cylinders of the one or more solar collectors is transferred to the liquid.

21. The method of claim 20, wherein the liquid has a volatile component and a non-volatile component so that when the volatile component is converted into a vapor, the concentration of the non-volatile component in the liquid

increases, and the method further comprises collecting the liquid with a higher concentration of the non-volatile component.

22. An apparatus that converts a liquid into a vapor comprising:

one or more solar collectors each comprising:

a transparent outer glass cylinder having a closed end and an open end;

an inner cylinder having a closed end and an open end, the inner cylinder being concentric with and disposed within the transparent outer glass cylinder so that the closed end of the inner cylinder is located proximate to the closed end of the transparent outer glass cylinder, an outer surface of the inner cylinder being made of a material that absorbs solar radiation to generate heat;

the longitudinal axes of the transparent outer glass cylinder and the inner cylinder being substantially horizontal; and

an enclosed and evacuated space formed between the transparent outer glass cylinder and the inner cylinder; and

a manifold engaged with the one or more solar collectors and that comprises one or more openings, each of the one or more openings being in communication with the open end of the inner cylinder of a respective one of the one or more solar collectors so that liquid supplied to the manifold is directed through the opening into the inner cylinder and vapor produced when the generated heat is transferred to the liquid is directed out of the inner cylinder through the opening, the manifold maintaining the level of the liquid flowing into the one or more solar collectors so that for each of the one or more solar collectors no more than 80% of the volume of the inner cylinder is filled with liquid,

for each of the one or more solar collectors, the open ends of the transparent outer glass cylinder and the inner cylinder are inserted into a respective one of the one or more openings, and the manifold comprises a means for forming a fluid seal between the one or more solar collectors and the manifold,

the manifold further comprises one or more inlet openings that allow the liquid to enter the manifold and one or more first outlet openings that allow the vapor to exit the manifold.

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