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(54) **SOLAR TROUGH AND RECEIVER**

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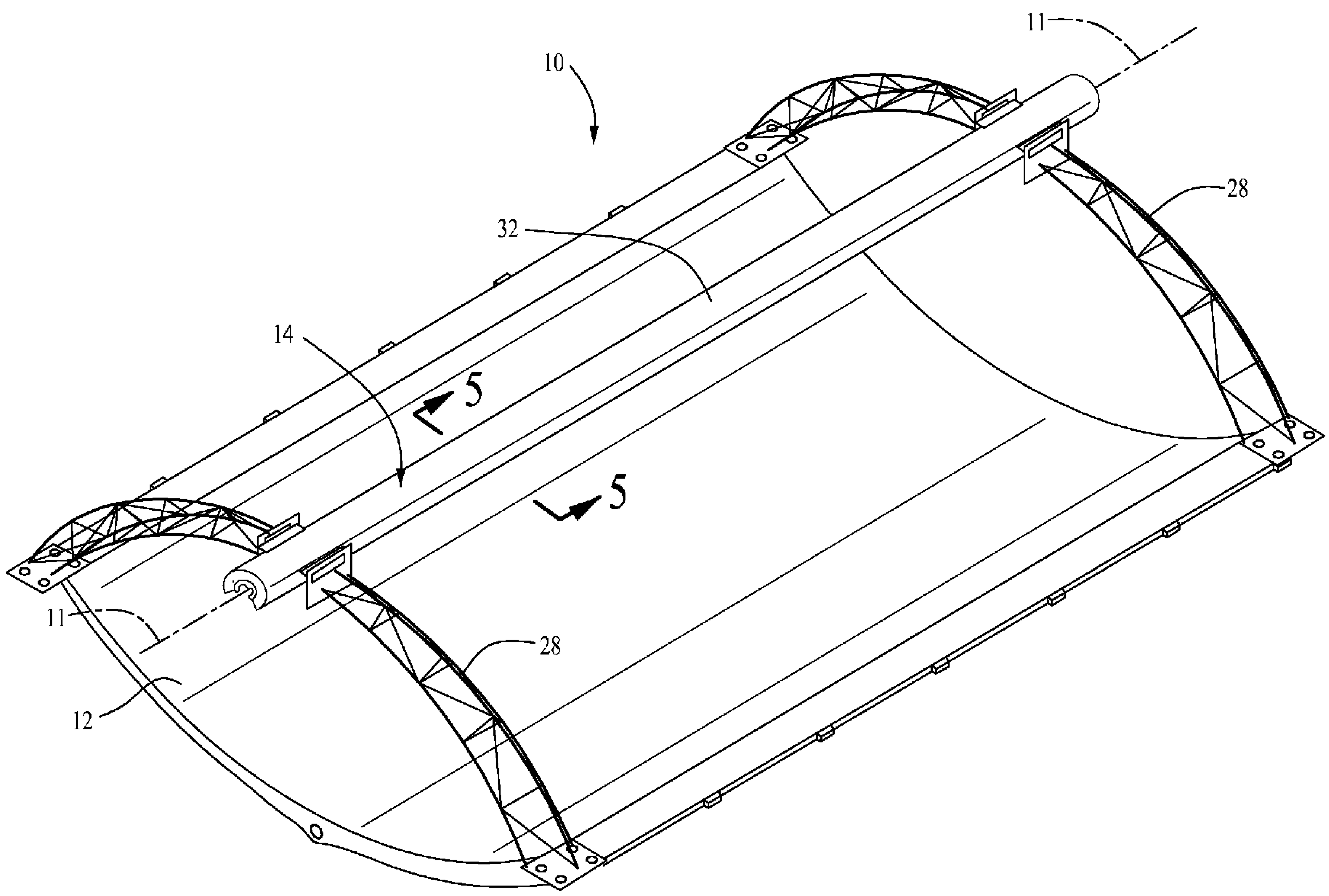
(57) **ABSTRACT**

A solar receiver unit comprises a generally tubular body having an internal passage for conducting a heat-transfer fluid, and an inlet chamber for receiving concentrated sunlight from a solar reflector when in use. The inlet chamber is shaped to direct reflection of concentrated sunlight at least one time in a direction that provides the reflected sunlight with an additional opportunity to heat the heat-transfer fluid.



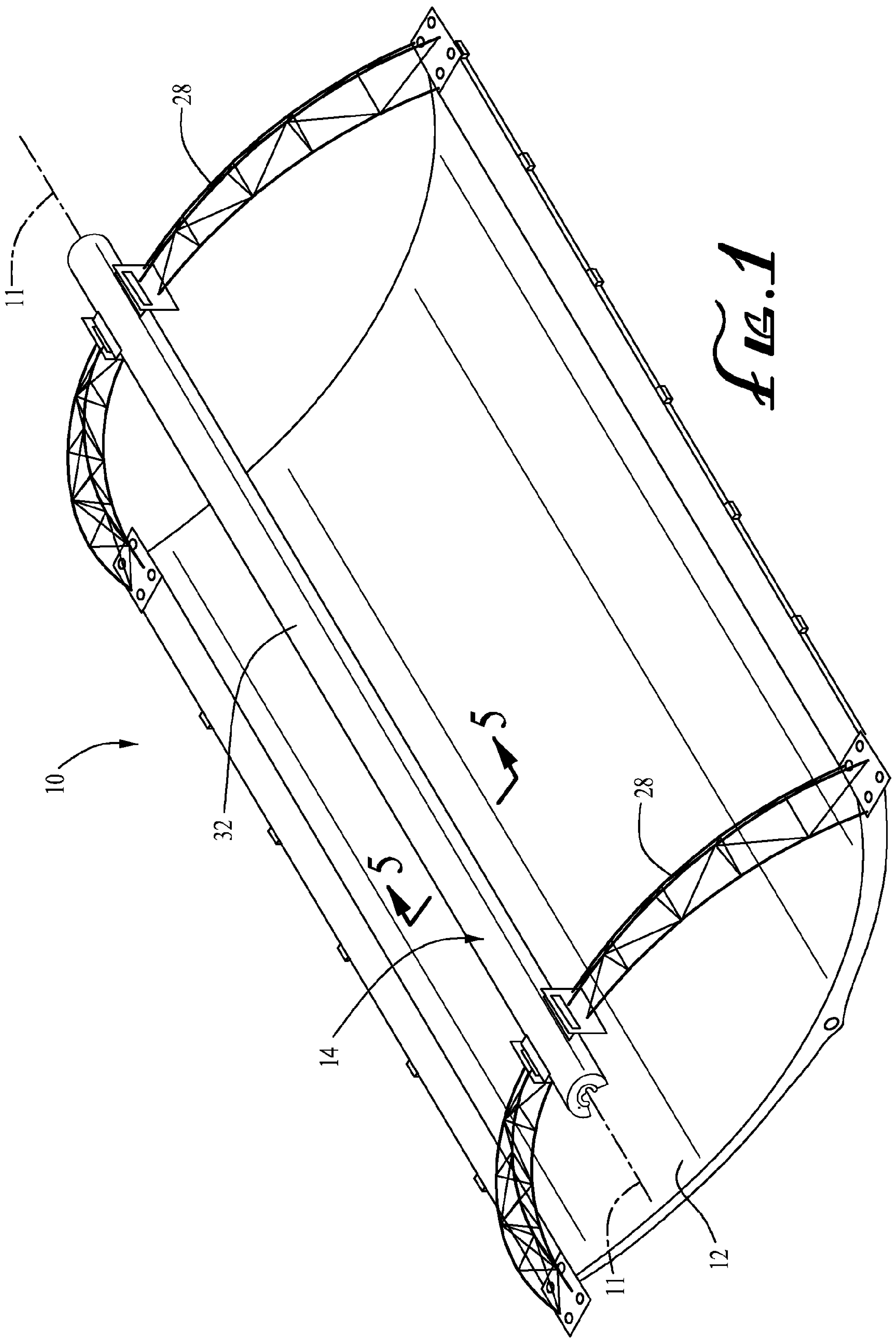


FIG. 1

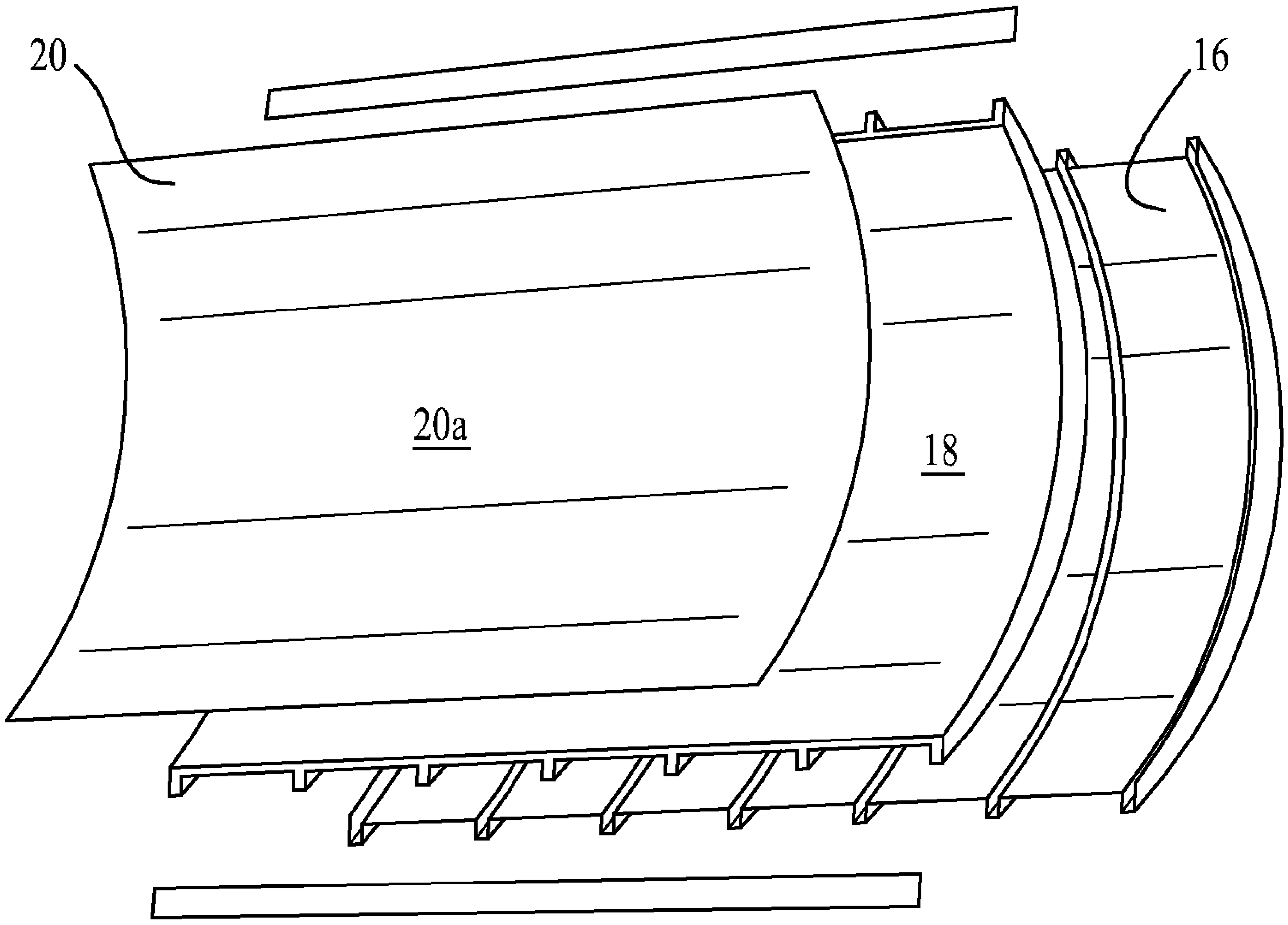


FIG. 2A

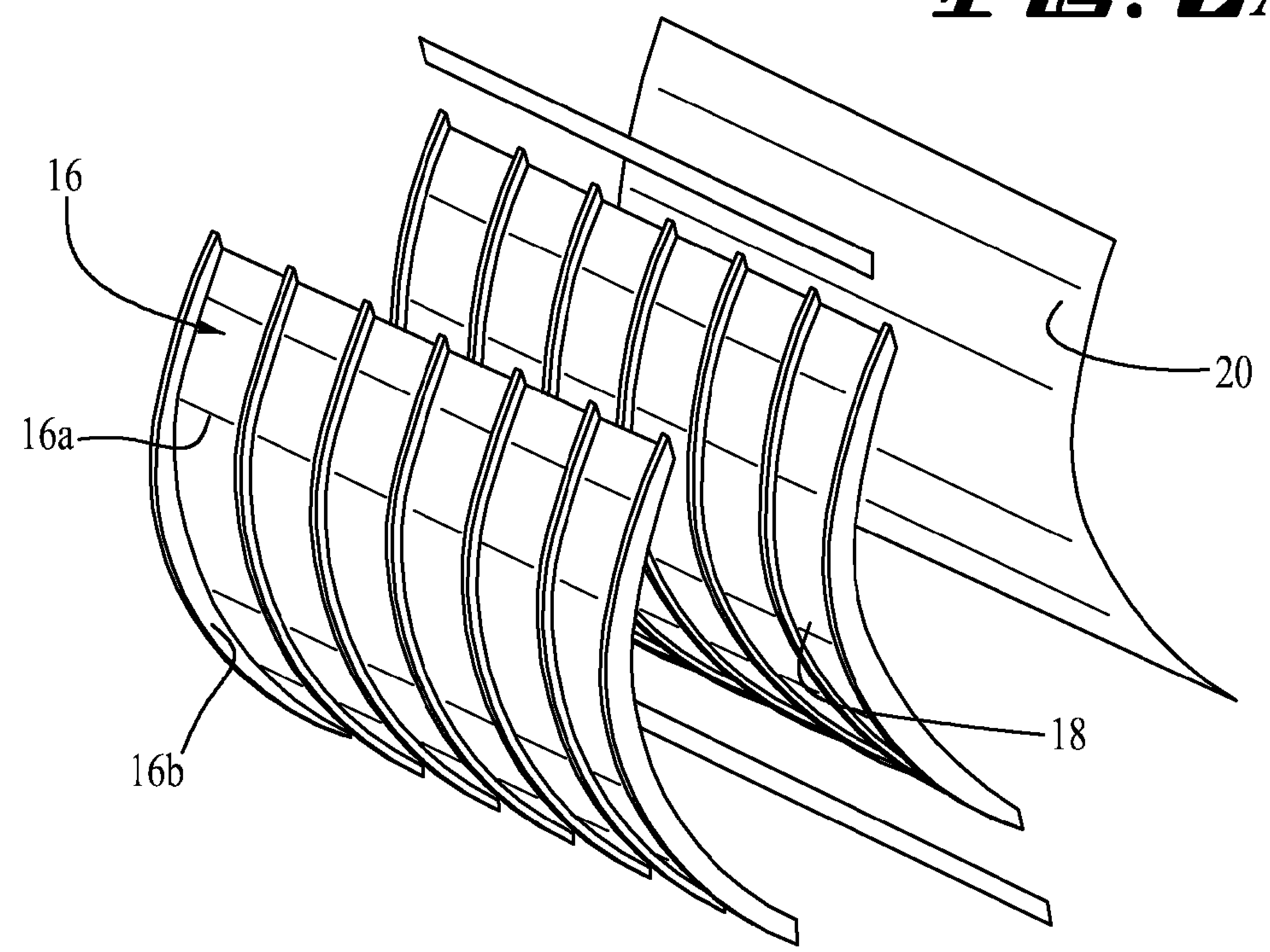


FIG. 2B

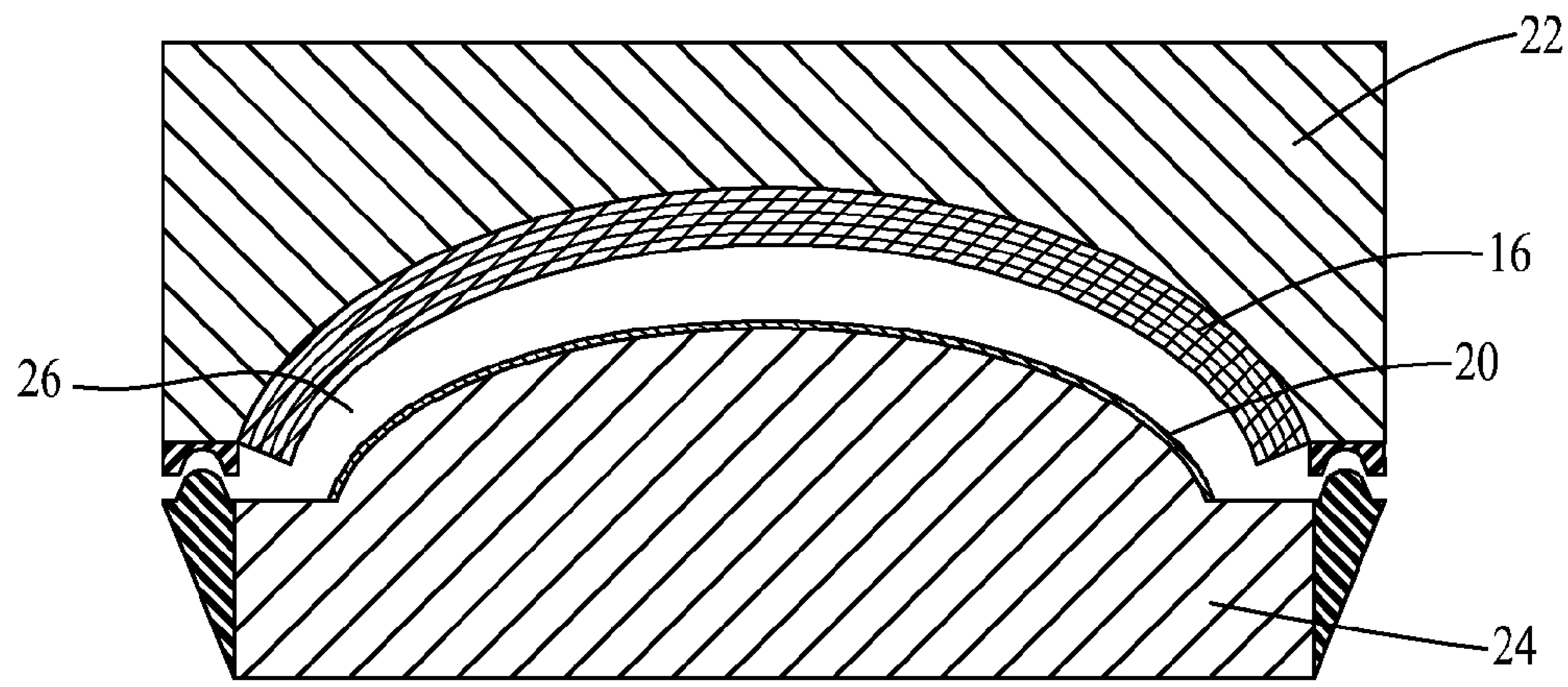


FIG. 3

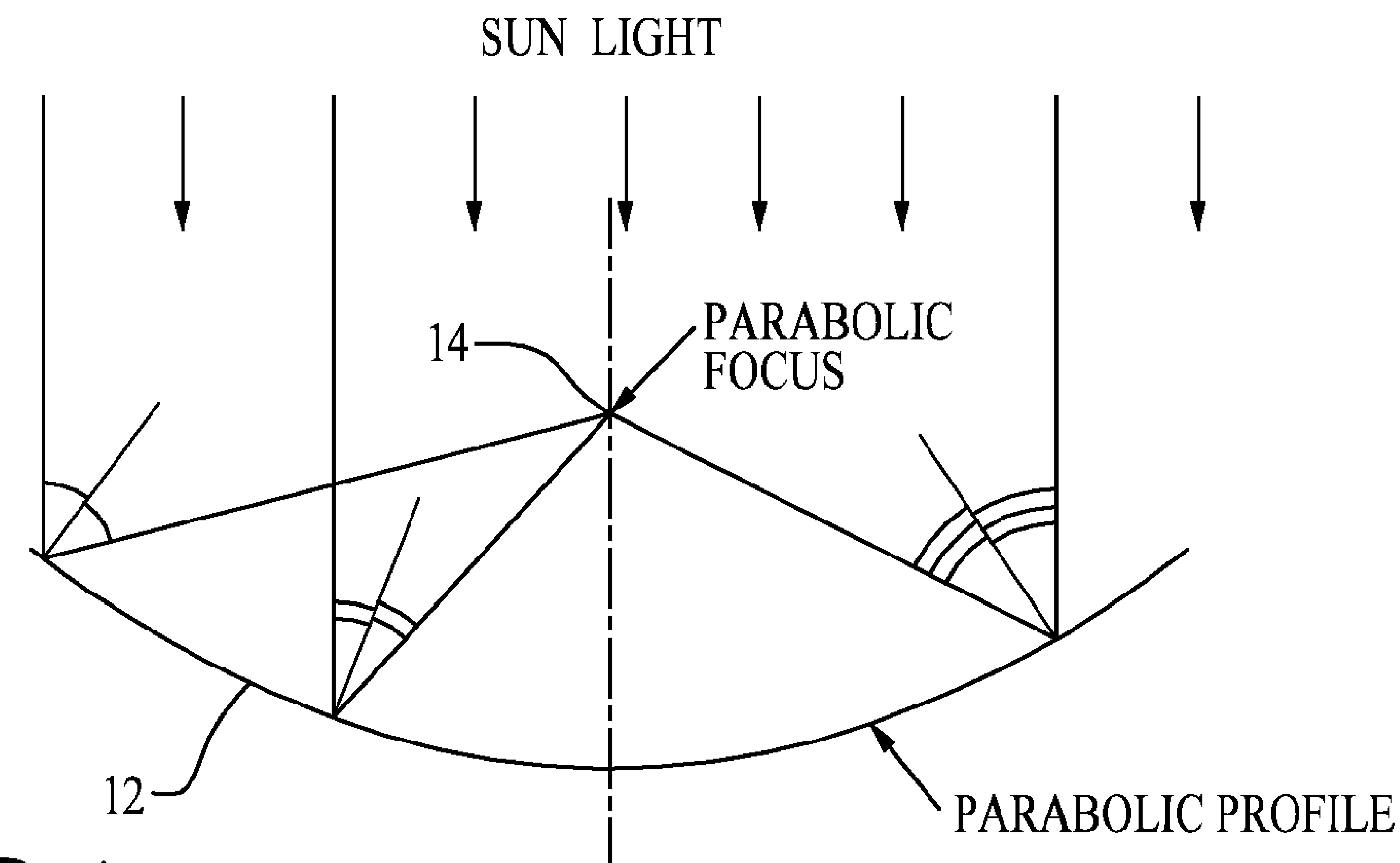


FIG. 4

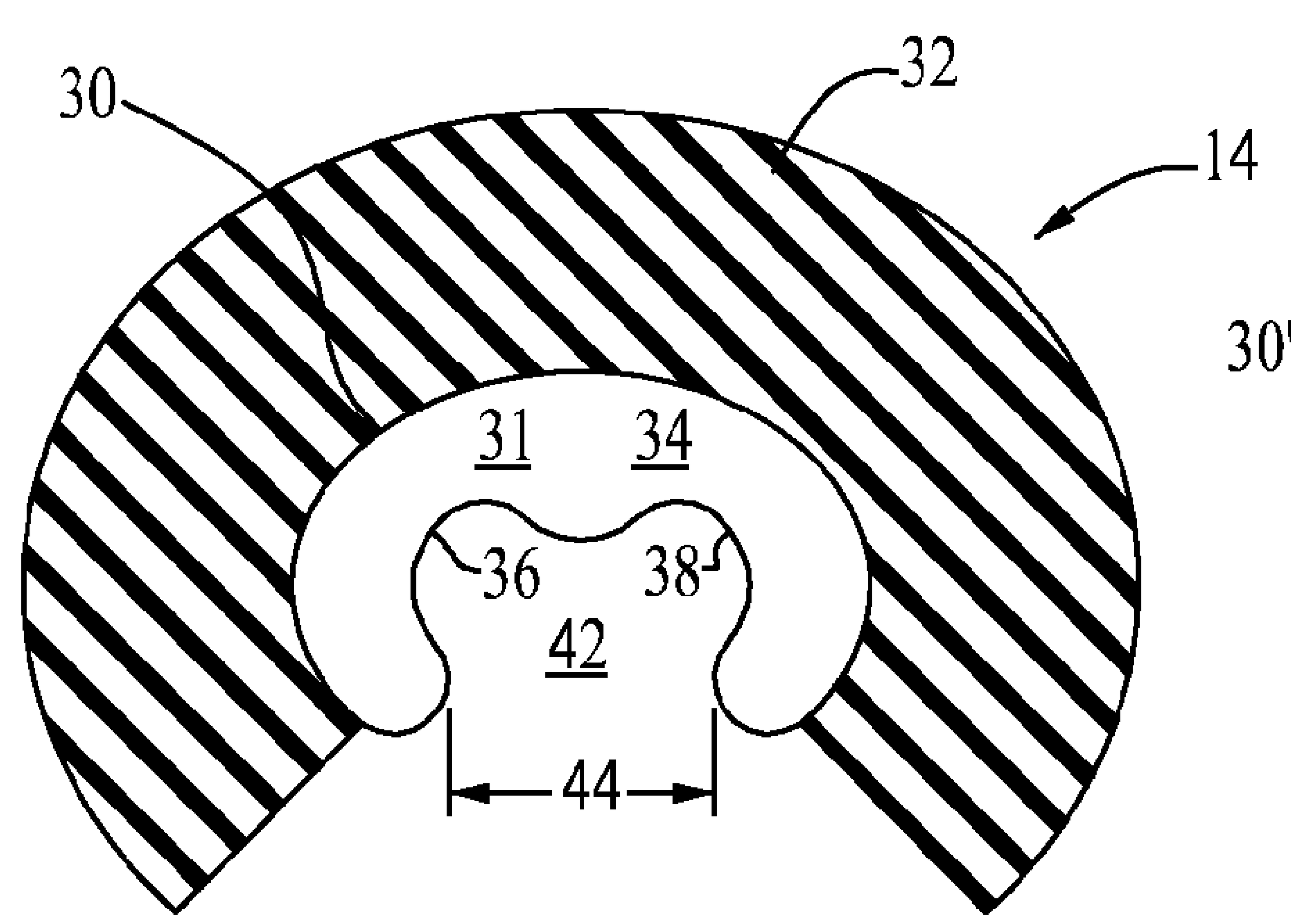


FIG. 5

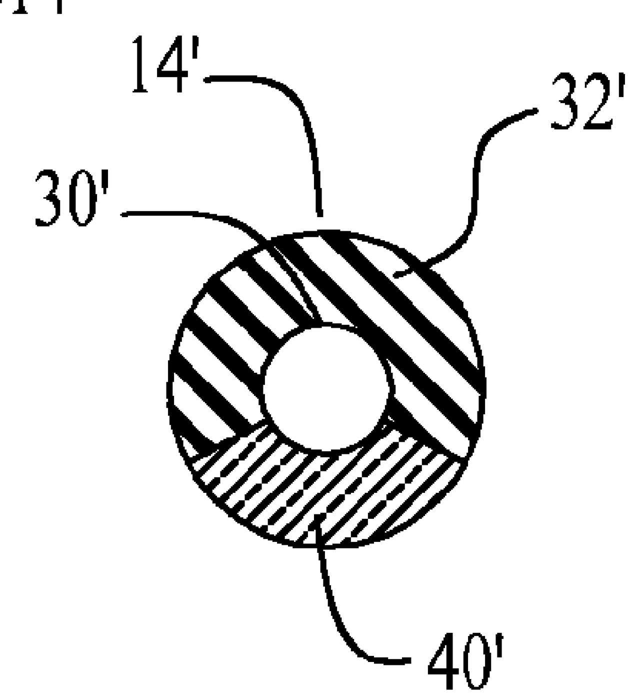


FIG. 9

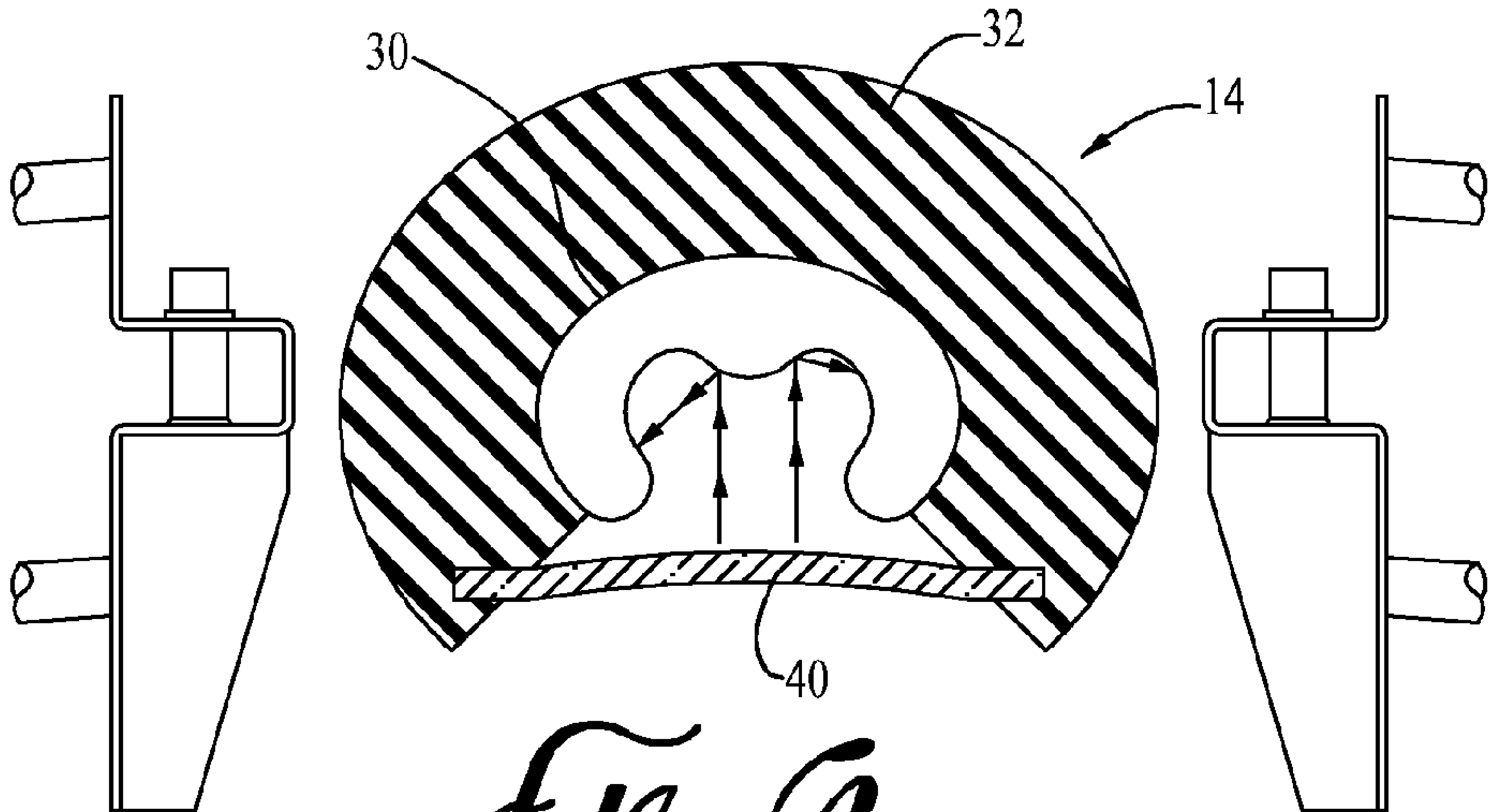


FIG. 6

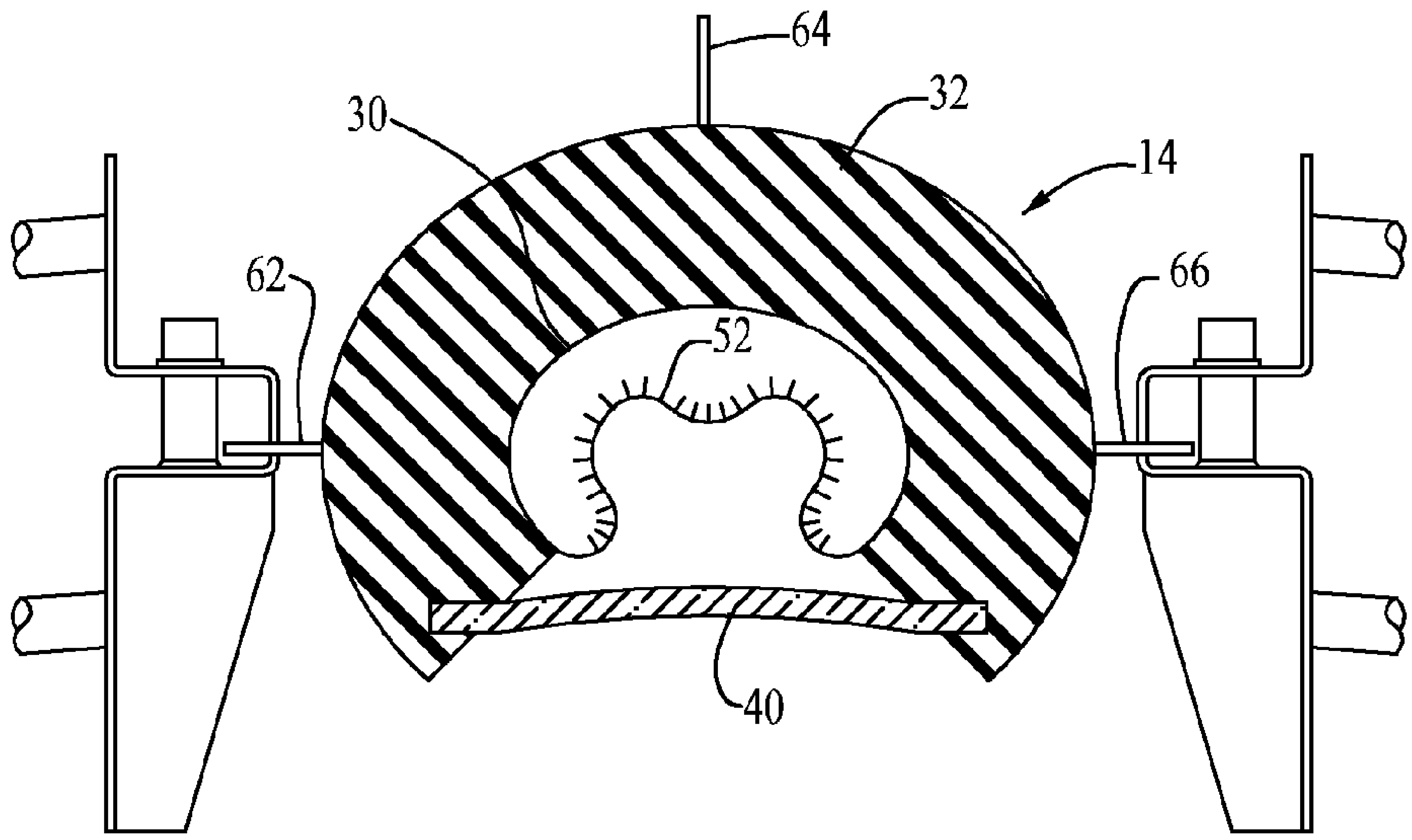


FIG. 7

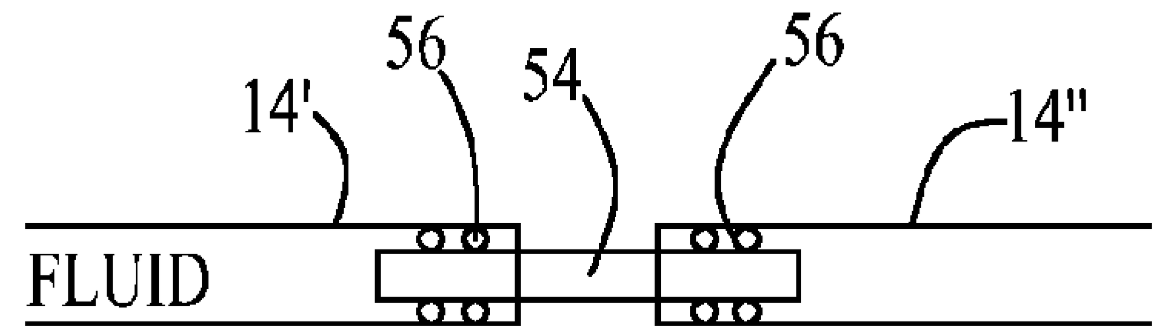


FIG. 8A

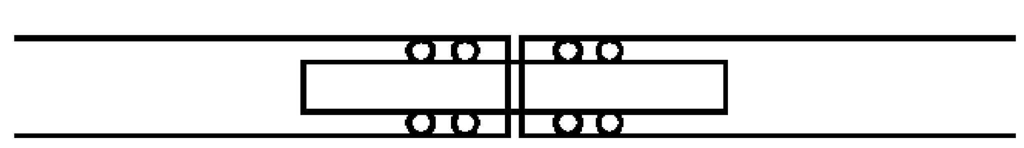


FIG. 8B

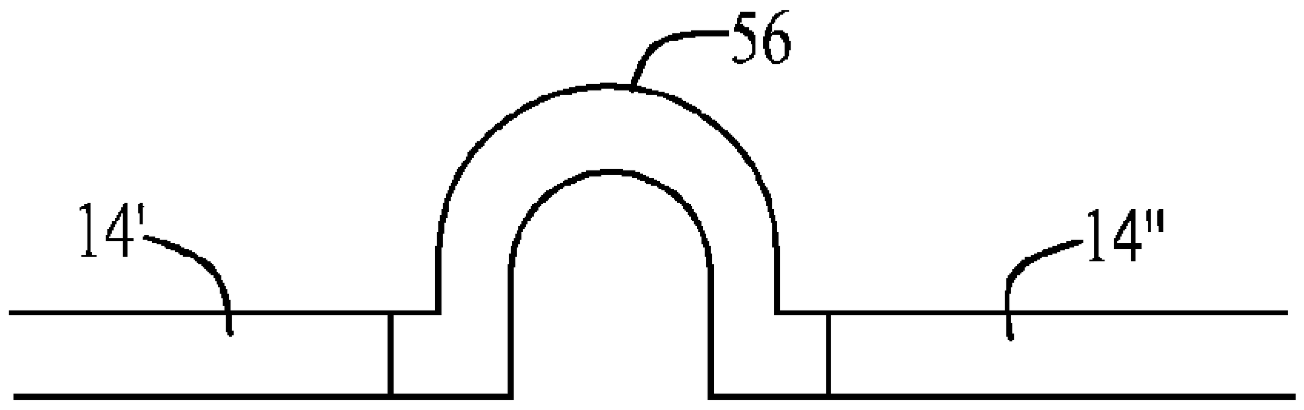


FIG. 8C

SOLAR TROUGH AND RECEIVER

PRIORITY CLAIM

[0001] Priorities of co-pending U.S. Provisional Patent Application No. 61/90,505 filed Aug. 20, 2008, co-pending U.S. Provisional Patent Application No. 61/90,509 filed Aug. 20, 2008 and U.S. Provisional Patent Application No. 61/122304 filed Dec. 12, 2008 are claimed, and the content of these applications are hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] This invention relates to improvements in the capture and use of solar energy. This invention relates more particularly to solar energy collectors and, more particularly, to solar energy collectors comprising a generally parabolic trough for concentrating impinging sunlight on a receiver and a receiver for receiving the concentrated sunlight.

BACKGROUND

[0003] The use of solar energy has been limited, in part, by the costs associated with capturing and using it in a sufficiently economic manner. Solar panels for converting sunlight into electricity, as well as solar collectors for converting sunlight into heat, are still relatively expensive when the costs of both manufacture and installation are considered.

[0004] A solar collector typically comprises a solar receiver, such as one or more solar cells or a heat-transmitting medium, and a solar concentrator for collecting and concentrating the sunlight onto the receiver, where it is converted to heat and/or electrical power at an efficiency that is better than using un-concentrated sunlight.

[0005] Parabolic solar concentrators are typically formed as generally parabolic troughs that consist of a rigid space frame holding parabola-shaped glass mirrors. These are highly engineered structures designed for maximum efficiency. They often have large apertures of up to 5 meters and thus require significant structures that require significant assembly in the field.

[0006] State-of-the-art solar receivers comprise a generally circular tube of steel, copper or alloy covered by glass. The space between the glass and the tube contains a vacuum that is used as insulation to reduce heat loss to the environment. This can be very effective but requires high maintenance to maintain the vacuum and check for glass breakage. The surface of the receiver tube is typically covered with a special coating, called a selective coating, that has high absorptivity in the solar spectrum (i.e., it absorbs sunlight well) but has low thermal emissivity.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] In the following Detailed Description Of The Embodiments, reference is made to the accompanying drawings which form a part thereof, and in which are shown by way of illustration specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention. In the accompanying drawings:

[0008] FIG. **1** is a top right perspective view of a preferred solar trough and receiver unit;

[0009] FIGS. **2**A and **2**B are, respectively, a right front perspective view in explosion and a left rear perspective view in explosion of a preferred solar trough;

[0010] FIG. **3** is a schematic illustration of the preferred method for fabricating the preferred solar trough;

[0011] FIG. **4** is a schematic illustration of sunlight being reflected by the preferred solar trough to impinge on the receiver of the preferred trough and receiver unit illustrated in FIG. **1**;

[0012] FIG. **5** is a cross-sectional view of the preferred receiver in FIG. **1**, taken along line **5**-**5** therein;

[0013] FIG. **6** is a cross-sectional view of the preferred receiver as illustrated in FIG. **5**, showing the addition of a preferred optional cover;

[0014] FIG. **7** is a cross-sectional view of the preferred receiver as illustrated in FIG. **5**, showing the addition of preferred heat-dissipating fins within the receiver;

[0015] FIG. **8**A-C are respective side elevation views in schematic of possible expansion joint arrangements that can be used as a component of preferred solar trough and receiver units; and

[0016] FIG. **9** is a cross-sectional view in schematic of a modified receiver.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0017] FIG. **1** is a top right perspective view of a solar trough and receiver unit **10** (hereinafter referred to as the "collector unit **10**"). The collector unit **10** comprises a generally parabolic trough **12** for collecting and concentrating sunlight onto a generally central receiver **14** that extends along a longitudinal axis **11**. The receiver **14** can contain circulating fluid which is heated for thermal application or photovoltaic ("PV") cells mounted on the receiver **14** for concentrated PV applications. In concentrating PV applications, the fluid in receiver **14** serves as a cooling fluid for the PV cells.

[0018] As described in more detail below, the receiver **14** is supported at or near the focal point of the generally parabolic trough **12** by a support structure, the preferred structure being illustrated at **28** and described in detail below. As will become clearer, the preferred embodiment described herein reduces the specific cost for constructing and installing the receiver, simplifies the production and installation of parabolic troughs, and reduces the delivered cost of energy from the resulting solar system.

[0019] The trough **12** is preferably formed as a unibody structure rather than as a distinct space frame with mounted components. The preferred troughs are accordingly easily assembled in the factory, require minimal field assembly, are less material intensive than conventional solar collectors, weigh less than conventional concentrators, are less fragile because they do not require glass mirrors as reflective surfaces, and can be stacked for easy storage and transportation.

[0020] The preferred receiver support structure is a "bridge" design **28** as opposed to the conventional method of supporting the receiver by means that extend from the center of the trough (which can be used if desired). The preferred "bridge" structure **28** is illustrated in FIG. **1** and described later. The preferred bridge-type receiver support significantly increases the strength of the trough unit, and reduces the mass of the material used in the trough.

[0021] The preferred trough's reflective surface may be any polished metal, any highly reflective material and/or a reflective coating. It is also possible for the surface to be flat segments or specifically curved mirrors.

[0022] The preferred individual trough units are designed to be close coupled to form a row of solar collectors where desirable. This minimizes the gap between reflective surfaces, thus reducing losses.

[0023] The preferred solar collector system is designed for automated cleaning.

[0024] In practice, the preferred troughs are preferably transported without the receiver support attached to the trough so that the trough units can be easily stacked or nested to allow for more efficient transportation.

[0025] The preferred trough units are sufficiently light such that two men can easily lift them and place them on their mounts.

[0026] Turning to FIGS. **2**A and **2**B, a right front perspective view in explosion and a left rear perspective view in explosion of the preferred trough unit **12** are respectively shown. The basic trough unit preferably consists of three major components: a back shell **16**, an interjacent foam core **18** and a front reflective layer **20**. The back shell **16** can be formed from steel or other metal, plastic or composite material. Currently, the shell is preferably stamped steel that is painted or coated to inhibit corrosion. Channels **16***a* and/or ribs **16***b*, preferably formed integrally by means of the stamping operation, are of sufficient dimensions to give the shell a required degree of stiffness. A generally centered longitudinally-extending spar (not illustrated) may also be placed between the back shell and the front reflective layer to increase the stiffness in the longitudinal direction. In practice, the preferred back shell **16** also has pivot points, mounting and other connection points for actuation and hardware.

[0027] The foam core **18** binds the back shell **16** and the reflector **20** together, provides spacing between the back shell **16** and the reflector surface **20**, and adds stiffness to the unit. The preferred foam is introduced as a liquid during the construction of the trough unit and solidifies during its curing process, becoming permanently bonded to the surrounding surfaces. Once the foam has set, the parabolic shape is permanently established in the reflector.

[0028] The foam core is preferably a closed cell foam such as a polyurethane foam. Polyurethane foam is preferred because it has high bond strength and is easy to apply as a liquid. Additionally, some polyurethanes have nearly the same coefficient of expansion as mild steel so that there is minimal thermally-induced strain between the back shell and the foam core. Since polyurethane foam also has a high modulus of elasticity, it can easily accommodate the small differential strain between the foam and the reflector.

[0029] The foam may be of various densities, but is preferably 1 to 5 lbs/ft^3. The foam-contacting surfaces of the back shell **16** and the reflector **20** may be unprepared prior to binding, or may be prepared by etching or otherwise making the surface suitable for bonding to the foam.

[0030] The reflector component **20** is a structure to which a front reflective layer **20***a* is attached or onto which it is deposited. The reflector component **20** is preferably a thin sheet of metal, preferably aluminum that is highly polished on its reflective surface and coated to inhibit corrosion. Other possible materials are stainless steel and, particularly with more highly reflective layers attached to the reflection side of the reflector, plastics and composite materials and glass mirrors. One example of a reflective layer that can be attached to a substrate to form the reflector component **20** is a reflective film such as ReflecTec® mirror film (a product of ReflectTec, Inc. of Arvada, Colo.). Alternatively, a reflective aluminum sheet such as Mirosun® reflective sheets (a product of ALANOD Aluminum Veredlung of Ennepetal, Germany) can be utilized with or without a substrate.

[0031] Fabrication of the trough is relatively simple. Referring to FIG. **3**, the prepared reflector component **20** is placed in a tooling fixture or jig such as a vacuum chuck **24**, which holds the reflector material or sheet in the correct alignment, position and shape. The reflector component **20** is now prepared to be mated with the back shell **16** in its fixture.

[0032] The prepared back shell **16** is fitted in a different tooling fixture **22** (e.g., by vacuum, magnetic or othermeans). With both pieces in their respective fixtures, they are ready to be brought together for final assembly. The mating of the two fixtures provides for the correct spacing between the back shell and the reflector. If a spar is required in the unit it is placed in the assembly before the two tooling fixtures are mated. The space **26** between them is filled with a liquid expanding polyurethane foam material that expands to form the foam core **18**. Because low temperatures may result in an incomplete reaction within the foam, and in poor bond strength and structural properties, the fixtures are preferably heated so that the back shell **16** and reflector **20** are at a temperature that facilitates the reaction, distribution of the foam, faster cure time and bonding of the foam. In accordance with the preferred embodiment, a 2-part urethane foam is premixed and injected into the cavity between the shell **16** and reflector **20**. One or more holes in the back shell can be provided as a means by which the liquid foam is injected into the cavity between the two pieces. The volume of the foam is preferably metered to assure the correct amount of foam is introduced into the cavity, although a slight overfill may be required. The unit takes approximately 3 to 5 minutes to cure completely. The trough's formation is then complete and the trough unit is removed from the tooling fixture. Cleanup, post processing and addition of small parts can be completed at this time.

[0033] Referring to FIGS. **2**A and **2**B, it can be noted that the reflector component **20** of the completed trough unit is held in the correct shape by the cured foam layer **18**. Accordingly, it may be noted that a substantial amount of variation can be tolerated in the back shell **16**, since the foam **18** will compensate for the variations by filling in the gaps between the shell and reflector component during the formation process. Accordingly, to a substantial extent, cost becomes the driving factor with respect to the shell rather than precision so that less precise processes such as stamping are feasible in manufacturing the shell.

[0034] The trough unit **12** can support the receiver **14** in the conventional manner, but the preferred supporting structure is a novel bridge (or truss) **28** (FIG. **1**) that spans the width of the trough and attaches to the trough's outer longitudinal edges **10***a*, **10***b*. Each trough unit has at least one receiver-supporting bridge, and a bridge can also be used to lock the adjoining longitudinal ends of adjoining troughs together to form a row of troughs. Linked in this manner, a row would have a minimum number of receiver-support bridge units equal to or greater than the number of troughs plus one.

[0035] The full stiffness and strength of the trough is achieved only after the receiver support is installed. Without the installed receiver-supports, the troughs are easily stackable for convenient shipping and movement, so it is preferred that the receiver support is mated with the trough in the field, both to avoid damage to the support and to also permit easier stacking of the troughs.

[0036] The receiver support can also carry provisions for installation of a water hose/line (not shown) for periodically washing the reflector surface. This hose/line is preferably provided with nozzles or perforations at longitudinally-space intervals along the trough. The receiver-support bridge accordingly also supports a water (or special washing fluid) line, which delivers water that sprays down the reflective surface of the reflector **20** and, if present, a glass cover shielding the receiver.

[0037] Preferably, the hose/line extends along or slightly above one longitudinal edge region of the trough unit. During washing, the trough is pivoted so that the edge region bearing the hose is higher than the other longitudinally extending edge; the trough units are typically mounted on structures allowing them to pivot in this manner to enable the trough(s) to follow the sun's movement during the day. The water/cleaning solution is deployed generally laterally across the trough (or glass cover if present) from the hose, preferably through a plurality of laterally-facing, longitudinally disposed nozzles that impart sufficient velocity to the water/cleaner to enable the water/cleaner to run across the reflective surface and over the lower opposite edge of the trough, carrying the accumulated dust and dirt away.

[0038] Alternatively, an automated cleaning machine may be used to clean each multi-unit row of collector units. Due to the bridge design and the close coupling of the collector units, the path is clear down the center of the collector units for an automated cleaner to traverse the length of a row of collectors. A cleaning machine may be placed at one end of a row and travel the length of a row, typically 100 to 200 meters. The automated cleaner can be used to clean and/or polish the reflective surface of the reflector **20** using air, water, brushes or any combination of those, and preferably cleans the reflector and the receiver glass, if any, simultaneously.

[0039] The receiver **14** (FIG. **1**) may be of the type utilizing a heat-transfer liquid or may instead be of the photovoltaic type. The receiver **14** comprises a tube situated at or near the focal point of the parabolic concentrator **12** so that concentrated sunlight is focused on the receiver's face, or just slightly inside or outside as needed to disburse the concentrated sunlight over the correct area.

[0040] FIG. **4** is a schematic illustration of sunlight being reflected by the preferred solar trough to impinge on the receiver **14** of the preferred trough and receiver unit illustrated in FIG. **1**. FIG. **5** is a cross-sectional view of a preferred receiver of the heat-transfer type taken along line **5-5** in FIG. **1**. While the reflector **12** is described and illustrated as having a generally parabolic shape, the shape may not be a true parabola owing to a correction factor that changes the shape slightly from a true parabola to compensate for the fact that the sun's rays are not exactly parallel and thereby attain a better focus of the concentrated rays.

[0041] Turning to FIG. **5**, the receiver **14** comprises a generally longitudinally-extending tube **30**, the interior of which functions as a fluid passageway **31** that accommodates the generally longitudinal flow of heat-transfer fluid **34** that is pumped through the tube to absorb the solar energy as heat. The receiver may be formed from steel, aluminum, stainless steel, copper or any other metal or metal compound having the desired heat transfer properties and material properties that can withstand the temperatures and environmental conditions to which the receiver is subjected. The heat-transfer fluid is typically a liquid but may be a gas.

[0042] The trough-facing surface of the tube **30** is shaped to form a receiver chamber **42** that receives the concentrated solar rays from the trough so that the sunlight can impinge on the wall of the receiver chamber portion of the tube and heat the heat-transfer fluid within the fluid passageway A portion of the impinging sunlight from the trough is not absorbed, but is instead reflected from the receiver chamber face and would represent inefficiency in energy transfer; however, the shape of the receiver chamber is such that partially redirected (reflected) concentrated rays are mostly redirected (i.e, reflected) within the receiving chamber to allow for another opportunity for solar energy absorption. In the preferred receiver, the receiver chamber is an integral part of the tube **30**.

[0043] As illustrated in FIG. **5**, the preferred receiver chamber **42** is integral with the tube, and is formed by a recess having a generally longitudinally-extending concave face or, as illustrated here, faces **36**, **38**. The receiver chamber **42** extends longitudinally along the trough-facing side of the receiver to receive the concentrated solar rays from the trough. The tube may have one such face or more than **2**, but two is preferred. The particular shape of the tube serves to approximate a black body, which is designed to limit the emission of thermal radiation. Those skilled in the art will recognize that one could utilize two or more contiguous tubes instead of one; e.g., a tube with face **36**, and a second tube with face **38**. Alternatively, several relatively smaller tubes could be arranged to achieve the same purpose.

[0044] As illustrated in FIG. **6**, the faces of the receiver are aligned so that the concentrated solar rays received from the reflector strike the tube surface at angles that cause a substantial number of reflected rays to remain internally within the receiver chamber **42** for at least one reflection, resulting in initially non-absorbed energy being reflected back onto the receiver chamber's absorbing face, and thereby giving the solar energy of the rays an additional opportunity to be absorbed to thereby increase efficiency.

[0045] The tube's surface is preferably coated with a selective coating, which is typically designed to selectively absorb wavelengths within the solar spectrum with the greatest energy content and emit as little heat as possible. Such coatings are well known in the art. A typical selective coating may have an absorption rate of 93%, the remaining 7% being reflected back. Accordingly, the rays initially reflected from the receiver chamber's absorption face after entering the receiver chamber, undergo at least one internal reflection so they are incident again on the tube's surface and can be further absorbed as heat. Those of ordinary skill in the art will recognize that the faces themselves need not be concave but only need be configured to retain a substantial proportion of the reflected rays within the solar chamber.

[0046] It is desirable to minimize heat loss from the receiver so that the heat-transfer fluid retains a maximal amount of solar energy. Heat loss from the receiver chamber happens primarily by two mechanisms: radiation and convection. Radiation losses are roughly constant for a constant receiver temperature. Convective losses to the air surrounding the receiver are variable depending primarily on ambient environmental conditions such as temperature and wind speed, while second order conduction losses occur through mounts and insulation.

[0047] The shape of receiver chamber **42** described herein aids in the retention of heat, which can be radiated and convected from the receiver surface. First, the aperture **44** of the preferred chamber **42**, through which the concentrated solar rays from the trough enter, is preferably narrower than the receiver's diameter, leaving only a narrow window for radiation to escape and thereby approximating a blackbody. Second, and for the same reason, the convective heat window is smaller. Additionally, the shape of the preferred chamber **42** helps to maintain a pocket of heated air close to the receiver face within the chamber, aiding significantly in the reduction of convective heat transfer.

[0048] The receiver chamber **42** may be protected by a transparent cover **40** that extends along the length of the tube to generally close the receiver chamber **42**. The cover isolates a pocket of air next to the tube's faces in the receiver chamber **42**, and acts as insulation to minimize heat losses to the environment by essentially minimizing free and forced convection with the environment. Those of ordinary skill in the art will appreciate that gasses other than air can be utilized within the receiver chamber for the same purposes.

[0049] The cover **40** is preferably slightly concave, with respect to the outside, as an additional heat-transfer limiting mechanism. Specifically a small boundary layer of hot air will stay in the enclosed region thus defined and act as additional insulation. Additionally, the concave face protects the faces **36**, **38** from direct exposure to wind-forced convention. The cover **40** is preferably a narrow piece of borosilicate glass, and is preferably coated to decrease reflectance within the solar spectrum; such coatings are commercially available and well known to those of ordinary skill in the art.

[0050] It may be noted that the inclusion of the cover is optional, and may or may not be used depending on the application. There is a trade-off between decreasing the heat loss through the use of the cover while causing some loss owing to sunlight reflection from the cover.

[0051] The external receiver surfaces which are not exposed to the concentrated sunlight are preferably covered with a standard industrial pipe insulation **32**. The exposed outer surface of the insulation is preferably coated with a black paint or a high solar absorptivity coating so that the insulation absorbs as much direct and diffuse solar radiation as possible. This increases the insulation's surface temperature, and thereby decreases the temperature gradient across the insulation and, consequentially, the heat losses from the fluid chamber that is conducted through the insulation, thereby making the receiver more efficient.

[0052] In summary, the preferred receiver's fluid-conducting tube is thereby shaped and fabricated to maximize the absorption of solar energy by the heat-transfer fluid flowing within the fluid passageway therein, while associated heat losses to the environment are minimized. Moreover, the configuration of the receiver is such that thermally induced stresses are reduced.

[0053] Referring to FIG. **5**, thermally induced stresses are induced by temperature differences between the outside or top of the receiver and the trough-facing side of the receiver. The temperature within the receiver chamber **42** can reach approximately 400° to 550° C. or more, causing expansion of the concave faces that tries to bend the receiver along its longitudinal axis, while the lower temperature of the top surface of the receiver causes an expansion of the top side that is different than that of the receiving chamber. Thus, there is an imbalance of exerted forces due to thermal expansion. The receiver may accordingly be configured with a moment of area of the receiver chamber, which is at roughly one uniform temperature, and a moment of area of the top section which is at a second lower but roughly uniform temperature, that are balanced such that thermal stress created in each of these chambers are substantially balanced to minimize induced bending. In other words, the stress created from differential thermal expansion resulting from the solar chamber faces being hotter than the adjoining top section is substantially minimized by this configuration, permitting the receiver to grow substantially evenly about its longitudinal axis to yield minimum thermally-induced bending.

[0054] The preferred receiver may also be provided with internal "turbulators"; i.e., surfaces, partial flow obstructions or other devices designed to cause a mixing action within the heat-transfer fluid that causes the relatively hotter fluid near the receiver chamber wall to be mixed and/or entrained into the relatively greater volume of flowing fluid. In laminar flow, the fluid along the walls of the fluid chamber tends to flow more slowly then the remaining fluid owing to its contact with the walls, and creating a "boundary layer" of fluid that is hotter than the main fluid body. Turbulators are intended to disrupt the boundary layer effect, causing a mixing of the heat-transfer fluid as it flows through the receiver, and thereby increasing the heat-transfer efficiency because heat is carried away from the receiver chamber walls more efficiently since the temperature gradient from the wall to the fluid is greater.

[0055] The turbulators have multiple functions. First, they stir the fluid, thereby decreasing its thermal gradient and removing the hottest fluid from the relatively hotter absorption surfaces of the receiver. Lower fluid temperature near the absorption surface results in an increase in heat transfer effectiveness. Second, some turbulators can effectively act as heat transfer fins, increasing receiver efficiency. Third, turbulators can allow for lower flow rates of the heat transfer fluid, thus reducing pumping power requirements, because a higher flow rate is not needed to create the turbulence necessary to mix the relatively hotter heat-transfer fluid along the wall into the relatively cooler fluid. Turbulators may be installed continuously or periodically in the receiver tube fluid section.

[0056] A turbulator may be one or more a suitably bent wires, one or more bodies of porous or mesh material, or other flow-disrupting surface member(s) disposed within the fluid path of the fluid chamber to disrupt laminar flow and create sufficient turbulence to mix the relatively hotter fluid with the rest of the flowing fluid. A turbulator may be disposed continuously throughout the fluid path or a plurality of turbulators may be serially disposed along the fluid path.

[0057] The configuration of another heat transfer enhancement mechanism is illustrated in FIG. **7** wherein a plurality of fins **52** extend inwardly from the inner, ray-receiving wall of the fluid passageway to increase the heat transfer area along the fluid path. These will also cause a mixing action and increased turbulence, but not to the extent of the turbulators. Moreover, the preferred fins are in thermal contact with the fluid tube wall and thus are also thermally coupled to the receiver's optical chamber's absorption face to aid in the conduction of heat from the solar chamber faces into the heat transfer fluid. In the preferred embodiment, the fins are integral to the receiver chamber wall. The fins not only function as heat exchanger fins that increase the effectiveness of heat transfer to the portions of the receiver body from which they extend, but can also increase the stiffness of the receiver and may thereby allow thinner walls to be provided around the receiver chamber and fluid chamber for at least some applications.

[0058] Since the receiver is not normally glass shielded or vacuum insulated, as are conventional receivers, the solar collector units and rows of solar collectors can be very long. The preferred receivers described herein may be as long as practically transportable to the installation site; e.g., lengths of up to 50 feet or more. This has several advantages: first it reduces the number of connections between receiver sections by a factor of 3 to 4 when constructing rows of solar collectors. Because connections are dead spaces which cannot be used to absorb sunlight, losses are accordingly decreased. Second, the time taken to install the collector units is reduced, thereby reducing installation costs, because the long receiver requires fewer connections.

[0059] Third, fewer expansion joints are required by the longer receivers. The change in temperature from cold non-operating conditions to hot peak power conditions may be 350° C. or more on average, and the receiver length will accordingly grow significantly, requiring the use of expansion joints to accommodate the growth. Since the receiver joint connections are coincident with expansion joints, the number of expansion joints is greatly reduced by using long receivers. Moreover, expansion joints may be installed less frequently in connection with the receiver disclosed herein by placing hard connectors at some coupling joints. Moreover, since expansion joints are associated with losses in the system, the use of longer receivers is more efficient because they provide greater area available to receive concentrated light. Very long receivers would not be possible in the more standard glass insulated receiver. The preferred absence of glass shielding and vacuum seals herein, however, removes limitations on how much any section of receiver may grow.

[0060] Because the preferred receiver does not use a vacuum insulated shield and, as such, has options available for expansion joints other than the standard bellows joint used with state of the art receivers, the preferred receiver can conveniently use a simpler expansion joint. FIG. **8**C is a schematic illustration of the preferred configuration for an expansion joint wherein neighboring and regions of adjacent receivers **14'**, **14"** are coupled together at opposite ends of a flexible tube or hose **56** formed from a material that can withstand in the temperature of the heat-transfer fluid.

[0061] Another configuration is a telescoping configuration, which is sealed with o-rings **58** or other shaft seal mechanism. FIGS. **8**A and **8**B schematically illustrate one such expansion joint wherein two receivers **14'**, **14"** are coupled together via a tube **54** having an internal fluid passageway through which the fluid chambers of both receivers communicate. The tube **54** is inserted into the adjacent end regions of the two receivers through a seal or O-ring **58** that permits longitudinal movement of each receiver **14'**, **14"** with respect to the tube **54** without blocking the flow of heat-transfer fluid from one fluid chamber to the other. As the receivers expand (FIG. **8**B) or contract (FIG. **8**A), the change in receiver length is accommodated by the seals **58**, which permit the consequential relative movement between the receivers.

[0062] The expansion joints are designed as to be fully collapsed (maximum expansion) when the receiver is at its maximum operating temperature. This has the effect of further minimizing the "dead area", which cannot be used as absorber surface.

[0063] The preferred receiver also preferably includes mounting guides that prevent rotation of the receiver about its longitudinal axis when mounted on the trough. For example, tabs **62**, **64**, **66** (FIG. **7**) protrude generally radially, with respect to the longitudinal axis of the receiver, from the outer surface of the receiver to prevent rotation of the receiver about the longitudinal axis and keep the receiver chamber and aperture aligned to a high degree with the focal point of the generally parabolic trough reflector. The tabs accordingly fit into slots in the support bridge **28**, which are preferably shaped to allow expansion and contraction of the receiver along the receiver's longitudinal axis while restricting said rotation. The tabs are preferably of minimal length with respect to the receiver, and are located near the bridge mounting.

[0064] FIG. **9** is a cross-sectional view of an alternative receiver configuration. The tube **30'** of receiver **14'** may be any shape from a standard round tube or pipe to a tube with one or more flat, convex and/or concave ray-receiving faces Alternative shapes may be easier to manufacture and insulate, and may therefore be less expensive albeit less efficient. However for certain operating conditions, such as lower operating temperature of the system, these designs may be very cost effective. Additionally, for example, a flat bottom design may be more conducive for photovoltaic applications such as those in which photovoltaic cells are attached to the receiver surface at or near the focal point of a solar concentrator. A cover **40'** may be optionally included to form a chamber that can be filled with flowing or entrapped air or other fluid.

[0065] Although a preferred trough and receiver unit and the various preferred and alternative components thereof, as well as some of the advantages that can be derived from them, have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the invention as defined solely by the appended claims.

I claim:

1. A solar trough and receiver unit comprising:

a generally tubular receiver having an internal passage for conducting a heat-transfer fluid and an inlet chamber for receiving concentrated sunlight;

a generally parabolic trough for collecting and concentrating sunlight into the inlet chamber of the receiver to cause the heat-transfer fluid within the receiver to thereby be heated,

the inlet chamber being shaped to reflect said concentrated sunlight at least one time in a direction that provides said reflected sunlight with an additional opportunity to heat heat-transfer fluid within the receiver.

2. The solar trough and receiver unit of claim **1** wherein the inlet chamber is an integral part of the receiver.

3. The solar trough and receiver unit of claim **2** wherein the inlet chamber has a sunlight-receiving surface that is shaped to direct the majority of reflections back onto a the tube.

4. The solar trough and receiver unit of claim **1** wherein the inlet chamber has a sunlight-receiving face that is shaped to direct the majority of reflections back onto the receiving face.

5. The solar trough and receiver unit of claim **1** wherein the inlet chamber has a solar ray-receiving surface that is shaped to direct the majority of reflections back onto the tube.

6. The solar trough and receiver unit of claim **5** wherein the shape of the receiving surface causes at least a substantial portion of the concentrated solar rays from the trough to be incident on the receiver at non-perpendicular angles so that reflections from the receiving surface of concentrated sunlight from the trough are incident on the receiver at least one more time.

7. The solar trough and receiver unit of claim **3** wherein the inlet chamber includes at least at least one generally concave face impinged by the concentrated sunlight.

8. The solar trough and receiver unit of claim **3** wherein the inlet chamber includes at least a pair of generally concave faces impinged by the concentrated sunlight.

9. The solar trough and receiver unit of claim **8** wherein at least one longitudinally-extending channel is defined along the receiver by the generally concave faces.

10. The solar trough and receiver unit of claim **9** including a substantially transparent cover extending longitudinally along the length of the receiver to generally enclose the inlet chamber.

11. The solar trough and receiver unit of claim **3** including a substantially transparent cover extending longitudinally along the length of the receiver to generally enclose the inlet chamber.

12. The solar trough and receiver unit of claim **11** including a fluid within the covered inlet chamber space to substantially insulate the receiver from heat loss through the cover.

13. The solar trough and receiver unit of claim **12** wherein the fluid is a gas.

14. The solar trough and receiver unit of claim **13** wherein the gas is air.

15. The solar trough and receiver unit of claim **12** wherein the fluid is a liquid.

16. The solar trough and receiver unit of claim **11** wherein the cover is slightly concave.

17. The solar trough and receiver unit of claim **1** wherein the external receiver surfaces which are not exposed to the concentrated sunlight are generally covered with a layer of thermal insulation.

18. The solar trough and receiver unit of claim **17** wherein the layer of insulation has an outer surface coated with a high solar absorptivity coating so that the insulation absorbs sufficient solar radiation to increase the insulation's surface temperature and thereby decreases the temperature gradient across the insulation in order to minimize heat loss through the insulation layer.

19. The solar trough and receiver unit of claim **1** including a turbulator to create sufficient turbulence within the heat transfer fluid to decrease the thermal gradient within the receiver.

20. The solar trough and receiver unit of claim **19** wherein the turbulator is disposed continuously within the receiver passage.

21. The solar trough and receiver unit of claim **19** wherein a plurality of turbulator surfaces are positioned generally serially within the receiver passage.

22. The solar trough and receiver unit of claim **1** wherein the receiver lacks glass shielding around the receiver.

23. The solar trough and receiver unit of claim **1** wherein the receiver is longitudinally longer than the trough.

24. The solar trough and receiver unit of claim **1** wherein the longitudinal length of the receiver is up to approximately 50 feet.

25. The solar trough and receiver unit of claim **1** including at least one telescoping expansion joint for coupling the receiver to an adjacent receiver, the joint comprising

a generally tubular member having an internal fluid passage and further having end regions sized to fit within each of the adjacent receivers to permit telescoping movement therewith in response to thermally induced expansions and contractions of the adjacent receivers while retaining the fluid passages of the adjacent receivers in communication, and

a seal member within the region between the unit's receiver and the generally tubular member for sealingly engaging the generally tubular member and receiver while permitting said telescoping movement.

26. The solar trough and receiver unit of claim **1** including at least one telescoping expansion joint for coupling the receiver to an adjacent receiver, the joint comprising

a tubular member having an internal fluid passage and terminating in a pair of generally longitudinally-spaced end regions,

the receiver having at least one end region sized to fit within an end region of the tubular member, the tubular member permitting telescoping movement therewith in response to thermally induced expansions and contractions of the adjacent receivers while retaining the fluid passages of the adjacent receivers in communication through the generally tubular member, and

a seal member within the region between the receiver and tubular member for sealingly engaging the tubular member and receiver while permitting said telescoping movement.

27. The solar trough and receiver unit of claim **1** further including a first length of flexible tubing for coupling the fluid passage of the receiver to a source of heat-transfer fluid at an upstream end region of the receiver, and a second length of flexible tubing at a downstream end region of the receiver for conducting the heat-transfer fluid from the fluid passage of the receiver.

28. The solar trough and receiver unit of claim **27** wherein the source of heat-transfer fluid is an adjacent receiver.

29. The solar trough and receiver unit of claim **1** wherein the receiver includes a plurality of internal heat-exchanging fins extending into the fluid passageway and structured to conduct heat from the inlet chamber into the heat-exchange fluid.

30. The solar trough and receiver unit of claim **28** wherein the fins extend substantially the longitudinal length of the receiver.

31. The solar trough and receiver unit of claim **1** wherein the trough includes

a back shell,

a front reflective layer, and

an interjacent foam core **18** binding the back shell and the reflector together.

32. The solar trough and receiver unit of claim **31** wherein the foam core is a closed cell foam having substantially the same thermal coefficient of expansion as the back shell and sufficiently high modulus of elasticity to accommodate the differential strain between the foam and the reflector.

33. The solar trough and receiver unit of claim **32** wherein the foam is a polyurethane foam.

34. The solar trough and receiver unit of claim **33** wherein the foam has a density of approximately 1 to 5 lbs/ft^3.

35. The solar trough and receiver unit of claim **1** including a support structure positioned on the trough to support the receiver near the region of maximally concentrated sunlight reflected from the trough.

36. The solar trough and receiver unit of claim **35** wherein the trough has a pair of longitudinally-extending edge regions separated by the width of the trough, and the support structure is a bridge spanning the width of the trough.

37. The solar trough and receiver unit of claim **36** wherein the bridge is coupled to the trough at the trough's outer longitudinally-extending edge regions.

38. The solar trough and receiver unit of claim **37** wherein the trough has a pair of longitudinally-spaced end regions, and the bridge is coupled to the receiver at one of the receiver's end regions.

39. The trough and receiver unit of claim **36** wherein the trough has a pair of longitudinally-spaced end regions, and the bridge is coupled to the receiver at one of the receiver's end regions.

40. The solar trough and receiver unit of claim **39** wherein a second trough is adjacent the trough at their respective end regions, and the bridge is coupled to the adjacent end regions on at least one side of the adjacent troughs to secure the adjacent troughs together.

41. The solar trough and receiver unit of claim **40** wherein the receiver extends longitudinally along the pair of troughs.

42. The solar trough and receiver unit of claim **41** wherein the receiver is supported by the pair of troughs.

43. The solar trough and receiver unit of claim **36** wherein one of the bridge and the receiver includes mounting tabs protruding from its outer surface and

the other of the bridge and receiver has tab-receiving slots for supporting the receiver, the tabs and slots being sized and shaped to prevent rotation about the receiver's longitudinal axis of the inlet chamber with respect to the trough.

44. The solar trough and receiver unit of claim **43** wherein the tabs and slots are sized and shaped to allow expansion of the receiver along that axis.

45. The solar trough and receiver unit of claim **43** wherein the inlet chamber of the receiver has an aperture through which concentrated sunlight from the trough enters the inlet chamber, and

the tabs and slots are positioned to keep the receiver's inlet chamber's aperture generally aligned with the area of maximum concentration of the incoming sunlight.

46. The solar trough and receiver unit of claim **36** including means supported by the bridge for delivering cleaning liquid against the reflector for periodic washing of the reflector surface.

47. The solar trough and receiver unit of claim **46** including a generally tubular cleaning fluid member extending adjacent to at least one of the longitudinally-extending edge regions of the trough for conducting cleaning fluid, and

at least one outlet from the cleaning fluid member for directing at least some of the conducted cleaning fluid against the trough in a direction generally transverse to the longitudinal.

48. A solar receiver unit comprising:

a generally tubular body having an internal passage for conducting a heat-transfer fluid, and an inlet chamber for receiving concentrated sunlight from a solar reflector when in use;

the inlet chamber being shaped to reflect said concentrated sunlight at least one time in a direction that provides said reflected sunlight with an additional opportunity to heat the heat-transfer fluid.

49. The solar receiver of claim **48** wherein the chamber is an integral part of the tube.

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