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(54) SOLAR COLLECTOR WITH FOIL ABSORBER

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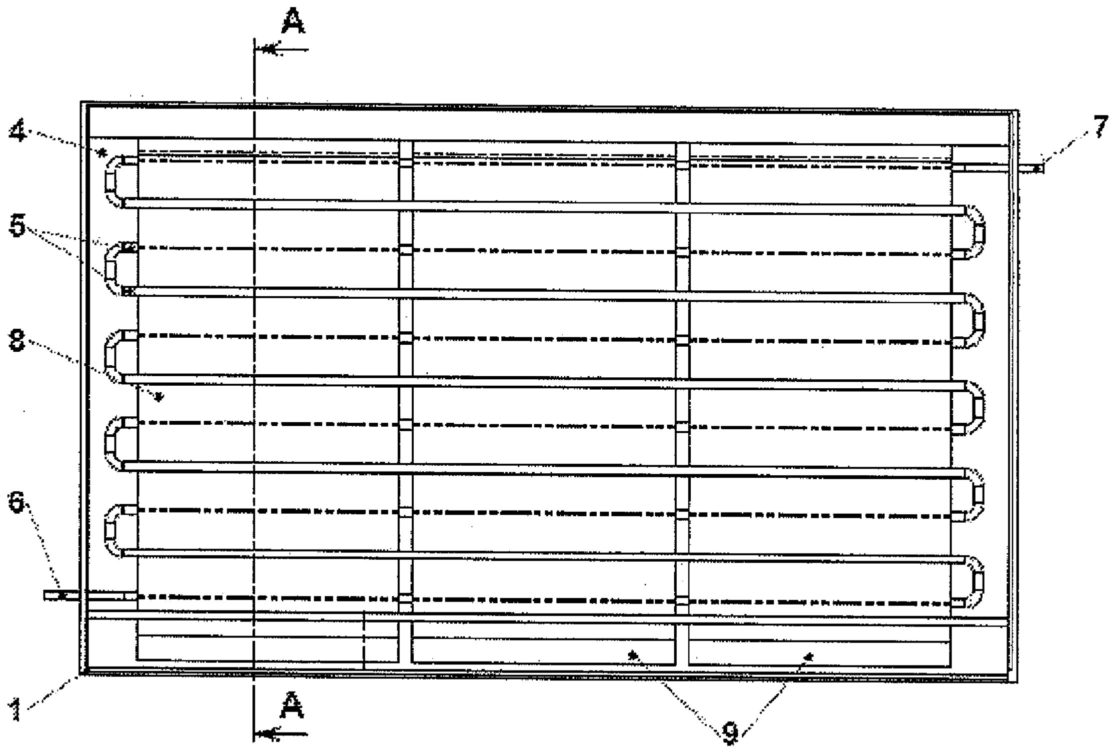
(57) **ABSTRACT**

The present invention provides a solar collector comprising a collector device and a heat-transfer device which includes a heat conductive conduit for heat-transfer fluid, the conduit being in physical contact with the collector device, characterized in that: the collector device comprises flexible metallic foil of which at least one side is adapted for exposure to solar radiation by the presence thereon of a heat absorptive coating; and the physical contact is maintained by tension effective to stretch the foil over the conduit. In an embodiment of the invention the tubes **5** of the conduit are arranged in one plane, the tension is maintained by bars **10** arranged in another plane, substantially parallel to the plain of the tubes. Foil **8** is placed so as to contact alternately with the tubes and with tension-maintaining bars **5**.



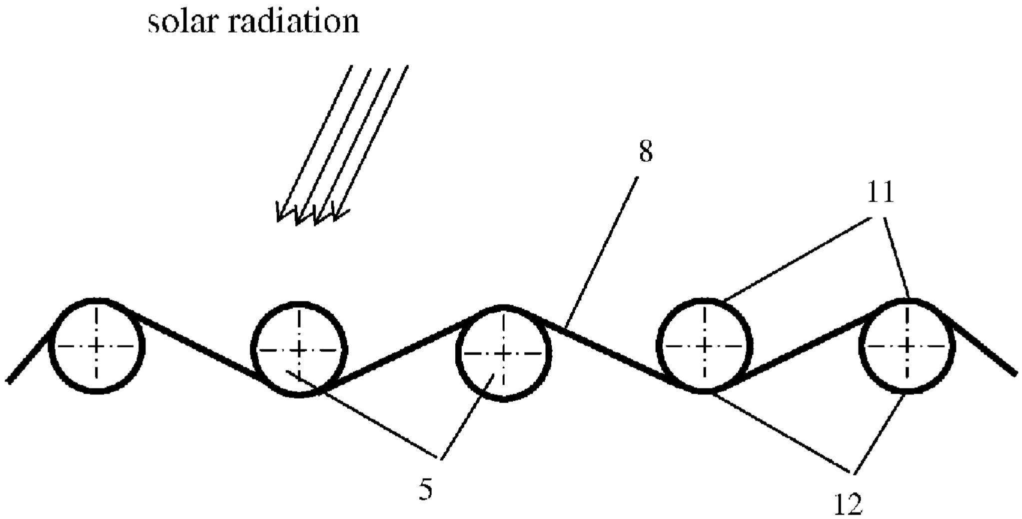


FIG. 1A

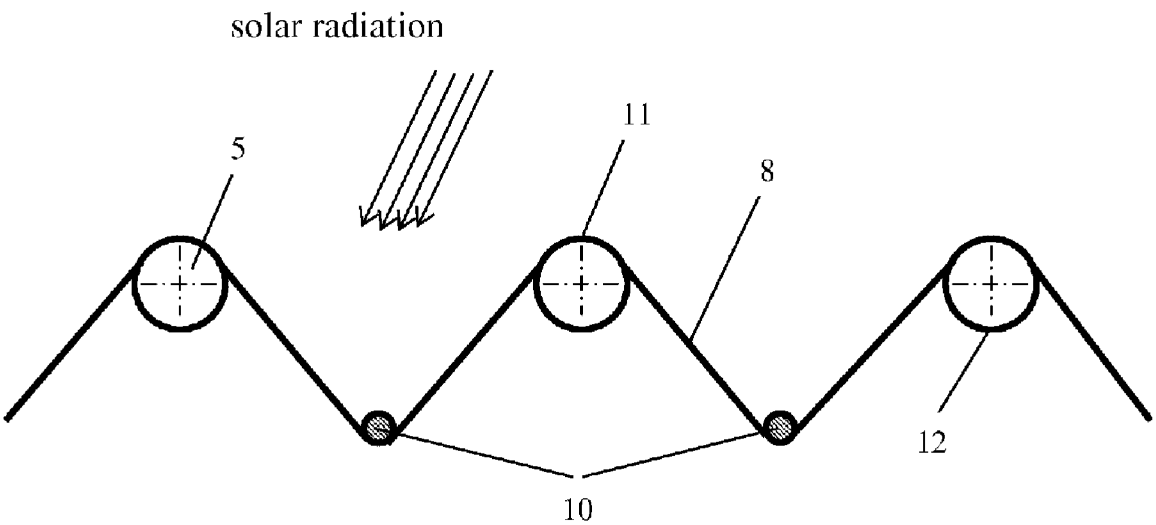


FIG. 1B

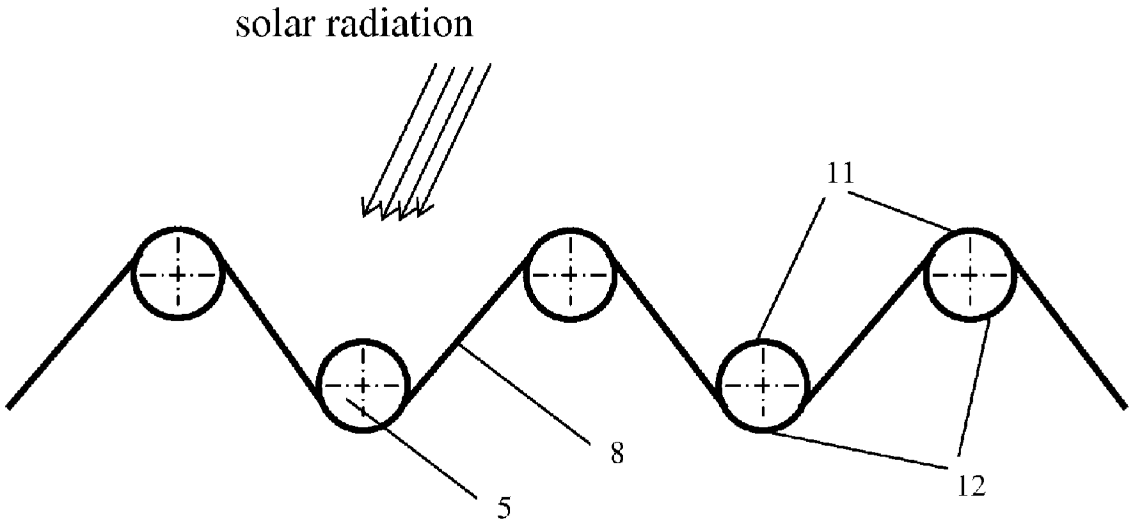


FIG. 2A

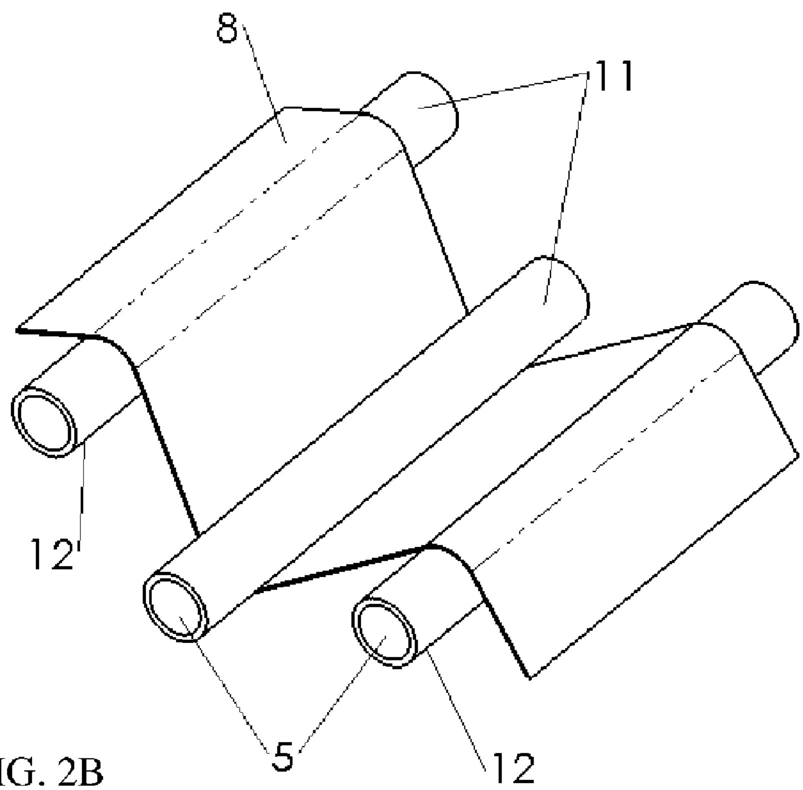


FIG. 2B

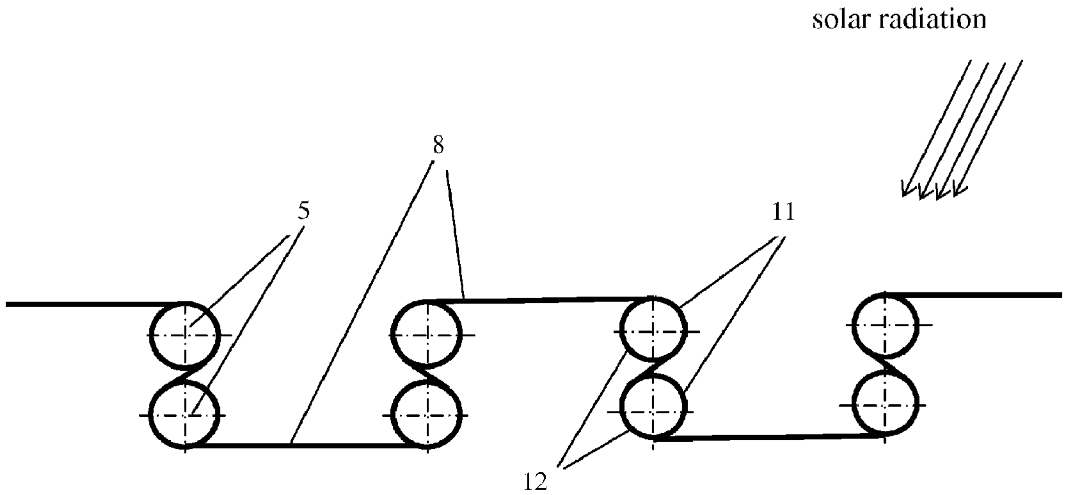


FIG. 3A

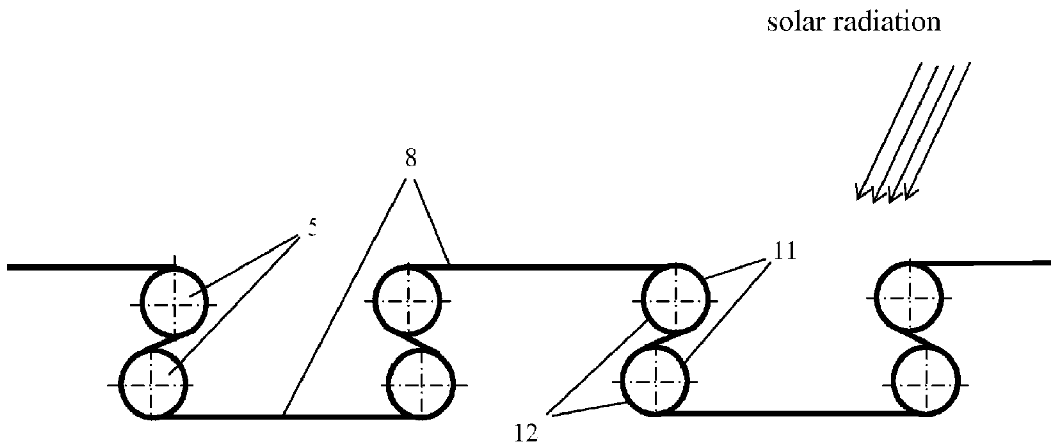


FIG. 3B

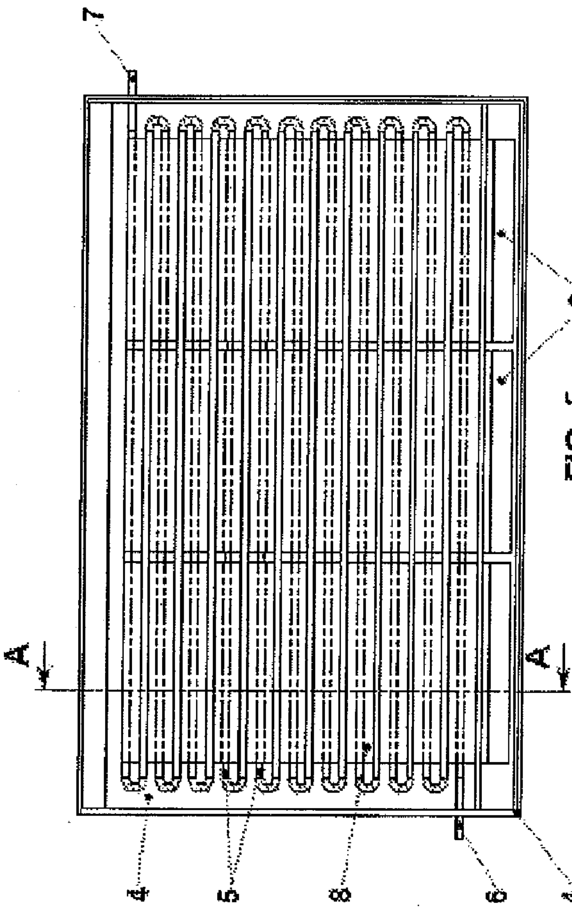


FIG. 5

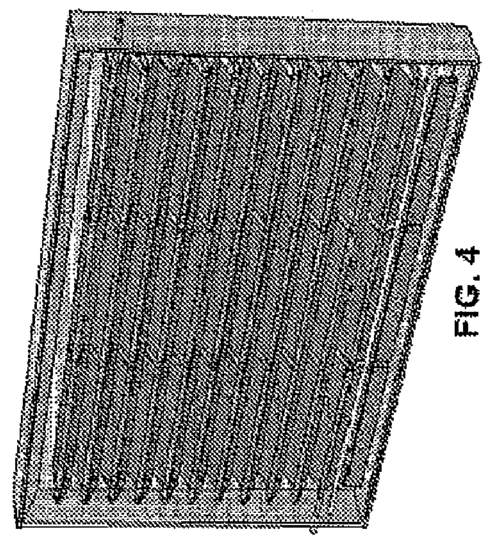


FIG. 4

A-A

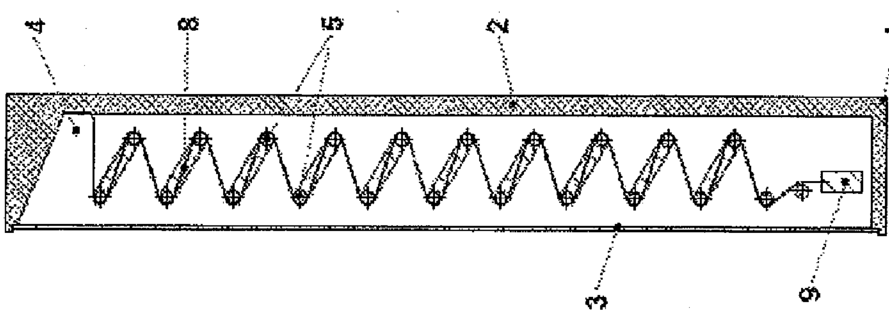


FIG. 6

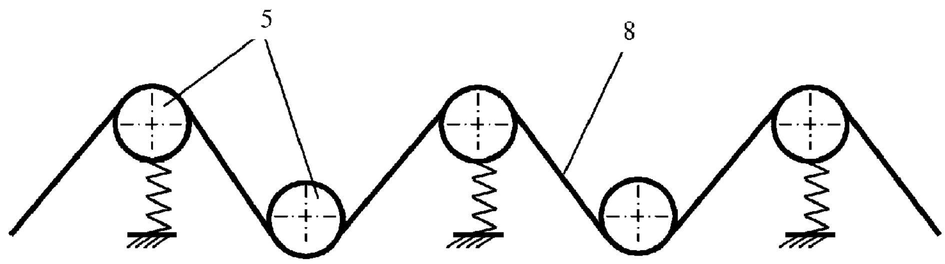


FIG. 7A

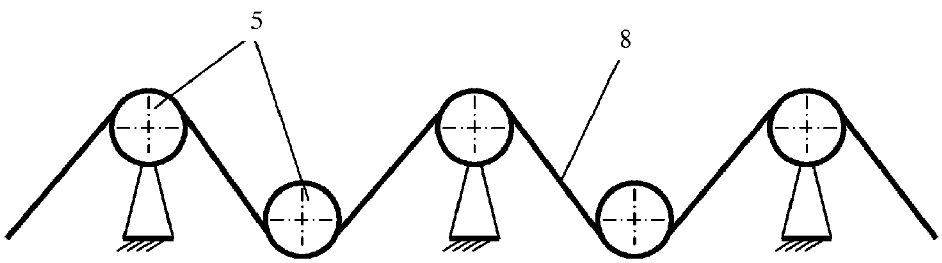


FIG. 7B

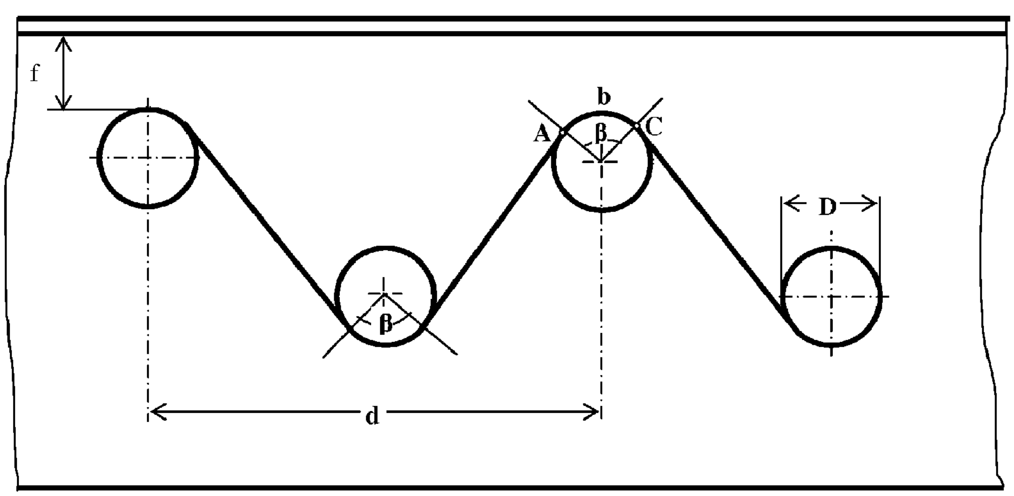


FIG. 8

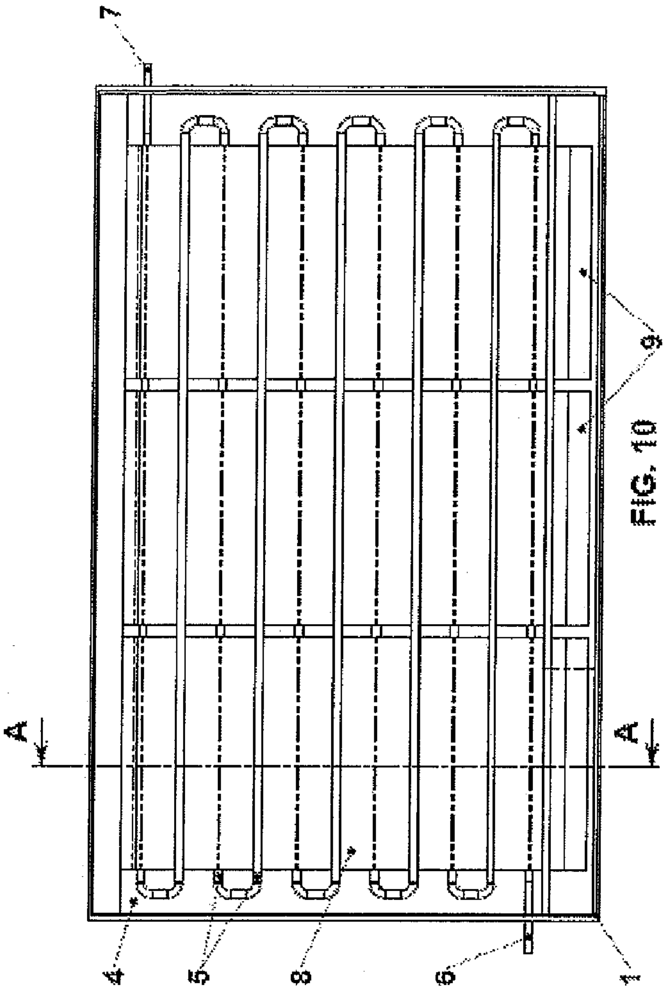


FIG. 10

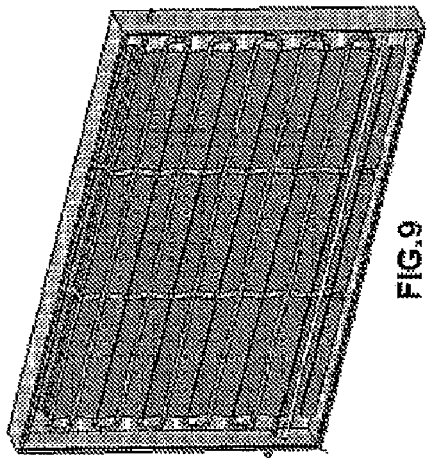


FIG. 9

A-A

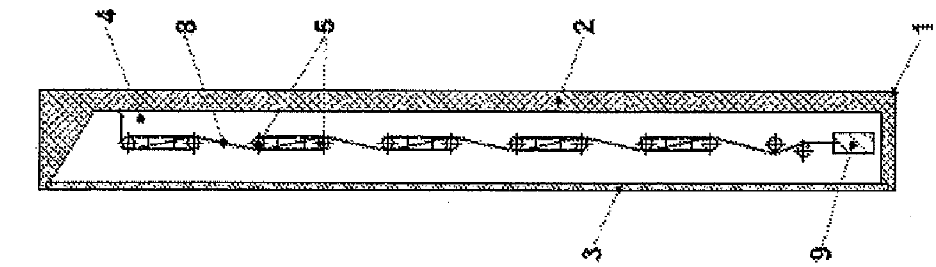


FIG. 11

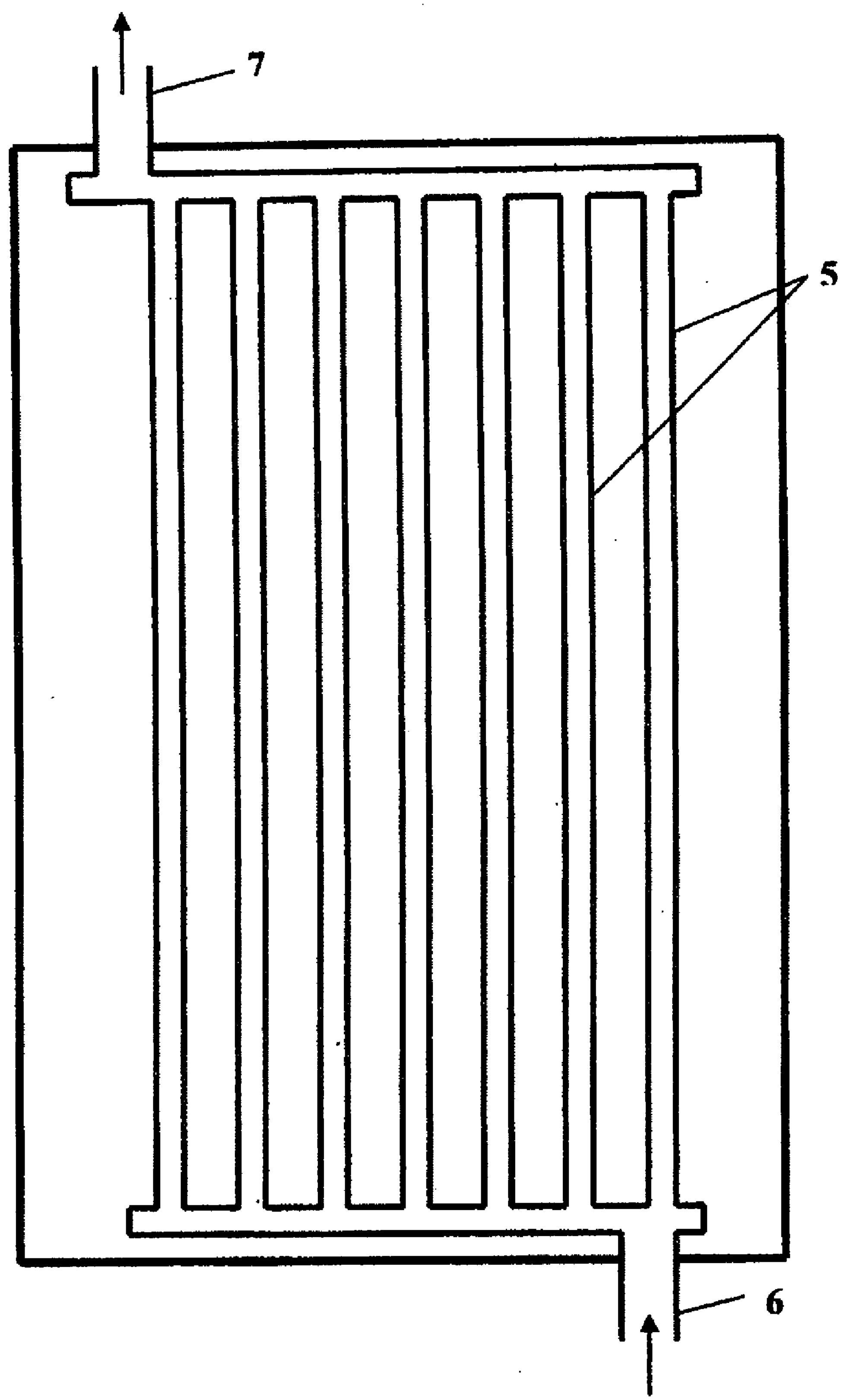


FIG. 12

SOLAR COLLECTOR WITH FOIL ABSORBER

DEFINITIONS

[0001] In the present specification and claims the following definitions apply:

[0002] Solar collector—a device that absorbs solar radiation and converts it into heat.

[0003] Absorber plate—an element of the solar collector responsible for absorbing solar radiation.

[0004] Absorptivity—a capability of a body to absorb radiant energy.

[0005] Emissivity—a capability of a body to emit radiant energy.

[0006] Absorptance—a ratio of the radiation absorbed by a surface to the total energy falling on that surface; a quantitative measure of absorptivity.

[0007] Emittance—a ratio of the radiation emmited by a surface to the total energy falling on that surface; a quantitative measure of emissivity.

[0008] Selective absorber surface (or simply, selective surface)—a specially adapted surface that has high radiation absorptance in a range of solar radiation wavelength and low thermal emittance in a range of thermal infrared wavelength of the electromagnetic spectrum. Quantitatively selectivity of the surface can be expressed by a ratio of absorptance to emittance.

[0009] Flexible metallic foil—a foil or sheet having a thickness not more than 0.2 mm.

[0010] Heat-transfer fluid—a fluid capable of storing heat absorbed at one or more locations and of transferring absorbed heat at one or more other locations.

BACKGROUND OF THE INVENTION

[0011] Apparatus for utilization of solar energy, usually called solar collector, is a device used to capture energy from the sun in the form of radiation and to convert this radiation into heat or other type of energy, which can in turn be utilized for various purposes. Solar collector comprises basically: 1) an absorber plate which, as the term implies, is intended to absorb the sun energy and transform it to heat, and 2) tubes adapted to contain a heat-transfer fluid.

[0012] Absorber plate of solar collector is usually housed within a thermally insulated flat chamber having a solar window of glass or plastic. The surface of the absorber plate, which faces the direction of solar radiation (i.e., the sun), is painted or treated to produce a blackened surface for radiation absorption. After solar radiation is absorbed, the absorbed heat must be transferred from the absorber plate to a heat-transfer fluid, which is generally pumped through a heat-conductive conduit (system of tubes) disposed in the interior of the solar collector chamber.

[0013] In order to provide an efficient heat-transfer from the absorber plate to the heat-transfer fluid in the tubes it is required that the absorber plate be capable to absorb maximum of solar radiation falling thereon, and transform the absorbed radiation into a heat with minimal losses.

[0014] In other words the absorber plate surface must be selective, i.e. have a high value of absorptance in the solar radiation wavelength range and a low value of emittance in the thermal infrared radiation wavelength range to minimize re-radiation losses.

[0015] In order to produce an absorber plate with selective surface, the surface of the plate is painted with fluorescent colorants. Alternatively, the materials exhibiting high values of selectivity are deposited onto the surface of the absorber plate. To transform the absorbed heat from the absorber plate to the tubes an efficient thermal-conduction contact between the plate and the tubes is required. Such contact is usually attained by creating special joints between the absorber plate and the tubes, for example, by soldering, welding or cladding. To produce heat conductive joints the materials of the absorber plate (e.g. aluminum) and the tubes (e.g. copper) are metallurgically fused together, resulting in the molecular bonding of both the plate and the tube materials.

[0016] Achieving the desired joint fusion such as where a thin fin joins a relatively thicker wall tube, is difficult and often relies on special joint design and use of multiple weld passes. U.S. Pat. No. 4,362,921 (Rudd) describes a method of welding a planar solar panel element to a tube using high-frequency electric currents wherein the tubing is formed with a pair of abutting lips to facilitate the welding process. U.S. Pat. No. 3,999,029 (Orr) also describes a process of welding a fin to a tube using high-frequency electrical resistance heating, facilitating the welding by first deforming the tube.

[0017] High energy density welding methods such as electron beam welding and laser welding have been used with consistent energy absorption by achieving high depth-to-width aspect ratio welds. These methods generally utilize keyhole melting and do not require joint preparation and back fill. However, when these methods are used for higher aspect ratio welds, there are increased chances for cold shut voids, root porosity, other root defects and missed joints. Milewski et al. (U.S. Pat. No. 5,760,365) describe a method to overcome problems associated with high depth-to-width aspect ratio welds wherein the weld joint is considered as an optical element and an optical ray tracing technique is used to model a laser beam and join geometry of a weld. The method provides a complex modeling technique to optimize welding parameters.

[0018] Reichert et al in EP 1,217,315 and US 2002/0073988 disclose a solar collector element having an absorber part and a tube for a heat-transfer fluid connected thereto on a first side. The absorber part consists of a composite material having a metallic substrate and an optically active three-layer coating on a second side of the substrate.

[0019] The contact between the absorber part and the tube is performed by means of a material-to-material laser welded bond which bond can be formed by a pulse welding process. In one of the embodiments, the bottom layer of the optically active (i.e. selective) three-layer coating is applied by sputtering, while the tube and the absorber part are joined where they are in abutment with one another by weld seams running on both sides of the tube and are formed from weld spots which are spaced apart from one another.

[0020] U.S. Pat. No. 6,300,591 (Fuerschbach, et al.) teaches a method of laser welding a metal fin of solar collector to a tube which method comprises, placing the metal fin into approximate contact with the metal tube to form a juncture area to be welded. The fin and the tube thereby form an acute angle of contact and focus a laser beam through that angle of contact at the juncture area to be welded. The laser beam heating the juncture area to a welding temperature thereby causes welding to occur between the fin and the tube. According to the invention both the fin and the tube are made of aluminum or copper.

[0021] Designs of solar collector which do not involve a molecular-bonding joint between the absorber plate (fin) and the tubes are also known in the prior art.

[0022] Van der Aa in U.S. Pat. No. 4,416,261 teaches a solar collector comprising an absorber plate which exchanges heat with the evaporator section of a heat pipe. In the disclosed design the absorber plate merely surrounds the surface of the tube, i.e., the absorber plate and the tube are thermally-conductively connected.

[0023] Rabedeaux in U.S. Pat. No. 4,290,419 discloses a solar collector unit which, according to the inventor, utilizes energy from radiation, conduction and convection. Said unit is a chamber which is thermally insulated from the surrounding atmosphere. The chamber comprises a plurality of contiguous serpentine tube coils with a plurality of space fin elements along the entire tube length. The fins are positioned around the periphery of the tube. The surface of the tubes and fins exposed to the rays of the sun are painted with a black or a dark-green color. The chamber is filled with a pressurized dry gas such as oxygen, nitrogen or nitrous oxide. When the disclosed system is in operation, the solar rays impinge on the coated surfaces to absorb heat energy. As a consequence, the surfaces of the tube and fins, as well as the gas become heated, and the heat in the chamber causes turbulence in the gas, enhancing thereby heat transfer. The disclosed construction is rather complicate and may cause difficulties in its manufacturing; moreover the surface of the contact between the tubes and the fins is too small, therefore it is not clear in which way the conduction constituent contributes to the overall heat transfer.

[0024] Newman in U.S. Pat. No. 5,653,222 discloses a solar collector comprising a planar glazing and a rear housing formed into a number of semi-circular cells intended to receive a fin-tube absorber with minimal direct contact. Said absorber is preferably constructed of copper with a fin having a thickness of about 0.2 mm and a tube having a wall thickness of at least 0.5 mm.

[0025] Bloem in U.S. Pat. No. 4,491,175 discloses a solar collector in which a contact between the plate and the tube is implemented by pressing. In order to obtain suitable clamping, the plate and the tube are mounted in a special device which is rather complicate.

[0026] Quantitatively, an efficiency of the solar collector can be assessed by an efficiency factor, which, inter alia, includes a term, taking into account the resistance to heat transfer that arises if the tubes are not adequately contacted with the plate. This term is usually designated as 1/C, wherein C is a conductance of the contact. The value of C considerably influences on the efficiency factor. As shown by Whiller (Austin Whiller, Design Factors Influencing Solar Collector Performance, In: Low Temperature Engineering Application of Solar Energy, published by the American Society of heating, Refrigerating and Air-Conditioning Engineers, 1967, p. 37) an increase of C-value from 3.5 to 35 W/m/K raises the efficiency factor by no less than 30%. According to Whiller the methods known in the prior art can assure bondless tube-and-plate contacts with C-value not more than 9 W/m/K. This value is rather small compared to tube-and-plate contacts employing molecular-bonding (50÷100 W/m/K).

[0027] Unlike the foregoing prior art, in the apparatus of the present invention absorber plate is designed as a flexible metal foil which bondlessly contacts with the tubes, i.e. no molecular-bonding joint is involved in the contact. More specifically, a contact between the foil and each tube is maintained by tension effective to stretch the foil over the tubes. A heat-transfer between the foil and each tube takes place by a heat conduction mechanism through a physical contact between the tube and the foil, as well as through a narrow air gap between them. Unlike conventional plate-and-tube contacts, the foil-and-tube contact of the present invention can assure C-values of about 150 W/m/K and even more, that corresponds to collector efficiency factor of more than 0.8 (evaluated by the foregoing method of Whiller). However, these high C-values (and, respectively, the values of efficiency factor) can be attained, if a length of the wrap arc (designated as AbC on FIG. **8**) is about 4 mm or more.

[0028] It is an object of the present invention to provide a simple cost-saving apparatus for utilization of solar energy which ensures an efficient heat transfer between the absorber plate and the tubes, and which construction does not employ molecular-bond contacts between the absorber plate and the tubes, thus resulting in easy maintenance, repair and renewal, and which is not a subject to warping at elevated temperatures (unlike the thermal methods employing welding and soldering).

[0029] Other objects, features and advantages of the present invention will become more apparent upon a reading of detailed description.

SUMMARY OF THE INVENTION

[0030] The present invention provides an apparatus for utilization of solar energy which comprises a collector device and a heat-transfer device. The latter comprises one or more heat conductive conduits for heat-transfer fluid, which conduit(s) is (are) at least partially in physical contact with the collector device, which is characterized by the following features:

[0031] (1) it comprises one or more flexible metallic foils of which at least one side is adapted for exposure to solar radiation by the presence thereon of a heat absorptive coating; and

[0032] (2) the physical contact is maintained by tension effective to stretch said flexible metallic foil(s) over said conduit(s).

[0033] The foil-and-tube contact employed in the apparatus of the present invention is a bondless one, that is, no molecular bonding of both the foil material and the tube material is involved in the process of producing this contact. The tension which stretches the foil(s) over the conduit(s) is implemented by tension devices, such as springs, weights and/or their combinations. The tubes can be arranged in a single plane (FIG. **1**), or in two planes (FIGS. **2** and **3**). The foils(s) wrap(s) the tubes at wrap angles, preferably, between 10 degrees and 60 degrees (FIGS. **1** and **2**), or preferably, at a wrap angle about 180 degrees (FIG. **3**).

[0034] The heat conductive conduit can comprise one tube, or a plurality of tubes, in the latter case the tubes can be adapted for serial or parallel transport of the heat-transfer fluid.

[0035] Said high absorptivity coating has preferably a thickness of 100 nm to 1000 nm and can be applied by vacuum deposition methods, e.g. flash evaporation, or electron-beam evaporation. Preferably the deposited high absorptivity coating comprises a mixture of aluminum and alumina and also exhibits low emissivity. This coating can have constant (non-variable along the surface) emittance ϵ and absorptance α values, or alternatively the values of ϵ and α can vary along the surface of the absorber plate in a regular manner. It is known to everybody skilled in the art, that an ideal selective surface has absorptance $\alpha=1$ and emittance $\epsilon=0$, however these values of α and ϵ can not be reached, since usually the nature of the surfaces is that the higher absorptance, the higher emittance. This means, that in practice we have to sacrifice either high absorptance, or low emittance, when searching a compromise solution. For example, at the present time the selective surfaces available in the market of solar collectors have ϵ about 0.07 and α about 0.95.

[0036] In major designs of solar collectors the temperature of the heat-transfer fluid varies along the height of the absorber plate (temperature gradient); more specifically, the temperature is less in the lower locations and higher in the upper locations. This result follows from the circulation of the heat-transfer liquid within the solar heating system, based on the principle called natural thermo-syphon. Besides solar collector the solar heating system also includes a tank for storage of heat-transfer fluid. When the absorber plate (which in the present invention is performed as foil) transfers a part of its energy to the water in the tubes, the water gets heated. The heated water becomes lighter, and hence rises to the storage tank thus bringing in fresh cold water to the tubes. This cold water receives heat from the absorber plate (foil) and rises, and the process continues in a similar manner.

[0037] In the case of higher foil temperatures, when heat-transfer fluids with boiling temperatures more than 100° C. (e.g. ethyleneglycole) are used, significant temperature gradient is observed. If a conventional selective surface with ϵ-values about 0.07 is used, the radiation heat losses in the surface locations with high temperatures will increase. In such a case a use of the absorber surface with distinct values of ϵ and α at different locations (horizontal levels) of the absorber surface can be efficient.

[0038] In the present invention the problem is solved by decreasing emittance ϵ in the upper locations which have a relatively high temperature (and therefore higher emissivity) to a value about 0.04, while sacrificing the absorptance ($\alpha\approx0.90$) in upper locations only. From the other side, in the lower locations, where the temperature is less, and radiation heat losses are not significant, we can afford rather high emmitance ($\epsilon\approx0.20$), because the emmisivity at low temperatures is very small. This allows attaining very high absorptance in the lower locations ($\alpha\approx0.99$). Thus, the use of the absorber surface with different values of α and ϵ at different locations allows to optimize the absorptivity/emmisivity characteristics and to reduce radiation losses.

[0039] As flexible metal foil aluminum, aluminum alloy, or cooper can be used. Since, the foil is intended to be stretched over the tubes, the preferable material for the foil is aluminum alloy with a value of ultimate tensile strength greater than 180 MPa. From the other side, the stretched foil must assure tight foil-and-tube contact. Therefore, among latter alloys, more preferable are those that have undergone a thermal treatment to reduce their hardness (the so called 'dead soft' alloys, usually designated by the temper 'O'). Examples of 'dead soft' alloys are 2014 temper O, 3004 temper O, and others. Among said 'dead soft' alloys yet more preferable are those that are characterized by the value of Brinell hardness between 45 and 55. The preferable foil thickness used in the present invention is 40 to 200 μm.

BRIEF DESCRIPTION OF THE DRAWINGS

[0040] In this section the term 'tube-and-foil configuration' means a way of arrangement of the conduit tubes and disposing the foil therebetween.

[0041] FIG. **1** is a schematic illustration (cross-sectional view) of a design with a single-plane tube-and-foil configuration without tension bars (FIG. **1**A) and with tension bars (FIG. **1**B).

[0042] FIG. **2** is a schematic illustration of a design with two-plane tube-and-foil configuration (FIG. **2**A is a cross-sectional view, and FIG. **2**B is a perspective view).

[0043] FIG. **3** is a schematic illustration (cross-sectional view) of other two-plane tube-and-foil configurations.

[0044] FIG. **4** is a perspective view of the apparatus and tube-and-foil configuration therein according to the first embodiment.

[0045] FIG. **5** is a top-plan view of the apparatus and tube-and-foil configuration therein according to the first embodiment.

[0046] FIG. **6** is a cross-sectional view of the apparatus and tube-and-foil configuration therein, taken through line A-A of FIG. **5**.

[0047] FIG. **7** is a schematic illustration of the tube supports in the apparatus (FIG. **7**A—fixed support, FIG. **7**B—spring support).

[0048] FIG. **8** is an illustration of a geometric design of the apparatus according to the first preferred embodiment.

[0049] FIG. **9** is a perspective view of the apparatus and tube-and-foil configuration therein according to the second embodiment.

[0050] FIG. **10** is a top-plan view of the apparatus and tube-and-foil configuration therein according to the second embodiment.

[0051] FIG. **11** is a cross-sectional view of the apparatus and tube-and-foil configuration therein, taken through line A-A of FIG. **10**.

[0052] FIG. **12** is a schematic illustration of a manifold-type conduit.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0053] Although the present invention will be described in detail with reference to the examples of the apparatus design, the invention is not limited to these examples.

[0054] The apparatus of the present invention differs from those of the prior art by using a thin metal foil, or foils, which replaces the absorber plate of conventional solar collector, and by a method of creating a contact between the foil and the tubes. The term 'foil' used in the following description refers as well as to a single foil, and to more than one foil.

[0055] The foil-and-tube contact, employed in the apparatus of the present invention, is a tight bondless physical contact, which is maintained by tension effective to stretch the foil over the tubes. As tension device a weight, a spring, and/or their combination can be used. In some modes tension-maintaining bars are also used. Various embodiments of the invention differ one from another by a layout of the tubes in the apparatus chamber, by method of disposing the foil between the tubes, and by employing various tension devices as well. The tubes (position **5** on the figures) can be arranged in one plane as depicted on FIGS. **1**A and **1**B or in two planes as depicted on FIGS. **2** and **3**. The foil (position **8** on the figures) can be placed so as to contact alternately with the tubes at a location facing the direction of solar radiation **11** and at a location not facing the direction of solar radiation **12** (FIGS. **1**A and **2**). Alternatively, the foil can be placed between the tubes as shown on FIG. **3**. Further the foil can be placed similar to the design, depicted on FIG. **2**A, with the difference that the tubes of one plane are replaced with tension-maintaining bars **10** (FIG. **1**B). It is highly desirable that the tension-maintaining bars are made of low thermal conductivity material.

[0056] FIGS. **4** to **6** describe apparatus according to the first preferred embodiment of the invention.

[0057] As can be seen by reference to FIGS. **4** to **6** the apparatus, according to the first embodiment, comprises a deep framework **1** fabricated from metal, fiber or similar material. The bottom and sides of the framework **1** are covered with insulation material **2** of a sufficient depth to thermally insulate the interior of the absorber from the surrounding framework. A pane of clear glass **3** serves as a cover for the absorber, and together with framework **1** form chamber **4**. Chamber **4** contains a conduit with contiguous serpentine coil-tubes **5** arranged in two planes, defined as upper (nearest to the direction of solar radiation) and lower (furthest from the direction of solar radiation). The tubes in the lower plane are disposed in a staggered manner in relation to the tubes in the upper plane. The conduit begins at inlet **6** and ends at outlet **7**. Tube coils **5** are surrounded by at least one metal foil **8**, of which at least one side is adapted for exposure to solar radiation by the presence thereon of a heat absorbtive coating. Preferably, the foil is made of aluminum, aluminum alloy, or cooper. A width of each foil is preferably between 10 and 30 cm, but wider foils can be also used. A contact between each foil and the tubes is in a manner which alternates between a location on the tubes not facing the direction of solar radiation and that facing the direction of solar radiation. Thus each foil has a zigzag-like profile. Locations on the tubes which are not in contact with the foil(s) are painted with black. A tightness of the contact between the tubes and the foil is maintained by tension effective to stretch the foil over the tubes. The tension can be effected by springs, weights (if working position of the solar collector is such, that tubes **5** are disposed horizontally), or their combinations.

[0058] In order to prevent sagging of tubes **5** a support (or a number of supports), which is (are) installed beneath the tubes can be employed (FIGS. **7**, A and B). The number of supports is kept to a minimum necessary to maintain the operation of the apparatus. It is mandatory to manufacture the support(s) of a low thermal conductivity material, for example, ceramic.

[0059] When apparatus servicing (e.g. maintenance, repair or renewal) is required, the tension of the foil can be loosen and the support(s) can be easily removed, thereby removing the contact between the foil and the tubes. After service operations are completed, the contact can be easily renewed. In this sense foil-and-tube contact employed in the present invention can be named reversible.

[0060] Tubes **5** in chamber **4** can be adapted for serial or parallel transport of heat-transfer fluid and can be arranged in longitudinal direction or inversely. The tubes, prior to be mounted in the camber, can be polished from the outer surface to obtain an improved thermal conductivity contact between the tubes and the plate. Additionally to, or instead of the polishing, the thermal conductivity contact can be improved by applying a thermal conductive material onto those tube locations, which are intended to contact with the foil. It is mandatory that this material fills up voids caused by a roughness of the tube surface and a roughness of the foil surface.

[0061] All the foregoing features can be combined in various combinations thereby producing a plurality of modes of the first preferred embodiment.

[0062] Main geometric characteristics of the design of the apparatus according first preferred embodiment are as follows (FIG. **8**): d—a distance between the axes of two neighbor tubes belonging to the same plane, β—a wrap angle, D—an outer diameter of the tube, and f—a distance between the conduit and the absorber cover. Preferable values of these parameters are as follows: d is 20 to 25 cm, β is 10 to 60 degrees, D is 8 to 20 mm, and f is 9 to 11 cm.

[0063] FIGS. **9** to **11** describe the second preferred embodiment of the invention.

[0064] As can be seen by reference to FIGS. **9** to **11** the apparatus, designed according to the second embodiment, comprises same elements as solar collector of the first embodiment, with the difference that the tubes are arranged in a single plane, and the foil contacts alternately the tubes belonging to the same plane (unlike the apparatus of the first preferred embodiment, where the foil alternately contacts the tubes belonging to the upper plane and the lower plane).

[0065] According to the third embodiment of the invention the solar collector tubes have a 'crankshaft'-like arrangement (FIG. **3**). In this arrangement the tubes are disposed in two planes, the upper and the lower. The foil-and-tube system can be considered as consisting of repeating elements, each of them comprising four tubes (two tubes in the upper plane and two tubes in the lower one) and a foil, disposed between the tubes. In each of the foregoing elements the foil is disposed in the following way: firstly it contacts the first tube of the upper plane at tube location facing the direction of solar radiation, then it subsequently contacts the two tubes of the lower plane at tube location not facing the direction of solar radiation, and finally the foil contacts the fourth tube at tube location facing the direction of solar radiation. The foregoing foil-and-tube configuration permits to attain the wrap angle value of about 180 degrees, which corresponds to the value of wrap arc length of about π D/2.

[0066] It can be appreciated by a person skilled in the art that the second and the third preferred embodiments of the invention can comprise features described in the first embodiment, e.g. longitudinal or transverse direction of the tubes in the chamber, use thermal conductive material at the foil-and-tube contact, tube polishing, supports and tension members, etc.

[0067] The three foregoing embodiments may have a variety of modes. In one of them a manifold-like conduit instead of the conduit with serpentine coil tubes is employed (FIG. **12**). Similar to the conduit with serpentine coil tubes the tubes of the manifold-like conduit can be arranged in a single plane or in two planes. In another mode glass pane **3** is replaced by two spaced glass panes, having between them a sealed and evacuated space. Such design is intended to improve a thermal insulation of chamber **4** from the surrounding atmosphere, albeit it may increase a production cost.

[0068] It should be noted that only the preferred embodiments of the invention have been disclosed, and the scope of the invention is not limited to any one particular shape, size, configuration, or material.

[0069] It is contemplated that various modifications of the described modes and embodiments of carrying out the invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention.

1. An apparatus for utilization of solar energy which comprises a collector device and a heat-transfer device which includes at least one heat conductive conduit for heat-transfer fluid, the conduit being at least partially in physical contact with said collector device, characterized in that:

(A) said collector device comprises at least one flexible metallic foil of which at least one side is adapted for exposure to solar radiation by the presence thereon of a heat absorptive coating; and

(B) said physical contact is maintained by tension effective to stretch said at least one foil over said at least one conduit.

2. The apparatus according to claim **1**, which is further characterized by at least one of the following features:

(a) said at least one conduit comprises a plurality of tubes adapted for serial or parallel transport of said heat-transfer fluid;

(b) said at least one foil is in contact with said at least one conduit at a wrap angle value between: 10 degrees to 60 degrees;

(c) said foil has a thickness in the range of 40 to 200 μm;

(d) said tension is produced by at least one device is selected from springs, weights and combinations thereof;

(e) said foil comprises aluminum or an aluminum alloy having preferably a value of ultimate tensile strength greater than 180 Mpa;

(f) said coating comprises at least one layer produced by vacuum deposition;

(g) said coating comprises a mixture of aluminum and alumina;

(h) said coating has a thickness of between 100 nm and 1000 nm.

3. The apparatus according to claim **2**, wherein said at least one conduit comprises a plurality of tubes adapted for serial or parallel transport of said heat-transfer fluid, and said plurality of tubes is configured as an array of tubes in one plane or in a plurality of substantially parallel planes.

4. The apparatus according to claim **3**, wherein part of said plurality of tubes is in contact with said foil at a location on said tubes not facing the direction of solar radiation.

5. The apparatus according to claim **3**, wherein said plurality of tubes is configured as an array of substantially parallel tubes in a single plane.

6. The apparatus according to claim **5**, wherein said tubes are in contact with said foil in a manner which alternates between a location on said tubes not facing the direction of solar radiation and a location on said tubes facing the direction of solar radiation.

7. The apparatus according to claim **3**, wherein said plurality of tubes is configured as an array of tubes in two substantially parallel planes, defined as an upper plane nearest to the direction of solar radiation and a lower plane furthest from the direction of solar radiation.

8. The apparatus according to claim **7**, wherein the tubes in each of said planes are arranged with spaces between the tubes, the tubes in the lower plane being so disposed in a staggered manner in relation to the tubes in the upper plane, such that the tubes in the lower plane are exposed to solar radiation penetrating the spaces between the tubes in the upper plane.

9. The apparatus according to claim **8**, wherein said tubes are in contact with said foil in a manner which alternates between a location on said tubes not facing the direction of solar radiation and a location on said tubes facing the direction of solar radiation.

10. The apparatus according to any one of claims **1** to **9** wherein said heat absorptive coating is characterized by different values of absorptance and emittance in the foil loci with different temperatures of heat-transfer fluid.

11. The apparatus according to claim **1**, substantially as hereinbefore described.

12. The apparatus according to claim **1**, substantially as hereinbefore described, with particular reference to and as illustrated in the accompanying drawings.

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