SOLAR RADIATION RECEIVER

DESCRIPTION

OBJECT OF THE INVENTION

The present invention discloses a solar radiation receiver, applicable to the conversion of solar energy into thermal and electrical energy. Its use has a relevant interest in the power generation industry.

PROBLEM TO BE SOLVED. BACKGROUND OF THE INVENTION

Currently there are three big technologies exploiting solar energy to turn it into thermal and electrical energy, cylinder-parabolic receivers, tower solar system with heliostat field, and parabolic dishes. The present invention is centered in the latter technology, wherein solar radiation strikes on a paraboloid (a "parabolic dish", that is usually a paraboloid with a circular section), and a heat machine is located at its focus. This heat machine is usually a perfected Stirling engine (initially described by Robert Stirling in his patent of 1816, see document GB 4081 A.D. 1816) which operates between a hot focus (a solar radiation receiver) and a cold focus. The mechanical energy that the Stirling engine or an equivalent engine, produces, actuates an alternator that generates electrical energy.

As aforementioned, in the systems with parabolic dishes the solar radiation is received on the receiver. Said receiver heats a working gas, which actuates the heat engine. For a given thermal energy, increasing the receiver performance involves increasing the working gas temperature, and consequently, increasing the engine performance. This causes the total performance of the machine to be more efficient.

The Stirling engines that have been used in these solar plants have utilized receivers formed by a tube bundle, which is located facing the paraboloid axis. However, in this configuration, the surface which has been used by the thermal energy coming from the concentrator (the parabolic dish), is only a percentage of the concentrator projection. Besides, the tube bundles that are used in the state of the art are devices made up of a plurality of pieces, which are welded to each other and to the collector. This type of welded construction generates, relatively often, mechanical tension problems when the

device is subjected to thermal cycles, which many times result in material stressing and its subsequent breaking. On the other hand, it is quite common that those devices that follow the Stirling cycle use hydrogen as the working fluid to improve their performance. Given that H_2 burns in contact with the air, the shapes provided for in the current state of the art imply a risk of fire and explosion.

To solve the aforementioned problems, the present invention proposes a solar receiver (that in some shapes it is flat, and in others it is not), that uses the entire projected surface of the concentrator, so the used area is maximum. Moreover, its construction is more robust and safer than the tube bundle solution that has been typically used up to now, since it avoids the currently existing problems arising from the welded joints of the different components.

Diverse shapes of solar receivers linked to Stirling engines are known in the current state of the art there. Thus, document GB 2296047 A1 describes a Stirling engine with a crankshaft over which a structure is assembled, and a series of flexible diaphragms defining the working chambers, hot and cold, wherein the working fluid flows, is linked thereto. Document CN 201433829 Y discloses a heat cavity absorber for the Stirling engine of a solar device, with U-shaped channels. However, no device with the specific characteristics shown by the present invention has been disclosed.

DESCRIPTION OF THE INVENTION

The described invention discloses a solar radiation receiver that has inlet and outlet collectors, and a series of conduits that go from the inlet collector to the outlet collector, and through which such conduits a working fluid flows that is heated upon receiving solar radiation. The receiver comprises: a) an upper layer where the solar radiation strikes; b) at least one intermediate layer, located under the upper layer, where the conduits, through which the working fluid flows, are placed; and c) a lower layer, located under the at least one intermediate layer, into which the inlet and outlet collectors for the working fluid are coupled. The device construction is carried out in such a way that the upper layer, the at least one intermediate layer, and the lower layer, make up one single piece.

The conduits through which the working fluid flows, have either a triangular section, or a rectangular one with rounded ends, or elliptical, or

regular polygonal, or circular, or a combination of two of the aforementioned geometries.

When there is more than one intermediate layer in the receiver, each of these intermediate layers is provided in the inside thereof with conduits through which the working fluid flows.

The conduits that are located in the intermediate layer(s) are arranged laid out like a labyrinth, covering the whole used surface of the intermediate layer(s) of the receiver.

Said piece from which the receiver is made, is an alloy capable of withstanding high temperatures, above 600 °C, like steel, stainless steel or alloys like Inconel® or Hastelloy®.

The receiver can be shaped according to different geometrical shapes, exhibiting some of these configurations geometries such as: circular or circular sector, hollow semi-cone, hollow semi-sphere or a hollow polyhedron cut in half.

DESCRIPTION OF THE FIGURES

The invention is easily understood in view of the contents of the specification together with the figures, in which numerical references are used to indicate the different elements that form the invention.

- Figure 1 is a schematic view of an external combustion heat engine applicable to heliothermal devices with parabolic dishes.
- Figure 2 is a perspective view of a receiver, in its flat shape, with a partial section, wherein the conduits through which the working fluid flows can be observed.
- Figure 3 is a detailed view of the receiver section, wherein the different shapes of the conduits are shown.
- Figure 4 shows other shapes as alternatives to the flat receiver shape, such as a semi-cone shaped receiver (figure 4A), hemisphere-shaped (figure 4B) or with the shape of a regular polyhedron cut in half (figure 4C) like a dodecahedron.

Next a list is provided with the different elements represented in the figures that form the invention: 1 = solar radiation (direct or reflected); 2 = receiver; 3 = heat engine coupled to the parabolic dish; 4 = alternator; 5 = upper layer; 6 = intermediate layer; 7 = lower layer; 8 = conduits; 9 = inlet and outlet collectors of the working fluid; a = semi-minor axis of the ellipse; b = semi-major

axis of the ellipse; c = radius; d = thickness of the upper layer; e = thickness of the intermediate layer; f = thickness of the lower layer; m = side of the polygon; r = radius of the circle; t = basis of the conduit; l = sides of the conduit; v = conduit vertex.

DETAILED DESCRIPTION OF THE INVENTION

As it has already been stated, and as it can be seen in figure 1, the invention consists of a solar receiver applicable in heliothermical parabolic dishes that use external combustion engines. A Stirling engine (3) or the like is located in the focus of a parabolic dish (not shown); the heat engine (3) has a solar radiation (1) receiver (2), with a series of channels through which a working fluid (usually H_2) flows, and a set of coolers-regenerators. All these elements are assembled over an engine base as the state of the art documents disclose, and that is why they have not been shown in figure 1. Usually each cylinder arrangement of the heat engine (3) has a cooler, a regenerator and a receiver (2) connected thereto; in this case, the receiver (2) has a "flat" shape with a disc or circle shape, even though other arrangements are also possible, as it will be described hereinafter.

The working fluid that flows in the heat engine (3) reaches the solar receiver (2) when a heat engine (3) cycle has been completed; this way, and due to the heat transfer processes taking place in the receiver (2) upon receiving the solar radiation (1), the working fluid increases its enthalpy and then it is directed to the Stirling heat engine (3) where it flows. The working fluid expands in the heat engine (3), providing movement to the crankshaft or the like (not shown), which actuates an alternator (4) thus producing electric energy. Therefore, the purpose of the receiver (2) is to increase the enthalpy of the working fluid, which flows cyclically in the heat engine (3) to produce electricity through an alternator (4).

The receiver (2) receives solar radiation (1) by reflection on the internal surface of the paraboloid, given that said receiver (2) is located at the focus of the parabolic dish (not shown), and oriented towards the paraboloid. Therefore, the solar radiation (1) reaching the parabolic dish concentrates on its focus, heating the receiver (2) uniformly. Alternatively, the radiation can reach the receiver through concentration lenses such as Fresnel-type or the like.

Figure 2 represents a view of the receiver (2), wherein one of its quarters

is sectioned. Said section is in turn cut along a plane AA to show the conduits (8) through which the working fluid that is heated in the receiver (2) flows, and then said fluid flows into the Stirling heat engine (3) or the like. The receiver (2) is provided with a series of collectors (9) through which the working fluid enters and exits. Initially, the working fluid coming from the Stirling engine (3) reaches one of the inlet collectors (9), flows through the conduits (8) of the receiver (2), being heated due to the incident solar radiation (1) striking the receiver (2). Once it has covered the path described by the conduit (8), the working fluid leaves the receiver (2) going to the Stirling engine (3) through which the according outlet collector (9), said working fluid flowing into the engine (3).

The receiver (2) is an element made of one single piece, even though given its structure a hypothetical discretization in three layers or strata can be carried out, as it can be observed in figure 2 and, in more detail, in figure 3. There is a first upper layer (5) whose external part is the one receiving solar radiation (1), since that external part is the surface of the receiver (2). Said upper layer (5) has a thickness "d". Under the first upper layer (5) there is, at least, one intermediate layer (6), with a thickness "e", although other embodiments can include more than one of said intermediate layers (6). In any case, each and every one of the intermediate layers (6) are provided with conduits (8) through which the working fluid flows towards the Stirling engine (3). For the purpose of making the invention clear, in figures 2 and 3 only one single intermediate layer (6) has been shown. Finally a lower layer (7), with thickness "f", is arranged under the intermediate layer (6).

Schematically, the heat transfer process is as follows: as the solar radiation (1) strikes the receiver (2) surface, thus heat is transferred by conduction along the upper layer (5). Next, said transfer by conduction is transmitted to the rest of the elements of the receiver (2): along the existing intermediate layers (6), down to the lower layer (7), and towards the conduits (8). Therefore, the working fluid that flows into the conduits (8) increases its enthalpy due to the heat transfer that is now received by convection, and, to a lesser degree, also due to radiation. The shape of the conduits (8) along the intermediate layer(s) (6) is labyrinthine, to increase the path thereof with respect to the used surface of the receiver (2) and thus to optimise the heat transfer. Therefore, most of the heat transfer takes place from all the layers (5, 6, 7) towards the fluid flowing through the conduits (8). Even so, part of the heat is

still transferred towards the lower layer (7) area. As those skilled in the art very well know, other heat transfer phenomena by radiation and convention to the atmosphere along the entire surface of the receiver (2) also take place, even though said processes can be considered less significant than the heat transfer from the different layers (5, 6, 7) to the fluid flowing through the conduits (8).

Figures 2 and 3 show (the latter with more details than the former) possible embodiments of the geometry conduits (8). For the purpose of simplifying the description, five embodiments of the conduits (8) section have been shown (figure 3), these shapes being: A, triangular; B, rectangular with rounded ends; C, elliptical; D, regular polygonal; and E, circular. Section A has a triangular shape (typically isosceles), with a base (t) and sides (l) converging at a vertex (v), pointing towards the lower layer (7). Section B has a rectangular shape, with a side "e" equal to the thickness of the intermediate layer (6), even though the top and the bottom end in a semicircle of radius "c". Section C is an ellipse with a semi-minor axis "a" and semi-major axis "b". Section D is a regular polygon with side "m"; in the case of figure 3, a regular octagon has been shown. Section E is a circle with a radius "r". Experience has shown that the geometries of these conduits (8) are the most adequate according to diverse physical parameters of the working fluid, like the Reynolds number, the velocity, its pressure, and its temperature.

Only some of the five configurations (A, B, C, D, or E) which are shown in figures 2 and 3, or combinations thereof, are provided; for instance, a conduit half polygonal – half circular, or other possible combinations based on the configurations A, B, C, D, or E. Figure 3 represents all the initial configurations over the same receiver, to show the possible alternatives, but it must be understood that for a given receiver (2), the geometry of the conduits (8) is only one of the options A to E shown (or combinations thereof).

Experimentally it has been proven that the best option to manufacture the receiver (2) is by means of an additive layer manufacturing process. In such a way that the upper layer(5), the intermediate layer(s) (6) and the lower layer (7) are manufactured in one single piece; said piece is, preferably, made in an alloy capable of withstanding high temperatures, above 600 °C. Experimentally it has been proven that adequate materials capable to withstanding these heat loads are steel, stainless steel, or alloys like Inconel® or Hastelloy®.

It is possible to provide different embodiments of solar receivers (2),

sometimes keeping the previously explained disc geometry or with other geometrical shapes like those described hereinafter. If a disc geometry is used, it is possible to shape the solar receiver (2) either like a complete circle, or like circular sectors, like one quarter of a circle sector, one eighth of a circle sector or other submultiples. Thus, the solar receiver (2) that can be seen in figure 2 can be valid, in its entirety, for a Stirling engine (3), or it could be that the sectioned circle quadrant of said figure 2 can be used to feed a cylinder of said Stirling engine (3). In any case, as any person skilled in the art may understand, the chosen embodiment does not affect the configuration explained herein, or the essence of the invention.

Figure 4 shows other possible embodiments of the receiver (2) with geometries differing from the dish shown in figure 2. Thus, figure 4A shows a receiver with a shape of a hollow semi-cone, in such a way that solar radiation (1) strikes inside the semi-cone, said radiation (1) being reflected along the semi-cone surface. Inside the walls of the semi-cone the structure of the conduits (8), described for the receiver of figure 2, is repeated, which have not been shown in figure 4 for purposes of clarity. Other geometrical shapes are also possible, like a hollow hemisphere, as shown in figure 4B, wherein solar radiation (1) also strikes the internal surface of the hemisphere, heating it, and then, heating the working fluid which flows in the internal conduits (not shown). Figure 4C shows a last embodiment of the receiver (2), in the configuration of a hollow regular polyhedron, like for instance, an octahedron, dodecahedron, icosahedra or other polyhedrons. Similarly, to the preceding cases, solar radiation (1) strikes the internal walls of the polyhedron, enduring successive reflection processes and heating the internal surface of the polyhedron. When heated, these walls carry out the heat transfer to the fluid that flows inside them, in the, already explained, corresponding conduits (and not shown in figure 4).

Any person skilled in the art will understand the scope of the invention and the advantages derived thereof. The terms used to describe the invention must be taken in the broad and not limitative sense, the main distinctive features of this invention being described in the following claims.

SOLAR RADIATION RECEIVER

DESCRIPTION

OBJECT OF THE INVENTION

The present invention discloses a solar radiation receiver, applicable to the conversion of solar energy into thermal and electrical energy. Its use has a relevant interest in the power generation industry.

PROBLEM TO BE SOLVED. BACKGROUND OF THE INVENTION

Currently there are three big technologies exploiting solar energy to turn it into thermal and electrical energy, cylinder-parabolic receivers, tower solar system with heliostat field, and parabolic dishes. The present invention is centered in the latter technology, wherein solar radiation strikes on a paraboloid (a "parabolic dish", that is usually a paraboloid with a circular section), and a heat machine is located at its focus. This heat machine is usually a perfected Stirling engine (initially described by Robert Stirling in his patent of 1816, see document GB 4081 A.D. 1816) which operates between a hot focus (a solar radiation receiver) and a cold focus. The mechanical energy that the Stirling engine or an equivalent engine, produces, actuates an alternator that generates electrical energy.

As aforementioned, in the systems with parabolic dishes the solar radiation is received on the receiver. Said receiver heats a working gas, which actuates the heat engine. For a given thermal energy, increasing the receiver performance involves increasing the working gas temperature, and consequently, increasing the engine performance. This causes the total performance of the machine to be more efficient.

The Stirling engines that have been used in these solar plants have utilized receivers formed by a tube bundle, which is located facing the paraboloid axis. However, in this configuration, the surface which has been used by the thermal energy coming from the concentrator (the parabolic dish), is only a percentage of the concentrator projection. Besides, the tube bundles that are used in the state of the art are devices made up of a plurality of pieces, which are welded to each other and to the collector. This type of welded construction generates, relatively often, mechanical tension problems when the device is subjected to thermal cycles, which many times result in material stressing and its subsequent breaking. On the other hand, it is quite

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common that those devices that follow the Stirling cycle use hydrogen as the working fluid to improve their performance. Given that H_2 burns in contact with the air, the shapes provided for in the current state of the art imply a risk of fire and explosion.

To solve the aforementioned problems, the present invention proposes a solar receiver (that in some shapes it is flat, and in others it is not), that uses the entire projected surface of the concentrator, so the used area is maximum. Moreover, its construction is more robust and safer than the tube bundle solution that has been typically used up to now, since it avoids the currently existing problems arising from the welded joints of the different components.

Diverse shapes of solar receivers linked to Stirling engines are known in the current state of the art there. Thus, document GB 2296047 A1 describes a Stirling engine with a crankshaft over which a structure is assembled, and a series of flexible diaphragms defining the working chambers, hot and cold, wherein the working fluid flows, is linked thereto. Document CN 201433829 Y discloses a heat cavity absorber for the Stirling engine of a solar device, with U-shaped channels.

Document US 4114597 A discloses a unitary solar collector for transfer of thermal energy which is a synthetic thermoplastic unit. The unit has a solar-energy transmitting region and a solar-energy absorbing regions. The unit is useful for heating purposes.

However, no device with the specific characteristics shown by the present invention has been disclosed.

DESCRIPTION OF THE INVENTION

The described invention discloses a solar radiation receiver that has inlet and outlet collectors, and a series of conduits that go from the inlet collector to the outlet collector, and through which such conduits a working fluid flows that is heated upon receiving solar radiation. The receiver comprises: a) an upper layer where the solar radiation strikes; b) at least one intermediate layer, located under the upper layer, where the conduits, through which the working fluid flows, are placed; and c) a lower layer, located under the at least one intermediate layer, into which the inlet and outlet collectors for the working fluid are coupled. The device construction is carried out in such a way that the upper layer, the at least one intermediate layer, and the lower layer, make up one single piece.

The conduits through which the working fluid flows, have either a triangular

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section, or a rectangular one with rounded ends, or elliptical, or regular polygonal, or circular, or a combination of two of the aforementioned geometries.

When there is more than one intermediate layer in the receiver, each of these intermediate layers is provided in the inside thereof with conduits through which the working fluid flows.

The conduits that are located in the intermediate layer(s) are arranged laid out like a labyrinth, covering the whole used surface of the intermediate layer(s) of the receiver.

Said piece from which the receiver is made, is an alloy capable of withstanding high temperatures, above 600 °C, like steel, stainless steel or alloys like Inconel® or Hastelloy®.

The receiver can be shaped according to different geometrical shapes, exhibiting some of these configurations geometries such as: circular or circular sector, hollow semi-cone, hollow semi-sphere or a hollow polyhedron cut in half.

DESCRIPTION OF THE FIGURES

The invention is easily understood in view of the contents of the specification together with the figures, in which numerical references are used to indicate the different elements that form the invention.

- Figure 1 is a schematic view of an external combustion heat engine applicable to heliothermal devices with parabolic dishes.
- Figure 2 is a perspective view of a receiver, in its flat shape, with a partial section, wherein the conduits through which the working fluid flows can be observed.
- Figure 3 is a detailed view of the receiver section, wherein the different shapes of the conduits are shown.
- Figure 4 shows other shapes as alternatives to the flat receiver shape, such as a semi-cone shaped receiver (figure 4A), hemisphere-shaped (figure 4B) or with the shape of a regular polyhedron cut in half (figure 4C) like a dodecahedron.

Next a list is provided with the different elements represented in the figures that form the invention: 1 = solar radiation (direct or reflected); 2 = receiver; 3 = heat engine coupled to the parabolic dish; 4 = alternator; 5 = upper layer; 6 = intermediate layer; 7 = lower layer; 8 = conduits; 9 = inlet and outlet collectors of the working fluid; a = semi-minor axis of the ellipse; b = semi-major axis of the ellipse; c = radius; d = thickness of

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the upper layer; e = thickness of the intermediate layer; f = thickness of the lower layer; m = side of the polygon; r = radius of the circle; t = basis of the conduit; l = sides of the conduit; v = conduit vertex.

DETAILED DESCRIPTION OF THE INVENTION

As it has already been stated, and as it can be seen in figure 1, the invention consists of a solar receiver applicable in heliothermic parabolic dishes that use external combustion engines. A Stirling engine (3) or the like is located in the focus of a parabolic dish (not shown); the heat engine (3) has a solar radiation (1) receiver (2), with a series of channels through which a working fluid (usually H_2) flows, and a set of coolers-regenerators. All these elements are assembled over an engine base as the state of the art documents disclose, and that is why they have not been shown in figure 1. Usually each cylinder arrangement of the heat engine (3) has a cooler, a regenerator and a receiver (2) connected thereto; in this case, the receiver (2) has a "flat" shape with a disc or circle shape, even though other arrangements are also possible, as it will be described hereinafter.

The working fluid that flows in the heat engine (3) reaches the solar receiver (2) when a heat engine (3) cycle has been completed; this way, and due to the heat transfer processes taking place in the receiver (2) upon receiving the solar radiation (1), the working fluid increases its enthalpy and then it is directed to the Stirling heat engine (3) where it flows. The working fluid expands in the heat engine (3), providing movement to the crankshaft or the like (not shown), which actuates an alternator (4) thus producing electric energy. Therefore, the purpose of the receiver (2) is to increase the enthalpy of the working fluid, which flows cyclically in the heat engine (3) to produce electricity through an alternator (4).

The receiver (2) receives solar radiation (1) by reflection on the internal surface of the paraboloid, given that said receiver (2) is located at the focus of the parabolic dish (not shown), and oriented towards the paraboloid. Therefore, the solar radiation (1) reaching the parabolic dish concentrates on its focus, heating the receiver (2) uniformly. Alternatively, the radiation can reach the receiver through concentration lenses such as Fresnel-type or the like.

Figure 2 represents a view of the receiver (2), wherein one of its quarters is sectioned. Said section is in turn cut along a plane AA to show the conduits (8) through which the working fluid that is heated in the receiver (2) flows, and then said fluid flows

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into the Stirling heat engine (3) or the like. The receiver (2) is provided with a series of collectors (9) through which the working fluid enters and exits. Initially, the working fluid coming from the Stirling engine (3) reaches one of the inlet collectors (9), flows through the conduits (8) of the receiver (2), being heated due to the incident solar radiation (1) striking the receiver (2). Once it has covered the path described by the conduit (8), the working fluid leaves the receiver (2) going to the Stirling engine (3) through which the according outlet collector (9), said working fluid flowing into the engine (3).

The receiver (2) is an element made of one single piece, even though given its structure a hypothetical discretization in three layers or strata can be carried out, as it can be observed in figure 2 and, in more detail, in figure 3. There is a first upper layer (5) whose external part is the one receiving solar radiation (1), since that external part is the surface of the receiver (2). Said upper layer (5) has a thickness "d". Under the first upper layer (5) there is, at least, one intermediate layer (6), with a thickness "e", although other embodiments can include more than one of said intermediate layers (6). In any case, each and every one of the intermediate layers (6) are provided with conduits (8) through which the working fluid flows towards the Stirling engine (3). For the purpose of making the invention clear, in figures 2 and 3 only one single intermediate layer (6) has been shown. Finally a lower layer (7), with thickness "f", is arranged under the intermediate layer (6).

Schematically, the heat transfer process is as follows: as the solar radiation (1) strikes the receiver (2) surface, thus heat is transferred by conduction along the upper layer (5). Next, said transfer by conduction is transmitted to the rest of the elements of the receiver (2): along the existing intermediate layers (6), down to the lower layer (7), and towards the conduits (8). Therefore, the working fluid that flows into the conduits (8) increases its enthalpy due to the heat transfer that is now received by convection, and, to a lesser degree, also due to radiation. The shape of the conduits (8) along the intermediate layer(s) (6) is labyrinthine, to increase the path thereof with respect to the used surface of the receiver (2) and thus to optimise the heat transfer. Therefore, most of the heat transfer takes place from all the layers (5, 6, 7) towards the fluid flowing through the conduits (8). Even so, part of the heat is still transferred towards the lower layer (7) area. As those skilled in the art very well know, other heat transfer phenomena by radiation and convention to the atmosphere along the entire surface of the receiver (2) also take place, even though said processes can be considered less significant than the heat transfer from the different layers (5, 6, 7) to the fluid flowing

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through the conduits (8).

Figures 2 and 3 show (the latter with more details than the former) possible embodiments of the geometry conduits (8). For the purpose of simplifying the description, five embodiments of the conduits (8) section have been shown (figure 3), these shapes being: A, triangular; B, rectangular with rounded ends; C, elliptical; D, regular polygonal; and E, circular. Section A has a triangular shape (typically isosceles), with a base (t) and sides (l) converging at a vertex (v), pointing towards the lower layer (7). Section B has a rectangular shape, with a side "e" equal to the thickness of the intermediate layer (6), even though the top and the bottom end in a semicircle of radius "c". Section C is an ellipse with a semi-minor axis "a" and semi-major axis "b". Section D is a regular polygon with side "m"; in the case of figure 3, a regular octagon has been shown. Section E is a circle with a radius "r". Experience has shown that the geometries of these conduits (8) are the most adequate according to diverse physical parameters of the working fluid, like the Reynolds number, the velocity, its pressure, and its temperature.

Only some of the five configurations (A, B, C, D, or E) which are shown in figures 2 and 3, or combinations thereof, are provided; for instance, a conduit half polygonal – half circular, or other possible combinations based on the configurations A, B, C, D, or E. Figure 3 represents all the initial configurations over the same receiver, to show the possible alternatives, but it must be understood that for a given receiver (2), the geometry of the conduits (8) is only one of the options A to E shown (or combinations thereof).

Experimentally it has been proven that the best option to manufacture the receiver (2) is by means of an additive layer manufacturing process. In such a way that the upper layer(5), the intermediate layer(s) (6) and the lower layer (7) are manufactured in one single piece; said piece is, preferably, made in an alloy capable of withstanding high temperatures, above 600 ºC. Experimentally it has been proven that adequate materials capable to withstanding these heat loads are steel, stainless steel, or alloys like Inconel® or Hastelloy®.

It is possible to provide different embodiments of solar receivers (2), sometimes keeping the previously explained disc geometry or with other geometrical shapes like those described hereinafter. If a disc geometry is used, it is possible to shape the solar receiver (2) either like a complete circle, or like circular sectors, like one quarter of a circle sector, one eighth of a circle sector or other submultiples. Thus, the solar

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receiver (2) that can be seen in figure 2 can be valid, in its entirety, for a Stirling engine (3), or it could be that the sectioned circle quadrant of said figure 2 can be used to feed a cylinder of said Stirling engine (3). In any case, as any person skilled in the art may understand, the chosen embodiment does not affect the configuration explained herein, or the essence of the invention.

Figure 4 shows other possible embodiments of the receiver (2) with geometries differing from the dish shown in figure 2. Thus, figure 4A shows a receiver with a shape of a hollow semi-cone, in such a way that solar radiation (1) strikes inside the semi-cone, said radiation (1) being reflected along the semi-cone surface. Inside the walls of the semi-cone the structure of the conduits (8), described for the receiver of figure 2, is repeated, which have not been shown in figure 4 for purposes of clarity. Other geometrical shapes are also possible, like a hollow hemisphere, as shown in figure 4B, wherein solar radiation (1) also strikes the internal surface of the hemisphere, heating it, and then, heating the working fluid which flows in the internal conduits (not shown). Figure 4C shows a last embodiment of the receiver (2), in the configuration of a hollow regular polyhedron, like for instance, an octahedron, dodecahedron, icosahedra or other polyhedrons. Similarly, to the preceding cases, solar radiation (1) strikes the internal walls of the polyhedron, enduring successive reflection processes and heating the internal surface of the polyhedron. When heated, these walls carry out the heat transfer to the fluid that flows inside them, in the already explained, corresponding conduits (and not shown in figure 4).

Any person skilled in the art will understand the scope of the invention and the advantages derived thereof. The terms used to describe the invention must be taken in the broad and not limitative sense, the main distinctive features of this invention being described in the following claims.

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SOLAR RADIATION RECEIVER

DESCRIPTION

OBJECT OF THE INVENTION

The present invention discloses a solar radiation receiver, applicable to the conversion of solar energy into thermal and electrical energy. Its use has a relevant interest in the power generation industry.

PROBLEM TO BE SOLVED. BACKGROUND OF THE INVENTION

Currently there are three big technologies exploiting solar energy to turn it into thermal and electrical energy, cylinder-parabolic receivers, tower solar system with heliostat field, and parabolic dishes. The present invention is centered in the latter technology, wherein solar radiation strikes on a paraboloid (a "parabolic dish", that is usually a paraboloid with a circular section), and a heat machine is located at its focus. This heat machine is usually a perfected Stirling engine (initially described by Robert Stirling in his patent of 1816, see document GB 4081 A.D. 1816) which operates between a hot focus (a solar radiation receiver) and a cold focus. The mechanical energy that the Stirling engine or an equivalent engine, produces, actuates an alternator that generates electrical energy.

As aforementioned, in the systems with parabolic dishes the solar radiation is received on the receiver. Said receiver heats a working gas, which actuates the heat engine. For a given thermal energy, increasing the receiver performance involves increasing the working gas temperature, and consequently, increasing the engine performance. This causes the total performance of the machine to be more efficient.

The Stirling engines that have been used in these solar plants have utilized receivers formed by a tube bundle, which is located facing the paraboloid axis. However, in this configuration, the surface which has been used by the thermal energy coming from the concentrator (the parabolic dish), is only a percentage of the concentrator projection. Besides, the tube bundles that are used in the state of the art are devices made up of a plurality of pieces, which are welded to each other and to the collector. This type of welded construction generates, relatively often, mechanical tension problems when the device is subjected to thermal cycles, which many times result in material stressing and its subsequent breaking. On the other hand, it is quite

common that those devices that follow the Stirling cycle use hydrogen as the working fluid to improve their performance. Given that H_2 burns in contact with the air, the shapes provided for in the current state of the art imply a risk of fire and explosion.

To solve the aforementioned problems, the present invention proposes a solar receiver (that in some shapes it is flat, and in others it is not), that uses the entire projected surface of the concentrator, so the used area is maximum. Moreover, its construction is more robust and safer than the tube bundle solution that has been typically used up to now, since it avoids the currently existing problems arising from the welded joints of the different components.

Diverse shapes of solar receivers linked to Stirling engines are known in the current state of the art there. Thus, document GB 2296047 A1 describes a Stirling engine with a crankshaft over which a structure is assembled, and a series of flexible diaphragms defining the working chambers, hot and cold, wherein the working fluid flows, is linked thereto. Document CN 201433829 Y discloses a heat cavity absorber for the Stirling engine of a solar device, with U-shaped channels.

Document US 4114597 A discloses a unitary solar collector for transfer of thermal energy which is a synthetic thermoplastic unit. The unit has a solar-energy transmitting region and a solar-energy absorbing regions. The unit is useful for heating purposes.

Document WO 01/61254 A1 discloses a high temperature solar absorber which is comprised of a crucible-shaped absorber wall constructed as a hollow wall and comprising an inner wall and a supporting wall, the absorber wall being made of a high-temperature ceramic material. The interior of the hollow wall is provided with a channel structure which is filled with a porous material. A gaseous fluid is guided through the channel structure from an inlet to an outlet. Incident solar radiation is absorbed by the absorber wall and is convectively transferred to the fluid.

However, no device with the specific characteristics shown by the present invention has been disclosed.

DESCRIPTION OF THE INVENTION

The described invention discloses a solar radiation receiver that has inlet and outlet collectors, and a series of conduits that go from the inlet collector to the outlet collector, and through which such conduits a working fluid flows that is heated upon receiving solar radiation. The receiver comprises: a) an upper layer where the solar

radiation strikes; b) at least one intermediate layer, located under the upper layer, where the conduits, through which the working fluid flows, are placed; and c) a lower layer, located under the at least one intermediate layer, into which the inlet and outlet collectors for the working fluid are coupled. The device construction is carried out in such a way that the upper layer, the at least one intermediate layer, and the lower layer, make up one single piece.

The conduits through which the working fluid flows, have either a triangular section, or a rectangular one with rounded ends, or elliptical, or regular polygonal, or circular, or a combination of two of the aforementioned geometries.

When there is more than one intermediate layer in the receiver, each of these intermediate layers is provided in the inside thereof with conduits through which the working fluid flows.

The conduits that are located in the intermediate layer(s) are arranged laid out like a labyrinth, covering the whole used surface of the intermediate layer(s) of the receiver.

Said piece from which the receiver is made, is an alloy capable of withstanding high temperatures, above 600 °C, like steel, stainless steel or alloys like Inconel® or Hastelloy®.

The receiver can be shaped according to different geometrical shapes, exhibiting some of these configurations geometries such as: circular or circular sector, hollow semi-cone, hollow semi-sphere or a hollow polyhedron cut in half.

DESCRIPTION OF THE FIGURES

The invention is easily understood in view of the contents of the specification together with the figures, in which numerical references are used to indicate the different elements that form the invention.

- Figure 1 is a schematic view of an external combustion heat engine applicable to heliothermal devices with parabolic dishes.
- Figure 2 is a perspective view of a receiver, in its flat shape, with a partial section, wherein the conduits through which the working fluid flows can be observed.
- Figure 3 is a detailed view of the receiver section, wherein the different shapes of the conduits are shown.
- Figure 4 shows other shapes as alternatives to the flat receiver shape, such as

a semi-cone shaped receiver (figure 4A), hemisphere-shaped (figure 4B) or with the shape of a regular polyhedron cut in half (figure 4C) like a dodecahedron.

Next a list is provided with the different elements represented in the figures that form the invention: 1 = solar radiation (direct or reflected); 2 = receiver; 3 = heat engine coupled to the parabolic dish; 4 = alternator; 5 = upper layer; 6 = intermediate layer; 7 = lower layer; 8 = conduits; 9 = inlet and outlet collectors of the working fluid; a = semi-minor axis of the ellipse; b = semi-major axis of the ellipse; c = radius; d = thickness of the upper layer; e = thickness of the intermediate layer; f = thickness of the lower layer; m = side of the polygon; r = radius of the circle; t = basis of the conduit; l = sides of the conduit; v = conduit vertex.

DETAILED DESCRIPTION OF THE INVENTION

As it has already been stated, and as it can be seen in figure 1, the invention consists of a solar receiver applicable in heliothermic parabolic dishes that use external combustion engines. A Stirling engine (3) or the like is located in the focus of a parabolic dish (not shown); the heat engine (3) has a solar radiation (1) receiver (2), with a series of channels through which a working fluid (usually H_2) flows, and a set of coolers-regenerators. All these elements are assembled over an engine base as the state of the art documents disclose, and that is why they have not been shown in figure 1. Usually each cylinder arrangement of the heat engine (3) has a cooler, a regenerator and a receiver (2) connected thereto; in this case, the receiver (2) has a "flat" shape with a disc or circle shape, even though other arrangements are also possible, as it will be described hereinafter.

The working fluid that flows in the heat engine (3) reaches the solar receiver (2) when a heat engine (3) cycle has been completed; this way, and due to the heat transfer processes taking place in the receiver (2) upon receiving the solar radiation (1), the working fluid increases its enthalpy and then it is directed to the Stirling heat engine (3) where it flows. The working fluid expands in the heat engine (3), providing movement to the crankshaft or the like (not shown), which actuates an alternator (4) thus producing electric energy. Therefore, the purpose of the receiver (2) is to increase the enthalpy of the working fluid, which flows cyclically in the heat engine (3) to produce electricity through an alternator (4).

The receiver (2) receives solar radiation (1) by reflection on the internal surface of the paraboloid, given that said receiver (2) is located at the focus of the parabolic

dish (not shown), and oriented towards the paraboloid. Therefore, the solar radiation (1) reaching the parabolic dish concentrates on its focus, heating the receiver (2) uniformly. Alternatively, the radiation can reach the receiver through concentration lenses such as Fresnel-type or the like.

Figure 2 represents a view of the receiver (2), wherein one of its quarters is sectioned. Said section is in turn cut along a plane AA to show the conduits (8) through which the working fluid that is heated in the receiver (2) flows, and then said fluid flows into the Stirling heat engine (3) or the like. The receiver (2) is provided with a series of collectors (9) through which the working fluid enters and exits. Initially, the working fluid coming from the Stirling engine (3) reaches one of the inlet collectors (9), flows through the conduits (8) of the receiver (2), being heated due to the incident solar radiation (1) striking the receiver (2). Once it has covered the path described by the conduit (8), the working fluid leaves the receiver (2) going to the Stirling engine (3) through which the according outlet collector (9), said working fluid flowing into the engine (3).

The receiver (2) is an element made of one single piece, even though given its structure a hypothetical discretization in three layers or strata can be carried out, as it can be observed in figure 2 and, in more detail, in figure 3. There is a first upper layer (5) whose external part is the one receiving solar radiation (1), since that external part is the surface of the receiver (2). Said upper layer (5) has a thickness "d". Under the first upper layer (5) there is, at least, one intermediate layer (6), with a thickness "e", although other embodiments can include more than one of said intermediate layers (6). In any case, each and every one of the intermediate layers (6) are provided with conduits (8) through which the working fluid flows towards the Stirling engine (3). For the purpose of making the invention clear, in figures 2 and 3 only one single intermediate layer (6) has been shown. Finally a lower layer (7), with thickness "f", is arranged under the intermediate layer (6).

Schematically, the heat transfer process is as follows: as the solar radiation (1) strikes the receiver (2) surface, thus heat is transferred by conduction along the upper layer (5). Next, said transfer by conduction is transmitted to the rest of the elements of the receiver (2): along the existing intermediate layers (6), down to the lower layer (7), and towards the conduits (8). Therefore, the working fluid that flows into the conduits (8) increases its enthalpy due to the heat transfer that is now received by convection, and, to a lesser degree, also due to radiation. The shape of the conduits (8) along the intermediate layer(s) (6) is labyrinthine, to increase the path thereof with respect to the

used surface of the receiver (2) and thus to optimise the heat transfer. Therefore, most of the heat transfer takes place from all the layers (5, 6, 7) towards the fluid flowing through the conduits (8). Even so, part of the heat is still transferred towards the lower layer (7) area. As those skilled in the art very well know, other heat transfer phenomena by radiation and convention to the atmosphere along the entire surface of the receiver (2) also take place, even though said processes can be considered less significant than the heat transfer from the different layers (5, 6, 7) to the fluid flowing through the conduits (8).

Figures 2 and 3 show (the latter with more details than the former) possible embodiments of the geometry conduits (8). For the purpose of simplifying the description, five embodiments of the conduits (8) section have been shown (figure 3), these shapes being: A, triangular; B, rectangular with rounded ends; C, elliptical; D, regular polygonal; and E, circular. Section A has a triangular shape (typically isosceles), with a base (t) and sides (l) converging at a vertex (v), pointing towards the lower layer (7). Section B has a rectangular shape, with a side "e" equal to the thickness of the intermediate layer (6), even though the top and the bottom end in a semicircle of radius "c". Section C is an ellipse with a semi-minor axis "a" and semi-major axis "b". Section D is a regular polygon with side "m"; in the case of figure 3, a regular octagon has been shown. Section E is a circle with a radius "r". Experience has shown that the geometries of these conduits (8) are the most adequate according to diverse physical parameters of the working fluid, like the Reynolds number, the velocity, its pressure, and its temperature.

Only some of the five configurations (A, B, C, D, or E) which are shown in figures 2 and 3, or combinations thereof, are provided; for instance, a conduit half polygonal – half circular, or other possible combinations based on the configurations A, B, C, D, or E. Figure 3 represents all the initial configurations over the same receiver, to show the possible alternatives, but it must be understood that for a given receiver (2), the geometry of the conduits (8) is only one of the options A to E shown (or combinations thereof).

Experimentally it has been proven that the best option to manufacture the receiver (2) is by means of an additive layer manufacturing process. In such a way that the upper layer(5), the intermediate layer(s) (6) and the lower layer (7) are manufactured in one single piece; said piece is, preferably, made in an alloy capable of withstanding high temperatures, above 600 °C. Experimentally it has been proven that

adequate materials capable to withstanding these heat loads are steel, stainless steel, or alloys like Inconel® or Hastelloy®.

It is possible to provide different embodiments of solar receivers (2), sometimes keeping the previously explained disc geometry or with other geometrical shapes like those described hereinafter. If a disc geometry is used, it is possible to shape the solar receiver (2) either like a complete circle, or like circular sectors, like one quarter of a circle sector, one eighth of a circle sector or other submultiples. Thus, the solar receiver (2) that can be seen in figure 2 can be valid, in its entirety, for a Stirling engine (3), or it could be that the sectioned circle quadrant of said figure 2 can be used to feed a cylinder of said Stirling engine (3). In any case, as any person skilled in the art may understand, the chosen embodiment does not affect the configuration explained herein, or the essence of the invention.

Figure 4 shows other possible embodiments of the receiver (2) with geometries differing from the dish shown in figure 2. Thus, figure 4A shows a receiver with a shape of a hollow semi-cone, in such a way that solar radiation (1) strikes inside the semi-cone, said radiation (1) being reflected along the semi-cone surface. Inside the walls of the semi-cone the structure of the conduits (8), described for the receiver of figure 2, is repeated, which have not been shown in figure 4 for purposes of clarity. Other geometrical shapes are also possible, like a hollow hemisphere, as shown in figure 4B, wherein solar radiation (1) also strikes the internal surface of the hemisphere, heating it, and then, heating the working fluid which flows in the internal conduits (not shown). Figure 4C shows a last embodiment of the receiver (2), in the configuration of a hollow regular polyhedron, like for instance, an octahedron, dodecahedron, icosahedra or other polyhedrons. Similarly, to the preceding cases, solar radiation (1) strikes the internal walls of the polyhedron, enduring successive reflection processes and heating the internal surface of the polyhedron. When heated, these walls carry out the heat transfer to the fluid that flows inside them, in the, already explained, corresponding conduits (and not shown in figure 4).

Any person skilled in the art will understand the scope of the invention and the advantages derived thereof. The terms used to describe the invention must be taken in the broad and not limitative sense, the main distinctive features of this invention being described in the following claims.