(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 3 670 027 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
24.06.2020 Bulletin 2020/26

(21) Application number: **18382964.7**

(22) Date of filing: **20.12.2018**

(51) Int Cl.:
B22D 11/124 *(2006.01)* ***B22D 11/22*** *(2006.01)*
C21D 9/00 *(2006.01)* ***C21D 11/00*** *(2006.01)*
F27D 17/00 *(2006.01)* ***F28D 21/00*** *(2006.01)*
F28F 13/18 *(2006.01)* ***F28F 27/00*** *(2006.01)*

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(71) Applicants:
- **Fundación Tekniker**
  20600 Eibar (Guipuzkoa) (ES)
- **Fundación Tecnalia Research & Innovation**
  20009 San Sebastián, Guipúzcoa (ES)

(72) Inventors:
- **López Pérez, Susana**
  20600 Eibar (ES)
- **Febres Pascual, Jesus**
  20600 Eibar (ES)
- **Ubieta Astigarraga, Eduardo**
  20600 Eibar (ES)
- **del Hoyo Arce, Itzal**
  20600 Eibar (ES)
- **Iturralde Iñarga, Jon**
  20009 San Sebastián - Guipúzcoa (ES)
- **Gómez de Arteche Botas, Mercedes**
  20009 San Sebastián - Guipúzcoa (ES)
- **Arroiabe, Peru Fernandez**
  20500 Arrasate (ES)
- **Bou-Ali Saidi, Mohammed Mounir**
  20500 Arrasate (ES)
- **Martinez-Agirre, Manex**
  20500 Arrasate (ES)
- **Diaz de Mendibil Bermejo, Andoni**
  20009 San Sebastián - Guipúzcoa (ES)
- **Aguirre Mugica, Patricio**
  20009 San Sebastián - Guipúzcoa (ES)

(74) Representative: **Balder IP Law, S.L.**
Paseo de la Castellana 93
5a planta
28046 Madrid (ES)

(54) HEAT CAPTURING DEVICE

(57) Examples relate to a heat capturing device comprising: an upper side and lateral sides connected to the upper side, said connected sides define an energy capturing space. The device comprises an energy insulating layer, an intermediate energy reflecting layer and an inner energy capturing layer capturing energy from at least an object located inside the energy capturing space. The inner energy capturing layer comprises a structure of tubes which captures energy or heat. The width and the height of the inner energy capturing layer is based on at least one parameter of the object or on parameter of the inner energy capturing layer or on one parameter of the energy capturing space or a combination thereof.

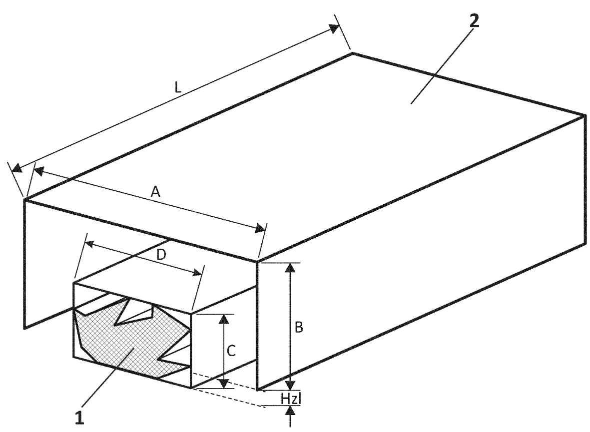

FIG. 1

EP 3 670 027 A1

Description

TECHNICAL FIELD

[0001] The present invention relates to the field of radiant energy or heat collector assemblies. More particularly, it refers to methods and systems for recovering or capturing heat in the form of radiant energy and using the recovered energy for further purposes such as heating of buildings, electricity production or steam generation. The heat capturing device can be applied in industries such as in steel mills, metallurgy, furnaces or glass production or any other energy intensive industry with high radiant emissions.

STATE OF THE ART

[0002] The European patent application EP2403668 (A2) discloses a heat retrieving system in which heat is retrieved via conduction and convection. This patent application uses the transportation rollers as heat exchangers. The patent application DE3019714 (A1) discloses a heat collection arrangement comprising water containing tubes. The prior art is silent on heat collection devices especially configured for capturing heat transferred by radiation. It is therefore required a technical arrangement recovering radiant energy or heat from an object or objects being at temperature higher than 500° C.

[0003] There is the general belief that optimal dimensions of the heat capturing device collecting energy tend to be minimum. However, the present application proves it is not necessarily the case because the dimensions or the size of a device collecting more energy than the known devices or systems depend on several factors. The present application achieves the unexpected technical effect of finding which are the dimensions of the heat capturing device that enable collecting more energy from an object at high temperature than the systems or devices in the prior art.

DESCRIPTION OF THE INVENTION

[0004] The present application overcomes the drawbacks of the prior art and allows higher energy or heat retrieval of the heat or energy radiated by an object or group of objects.

[0005] Claim 1 discloses the scope of the present realization. Preferred realizations are disclosed in claims 2-16. The described heat capturing device comprises an upper side and lateral sides connected to the upper side, said connected sides defining an energy capturing space. The device further comprises an energy insulating layer, an intermediate energy reflecting layer and an inner energy capturing layer capturing energy from at least a radiation emitting object (hereinafter referred to as "object") located at least partly in the energy capturing space. The inner energy capturing layer comprises at least one material containing structure. The material may be a heat transfer fluid (hereinafter referred to as fluid), for example a liquid such as silicon based thermal oil, for capturing energy. The material containing structure may be at least a tube having preferably a circular cross-section. The dimensions of the inner energy capturing layer (width and height of the inner energy capturing layer), and thus, the dimensions of the heat capturing device as a whole including the intermediate energy reflecting layer, the energy insulating layer and the energy capturing space defined, are based, at least, on the dimensions of the at least an object in the energy capturing space and based on at least a further parameter. Said further parameter may be at least one of: at least one further parameter of said at least an object or at least one parameter of the inner energy capturing layer or at least one parameter of the energy capturing space or a combination of said further parameters. Said further parameter or parameters of the inner energy capturing layer may be intrinsic parameters of the surface of the inner energy capturing layer defining the energy capturing space.

[0006] In the heat capturing device, the energy insulating layer may entirely cover the intermediate energy reflecting layer, and the intermediate energy reflecting layer may entirely cover the inner energy capturing layer.

[0007] A further plate or plates may be located at the entrance or exit of the energy capturing space for better retaining and/or reflecting the radiant heat or energy of the object or objects inside the energy capturing space. The plate or plates located at the entrance and/or exit of the energy capturing space may be made of a heat or energy reflecting material. The energy insulating layer may be covered with an outer casing or outer cover for protecting and encapsulating the heat capturing device. The described layers may be different layers which may be separated from each other. The heat capturing device may be connected to a bottom layer or plate or surface made of either reflecting or insulating heat material.

[0008] The parameter or parameters defining the width and the height of the inner energy capturing layer may be, for example, at least one of: the convection coefficient of the air inside the energy capturing space, the emissivity and absorptivity of at least one of the surfaces of the object, the emissivity and absorptivity of at least one of the surfaces of the inner energy capturing layer or a combination of said parameters. The emissivity and absorptivity of a surface are magnitudes indicating its effectiveness in emitting or absorbing (respectively) thermal radiation. Quantitatively, they are described as the ratio between the thermal radiation emitted/absorbed by a surface compared to the radiation emitted/absorbed by an ideal black body at the same temperature (which is maximum).

[0009] The parameter or parameters defining the height and width of the heat capturing device may be based on some intrinsic properties of the objects which are to be received in the energy capturing space or transported through the energy capturing space. The objects can be for example a slab, billet or beam resulting from a production process such as a metallurgic production process or preferably a piece of hot glass (e.g. bottle shaped glass) produced by a glass production factory. Said production processes may serially produce objects such as slabs or hot pieces of glass, and some properties of said serially produced objects or pieces are known. The objects may be solid or partly solid objects. The objects are preferably at a temperature higher than 500° C. The fact that the characteristics of the production of the object or objects are known in advance, means that the properties of the product after the production process and before entering the energy capturing space are known. The fact that the heat capturing device of the present application allows a modular construction permits the customization of the size or dimensions of the heat capturing device or tailoring the size of the heat capturing device according to the properties of the objects, thus allowing to capture the radiated heat from the objects when the objects are partly or completely in the energy capturing space or even slightly outside the energy capturing space. The width and the height of the inner energy capturing layer can be selected based on said properties of the object, which implies that the width and height of the heat capturing device as a whole is selected based on at least the properties of the objects or parameters taking into consideration the properties of the object. The heat capturing device and its size may be configured before the production process of the objects start. The modularity of the heat capturing device permits the heat capturing device to be assembled and/or remove parts of the heat capturing device easily.

[0010] The inner energy capturing layer, for example a tube bundle, may cover an inner surface of a tunnel-shaped surface defined by the energy capturing space or may have a tunnel-shaped arrangement, and the diameter of the tubes of the bundle may be the same or similar. The dimensions or the size of the tube bundle are defined in such a way that the heat captured by the heat capturing device is maximized, mainly the heat transmitted by radiation. The arrangement of the tube bundle may be perpendicular or parallel to the direction of movement of the objects being transported (e.g. objects entering, leaving or being transported through the energy capturing space or objects remaining for some time in the energy capturing space). Heat losses due to convection and radiation of the surfaces of the heat capturing device (e.g. the tubes of the bundle) are minimized using insulating materials. The heat capturing device, and more particularly the inner energy capturing layer may be designed to operate with the fluid flowing through the tubes at a medium fluid temperature around 350° C. In some examples and depending on the temperature of the objects from which radiated heat is going to be captured, the fluid may be at a temperature that satisfies a heat demand with temperatures between 600 and 140° C. In some other examples, the fluid may be at a temperature that satisfies a heat demand with temperatures between 140 and 40° C.

[0011] The tubes of the bundle may be separated from each other. More preferably, the distance between the center of two consecutive tubes may be between 1,25 and 2 times the external diameter of a tube of the bundle.

[0012] The bundle of tubes may be connected, e.g. welded, to at least two headers. The headers may be to feed the fluid to the inner energy capturing layer with the fluid being at a first temperature, to distribute the fluid through the inner energy capturing layer such the fluid may increase its temperature from the first temperature to a second temperature by absorbing heat from the object or objects, and to remove the fluid from the inner energy capturing layer with the fluid at the second temperature. In some examples, the second temperature may be higher than the first temperature. The headers may transport the fluid from/to a fluid storage or to any other device that may reuse the recovered energy for similar or different purposes such as heating of buildings, electricity production or steam generation.

[0013] The external surface of the bundle of tubes, i.e., the surface of the bundle of tubes facing the object, may be covered with a high absorptivity coating or with a high absorptivity paint. The paint may have as much absorptivity as possible in near and mid-infrared spectrum, and at least higher than the corresponding values of the base material of the inner capturing layer. For example, the paint may have an absorptivity around 0,97 for a wavelength between 2-3 microns.

[0014] The intermediate energy reflecting layer may have a flat structure such as a plate or a corrugated shaped structure or surface or layer behind the bundle of tubes. The corrugated shaped structure may be a sinus shaped surface or sinus shaped structure. The convex part of the corrugated shaped structure is located in correspondence with at least one of the tubes of the bundle and the concave part of the corrugated shaped structure is located in correspondence with at least one of the separations between the tubes. The corrugated or wavy or sinus shaped structure is designed to better focus the reflected heat towards the rear part of the tubes for allowing better heat or energy absorption of the reflected heat, thus allowing an enhanced heat exchange with the rear part of the tubes.

[0015] The heat capturing device may comprise an energy insulating layer surrounding the intermediate energy reflecting layer. The energy insulating layer may be made of ceramic fiber. The insulating layer may be a separate layer from the other layers.

[0016] The heat capturing device may further comprise an outer casing covering the energy insulating layer. The outer casing, that may be made of metal, contains and protects the heat capturing device.

[0017] The heat capturing device may comprise one or several sensors. The sensors may be of the same type or may be a combination of different types of sensors. The sensors may be: one or more sensors for measuring the temperature of the object or objects, one or more sensors for measuring the temperature of the energy capturing space, one or more sensors for measuring the temperature inside the tubes or the temperature of the fluid within the tubes, one or more sensors for detecting the object either entering into, or exiting out of or remaining in the energy capturing space or any combination of said sensors. The sensors may be connected to control means, such as a controller or processor or group of processors for processing the information received from the sensors. The control means may process the data received form the sensors and may issue instructions or control data based on the sensed data as provided by one or more of said sensors, based on the processed data or based in a combination of the data as received and the data after being processed.

[0018] The heat capturing device may comprise transport means for moving the object or objects relative to the energy capturing space. The transport means may be managed by control means, the control means configured to control the transport of the object from or to the energy capturing space. The heat capturing device automatically transports the object to or from the energy capturing space based on a certain temperature captured by at least one or more sensors exceeding or being below a predetermined threshold. Said threshold may define a temperature threshold. The transport means may transport the object through the energy capturing space or may leave the object in the energy capturing space for a predetermined time interval so that the inner energy capturing layer captures heat from the object. The transport means transport the object or objects through the energy capturing space in case the tunnel-shaped heat capturing device or tunnel-shaped inner energy capturing layer is open on both sides, that means no plate or door is placed at the entry and exit of the tunnel-shaped heat capturing device. In case a plate or door is located at the exit of the tunnel-shaped heat capturing device, the transport means use the open entry for entering and removing the object or objects to/from the energy capturing space.

[0019] The device may comprise further control means, wherein the control means are configured for controlling the quantity of fluid and/or the speed of the fluid circulating in the bundle of tubes, wherein the control means automatically control said quantity and/or speed of fluid based on the data captured by at least one of the sensors. The control means may process the data received from the sensors and based on said processing, the control means may issue instructions or control data. The instructions may control the transport means such as its speed, start and stop functions, may control the quantity of fluid circulating in the bundle of tubes, may control the quantity of fluid in the headers and may control the speed of fluid circulating in the tubes or in the bundle of tubes. The transport means are preferably controlled for transporting the object or objects such that the objects or objects are symmetrically placed or located inside the energy capturing space or symmetrically placed or located while being transported through the energy capturing space. The control means may control the transport means and the speed of transport of the object or objects entering or leaving the energy capturing space. This may be useful in cases in which the object or objects are transported through the energy capturing space. Moreover, the control means may control the time period an object or objects remain the energy capturing space and it can be implemented by the control means controlling the transport means for stopping and starting the transport means.

[0020] The instructions of the control means may control the transport means and all devices regulating the flow and/or temperature of fluid in the tubes or headers.

[0021] The distance of the respective lateral sides of the object to the respective corresponding closest surface or sides of the inner energy capturing layer (e.g. bundle of tubes) is preferably the same, or equal or almost the same, while the object (or objects) is in the energy capturing space.

[0022] A method for capturing energy as indicated by the heat capturing device may be implemented.

[0023] The heat captured by the inner energy capturing layer, and more particularly by bundle of tubes, may be defined as follows:

$$Q_2 = \frac{\varepsilon_2 \cdot \sigma \cdot T_2^4 - \alpha_2 \cdot \left\{ \dfrac{\dfrac{\varepsilon_2 \cdot \sigma \cdot T_2^4 + (1-\alpha_2) \cdot F_{23}.\sigma \cdot T_3^4}{[(1-\alpha_2)\cdot(F_{21}+F_{23})+\alpha_2]} + \dfrac{(1-\alpha_2)\cdot F_{21}\cdot(\varepsilon_1 \cdot \sigma \cdot T_1^4 + (1-\alpha_1)\cdot F_{13}\cdot \sigma \cdot T_3^4)}{[(1-\alpha_2)\cdot(F_{21}+F_{23})+\alpha_2]\cdot[(1-\alpha_1)\cdot(F_{12}+F_{13})+\alpha_1]}}{1-\left(\dfrac{(1-\alpha_2)\cdot F_{21}\cdot(1-\alpha_1)\cdot F_{12}}{[(1-\alpha_2)\cdot(F_{21}+F_{23})+\alpha_2]\cdot[(1-\alpha_1)\cdot(F_{12}+F_{13})+\alpha_1]}\right)} \right\}}{\dfrac{(1-\alpha_2)}{A_2}}$$

$$+ h_{conv} \cdot A_2 \cdot (T_2 - T_3)$$

[0024] Wherein the nomenclature is the following:

F_{ij} View factor from surface "i" to surface "j" (according to figure 4).
A_i Area of the different surfaces.
T_i Temperature of the different surfaces.
ε_i Emissivity of the different surfaces.

α_i Absorptivity of the different surfaces.
σ Stefan-Boltzman constant 5,67.10^{-8} W/m^{2}K^4.
h_{conv} Convection coefficient of the air inside the energy capturing space (tunnel).

Subscripts:

[0025]

1 Object.
2 Inner energy capturing layer or heat capturing device.
3 Surface that closes the energy capturing space.

[0026] A heat capturing system is further described. Said heat capturing system comprises a heat capturing device as previously described and at least one object located at least partly in the energy capturing space. In such system, the heat capturing device is configured to capture heat from the at least one object that is inserted into the energy capturing space defined by the upper side and lateral sides connected to the upper side of the heat capturing device. The at least one object is cooled by capturing the heat irradiated from the object by the inner energy capturing layer of the heat capturing device.

[0027] Additional advantages and features of the invention will become apparent from the detailed description that follows and will be particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] To complete the description and in order to provide for a better understanding of the invention, a set of drawings is provided. Said drawings form an integral part of the description and illustrate an embodiment of the invention, which should not be interpreted as restricting the scope of the invention, but just as an example of how the invention can be carried out. The drawings comprise the following figures:

Figure 1 shows a schematic representation of a system for carrying out the method of the invention.
Figure 2 shows a rectangle to rectangle in a perpendicular plane; all boundaries are parallel or perpendicular to x and ξ boundaries.
Figure 3 shows a rectangle to rectangle in a parallel plane; all boundaries are parallel or perpendicular to x and ξ boundaries.
Figure 4 shows a rectangular heat capturing device's and object's surfaces listed.
Figure 5 shows a view factor of the object's wall to heat capturing device's roof.
Figure 6 shows a view factor of the object's wall to heat capturing device's wall.
Figure 7 shows a view factor of the object's top wall to heat capturing device's wall.
Figure 8 shows a view factor of the object's top wall to heat capturing device's roof.
Figure 9 shows all heat transfer phenomena in the energy capturing space.
Figures 10-12 show a graphical representation of the listed cases 1-8 mentioned in the following Table 1, in which the heat capturing device and the object in the heat capturing device are represented. The representation may be considered as a proportional representation of the dimensions of the heat capturing device relative to the dimensions of the object.
Figure 13 shows a perspective view of an example tunnel-shaped heat capturing device using the tubes and the energy insulating layer, the tubes being positioned substantially perpendicular to the direction of displacement of the at least one object relative to the tunnel-shaped heat capturing device.
Figure 14 shows a cross-sectional representation of the tunnel-shaped heat capturing device and the further layers of the tunnel-shaped heat capturing device of figure 13.
Figure 15 shows a perspective view of another example tunnel-shaped heat capturing device using the tubes and the energy insulating layer, the tubes being positioned substantially parallel to the direction of displacement of the at least one object relative to the tunnel-shaped heat capturing device.
Figure 16 shows a cross-sectional representation of the tunnel-shaped heat capturing device and the further layers of the device of figure 15.
Figure 17 shows a perspective view of an example inner energy capturing layer.
Figure 18 shows a representation of an example architecture of some tubes of the tube bundle forming the inner energy capturing layer and a representation of the corrugated intermediate energy reflecting layer.

DESCRIPTION OF A WAY OF CARRYING OUT THE INVENTION

[0029] The present description represents exemplary embodiments on how to carry out the present invention.

Equation development for calculating the size and shape of the heat capturing device

[0030] The heat capturing device's geometry (see figure 1), in particular the width (A) and the height (B) of the inner energy capturing layer; the object's (or objects') geometry, in particular the height (C) and the width (D) of the object, considering that the object or objects are assimilated to a parallelepiped of smaller volume that can contain them; and the spatial relationship between the heat capturing device and the at least one object, in particular, the height of the position of the heat capturing device relative to the at least one object, influence the thermal behavior of the heat capturing device. The length (L) is the length to be covered in the process with one or more heat capturing devices lined up next to each other (not the length of an individual heat capturing device).

[0031] In the following lines it is explained the procedure carried out to reach an equation that gives the optimal geometry of the inner energy capturing layer, and thus of the heat capturing device as a whole, for some given conditions. This optimal geometry will maximize the heat flow absorbed by the inner energy capturing layer of the heat capturing device.

[0032] To obtain the equation some assumptions may be considered (see Figure 1):

- In the calculation of the view factors, the heat capturing device 2 and the at least an object 1 have been considered as 3D bodies, where they have a finite length (L). This has been done as the heat capturing device could, in some cases, have a length short enough to make considerable the radiation that is lost at the ends;
- The heat capturing device is in a symmetrical position to the centre of the at least an object;
- For the heat balance equation, it has been considered that the heat capturing device is perfectly insulated from behind (face not exposed to the radiation from the at least one object) due to the intermediate energy reflecting layer and the energy insulating layer included in the heat capturing device design;
- It may have to be specified:

    ◦ the average temperatures (T) of the objects' surface (the surface and the kernel temperature of the object are different), the heat capturing device and the ambient inside the energy capturing space (in the space between the piece and the heat capturing device);
    ◦ the optical properties of the at least one object surfaces and heat capturing device surfaces;
    ◦ the dimensions of the objects considered as the parallelepiped of smaller volume that can contain them (C and D);
    ◦ the height (Hzl) of the position of the heat capturing device relative to the lower surface of the piece (or object) (in case there is any restriction that avoids that both systems are over the same plane);
    ◦ the length (L) to be covered in the process with one or more heat capturing devices;
    ◦ the maximum and minimum dimensions (height and width) the heat capturing device could have due to process constraints;
    ◦ the estimated convection heat transfer coefficient (h_{conv}) of the air between the objects and the heat capturing device.

[0033] Other parameters used in the following calculation are Ai (area of the different surfaces) and α (absorptivity of different surfaces), Ti (temperature of the different surfaces), ε_i (Emissivity of the different surfaces), α_i (aabsorptivity of the different surfaces), σ (Stefan-Boltzman constant $5{,}67.10^{-8}$ W/m^2K^4) and h_{conv} (convection coefficient of the air inside the energy capturing space (tunnel). Sub-index 1 refers to the object, sub-index 2 refers to the heat capturing device and sub-index 3 refers to the surface that closes the energy capturing space (see figure 4).

Obtention of the view factor equation

[0034] Based on the equations from the book Thermal Radiation Heat Transfer by Howell, J. R., Mengüç, M. P.& Siegel, R. for "Rectangle to rectangle in a perpendicular plane; all boundaries are parallel or perpendicular to x and ξ boundaries" and "Rectangle to rectangle in a parallel plane; all boundaries are parallel or perpendicular to x and ξ boundaries" and using the properties of the view factors the final view factor between the surfaces have been obtained (See Figures 2 and 3).

Governing equation:

$$F_{1-2}=\frac{1}{(x_2-x_1)(y_2-y_1)}\sum_{l=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{i=1}^{2}\left[(-1)^{(i+j+k+l)}G(x_i,y_j,\eta_k,\xi_l)\right]$$

$$G=\frac{1}{2\pi}\left\{(y-\eta)(x^2+\xi^2)^{1/2}\tan^{-1}(K)-\frac{1}{4}\left[(x^2+\xi^2)\ln(1+K^2)-(y-\eta)^2\ln\left(1+\frac{1}{K^2}\right)\right]\right\}$$

where

$$K\equiv(y-\eta)/(x^2+\xi^2)^{1/2}$$

$$F_{1-2}=\frac{1}{(x_2-x_1)(y_2-y_1)}\sum_{l=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{i=1}^{2}(-1)^{(i+j+k+l)}G(x_i,y_j,\eta_k,\xi_l)$$

$$G=\frac{1}{2\pi}\left(\begin{array}{l}(y-\eta)\left[(x-\xi)^2+z^2\right]^{1/2}\tan^{-1}\left\{\dfrac{y-\eta}{\left[(x-\xi)^2+z^2\right]^{1/2}}\right\}\\ +(x-\xi)\left[(y-\eta)^2+z^2\right]^{1/2}\tan^{-1}\left\{\dfrac{x-\xi}{\left[(y-\eta)^2+z^2\right]^{1/2}}\right\}\\ -\dfrac{z^2}{2}\ln\left[(x-\xi)^2+(y-\eta)^2+z^2\right]\end{array}\right)$$

[0035] Using these equations, the view factor between the heat capturing device and the object has been calculated. During the procedure the nomenclature from Figure 4 has been used.

[0036] The first step is to pose a series of auxiliary variables, which are used in the view factors equations:

$$a=\frac{A_i}{2};b=Hzl+B_i-C_i;c=C_i;d=\frac{D_i}{2};e=a-d;z=\frac{A_i-D_i}{2}$$

$$x_{13\_22}=\begin{Bmatrix}Hzl+B_i-C\\ Hzl+B_i\end{Bmatrix};\ y_{13\_22}=\begin{Bmatrix}0\\ L\end{Bmatrix};\ a_{13\_22}=\begin{Bmatrix}0\\ e\end{Bmatrix};b_{13\_22}=\begin{Bmatrix}0\\ L\end{Bmatrix};$$

$$x_{11\_21}=\begin{Bmatrix}0\\ C_i\end{Bmatrix};\ y_{11\_21}=\begin{Bmatrix}0\\ L\end{Bmatrix};\ a_{11\_21}=\begin{Bmatrix}Hzl\\ Hzl+B_i\end{Bmatrix};\ b_{11\_21}=\begin{Bmatrix}0\\ L\end{Bmatrix};$$

$$x_{12\_21}=\begin{Bmatrix}z\\ D_i+z\end{Bmatrix};\ y_{12\_21}=\begin{Bmatrix}0\\ L\end{Bmatrix};\ a_{12\_21}=\begin{Bmatrix}0\\ Hzl+B_i-C_i\end{Bmatrix};b_{12\_21}=\begin{Bmatrix}0\\ L\end{Bmatrix};$$

$$x_{12\_22}=\begin{Bmatrix}z\\ D_i+z\end{Bmatrix};\ y_{12\_22}=\begin{Bmatrix}0\\ L\end{Bmatrix};\ a_{12\_22}=\begin{Bmatrix}0\\ A_i\end{Bmatrix};\ b_{12\_22}=\begin{Bmatrix}0\\ L\end{Bmatrix};$$

[0037] The coordinates x, y, a and b are represented graphically in the Figures 5-8.

Once the auxiliary variables are known, the view factor equations can be posed:

Object's side wall to heat capturing device's side wall:

[0038] View factor from one object's side wall to the opposite heat capturing device walls (11-21 or 13-23). As figure 4 is symmetrical, the view factors from one object's side wall to its opposite heat capturing device's side wall and from the other object's side wall to its opposite is the same:

$$F_{11\_21} = F_{13\_23}$$

[0039] From the equation above:

$$G_{11\_21} = \sum_{l=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{i=1}^{2}(-1)^{i+j+k+l} \cdot \left\{\frac{1}{2\cdot\pi} \cdot \left\{\left[B_{11\_21}(j,l)\cdot\sqrt{C_{11\_21}(i,k)}\cdot\tan\left[\frac{B_{11\_21}(j,l)}{\sqrt{C_{11\_21}(i,k)}}\right]\right] + \left[A_{11\_21}(i,k)\cdot\sqrt{D_{11\_21}(j,l)}\cdot\tan\left[\frac{A_{11\_21}(i,k)}{\sqrt{D_{11\_21}(j,l)}}\right]\right] - \left[\frac{z^2}{2}\cdot Ln\left[A_{11\_21}(i,k)^2 + B_{11\_21}(j,l)^2 + z^2\right]\right]\right\}\right\}$$

[0040] Where:

$$A_{11\_21}(i,k) = x_{11\_21}[i] - a_{11\_21}[k]$$

$$B_{11\_21}(j,l) = y_{11\_21}[j] - b_{11\_21}[l]$$

$$C_{11\_21}(i,k) = A_{11\_21}(i,k)^2 + z^2$$

$$D_{11\_21}(j,l) = B_{11\_21}(j,l)^2 + z^2$$

[0041] Finally:

$$F_{11\_21} = \frac{G_{11\_21}}{\left[\left(x_{11\_21}[2] - x_{11\_21}[1]\right)\cdot\left(y_{11\_21}[2] - y_{11\_21}[1]\right)\right]} = F_{13\_23}$$

Object's side wall to heat capturing device's roof:

[0042] As well as in the previous case, as the figure 4 is symmetrical, the view factor from one object's side wall to the heat capturing device's roof or tunnel's ceiling is the same as the view factor from the other object's side wall to the heat capturing device's roof:

$$F_{13\_22} = F_{11\_22}$$

[0043] From the equation above:

$$G_{13\_22} = \sum_{l=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{i=1}^{2}(-1)^{i+j+k+l} \cdot \left\{\frac{1}{2\cdot\pi} \cdot \left\{\left[\left(B_{13\_22}(j,l)\right)\cdot\sqrt{A_{13\_22}(i,k)}\cdot\tan\left[\frac{B_{13\_22}(j,l)}{\sqrt{A_{13\_22}(i,k)}}\right]\right] - \left[\frac{1}{4}\cdot\left[\left(A_{13\_22}(i,k)\right)-\left(B_{13\_22}(j,l)\right)^2\right]\cdot Ln\left[\left(A_{13\_22}(i,k)\right)+\left(B_{13\_22}(j,l)\right)^2\right]\right]\right\}\right\}$$

[0044] Where:

$$A_{13\_22}(i,k) = x_{13\_22}[i]^2 + a_{13\_22}[k]^2$$

$$B_{13\_22}(j,l) = y_{13\_22}[j] - b_{13\_22}[l]$$

[0045] Finally:

$$F_{13\_22} = \frac{G_{13\_22}}{\left[\left(x_{13\_22}[2]-x_{13\_22}[1]\right)\cdot\left(y_{13\_22}[2]-y_{13\_22}[1]\right)\right]} = F_{11\_22}$$

Object's upper wall to heat capturing device's wall:

[0046] In this case also due to the symmetrical shape of the heat capturing device, the view factor from the object's upper wall to any of the heat capturing device's walls is the same:

$$F_{12\_21} = \frac{G_{12\_21}}{\left[\left(x_{12\_21}[2]-x_{12\_21}[1]\right)\cdot\left(y_{12\_21}[2]-y_{12\_21}[1]\right)\right]} = F_{12\_23}$$

[0047] From the equation above:

$$G_{12\_21} = \sum_{l=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{i=1}^{2}(-1)^{i+j+k+l} \cdot \left\{\frac{1}{2\cdot\pi} \cdot \left\{\left[\left(B_{12\_21}(j,l)\right)\cdot\sqrt{A_{12\_21}(i,k)}\cdot\tan\left[\frac{B_{12\_21}(j,l)}{\sqrt{A_{12\_21}(i,k)}}\right]\right] - \left[\frac{1}{4}\cdot\left[\left(A_{12\_21}(i,k)\right)-\left(B_{12\_21}(j,l)\right)^2\right]\cdot Ln\left[\left(A_{12\_21}(i,k)\right)+\left(B_{12\_21}(j,l)\right)^2\right]\right]\right\}\right\}$$

[0048] Where:

$$A_{12\_21}(i,k) = x_{12\_21}[i]^2 + a_{12\_21}[k]^2$$

$$B_{12\_21}(j,l) = y_{12\_21}[j] - b_{12\_21}[l]$$

[0049] Finally:

$$F_{12\_21} = \frac{G_{12\_21}}{\left[\left(x_{12\_21}[2] - x_{12\_21}[1]\right) \cdot \left(y_{12\_21}[2] - y_{12\_21}[1]\right)\right]} = F_{12\_23}$$

Object's upper wall to heat capturing device's roof:

[0050] From the equation above:

$$G_{12\_22} = \sum_{l=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{i=1}^{2}(-1)^{i+j+k+l} \cdot \left\{\frac{1}{2\cdot\pi} \cdot \left\{\left[B_{12\_22}(j,l)\cdot\sqrt{C_{12\_22}(i,k)}\cdot\tan\left[\frac{B_{12\_22}(j,l)}{\sqrt{C_{12\_22}(i,k)}}\right]\right] + \left[A_{12\_22}(i,k)\cdot\sqrt{D_{12\_22}(j,l)}\cdot\tan\left[\frac{A_{12\_22}(i,k)}{\sqrt{D_{12\_22}(j,l)}}\right]\right] - \left[\frac{b^2}{2}\cdot Ln\left[A_{12\_22}(i,k)^2 + B_{12\_22}(j,l)^2 + b^2\right]\right]\right\}\right\}$$

[0051] Where:

$$A_{12\_22}(i,k) = x_{12\_22}[i] - a_{12\_22}[k]$$

$$B_{12\_22}(j,l) = y_{12\_22}[j] - b_{12\_22}[l]$$

$$C_{12\_22}(i,k) = A_{12\_22}(i,k)^2 + b^2$$

$$D_{12\_22}(j,l) = B_{12\_22}(j,l)^2 + b^2$$

[0052] Finally:

$$F_{12\_22} = \frac{G_{12\_22}}{\left[\left(x_{12\_22}[2] - x_{12\_22}[1]\right) \cdot \left(y_{12\_22}[2] - y_{12\_22}[1]\right)\right]}$$

Total view factor:

[0053] With the previous equations it is possible to calculate the total expression for the view factor from the object to the tunnel defined by the heat capturing device:

$$F_{12} = \left(F_{12\_21} + F_{12\_22} + F_{12\_23}\right)\cdot\frac{Di\cdot L}{A1} + \left(F_{11\_21} + F_{11\_22}\right)\cdot\frac{Ci\cdot L}{A1} + \left(F_{13\_21} + F_{13\_22}\right)\cdot\frac{Ci\cdot L}{A1} = \left(2\cdot F_{12\_21} + F_{12\_22}\right)\cdot\frac{Di\cdot L}{A1} + \left(F_{11\_21} + F_{11\_22}\right)\cdot\frac{Ci\cdot L}{A1}\cdot 2;$$

[0054] Developing the expression:

$$F_{12} = \left(2 \cdot \frac{\sum_{i=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{l=1}^{2}(-1)^{i+j+k+l} \cdot \left\{ \frac{1}{2\cdot\pi} \cdot \left\{ \left[B_{12\_22}(j,l) \cdot \sqrt{A_{12_{22}}(i,k)^2 + b^2} \cdot \tan\left[\frac{B_{12\_22}(j,l)}{\sqrt{A_{12_{22}}(i,k)^2 + b^2}} \right] \right] + \left[A_{12\_22}(i,k) \cdot \sqrt{B_{12\_22}(j,l)^2 + b^2} \cdot \tan\left[\frac{A_{12\_22}(i,k)}{\sqrt{B_{12\_22}(j,l)^2 + b^2}} \right] \right] - \left[\frac{b^2}{2} \cdot Ln\left[A_{12\_22}(i,k)^2 + B_{12\_22}(j,l)^2 + b^2 \right] \right] \right\} \right\}}{D_i \cdot L} + \frac{\sum_{i=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{l=1}^{2}(-1)^{i+j+k+l} \cdot \left\{ \frac{1}{2\cdot\pi} \cdot \left\{ \left[\left(B_{12\_21}(j,l) \right) \cdot \sqrt{A_{12\_21}(i,k)} \cdot \tan\left[\frac{B_{12\_21}(j,l)}{\sqrt{A_{12\_21}(i,k)}} \right] \right] - \left[\frac{1}{4} \cdot \left[\left(A_{12\_21}(i,k) \right) - \left(B_{12\_21}(j,l) \right)^2 \right] \cdot Ln\left[\left(A_{12\_21}(i,k) \right) + \left(B_{12\_21}(j,l) \right)^2 \right] \right] \right\} \right\}}{D_i \cdot L} \right) \cdot \frac{D_i \cdot L}{A_1}$$

$$+ \left(\frac{\sum_{i=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{l=1}^{2}(-1)^{i+j+k+l} \cdot \left\{ \frac{1}{2\cdot\pi} \cdot \left\{ \left[B_{11\_21}(j,l) \cdot \sqrt{A_{11\_21}(i,k)^2 + z^2} \cdot \tan\left[\frac{B_{11\_21}(j,l)}{\sqrt{A_{11\_21}(i,k)^2 + z^2}} \right] \right] + \left[A_{11\_21}(i,k) \cdot \sqrt{B_{11\_21}(j,l)^2 + z^2} \cdot \tan\left[\frac{A_{11\_21}(i,k)}{\sqrt{B_{11\_21}(j,l)^2 + z^2}} \right] \right] - \left[\frac{z^2}{2} \cdot Ln\left[A_{11\_21}(i,k)^2 + B_{11\_21}(j,l)^2 + z^2 \right] \right] \right\} \right\}}{C_i \cdot L} + \frac{\sum_{i=1}^{2}\sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{l=1}^{2}(-1)^{i+j+k+l} \cdot \left\{ \frac{1}{2\cdot\pi} \cdot \left\{ \left[\left(B_{13\_22}(j,l) \right) \cdot \sqrt{A_{13\_22}(i,k)} \cdot \tan\left[\frac{B_{13\_22}(j,l)}{\sqrt{A_{13\_22}(i,k)}} \right] \right] - \left[\frac{1}{4} \cdot \left[\left(A_{13\_22}(i,k) \right) - \left(B_{13\_22}(j,l) \right)^2 \right] \cdot Ln\left[\left(A_{13\_22}(i,k) \right) + \left(B_{13\_22}(j,l) \right)^2 \right] \right] \right\} \right\}}{C_i \cdot L} \right) \cdot \frac{Ci \cdot L}{A_1} \cdot 2;$$

[0055] With the view factor F_{12} it is possible to calculate the rest of the view factors:

$$F_{11} = F_{33} = 0$$

$$F_{21} = \frac{A_1}{A_2} \cdot F_{12}$$

$$F_{11} + F_{12} + F_{13} = 1 \rightarrow F_{13} = 1 - F_{12}$$

$$F_{31} = \frac{A_1}{A_3} \cdot F_{13}$$

$$F_{31} + F_{32} + F_{33} = 1 \rightarrow F_{32} = 1 - F_{31}$$

$$F_{23} = \frac{A_3}{A_2} \cdot F_{32}$$

$$F_{21} + F_{22} + F_{23} = 1 \rightarrow F_{22} = 1 - F_{21} - F_{23}$$

[0056] Where:

$$A_1 = 2 \cdot C_i \cdot L + D_i \cdot L$$

$$A_2 = A_i \cdot L + 2 \cdot B_i \cdot L$$

$$A_3 = 2 \cdot L \cdot \sqrt{\left(\frac{A_i - D_i}{2}\right)^2 + Hzl^2}$$

<u>Obtainment of the equation of the net heat flow to the heat capturing device.</u>

[0057] The optimal geometry of the heat capturing device is the one that maximizes the amount of net heat reaching the heat capturing device. The equation that quantifies the amount of heat reaching the heat capturing device is obtained from the energy balance of the heat capturing device, where:

$$\boldsymbol{Q_2 = Q_{net\_radiation} + Q_{net\_convection}}$$

[0058] Figure 9 shows the different heat fluxes considered. The heat capturing device is assumed to be perfectly insulated from the back.

[0059] For the calculation of the net heat flux transferred through radiation the object 1 and the heat capturing device 2 are considered as grey bodies (a body that emits radiation at each wavelength in a constant ratio less than unity to that emitted by a black body at the same temperature) and the surface 3 is considered a black body (a body that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence, an ideal emitter that at every frequency emits as much or more thermal radiative energy as any other body at the same temperature).

[0060] Solving the energy balance for the radiation, it is calculated the net heat flux transmitted to the heat capturing device:

$$Q_{i\_net\_radiation} = \frac{\varepsilon_i \cdot E_{bi} - \alpha_i \cdot J_i}{\frac{1-\alpha_i}{A_i}};$$

$$\frac{\varepsilon_i \cdot E_{bi} - \alpha_i \cdot J_i}{\frac{1-\alpha_i}{A_i}} = \sum_{j=1}^{3} \frac{J_i - J_j}{\frac{1}{A_i \cdot F_{ij}}};$$

[0061] Where:

$$E_{bi} = \sigma * T_i^4;$$

[0062] As the surface 3 that closes the energy capturing space behaves as a black body:

$$E_{b3} = J_3 = \sigma * T_3^4;$$

[0063] The Qnet_radiation is calculated clearing Q2_net radiation resulting in:

$$Q_{net\_radiation} = \frac{\varepsilon_2 \cdot \sigma \cdot T_2^4 - \alpha_2 \cdot \left\{ \frac{\frac{\varepsilon_2 \cdot \sigma \cdot T_2^4 + (1-\alpha_2) \cdot F_{23}.\sigma \cdot T_3^4}{[(1-\alpha_2) \cdot (F_{21}+F_{23}) + \alpha_2]} + \frac{(1-\alpha_2) \cdot F_{21} \cdot (\varepsilon_1 \cdot \sigma \cdot T_1^4 + (1-\alpha_1) \cdot F_{13} \cdot \sigma \cdot T_3^4)}{[(1-\alpha_2) \cdot (F_{21}+F_{23}) + \alpha_2] \cdot [(1-\alpha_1) \cdot (F_{12}+F_{13}) + \alpha_1]}}{1 - \left(\frac{(1-\alpha_2) \cdot F_{21} \cdot (1-\alpha_1) \cdot F_{12}}{[(1-\alpha_2) \cdot (F_{21}+F_{23}) + \alpha_2] \cdot [(1-\alpha_1) \cdot (F_{12}+F_{13}) + \alpha_1]} \right)} \right\}}{\frac{(1-\alpha_2)}{A_2}};$$

[0064] The next step is to calculate the energy transferred to the internal ambient through convection (Qnet_convection).

$$Q_{net\_convection} = h_{conv} \cdot A_2 \cdot (T_2 - T_3);$$

[0065] The value of the convection heat transfer coefficient (h_{conv}) may be introduced by the user.

[0066] Finally, the equation for the total net heat flux to the heat capturing device is presented below:

$$Q_2 = \frac{\varepsilon_2 \cdot \sigma \cdot T_2^4 - \alpha_2 \cdot \left\{ \frac{\frac{\varepsilon_2 \cdot \sigma \cdot T_2^4 + (1-\alpha_2) \cdot F_{23}.\sigma \cdot T_3^4}{[(1-\alpha_2) \cdot (F_{21}+F_{23}) + \alpha_2]} + \frac{(1-\alpha_2) \cdot F_{21} \cdot (\varepsilon_1 \cdot \sigma \cdot T_1^4 + (1-\alpha_1) \cdot F_{13} \cdot \sigma \cdot T_3^4)}{[(1-\alpha_2) \cdot (F_{21}+F_{23}) + \alpha_2] \cdot [(1-\alpha_1) \cdot (F_{12}+F_{13}) + \alpha_1]}}{1 - \left(\frac{(1-\alpha_2) \cdot F_{21} \cdot (1-\alpha_1) \cdot F_{12}}{[(1-\alpha_2) \cdot (F_{21}+F_{23}) + \alpha_2] \cdot [(1-\alpha_1) \cdot (F_{12}+F_{13}) + \alpha_1]} \right)} \right\}}{\frac{(1-\alpha_2)}{A_2}} + h_{conv} \cdot A_2 \cdot (T_2 - T_3);$$

Results

[0067] The optimal design is obtained by solving an optimization problem. This is formulated as the maximization of the total heat transferred between the piece (object) and the heat capturing device (more particularly the bundle of tubes of the inner energy capturing layer), subject to the physical and manufacturing constraints.

[0068] It should be noted that the minimum width and height that the heat capturing device can have (since in real processes these dimensions must leave a safety margin) are also input parameter.

[0069] The model-based optimization approach was used to formulate the design optimization problem. The supporting model was developed in Python 3.6 based on physics equations. Regarding the optimizer, the proposed solution is based on the L-BFGS-B algorithm implemented in the Scipy (v1.1.0) optimization package.

[0070] The following table presents different cases in which the input parameters of the system have been varied. Depending on the value of these, the optimum geometry of the heat capturing device varies.

Table 1

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
A minimum	0.255	0.255	0.255	0.255	0.255	0.255	0.255	0.455
B minimum	0.255	0.255	0.255	0.255	0.255	0.255	0.455	0.255
C	0.155	0.155	0.155	0.155	0.155	0.155	0.355	0.155
D	0.155	0.155	0.155	0.155	0.155	0.155	0.155	0.355
H	0	0	0	0	0	0	0	0
L	5	5	5	5	5	5	5	5
ε**1**	0.8	0.8	0.8	0.8	0.95	0.65	0.8	0.65
ε**2**	0.96687	0.96687	0.7	0.7	0.7	0.7	0.7	0.7
α**1**	0.8	0.8	0.8	0.8	0.95	0.65	0.8	0.65
α**2**	0.9664	0.9664	0.7	0.7	0.7	0.7	0.7	0.7
T1	900	900	900	900	900	900	900	900
T2	400	400	400	400	400	400	400	400
T3	24	24	24	24	24	24	24	24
$\mathbf{h_{conv}}$	10	0	10	5	10	10	10	10
A optimum	0.255	0.255	0.255	0.255	0.255	0.255	0.255	0.455
B optimum	0.255	0.73581	0.36354	0.59339	0.44862	0.27763	0.81044	0.32206

[0071] Figures 10-12 show a graphical representation of the listed cases 1-8 mentioned in the following Table 1. In particular such figures show a schematic representation of the size ratio between the object and the heat capturing device (named as collector in the figures for clarity purposes).

[0072] Case 1 (see Table 1) has been selected as a reference case where the optimal solution for the heat capturing device geometry matches with the minimal dimensions defined for it. As can be seen in cases 1 to 6 (see Table 1) with the same minimum values for the dimensions of the heat capturing device the optimal solution is affected by:

the operating conditions: case 2 and case 4 with lower convection losses;

the absorptivity and emissivity of the inner surfaces of the heat capturing device: case 3 and 4 with lower absorptivity and emissivity than the reference case 1;

the absorptivity and emissivity of the object: case 5 has high values (such as the ones corresponding to glass pieces) and case 6 has lower values; and

cases 7 and 8 illustrates also the effect of the shape of the object with the same operating conditions as the reference Case 1.

[0073] As can be seen although intuitively it might seem that the optimal dimensions of the heat capturing device will always tend to be the minimum, the results show how this is not so. This is a surprising and unexpected technical effect achieved by the claimed scope.

Conclusions

[0074] As seen in the previous section, with the optimization procedure it is possible to obtain the best geometric solution for the heat capturing device in many situations. These situations can be extrapolated to many industrial processes that produce high temperature pieces from which emitted radiation is captured for the heat capturing device herein described.

[0075] Figure 13 shows a perspective view of an example tunnel shaped heat capturing device 30 wherein the inner energy capturing layer comprises a bundle of tubes 31. The tubes 31 may have preferably a circular cross section. The heat capturing device 30 may be implemented using tubes 31 having other cross sections such as square or elliptical cross sections. The tubes 31 are connected to the represented headers 32. The tubes 31 of the bundle may be welded to the headers 32. The inner energy capturing layer 31 is covered by an intermediate energy reflecting layer 33 that in turn is covered by an energy insulating layer 34, preferably made of ceramic fiber with low thermal conductivity. The energy insulating layer 34 is covered by an outer casing 35, preferably made of a metal. The headers 32 transport the heat captured by the fluid inside the tubes of the heat capturing device 30 to either a heating station or to a heat exchanger (not shown). The heat capturing device 30 comprises control means which may control the flow of fluid in the tubes 31 of the bundle and may control at least one pump, cooling means and/or valves (not shown). The control means of the heat capturing device 30 may control the cooling means or control one or more heat exchangers for regulating the temperature of the fluid flowing in the tubes 31. The control of the pump and/or valves by the control means allow to control the quantity or volume of fluid circulating in the tubes 31. The fluid circulating in the tubes 31 of the bundle may be water, an organic thermal oil or silicone based thermal oil.

[0076] The objects introduced in the energy capturing space 36 are at high temperatures, such as typically greater than 500°C. The heat capturing device is designed to operate with medium temperatures in the fluid around 350° C.

[0077] Figure 14 shows a cross-sectional cut of the heat capturing device 30 of figure 13. It can be appreciated that all layers, namely the outer casing 35, the energy insulating layer 34, the intermediate energy reflecting layer 33 and the inner energy capturing layer 31 (e.g. the tubes) have a tunnel shape as shown which indicates that said layers also define the ceiling and the sides of the tunnel shape arrangement. All said layers may also be at least partly disposed in the floor of said tunnel shaped structure, such that the tubes 31 are also able to capture heat or energy from the floor side of the structure.

[0078] In some embodiments, the outer casing 35 may be disregarded, and it is not installed.

[0079] Preferably, the tubes 31 are not in direct contact with the intermediate energy reflecting layer 33 or reflecting plate, i.e., the inner energy capturing layer 31 (e.g. tubes) and the intermediate energy reflecting layer 33 are separated by air or some gas. In some embodiments the inner energy capturing layer 31 may contact the intermediate energy reflecting layer 33. The intermediate energy reflecting layer 33 may be in direct contact with the energy insulating layer 34, or both layers (intermediate energy reflecting layer 33 and energy insulating layer 34) may be separated by a chamber of air or gas or insulating fluid. The energy insulating layer 34 may be in contact with the outer casing 35 or may be separated by air.

[0080] The outer casing 35 may be made of steel or other metal or may be made of refractory material or heat resistant material.

[0081] Figure 15 shows a perspective view of another example tunnel-shaped heat capturing device 40 with the tubes 41 being positioned substantially parallel to the direction of displacement of the two objects 47 relative to the energy capturing space 46 defined by the tunnel-shaped heat capturing device 40. While Figure 15 shows two identical objects placed parallel to each other, any number of objects with any different shape and spatial relationship to each other could be placed in the energy capturing space 46.

[0082] In such example, the tubes 41 of the bundle may have preferably a circular cross section although any other cross sections such as square or elliptical cross sections may be implemented. The tubes 41 are connected to the represented headers 42 (not shown in this figure). The headers may be positioned at both openings of the tunnel such that their geometry corresponds to the geometry of the openings.

[0083] In such example, the intermediate energy reflecting layer 43 is attached to the inner surface of the outer energy insulating layer 44. The energy insulating layer 44 is located between the intermediate energy reflecting layer 43 and the outer casing 45. The energy insulating layer 44 may be made of ceramic fiber with low thermal conductivity.

[0084] Figure 16 shows a cross-sectional representation of the tunnel-shaped heat capturing device and the further layers of the device of figure 15.

[0085] Figure 17 shows a perspective view of an example inner energy capturing layer 50. In such example, the inner energy capturing layer 50 is formed by a bundle of tubes 51 for circulating the heat transfer fluid, a first header 52 and a second header 53. The tubes 51 are placed in parallel to each other and have the same diameter. Besides, the distance between two consecutives tubes 51 is the same along the entire inner energy capturing layer 50. The fluid 54 ingress in the tubes 51 via the first header 52 through a first opening 55. The first header 52 is divided in sections 56 wherein each section is communicated to a set of tubes 51 but isolated from the contiguous sections 56 within the first header 52. The second header 53 is divided in sections 57 wherein each section is communicated to a set of tubes 51 but isolated from the contiguous sections 57 within the first header 53. In such example, the fluid 54 that enters into the first section 56a of the first header 52 circulates through the tubes 51 connected to this first section 56a until the first section 57a of the second header 53, which in turn is connected to other tubes for keeping circulating the fluid towards a second section 56 b of the first header, and so on, until the fluid reaches the last section of the first header 53 through which the fluid 54 exits the inner energy capturing layer 50 via a second opening (not shown in this figure).

[0086] Figure 18 shows a representation of an example architecture of some tubes of the tube bundle forming the inner energy capturing layer and a representation of the corrugated intermediate energy reflecting layer.

[0087] In such example, the distance (d1) between the centers of two consecutive tubes is 1.25 times the outside diameter of one of the tubes. All tubes have the same diameter. The minimal distance (d2) between the outer surfaces of two consecutives tubes is 0.25 times the diameter of one of the tubes. Due to the particular pattern of the corrugated intermediate energy reflecting layer the radiation going through the existing space between tube is reflected in the reflective corrugated surface and directed back to the collecting tubes.

[0088] The invention is obviously not limited to the specific embodiments described herein, but also encompasses any variations that may be considered by any person skilled in the art (for example, as regards the choice of materials, dimensions, components, configuration, etc.), within the general scope of the invention as defined in the claims.

Claims

1. Heat capturing device comprising:

an upper side and lateral sides connected to the upper side, said connected sides define an energy capturing space, the device further comprising:

an energy insulating layer;
an intermediate energy reflecting layer; and
an inner energy capturing layer capturing energy from at least one object located at least partly in the energy capturing space;
wherein the dimensions of the inner energy capturing layer are based on the dimensions of the at least one object and based on a further parameter, said further parameter being at least one of: at least a second parameter of the at least one object, at least one parameter of the inner energy capturing layer, at least one parameter of the energy capturing space and any combination thereof.

2. The device according to claim 1, wherein the second parameter of said at least one object is selected from a group comprising the emissivity of at least one or more of the surfaces of the at least one object, the absorptivity of at least one or more of the surfaces of the at least one object and a combination thereof, said second parameter of said at least one object defining the width of the inner energy capturing layer.

3. The device according to any one of claims 1-2, wherein the further parameter defines the weight and the height of the inner energy capturing layer, said further parameter being at least one of: the convection coefficient of the air inside the energy capturing space, the emissivity of at least one of the surfaces of the object, the absorptivity of at least one of the surfaces of the object, the emissivity of at least one of the surfaces of the inner energy capturing layer, the absorptivity of at least one of the surfaces of the inner energy capturing layer and any combination thereof.

4. The device according to any one of claims 1-3, wherein the inner energy capturing layer is a bundle of tubes, the bundle of tubes covers a tunnel-shaped surface, wherein at least of one or more of the tubes of the bundle comprises a heat transfer fluid.

5. The device according to claim 4, wherein the distance between the center of two consecutive tubes is between 1,25 and 2 times the external diameter of a tube of the bundle.

6. The device according to any one of claims 4-5, wherein the bundle of tubes is connected to at least two headers to distribute the heat transfer fluid through the bundle of tubes and wherein the heat transfer fluid is feed to the bundle of tubes at a first temperature and removed at a second temperature, the second temperature being higher than the first temperature.

7. The device according to any of claims 4-6, wherein the external surface of the bundle of tubes is covered with high absorptivity coatings or high absorptivity paint.

8. The device according to any of claims 1-7, wherein the energy absorbed is heat and the heat absorbed by the inner energy capturing layer is defined as follows:

$$Q_2 = \frac{\varepsilon_2 \cdot \sigma \cdot T_2^4 - \alpha_2 \cdot \left\{ \frac{\frac{\varepsilon_2 \cdot \sigma \cdot T_2^4 + (1-\alpha_2) \cdot F_{23}.\sigma \cdot T_3^4}{[(1-\alpha_2) \cdot (F_{21}+F_{23}) + \alpha_2]} + \frac{(1-\alpha_2) \cdot F_{21} \cdot (\varepsilon_1 \cdot \sigma \cdot T_1^4 + (1-\alpha_1) \cdot F_{13} \cdot \sigma \cdot T_3^4)}{[(1-\alpha_2) \cdot (F_{21}+F_{23}) + \alpha_2] \cdot [(1-\alpha_1) \cdot (F_{12}+F_{13}) + \alpha_1]}}{1 - \left(\frac{(1-\alpha_2) \cdot F_{21} \cdot (1-\alpha_1) \cdot F_{12}}{[(1-\alpha_2) \cdot (F_{21}+F_{23}) + \alpha_2] \cdot [(1-\alpha_1) \cdot (F_{12}+F_{13}) + \alpha_1]} \right)} \right\}}{\frac{(1-\alpha_2)}{A_2}} + h_{conv} \cdot A_2 \cdot (T_2 - T_3)$$

Wherein the nomenclature is the following:

A_i Area of the different surfaces
T_i Temperature of the different surfaces, wherein T_1 is the temperature of the object, T_2 is the temperature of the fluid circulating through the heat capturing device, T_3 is the ambient temperature in the energy capturing space
ε_i Emissivity of the different surfaces
α_i Absorptivity of the different surfaces
h_{conv} Convection coefficient of the air inside the tunnel.
F_{ij} View factor from surface i to surface j (according to figure 4).
σ Stefan-Boltzman constant $5{,}67.10^{-8}$ W/m^2K^4.

Subscripts/Sub-index:

1 Object
2 Inner energy capturing layer
3 Surface that closes the energy capturing space

9. The device according to any one of claims 4-8, wherein the intermediate energy reflecting layer comprises a corrugated shaped surface behind the bundle of tubes, wherein the convex part of corrugated shaped surface is located in correspondence with at least one of the tubes of the bundle and the concave part of said surface is located in correspondence with at least one of the separations between the tubes.

10. The device according to any one of claims 4-9, wherein the device comprises at least one sensor for measuring the temperature of the at least one object, or at least one sensor for measuring the temperature of the energy capturing space, or at least one sensor for measuring the temperature inside the tube or the temperature of the fluid within the tube, or at least one sensor for detecting the object either entering into, or exiting out of or remaining in the energy capturing space or a combination of said sensors.

11. The device according to any one of claims 1-10, wherein the energy insulating layer covers the intermediate energy reflecting layer, and the intermediate energy reflecting layer covers the inner energy capturing layer, and wherein the device further comprises an outer casing covering the energy insulating layer.

12. The device according to any one of claims 1-11, wherein the device comprises transport means and control means, the control means configured to control the transport of the object from or to the energy capturing space, wherein the device automatically transporting the object to or from the energy capturing space based on a certain captured temperature measured by at least one or more said sensors, said certain temperature exceeding or being below a predetermined threshold.

13. The device according to any one of claims 11 or 12, wherein the control means are configured for controlling the quantity of fluid and/or the speed of the fluid circulating inside the bundle of tubes, wherein the control means automatically control said quantity and/or speed of fluid based on the data measured by at least one of the sensors.

14. The device according to any one of claims 1-13, wherein the device comprises a modular structure permitting to add parts to the device or remove parts from the device.

15. A heat capturing system comprising:

a heat capturing device according to any one of claims 1 to 14; and
at least one object located at least partly in the energy capturing space;
wherein the heat capturing device is configured to capture radiated heat from the at least one object by the

inner energy capturing layer.

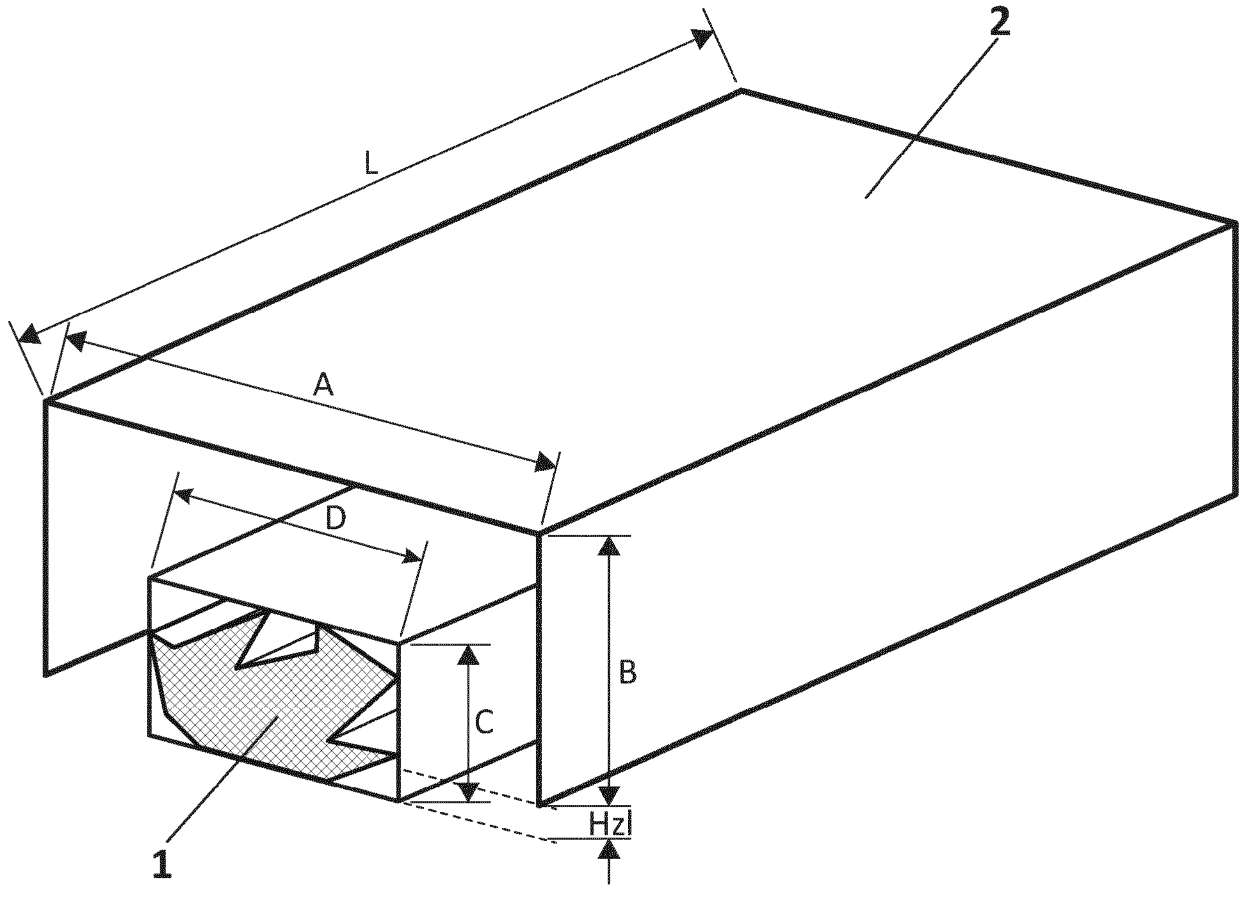

FIG. 1

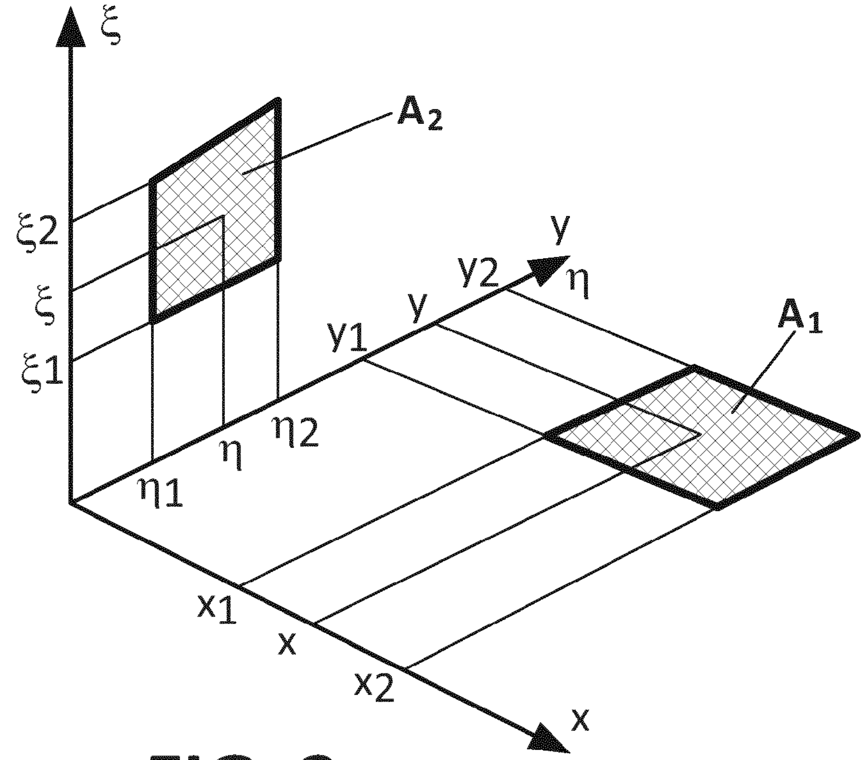
ξ
A2
ξ2
ξ
ξ1
y
y2
η
y
y1
A1
η2
η
η1
x1
x
x2
x

FIG. 2

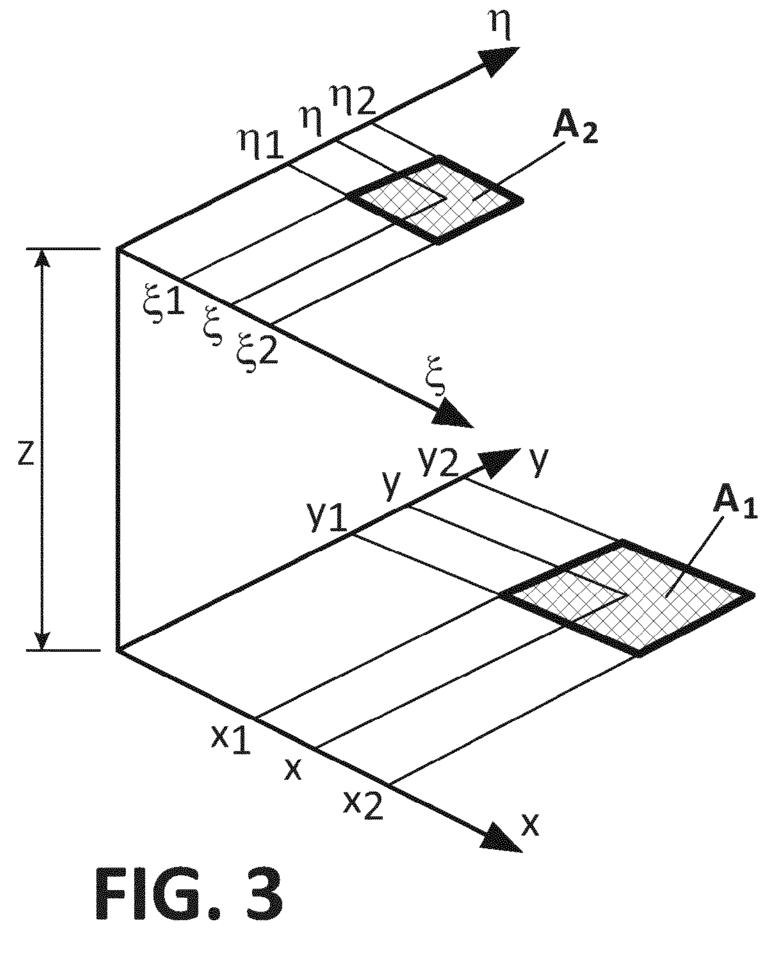
η
η2
η
η1
A2
ξ1
ξ
ξ2
ξ
z
y2
y
y
y1
A1
x1
x
x2
x

FIG. 3

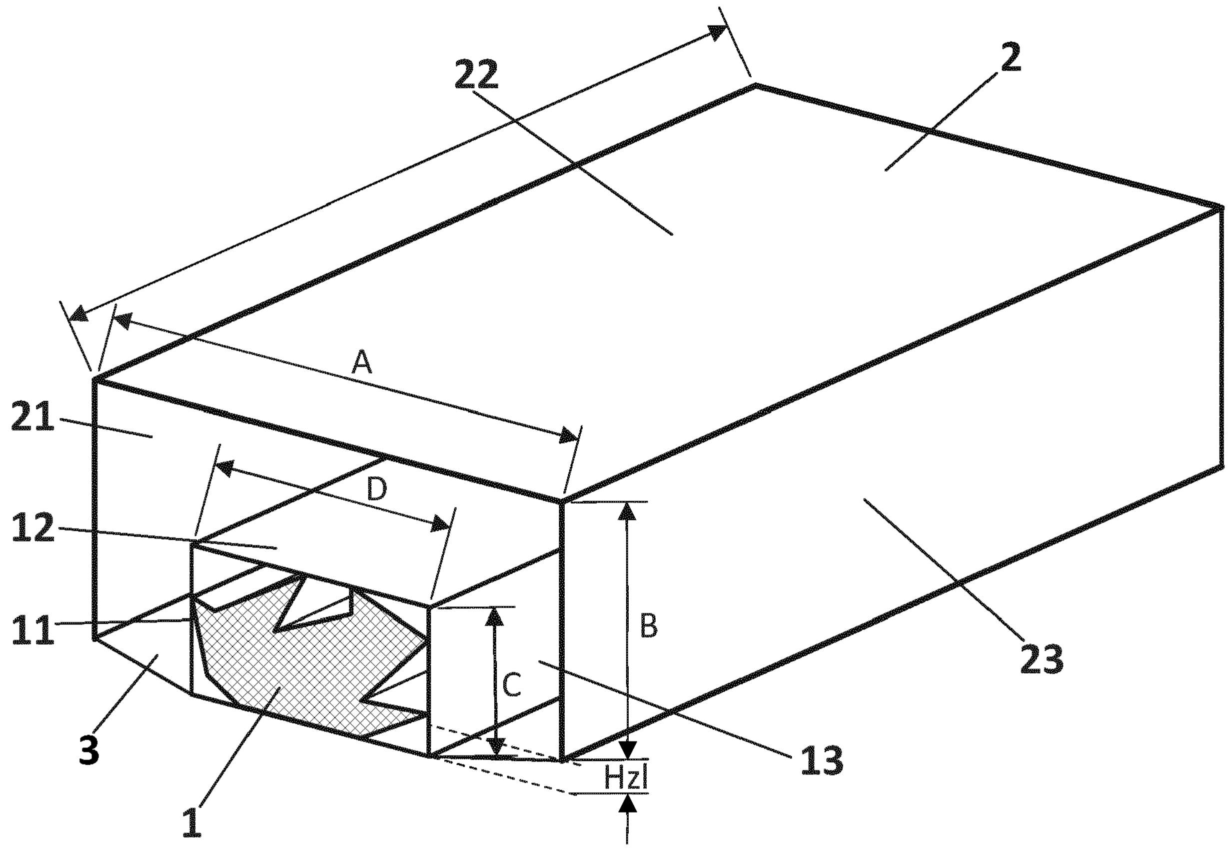

FIG. 4

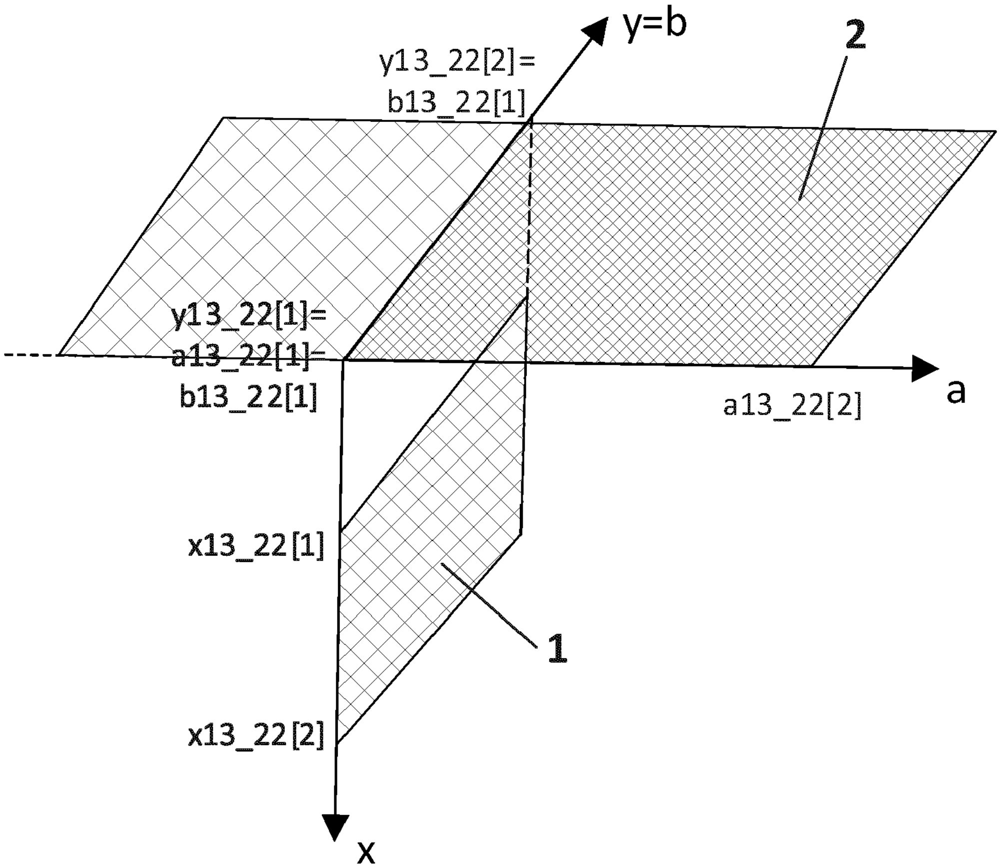
y=b
2
y13_22[2]=
b13_22[1]
y13_22[1]=
a13_22[1]=
b13_22[1]
a13_22[2]
a
x13_22[1]
1
x13_22[2]
x

FIG. 5

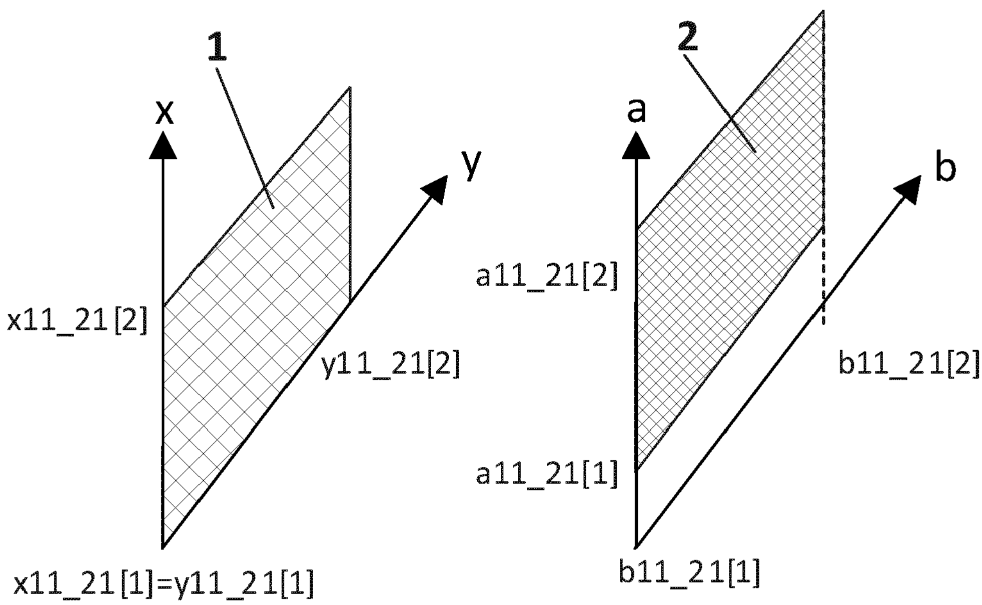
1
x
y
x11_21[2]
y11_21[2]
x11_21[1]=y11_21[1]
2
a
b
a11_21[2]
b11_21[2]
a11_21[1]
b11_21[1]

FIG. 6

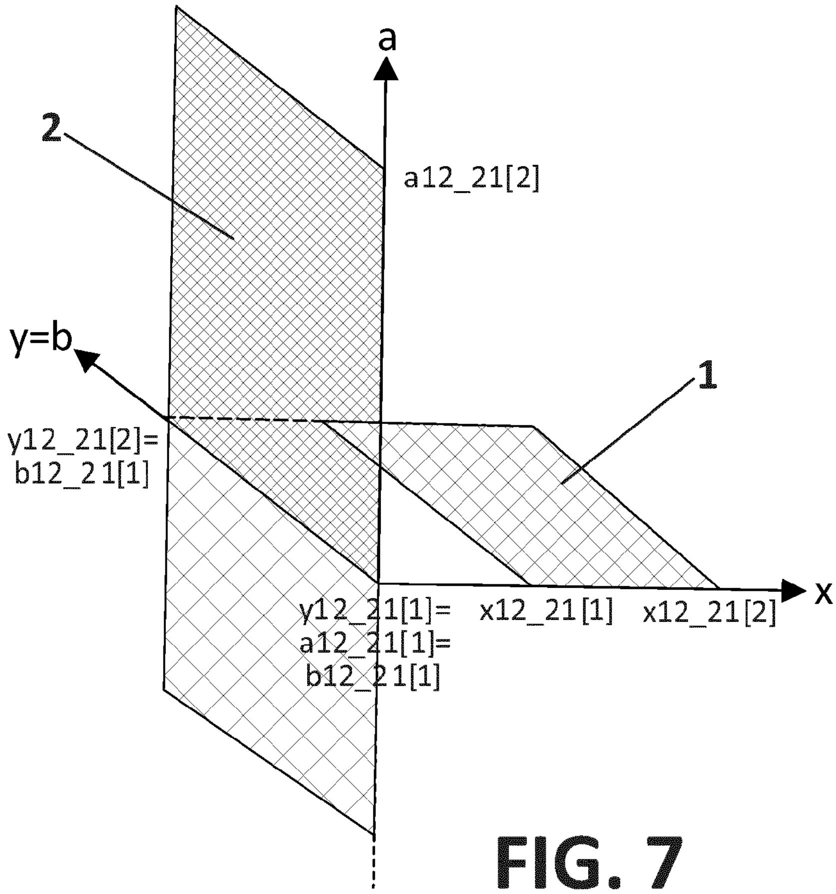
a
2
a12_21[2]
y=b
1
y12_21[2]=
b12_21[1]
x
y12_21[1]=
a12_21[1]=
b12_21[1]
x12_21[1]
x12_21[2]

FIG. 7

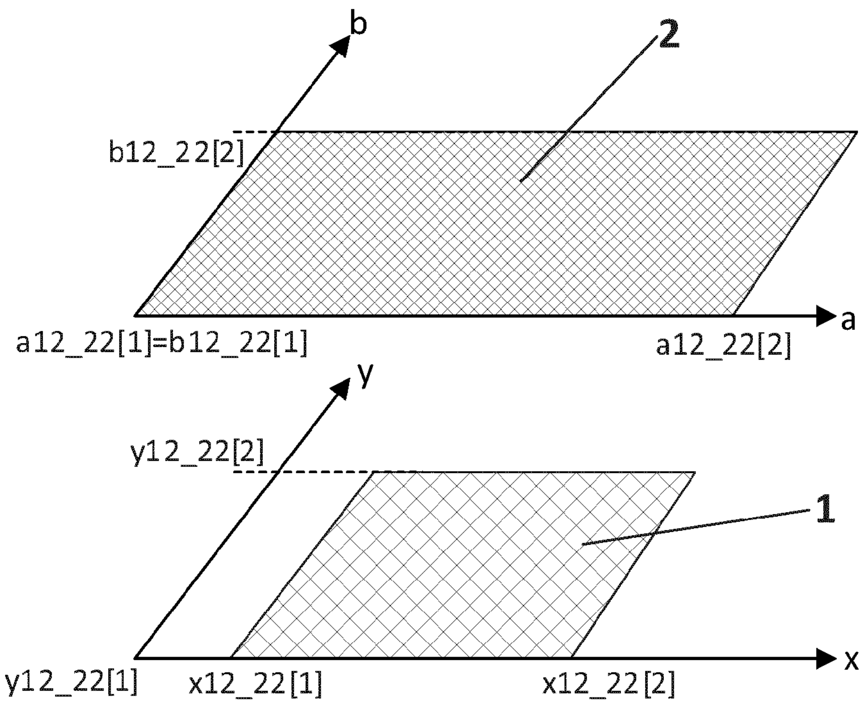
b
2
b12_22[2]
a
a12_22[1]=b12_22[1]
a12_22[2]
y
y12_22[2]
1
x
y12_22[1]
x12_22[1]
x12_22[2]

FIG. 8

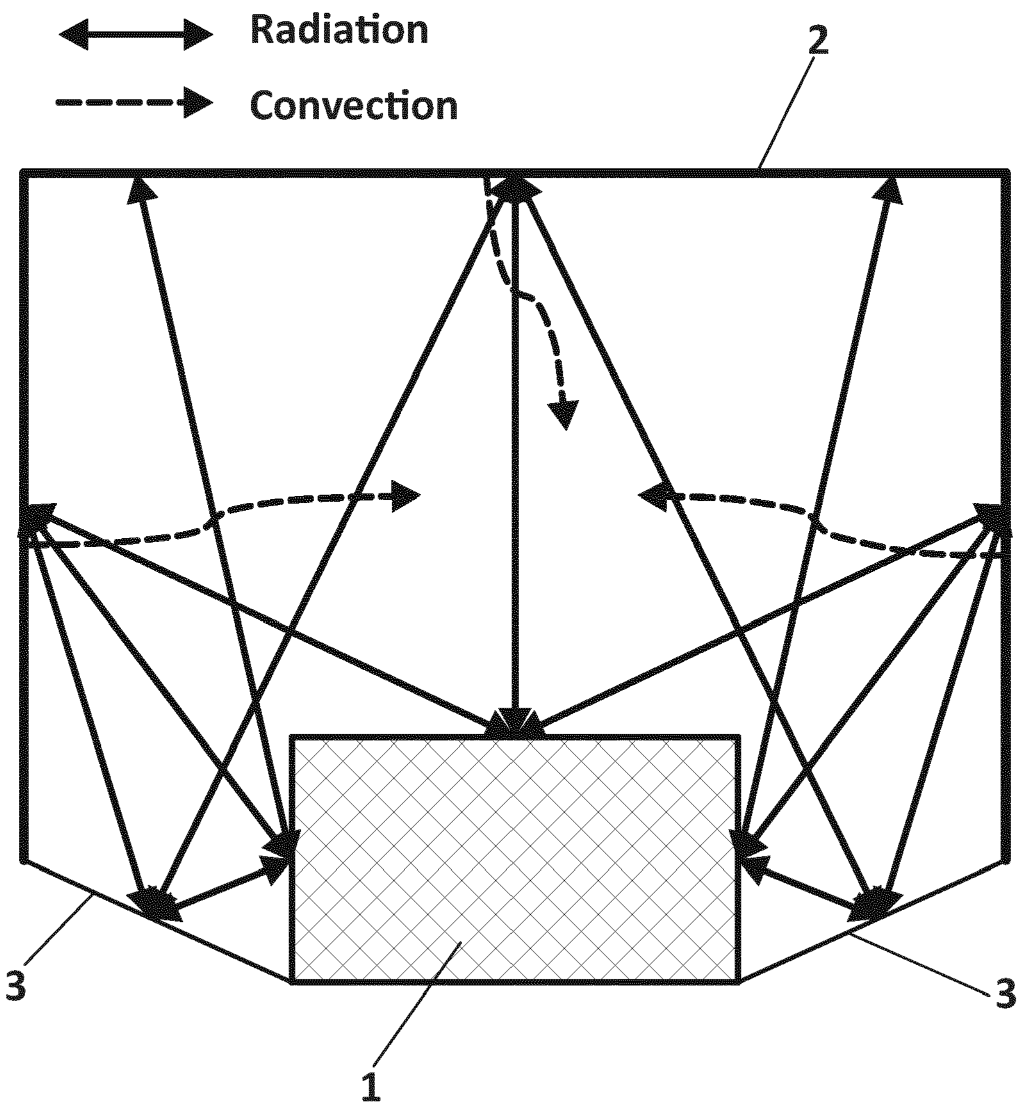

FIG. 9

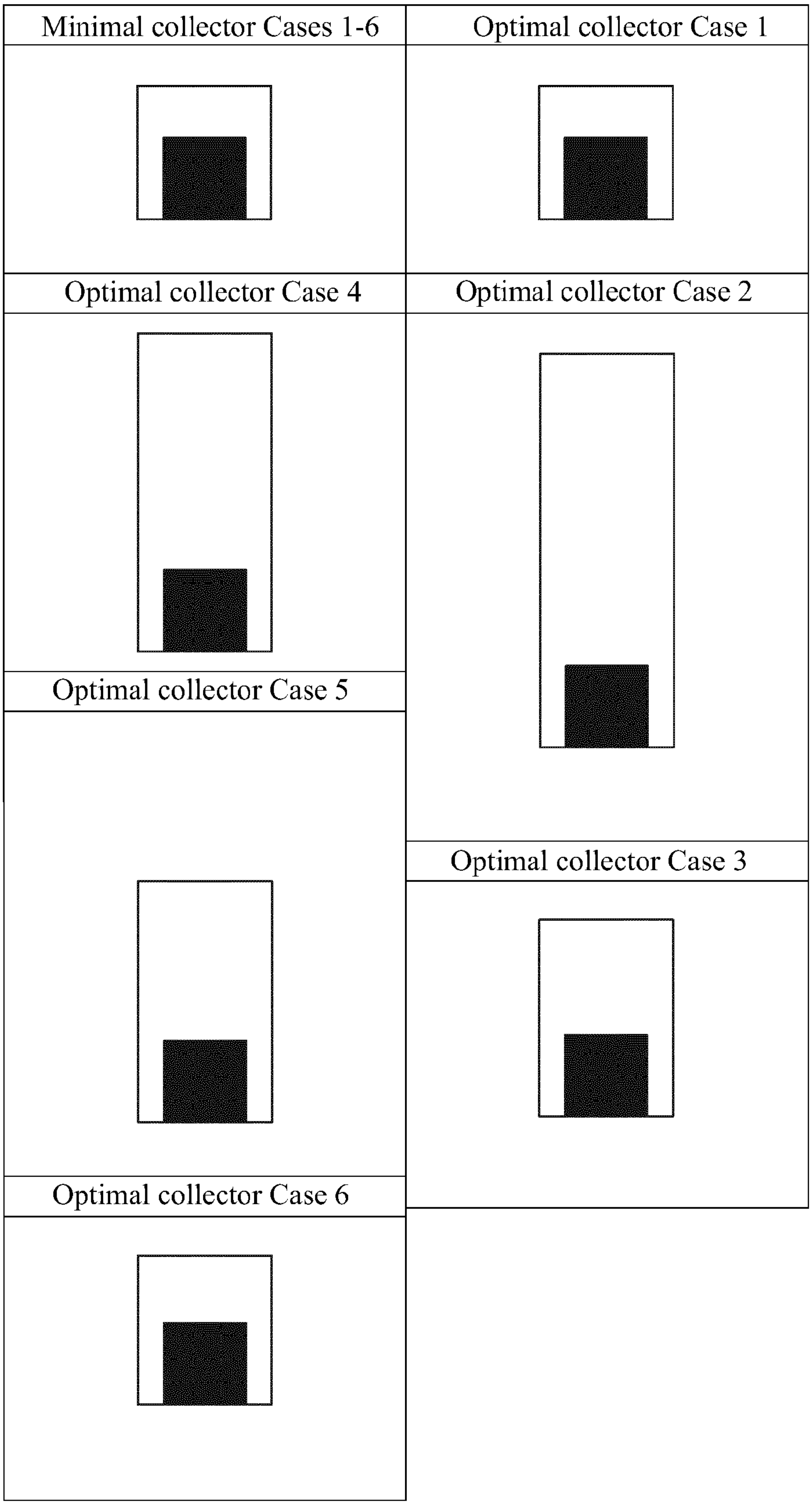
Minimal collector Cases 1-6
Optimal collector Case 1
Optimal collector Case 4
Optimal collector Case 2
Optimal collector Case 5
Optimal collector Case 3
Optimal collector Case 6

FIG. 10

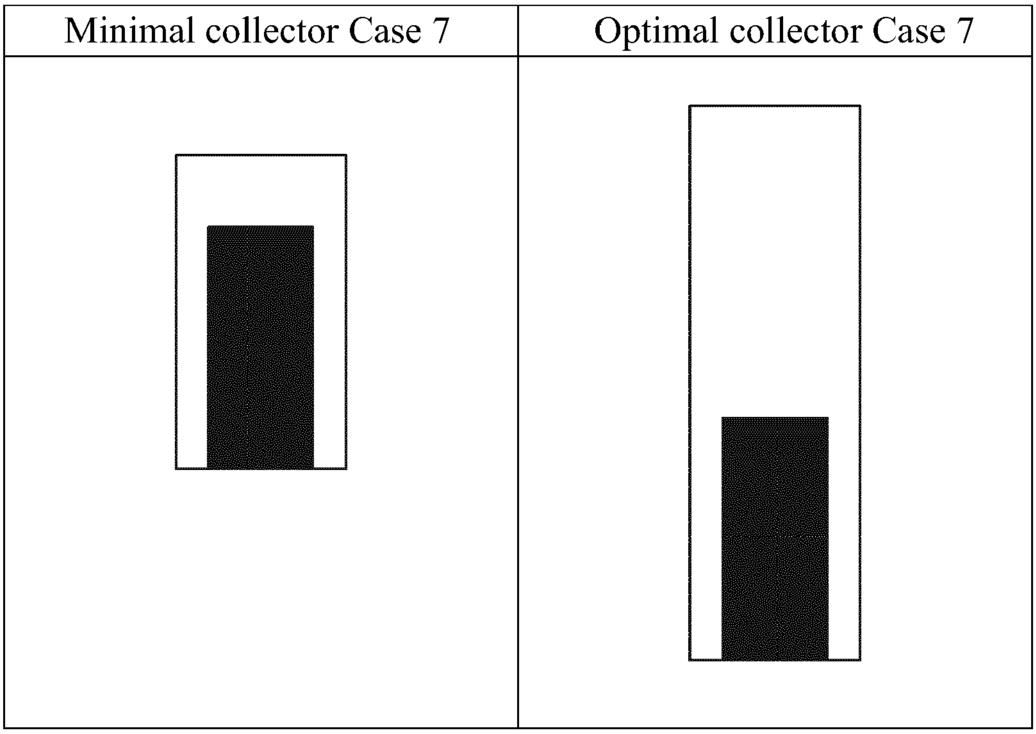
Minimal collector Case 7
Optimal collector Case 7

FIG. 11

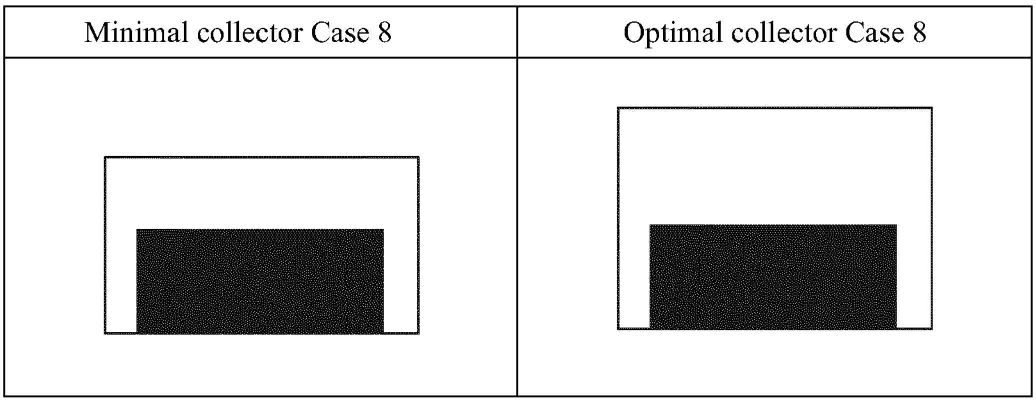
Minimal collector Case 8
Optimal collector Case 8

FIG. 12

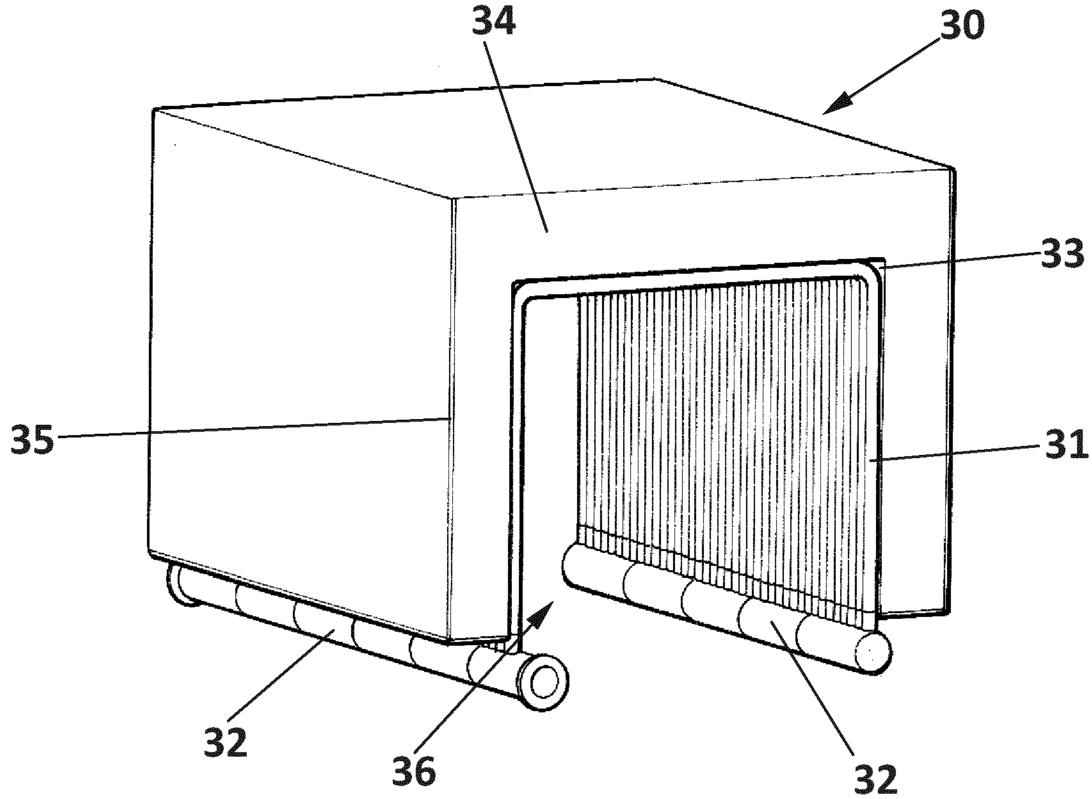

FIG. 13

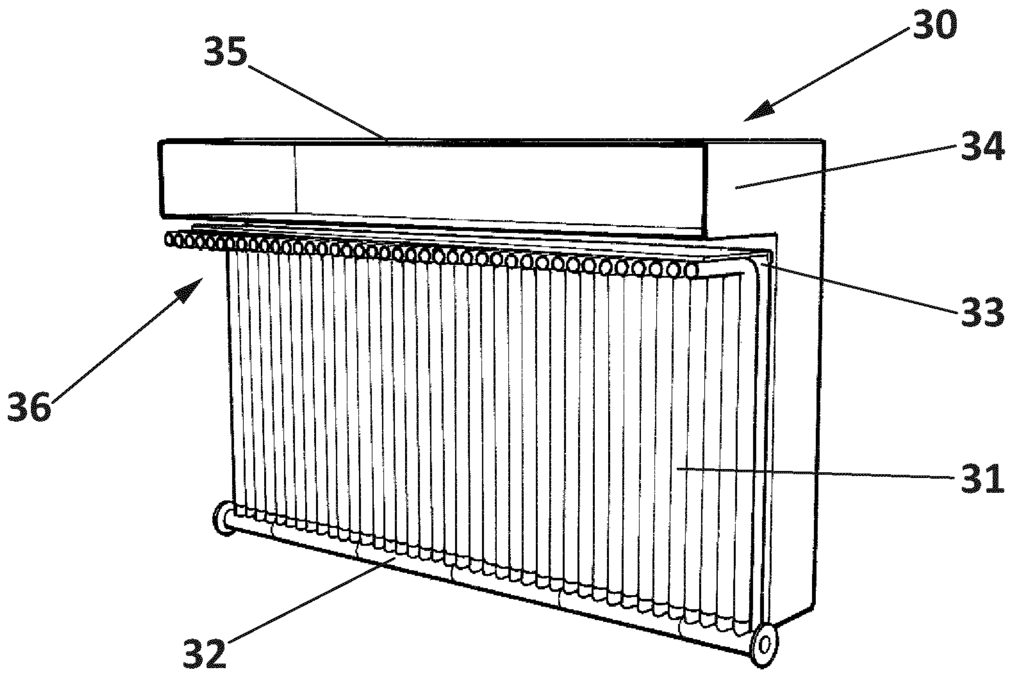

FIG. 14

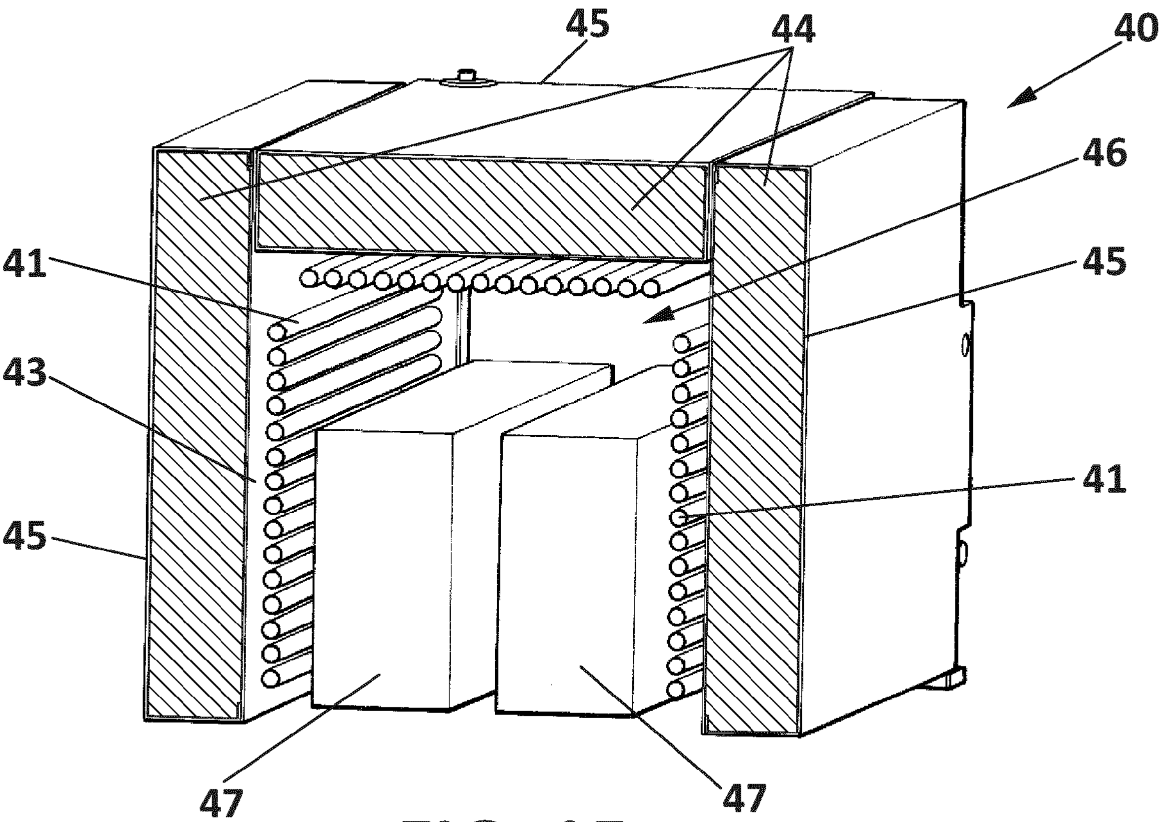

FIG. 15

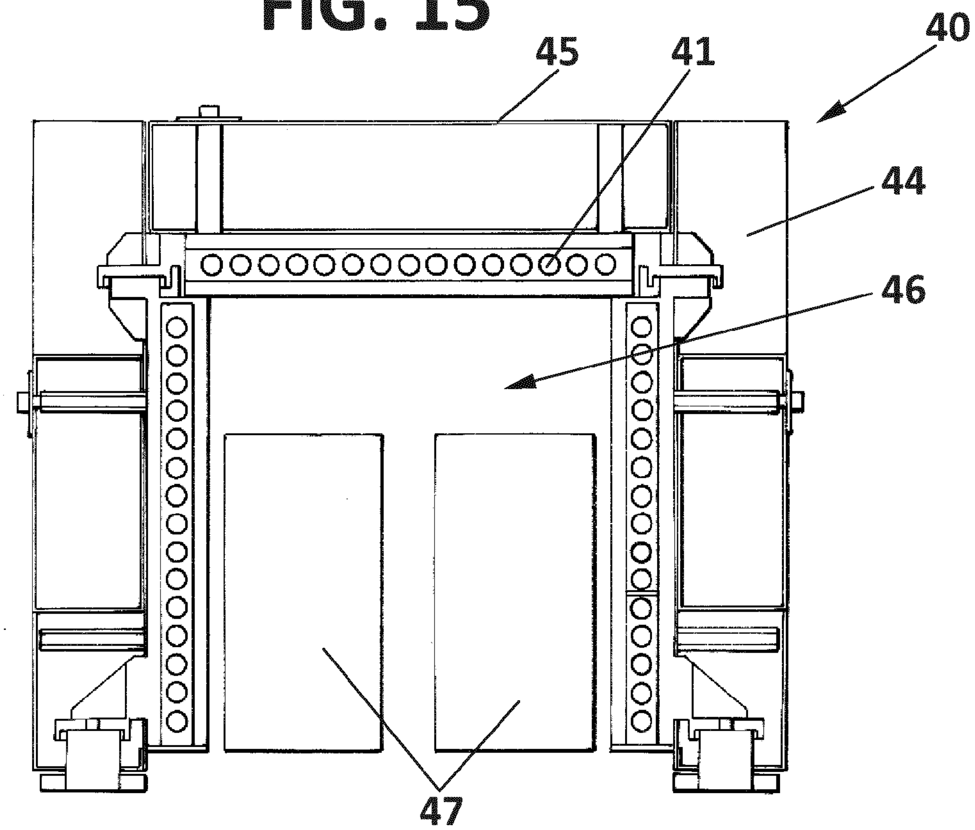

FIG. 16

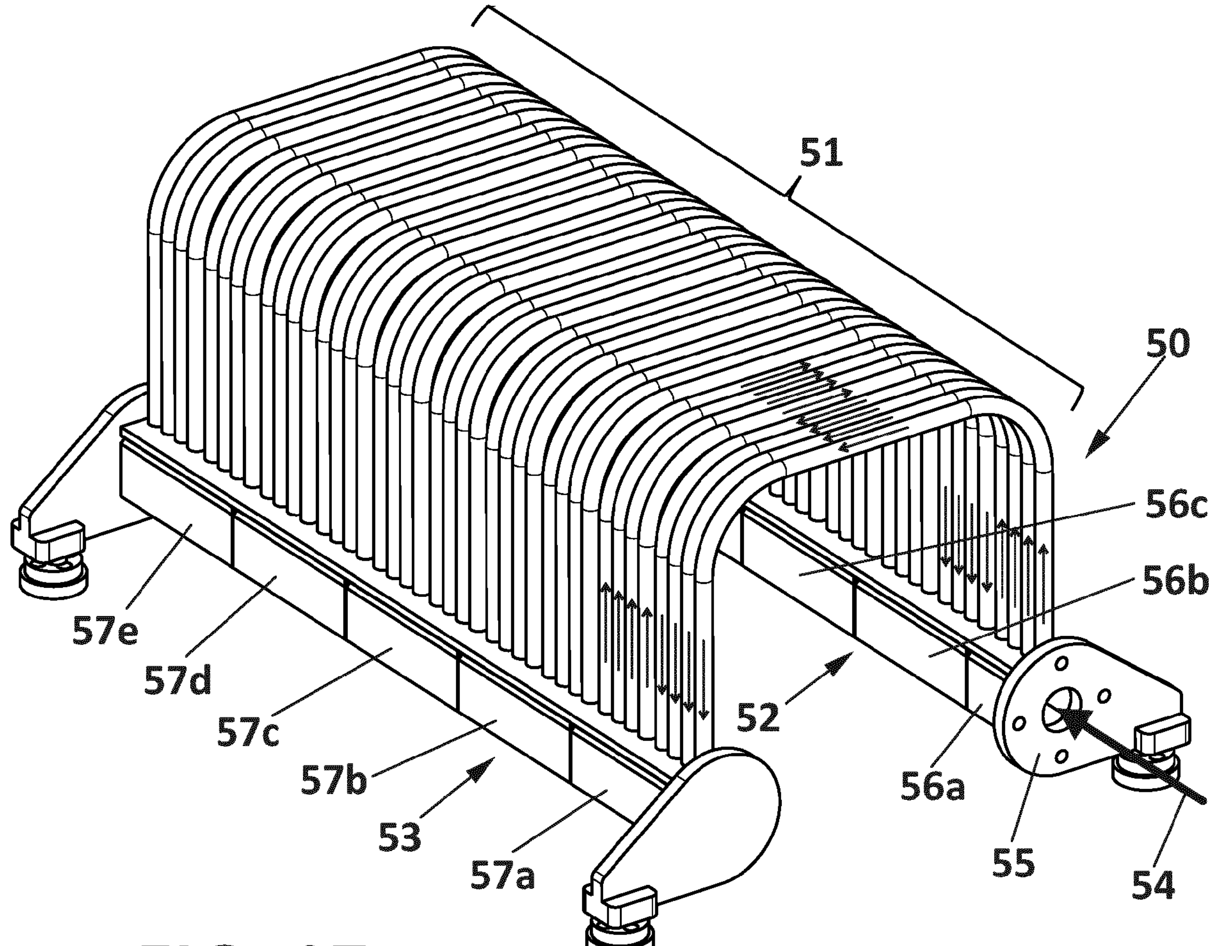
51
50
56c
56b
57e
57d
57c
52
57b
56a
53
55
57a
54

FIG. 17

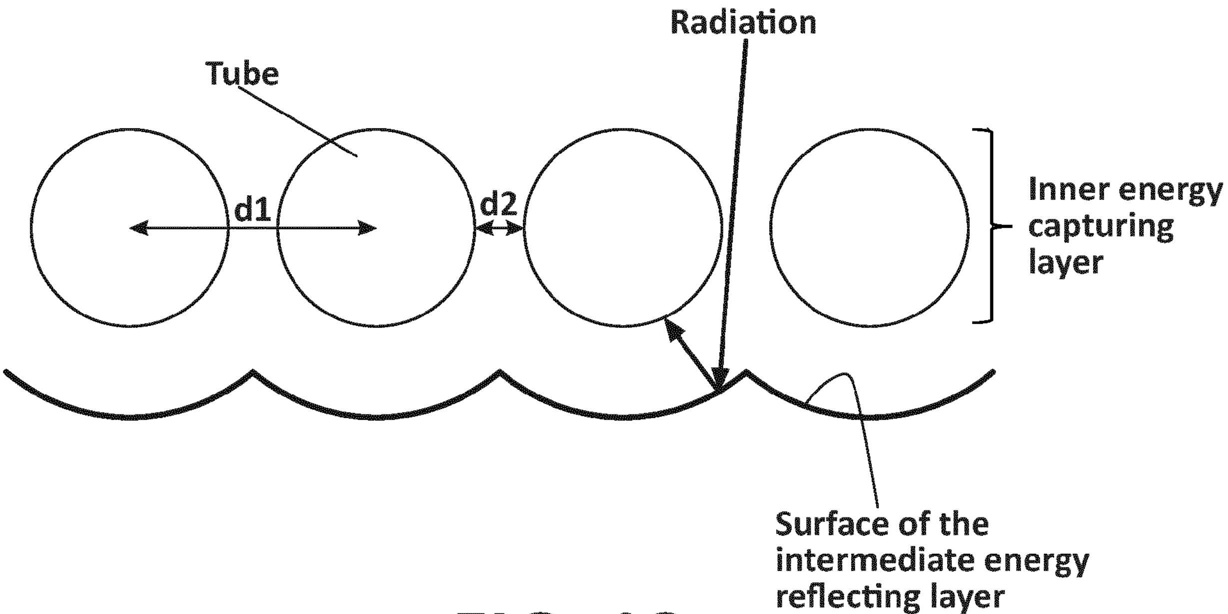
Radiation
Tube
d1
d2
Inner energy capturing layer
Surface of the intermediate energy reflecting layer

FIG. 18

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 18 38 2964

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	EP 2 861 771 A1 (G A P S P A [IT]) 22 April 2015 (2015-04-22) * paragraphs [0016] - [0026]; figure 2 *	1-8, 10-15 9	INV. B22D11/124 B22D11/22 C21D9/00 C21D11/00 F27D17/00 F28D21/00 F28F13/18 F28F27/00
A	WO 2016/178641 A1 (TOPAL ÖMER ALI [TR]) 10 November 2016 (2016-11-10) * page 1 - page 2; figure 3 *	1-15	
A,D	DE 30 19 714 A1 (MANNESMANN AG [DE]) 10 December 1981 (1981-12-10) * the whole document *	1-15	
A	DE 10 2011 107685 A1 (LUZ WERNER [DE]) 17 January 2013 (2013-01-17) * abstract; figures 1-4 * * paragraphs [0043] - [0056] *	1-15	
A	JP S56 131906 U (NN [JP]) 6 October 1981 (1981-10-06) * figures 1, 2 *	1-15	TECHNICAL FIELDS SEARCHED (IPC)
A	US 2011/049773 A1 (KIEFER BRUCE V [US] ET AL) 3 March 2011 (2011-03-03) * paragraphs [0011] - [0014]; figure 1 *	1,11	B22D F27D C21D F28D F28F
A	US 2018/050406 A1 (AMMON JORG [DE] ET AL) 22 February 2018 (2018-02-22) * paragraphs [0037] - [0040]; figure 2 *	9	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	27 May 2019	Leclaire, Thomas

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 18 38 2964

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

27-05-2019

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2861771 A1	22-04-2015	BR 112014031339 A2	27-06-2017
		CN 104603294 A	06-05-2015
		EA 201492085 A1	30-04-2015
		EP 2861771 A1	22-04-2015
		ES 2621346 T3	03-07-2017
		JP 6246801 B2	13-12-2017
		JP 2015528094 A	24-09-2015
		KR 20150037817 A	08-04-2015
		MA 20150359 A1	30-10-2015
		PL 2861771 T3	31-07-2017
		US 2015159232 A1	11-06-2015
		WO 2013186664 A1	19-12-2013
WO 2016178641 A1	10-11-2016	NONE	
DE 3019714 A1	10-12-1981	DE 3019714 A1	10-12-1981
		JP S6036453 B2	20-08-1985
		JP S56169724 A	26-12-1981
DE 102011107685 A1	17-01-2013	DE 102011107685 A1	17-01-2013
		WO 2013007813 A1	17-01-2013
JP S56131906 U	06-10-1981	NONE	
US 2011049773 A1	03-03-2011	TW 201113108 A	16-04-2011
		US 2011049773 A1	03-03-2011
		WO 2011031511 A1	17-03-2011
US 2018050406 A1	22-02-2018	CN 107980014 A	01-05-2018
		DE 102015106298 A1	27-10-2016
		US 2018050406 A1	22-02-2018
		WO 2016169551 A1	27-10-2016

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- EP 2403668 A2 **[0002]**
- DE 3019714 A1 **[0002]**