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(71) Applicant: **Akademia Gorniczo-Hutnicza im. Stanislawa Staszica w Krakowie**
30-059 Krakow (PL)

(72) Inventor: **Ciapala, Bartlomiej**
43-376 Godziszka (PL)

(74) Representative: **Kuczynska, Teresa et al**
Polservice
Kancelaria Rzecznikow Patentowych Sp. z o.o.
Bobrowiecka 8
00-728 Warszawa (PL)

(54) PLATE HEAT EXCHANGER UTILIZING PHASE CHANGE

(57) The subject of the invention relates to a phase-change heat exchanger comprising a plate (1) of the exchanger, a set of pipes (10) through which the working medium flows, heating elements (5) arranged directly below the plate (1) of the exchanger or integrated into it, and a hydraulic system with a control unit (8), wherein the plate (1) of the heat exchanger with the pipe system (10) and heating elements (5) is immersed in a tank (Z) filled with a liquid phase-change medium, preferably water, characterized in that the plate (1) of the heat exchanger is positioned near the bottom of the tank (Z) filled with phase-change medium, preferably horizontally, such that above the plate (1) of the exchanger, there is a column of phase-change medium, preferably water, and the plate (1) is equipped with a number of protrusions (4), arranged next to each other in parallel rows across the entire surface of the plate (1), wherein these protrusions (4) are in the form of elongated rectangular prisms with a base chosen from: a polygon or a figure formed from segments of curves, including figures formed from segments of ellipses, and side walls (2) that converge at an angle at the apex part of the protrusion (4), wherein the apex part is in the form of an apex (4') in which the side walls (2) converge at an angle α ranging from 30° to 120°, preferably between 45° and 90°, in a shape chosen from: an apex with a sharp-edged tip, a truncated apex, or an apex equipped with a convex socket part (12) running along the apex section of the protrusion (4).

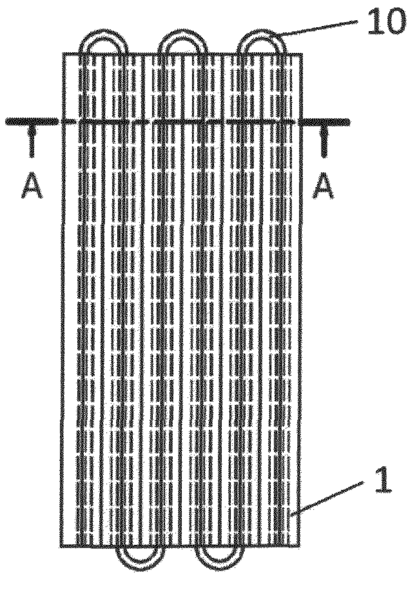

Fig.1

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Description

[0001] The subject of the invention is a plate heat exchanger utilizing phase change, particularly suited for use in thermal energy storage systems leveraging phase change or in devices for the production of ice and other solid materials obtained from the liquid phase through cooling.

[0002] Currently, most heat exchangers operating in phase-change thermal storage systems face significant limitations due to the fact that ice forming on the exchanger surface during the cooling process of the surrounding liquid substantially hinders heat transfer.

[0003] Heat exchangers equipped with a self-defrosting function are known; however, they employ moving parts for de-icing, which are not well-regarded by users-such as investors, installers, and manufacturers-due to their potential susceptibility to failure. At the same time, the phase change of water represents a significant reservoir of latent heat, which can be released or absorbed by the mass of water without a change in its temperature.

[0004] Patent publication CN101907410A discloses a plate-type ice storage system with a trough design, revealing a construction intended for cooling applications based on a plate heat exchanger that uses ice as the heat-absorbing medium without requiring plate heating to detach ice formed on the plates' surfaces. This solution pertains to a trough-like tank for ice storage, where a group of heat exchange plates with through-holes is installed, and is used simultaneously for heat exchange in an air conditioning system along with the production and storage of ice. Channels for the air conditioning water and channels for low-temperature coolant fluid are created between the heat exchange plates and the channels for air conditioning water for the air conditioning system, arranged at intervals of 40-120 mm, alternate with the channels for coolant fluid to absorb heat. The device is connected to an external closed-loop system for detaching and melting ice formed on the heat exchanger plates, delivering low-temperature air to building air conditioning systems. Additionally, the storage system described in this publication features a modular design and compact dimensions, making it suitable for residential use.

[0005] Patent JPH10122703A discloses a plate-type heat exchanger, wherein the heat exchanger and its plates are designed to operate with a freezing medium consisting of supercooled water.

[0006] The plates of the heat exchanger are shaped as flat plate sections with bent parts formed on them that run in the direction of the fluid flow. The peaks of these bent parts are brazed to the plate sections of adjacent plate of the heat exchanger, creating flow paths for the refrigerant and supercooled fluid with a uniform cross-section along the flow direction between the heat exchanger plates. This design allows for the proper shaping of the liquid stream without flow turbulence and for maintaining the heat exchanger in an ice-free state.

[0007] JP2000356482A discloses a plate heat exchanger and ice storage unit that perform a similar task but in a different way: the plate heat exchanger features multiple water-side channels, ensuring that even if one becomes blocked with ice, the remaining water-side channels can still be used for producing supercooled water.

[0008] JP3209115B2 discloses a thermal storage system similar to that in publication JPH10115442A, using a similar solution with a plate heat exchanger, wherein the ice formed is melted into a slurry. The pipe is equipped with a preheater to prevent ice from entering the heat exchanger and causing its freezing. The preheater is a pipe-in-pipe heat exchanger where water mixed with ice is heated by a high-temperature working medium to melt the ice.

[0009] JPH09189495A also discloses a plate heat exchanger in which ice buildup is counteracted through an appropriate configuration of working mediums and their flow paths.

[0010] JP2001021274A pertains to a plate heat exchanger used in ice storage systems for air conditioning installations that produce and melt ice and it discloses a design similar to previous publications, with the exchanger plate shaped flat, acting as an evaporator and equipped with linear groove-like depressions on its surface, wherein the exchanger plates are arranged vertically, parallel to each other, with spacing inside a tank that serves as an ice storage reservoir filled with water. The plate heat exchanger is connected in a loop with an external system containing a compressor, an external heat exchanger, a pipe network passing through the thermal storage tank and the plate heat exchanger inside the tank, as well as a control system for operational cycles, such as the cooling/ice production cycle and the heating/heat recovery cycle. During the cooling cycle, ice forms on the heat exchanger's surface in areas directly above the flow channels for the refrigerant formed inside the interconnected exchanger plates. However, the exchanger plate deforms due to the formation of ice.

[0011] WO 01/35037 A1 reveals an automatic ice-making device producing ice in form of lumps in specific shape, which includes a cooling unit comprising a compressor, condenser, and evaporator, along with several aligned individual locations for making ice lumps, usually cubes, which are connected to the evaporator and a water supply system. Water supplied to the ice-making locations is cooled during the device's cooling mode to form ice lumps, which are detached and fall when the control system switches the device to the ice collection mode, this mode being triggered by a control system when a sensor detects a specified ice thickness and in this mode the ice lumps-making locations are heated using hot gas directed to the evaporator, allowing the ice to be released and collected in a container. In another variant, air is directed between the ice pieces at locations of their making and the evaporator.

[0012] The publication US 6311501 B1 discloses an ice-making machine featuring an evaporator plate where an ice layer forms, which is detached from the exchanger plate using a stream of hot gas, used to heat the plate, but the publication also discloses the potential use of other heating means, including electric heaters embedded in the exchanger plate.

[0013] The publication US 5582018 describes the design of an evaporator plate in an ice-making device, having a surface which features, arranged in rows one beside the other, depressions forming ice-making locations, with sharp-edged adjacent flanks. On the opposite side of the evaporator plate, at the intersections of the depressions, are arranged refrigerant pipes. Ice pieces are detached by heating the plate surface with hot gas, controlled by a control system.

[0014] US 5477694 A describes a known ice production control system for an ice-making device, which includes various sensors, such as a sensor of water temperature in the tank and a sensor of liquid level in the tank, indicating the ice layer thickness on the evaporator plate, wherein when the desired ice layer thickness is reached, the control system, equipped with a set of valves and relays-such as a time relay-switches the device from the "freeze cycle" mode to produce ice to the "harvest cycle" mode to detach ice.

[0015] The challenges in existing heat exchanger solutions include achieving long-term maintenance of the thermal storage capacity, avoiding moving parts or parts subject to significant deformation during defrosting, and the relatively high energy demand for detaching accumulated ice.

[0016] The objective of the invention is to develop a plate heat exchanger situated within a tank containing a phase-change fluid, typically water, which would at least partially overcome the shortcomings of the known solutions described above, due to a simplified design, improved heat exchange efficiency, and would ensure obtaining high thermal storage capacity.

[0017] The design of the plate heat exchanger according to the invention does not include moving parts and ensures the long-term maintenance of the thermal power of the storage system. This is because the detached ice floats upwards, and in the area surrounding the exchanger plate, there is liquid phase-change fluid, preferably water. Additionally, the invention enables energy savings during the detachment of ice by leveraging the beneficial effects of hydrostatic pressure and buoyant force in facilitating ice release.

[0018] The invention proposes a solution for a phase-change plate heat exchanger in which the detachment of ice that limits heat transfer is achieved by heating the exchanger surface. The shape of the exchanger plate and the positioning of the working medium pipes and heating elements ensure that the buoyancy of the ice clears the heated exchanger, aiding in the earlier detachment of the ice.

[0019] The invention allows for maintaining low thermal resistance in the phase-change heat exchanger and increases the thermal storage capacity of heat storage systems relative to mass or volume unit.

[0020] Furthermore, in a variant application of the invention, it enables continuous ice production without the use of moving parts, which is advantageous from a cost perspective.

Summary of the Invention

[0021] Plate heat exchanger with phase change according to the invention comprises:

an exchanger plate,

a pipe assembly located beneath the exchanger plate, through which a working medium flows, comprising of straight sections of pipes running parallel to each other and spaced apart, connected at both ends by connecting segments, in the implementation variant bent, wherein the pipes of the pipe assembly are made of a material with high thermal conductivity and a low thermal expansion coefficient,

multiple heating elements located directly beneath the exchanger plate or embedded within it, and a hydraulic or cooling/refrigeration system with a control system comprising a controller connected to a sensor array for recording the parameters of the phase-change medium, a pump, and a heat receiver, with the pipe assembly being connected to this hydraulic system,

wherein the exchanger plate with the pipe assembly and heating elements is immersed in a tank filled with a liquid phase-change medium, preferably water,

is characterized in that the exchanger plate is positioned near the bottom of the tank filled with the phase-change medium, preferably horizontally, such that a column of the phase-change medium, preferably water, preferably of a height that is at least double a multiple of the height of the protrusion, no less than at least 20 cm or greater measured from the apex of the protrusion, is located above the exchanger plate 1, wherein the phase-change medium is characterized by a liquid density greater than its solid density, and the exchanger plate is made of a material with high thermal conductivity and low thermal expansion coefficient and is profiled in the form of linearly extending, preferably along the length of the plate, protrusions arranged side by side in parallel rows across the entire surface of the exchanger plate, wherein the protrusions have the shape of elongated rectangular prisms with a base selected from: polygon or shape formed by a fragment and/or fragments of ellipse and/or other curved lines, and with side walls that converge at an angle in the apex region of the protrusion, wherein the apex region forms an apex where the side walls converge at an angle α ranging from 30° to 120°, preferably at an angle α between 45° and 90°, in a form selected from: a sharp-edged apex, a truncated apex, or an apex provided with a socket convex part running along the apex region of the protrusion, moreover, in the regions of the exchanger plate located directly beneath the apexes of the protrusions, pipes of the pipe assembly are arranged, running along the entire length of each protrusion, preferably tangentially adjacent to its side walls, wherein the height of the protrusions and the apex angle α are selected such that the bottom edge of the pipe 3 is located no lower than ¼ of the height of the protrusion;

and in the immediate vicinity or directly on each of the side walls of each protrusion, in areas located below and spaced apart from the apexes of the protrusions, at least one heating element, and preferably more than one heating element, is situated, which is activated and controlled automatically by the control system with the controller in response to a signal from a sensor, preferably a temperature sensor, located in the tank of the phase-change medium above the exchanger plate, indicating the formation of an ice layer of a predetermined maximum threshold value on the exchanger plate, and deactivated automatically by the control system with the controller upon receiving a signal from the sensor indicating detachment of the ice layer from the exchanger plate .

[0022] In an embodiment, the tank containing the phase-change medium is a hermetically sealed tank, insulated on all sides with insulation, preferably placed underground.

[0023] In another embodiment, the tank containing the phase-change medium is an insulated tank that can be opened from the top, and preferably open at the top, allowing for the collection of the formed solidified phase-change medium, preferably ice or such as bismuth and gallium.

[0024] In an embodiment, in the immediate vicinity and/or directly on each of the side walls of each protrusion, at least two or more heating elements are arranged at mutual intervals, preferably such as resistance wire, electric heaters, or inductive elements, wherein these heating elements are distributed starting from the lowest part of the exchanger plate, at areas of the plate farthest from the individual apexes of the protrusions to higher areas, i.e. located closer to the apexes of the protrusions, but below the pipes of the working medium and spaced apart from them, wherein the activation of the heating elements located closer to the apexes of the protrusions occurs later than the activation of the heating elements located in the lower parts, located farthest from the apexes of the protrusions, with time intervals preferably between 45s and 30s, more preferably every 30 seconds of the delay, enabling ice detachment by buoyant force.

[0025] In an embodiment, multiple exchanger plates are horizontally arranged in the insulated tank containing the phase-change medium, starting from an area close to the bottom of the tank, spaced one above the other, such that above each plate 1, a column of the phase-change medium of the required height, at least twice the height of the protrusion, measured from the apex of the protrusion, but not less than 20 cm, is ensured, wherein each exchanger plate is isolated from the rest of the tank by an insulation layer located directly beneath each exchanger plate, preferably connected with the heat exchanger plate.

[0026] In an embodiment, the pipes of the working medium of the pipe assembly are connected to the side walls of the protrusions near the apexes of these protrusions of the exchanger plate, and preferably follow a path selected from meander or harp-like arrangement.

[0027] In an embodiment, the surface of the exchanger plate 1 is profiled such that in cross-section, it forms a series of adjacent triangles constituting protrusions with a height of up to 10 cm, preferably between 5 and 3 cm, wherein the surface of the exchanger plate is preferably structured.

[0028] In an embodiment, the protrusions are equipped with convex socket parts formed on the apexes of the protrusions, having in cross-section shape of fragments of curved lines, preferably fragments of ellipse, in a special embodiment fragments of a circle, which is a particular case of the ellipse, and straight sections, for tight mounting in them of the pipes of the pipe assembly to ensure surface contact with the pipe placed in them, wherein these convex socket parts are located on the walls of the protrusions or preferably on straight metal sheet sections extending from the walls. In a preferred embodiment, the curves are a fragment of the Lissajous curve

[0029] Besides, in an embodiment, convex socket parts are located on the side walls of the protrusions at points where heating elements are mounted, for placement of these heating elements therein. In addition, the socket convex part may also be located in the apex of the projection above the working medium pipe of the pipe assembly.

[0030] In an embodiment, the exchanger, with the exchanger plate and the tank containing the phase-change medium, has a form of a heat storage unit.

[0031] In an alternative embodiment, the exchanger, with the exchanger plate and the tank containing the phase-change medium, has a form of an ice-making device.

Advantages of the invention

[0032] The solution according to the invention utilizes the buoyant force and hydrostatic pressure of the liquid phase-change medium, ensuring the maintenance of the thermal capacity of the storage system. This is because the solidified medium, typically ice, rises due to buoyant force, while the area around the exchanger plate remains surrounded by the liquid medium, such as water, preventing any reduction in the intensity of heat exchange between the working medium and the medium filling the tank.

[0033] The triangular shape of the exchanger protrusions promotes vertical circulation of water within the tank during both heat absorption and heat release.

[0034] The use of heating elements in the form of electric heaters facilitates the supply of thermal energy derived from surplus electrical energy.

[0035] Embossed features on the exchanger plate, such as nesting convex sections, allow for easier installation of heaters and piping, as well as improved surface contact.

[0036] Due to the absence of moving parts, the exchanger plate and piping system can be manufactured using 3D printing technology, with the plate sheet potentially being structured.

[0037] The invention ensures low thermal resistance in the phase-change heat exchanger and increases the thermal storage capacity of heat storage systems relative to mass or volume unit.

Description of the drawing

[0038] The solution according to the invention is illustrated in the drawings as examples of embodiments, where:

Fig. 1 depicts a top view of the exchanger plate with working medium pipes,

Fig. 2 schematically shows a cross-sectional view along line A-A of Fig. 1, illustrating a transverse sheet of the exchanger plate,

Fig. 3 schematically presents an enlarged view of a protrusion on the exchanger plate in cross-section from the perspective of line A-A in Fig. 1,

Fig. 4 illustrates a schematic diagram of the hydraulic system of the heat exchanger according to the invention,

Fig. 5 schematically shows a side cross-sectional view of an example of a phase-change exchanger according to the invention with a single exchanger plate,

Fig. 6 schematically depicts a cross-sectional view of a heat exchanger with multiple exchanger plates according to the invention, and

Figs. 7a-c schematically illustrate the principle of operation of the exchanger plate according to the invention, while

Fig. 8 schematically presents an enlarged cross-sectional view of a protrusion on the exchanger plate in another embodiment of the invention.

Examples of Embodiments of the Invention

[0039] A phase-change plate heat exchanger in an embodiment of the invention includes an exchanger plate 1 located in a tank Z filled with a phase-change medium 14, preferably water 14, positioned in close proximity to the tank's bottom so that a column of phase-change medium lies above the plate. Below the exchanger plate 1, a pipe assembly 10 is mounted, through which the working medium flows. This assembly features parallel, spaced straight pipe sections 3 connected at both ends by curved sections. The pipes 3 of the pipe assembly 10 are made from a material with high thermal conductivity and low thermal expansion, such as e.g. copper. The pipe assembly 10 is connected to a hydraulic system that includes a control unit with a controller 8 linked to a set of sensors 7 for monitoring the phase-change medium's parameters within the tank Z. The system also includes a circulation pump 9 or a compressor and a heat receiver 6, such as an air conditioning system. The exchanger plate 1 is constructed from a material with high thermal conductivity and low thermal expansion. It features linear protrusions 4, advantageously oriented along the length of the plate and arranged in parallel rows across its entire surface. These protrusions 4 have the shape of elongated rectangular prisms with triangular bases. In alternative embodiments, the bases of the protrusions may take the form of other polygons, or figures created from segments of ellipses or polygon with convexities in the form of elliptical arcs. In another embodiment, they may have shapes derived from segments of Lissajous curves, distributed at the protrusion's apex 4' and, optionally, along the side walls 2 of the protrusions 4. The side walls 2 of the protrusions 4 converge at an apex angle α at the top section 4' of the protrusion 4, the top section forming an apex 4' where the side walls 2 meet at an angle α ranging from 30° to 120°, preferably between 45° and 90°, particularly at an angle of 60°. In embodiments of the invention, the apex 4' of the protrusion may be sharp-edged, truncated, or equipped with a convex socket part 13 running along the apex section of the protrusion 4 for securing the working medium pipes 3.

[0040] The working medium pipes 3 are mounted close to the apexes 4' of the protrusions 4 on the underside of the exchanger plate 1, as close as possible to plate 1 of the exchanger and preferably in contact with its surface or, in an alternative embodiment, are attached, preferably mechanically, to the plate surface in the apex regions 4' of the protrusions 4.

[0041] In some embodiments, the protrusions 4 feature convex socket parts 13 formed at their apexes 4' with cross-sectional shapes in a form of curved segments, such as e.g. elliptical segments for securely mounting in them the pipes 3 of the pipe assembly 10. These socket parts 13 ensure tight contact surface between the pipe 3 and the protrusion 4 and are located on the protrusion's 4 side walls 2 or, preferably, on straight sections of metal sheet extending from the side walls 2. In other embodiments, the cross-sectional curve of the socket parts 13 may represent a segment of a Lissajous curve. In yet another embodiment, these socket parts 13 have a cross-section in a form of a segment of a circle, which is a specific case of an ellipse.

[0042] The exchanger plate 1 is positioned near the bottom of the tank Z filled with the phase-change medium, preferably horizontally, so that a column of phase-change medium lies above it. This column preferably should have a height at least twice or several times the height of the protrusions 4, with a minimum height of 20 cm or greater from the apex 4' of the protrusion. The phase-change medium is preferably a water and should not penetrate under the surface of the plate 1.

[0043] The working medium pipes 3 of the pipe assembly are mounted in areas of the exchanger plate 1 situated directly below the apexes 4' of the protrusions 4, tangentially, adjacent to their side walls. The height of the protrusions 4 and the apex angle α are selected such that the lower edge of the working medium pipe 3 is no lower than one-quarter of the height of the protrusion 4. In one embodiment, the apex 4' of the protrusion 4 is truncated, forming a trapezoidal shape of the protrusion 4 to achieve additional contact with the surface of the exchanger plate 1.

[0044] Directly beneath the exchanger plate 1, in an example of embodiment made of a metal sheet with a thickness of 0.5 to 1 mm, preferably copper, one or more heating elements 5 are installed. These are positioned either in close proximity to or directly on each of the side walls 2 of each protrusion 4 below and at a distance from the apexes 4' of the protrusions. In a preferred embodiment, more than one heating element 5, preferably three heating elements 5 are installed on each side wall 2 of a protrusion 4. The heating element(s) 5 is(are) either attached to or embedded within the plate 1, with more than one heating element 5 included in the preferred embodiment.

[0045] In an example of embodiment, for housing the heating elements 5, convex socket parts 13 are provided, which are also located on the side walls 2 of the protrusions 4, at points of attachment of the heating elements 5 designed to accommodate the heating elements 5.

[0046] The heating element 5 is automatically activated and deactivated by a control system with a controller 8. Activation occurs upon receiving a signal from a sensor 7, such as a temperature sensor 7 in a form of a pt1000 thermocouple, located in the upper, typically unheated, portion of the exchanger plate. This sensor 7 is positioned near the path of the working medium pipes 3 in their close vicinity and close to the apexes 4' of the protrusions 4 and measures the temperature to detect the formation of an ice layer on the exchanger plate 1. When the thickness of the ice layer exceeds a predefined maximum limit, the heating elements 5 are automatically activated to detach the ice layer from the exchanger plate 1. The heating elements 5 are automatically turned off by the control system with the controller 8, when the sensor 7 detects a rise in temperature to the level of the liquid phase-change medium 14, i.e. a liquid, preferably water 14 in the tank Z. This temperature rise indicates the detachment of the ice layer or another frozen phase-change medium, which must have temperature lower than its liquid form, from the exchanger plate 1. The sensor 7 may be placed in the phase-change medium tank above the exchanger plate 1.

[0047] The heating of the plate 1 ceases and heat receiving begins again when a temperature sensor 7 (e.g. a pt1000 thermocouple) placed in the upper (optionally unheated) part of the exchanger plate 1, i.e. in the vicinity of and in close proximity to the course of the working medium pipes 3 in the vicinity of the apexes 4' of the protrusions, registers a rise in temperature to the level of temperature of the liquid in tank Z.

[0048] The heating elements 5 may be placed only in the lowest portions of the exchanger plate 1, i.e. in the areas of the plate 1 farthest from the individual apexes 4' of the protrusions, or also in its higher sections, i.e. situated closer to the apexes 4' of the protrusions but below the working medium pipes 3. The heating in higher sections, i.e. situated closer to the apexes 4' of the protrusions begins later than in the lower sections, situated further from the apexes that is furthest from the apexes 4' of the protrusions of the exchanger plate 1, what enables the detachment of ice through buoyant forces. In other words, during the ice detachment phase, the control system first activates the heating elements 5 located farthest from the apexes 4' of the protrusions 4 of the exchanger plate 1, i.e. located at the lower portion of the plate 1 and next activates subsequent heating elements 5 progressively one after another, sequentially at timed intervals, e.g. every 30 seconds, starting from those farther from the apexes 4' of the protrusions 4 of the plate 1 in the direction to the heating elements 5 closest to the apexes 4' of the protrusions 4 of the plate 1. The heating element may also be placed directly at or near the apexes 4' of the protrusion.

[0049] The phase-change medium used in the heat storage system with the heat exchanger plate 1 according to the invention must have a liquid-phase density greater than its solid-phase density. Water is a preferred medium due to this property. As a result, solid-phase medium such as ice is buoyantly lifted away from the exchanger plate 1 by hydrostatic pressure and buoyant forces. This ensures that the liquid phase medium, preferably water, remains around the exchanger plate 1, allowing efficient heat exchange between the phase-change medium and the working medium flowing through the pipes 3.

[0050] In Figures 2, 5, and 6 of the drawing, the cross-sectional view of the heat exchanger is shown. The working medium pipes 3 are placed at the apexes of all individual protrusions 4 of the plate 1 of the heat exchanger, preferably, one pipe 3 of the hydraulic or cooling circuit 10 (depicted in the drawing as white points) is placed in each apex 4'. In the lowest areas, i.e., those areas of the exchanger plate 1 which are furthest from the respective apexes 4', heating elements 5, preferably in the form of resistance heaters, heating wire, or inductive heaters are located. It is also possible to use additional pipes with hot fluid.

[0051] In an embodiment of the invention or a variant of the invention, the heat exchanger plate 1 is installed in an ice production device-at the bottom of an open tank Z. In this arrangement, the heat exchanger plate 1 during heat extraction becomes covered with ice, as described above, but the open upper part of the tank allows for regular removal of the ice produced.

[0052] In an embodiment, several plates 1 of the heat exchanger, for example (see Fig. 6), three heat exchanger plates 1 are arranged horizontally, in an insulated tank Z filled with phase-change fluid. The plates 1 are placed one above the other, in such a way that above each plate 1, there is a column of phase-change fluid with the required height, at least twice the height of the side wall 2 of the protrusion 4, measured from the apex 4' of the protrusion 4, but not less than 20 cm. Each of the plates 1 is isolated from the rest of the tank by a layer of insulation 12 placed directly beneath each plate 1 of the heat exchanger, preferably bonded to the plate 1.

[0053] In an embodiment, the pipes 3 of the working medium in the pipe assembly 10 are connected to the side walls 2 of the protrusions 4 near the apexes 4' of these protrusions of the heat exchanger plate 1, and preferably follow a path chosen from meandering, harp -shaped, or double harp -shaped configurations.

[0054] In an embodiment, the surface of the exchanger plate 1 is shaped such that in cross-section, it forms a set of adjacent triangles, which are the protrusions 4 with a height of up to 10 cm, preferably between 5 and 3 cm. The surface of the exchanger plate 1 is preferably structured.

[0055] In an embodiment of the invention, the phase-change heat exchanger according to the invention is used in a thermal storage unit of the type known as a thermos (see Fig. 5), containing a hermetically sealed tank Z filled with water or another phase-change fluid. In the bottom of the tank Z, the heat exchanger is installed, which, during heat extraction from the water, becomes covered with ice. When the heating elements 5 in the form of defrosting heaters are activated, water appears between the ice block and the surface of the exchanger plate 1. When the gap filled with water exceeds the size of the capillary, the unbalanced buoyant force acting on the ice block increases. The shape of the exchanger plate 1 ensures that the gap takes the shape of a siphon, which directly encourages its widening due to the hydraulic pressure of the water column. During heat delivery to the thermal storage unit (e.g., in summer), heating is not necessary, and heat is directly transferred to the surroundings of the heat exchanger plate 1, initially melting the ice adhered to it, and then warming the phase-change liquid accumulated at the bottom of the tank Z. Heating to the appropriate high temperature generates convection currents in the water, which is beneficial, as the coldest liquid sinks to the plate 1 of the exchanger, increasing heat transfer efficiency, while the warmest liquid, when it reaches the upper layers of the liquid, is cooled by the melting ice.

[0056] In a variant embodiment, the heat exchanger plate 1 is installed in an ice production device-at the bottom of an open tank Z. The exchanger plate 1 becomes covered with ice during heat extraction, as in the previous example, but the open upper part of the tank allows for regular removal of the produced ice.

<u>Operation of the heat exchanger according to the invention</u>

[0057] The heat exchanger begins heat absorption by being in full contact with the water 14 filling the tank Z. After the water is cooled below a certain temperature, ice forms on the surface of the exchanger plate 1 (Fig. 7b), particularly in the direct vicinity of the working medium pipes 3 near the apexes 4' of the protrusions 4. After stopping heat absorption and activating or starting the heating elements 5 (heaters), the ice begins to melt starting from the side wall 2 of the exchanger plate 1 (Fig. 7c), initially in the direct vicinity of the heating elements 5 until the ice is completely detached (Fig. 7a) from the walls of the exchanger plate 1 and lifted upwards by buoyant force. The heat exchanger returns to its initial state as shown in Fig. 7a.

[0058] The phase-change exchanger plate 1 according to the invention is placed in a self-supporting, all-insulated tank Z filled with water, serving as a thermal energy and cold storage. During operation, the tank fills with ice, making it an effective heat absorber at times when cooling is required.

<u>Another detailed example of the operation of the device according to the invention</u>

[0059] Heat flows through the plate (1) of the heat exchanger from the phase-change fluid located above the exchanger plate 1 to the working medium, such as a glycol-water solution, refrigerant, circulating through the set of pipes (3) (optimally thin-walled) attached directly or indirectly to the exchanger plate (1) in any desired hydraulic configuration (10), such as the meandering arrangement shown in Fig. 1. It is also possible to use a harp-like, double harp, or other configurations. The working medium, pumped by pump 9, compressor, or flowing by gravity, releases heat at the heat receiver 6, e.g., a heat pump. After the phase-change fluid above the exchanger plate 1 reaches its freezing temperature, it solidifies in close proximity of the piping 3 in the upper part of the exchanger plate 1, i.e., at the apex 4'. Once the temperature indicated by the temperature sensor 7, which correlates with the thickness of the ice accumulated on the plate 1, reaches the experimentally determined value, the controller 8 stops the circulation in the working medium circuit, e.g., by halting the operation of the circulation pump 9, and activates the heating elements 5 in the appropriate sequence, so that the ice starts to melt first near the lower part of the heat exchanger plate

1. After a sufficiently wide gap is melted, the buoyant force acting on the remaining ice mass detaches it from the exchanger plate 1 and lifts it upwards (see Fig. 7).

[0060] An example of embodiment and of application of the heat exchanger 2 according to the invention may be the hydraulic-sealed and thermally insulated tank Z filled with water, containing three insulated 12 underside exchanger plates 1 arranged one above the other with spacing in a horizontal orientation, as shown in Fig. 6.

Detailed example of implementation according to the invention

[0061] An example implementation of the invention involves a heat exchanger plate 1 with dimensions 1.5 m by 2 m placed in the bottom of a closed, hermetically sealed, thermally insulated tank Z filled with water. The plate 1 is made of 0.5 to 1 mm thick copper sheet and is bent in such a way that the repeatable triangular shapes of the protrusions 4 visible in cross-section form equilateral triangles with a side length of 10 cm. The underside of the plate 1 is soldered with a piping system 10 made from thin-walled copper pipes with an outer diameter of 12 mm and wall thickness of 1 mm in the form of working medium pipes 3. The piping system, configured in a meandering arrangement, allows the working medium of the heat pump such as refrigerant R290, to circulate. In the piping, the refrigerant evaporates, lowering the surrounding temperature and enabling the formation of ice on the surface of the heat exchanger plate 1. Parallel to the piping system 10 are placed the electric heating elements 5 in the form of resistance wire with a total power of 5 kW, adhered to the copper plate 1 of the exchanger at the following locations: at the lowest point of the plate 1, in the middle of the section between the lowest and highest parts of the exchanger plate 1, and at the higher part of the plate 1 of the heat exchanger. When the controller 8 detects, based on readings from the set of sensors 7, that the heat transfer efficiency of the heat exchanger has significantly decreased, the operation of the compressor 9 is stopped, and the heating elements 5 are sequentially activated-from bottom to top. After the pre-determined heating sequence is completed (lower heating elements 5 are activated at second 0, intermediate ones after 45 seconds, upper ones after 1 minute and 45 seconds; the entire heating process ends after 3 minutes), the heating elements 5 switch off, and the operation of the compressor 9 is resumed.

Detailed example of implementation of the exchanger plate 1

[0062] Plate 1 of the exchanger is in the form of a 0.5mm thick copper plate, the protrusions 4 arranged on plate 1 have 5cm wide side walls and cross-section in the form of an equilateral triangle with an apex angle α= 60°, the heating power per metre length of one wall of the protrusion 4 is 25W.This gives 1,000W/m2 of the exchanger surface area and has the potential to melt in 60 seconds a layer of ice sufficient for capillary and adhesive forces to be weakened sufficiently for buoyancy force to dominate.

[0063] The convex socket parts 13 on the apexes 4' of the protrusions 4 (for the working medium pipes 3) and possibly on the walls of the protrusions 4 (for heating elements 5) are shaped as a section of an ellipse, the ends of which are seated on the walls of the protrusions 4 or on the straight sections of metal sheet coming out of the walls of the protrusions. The size of the convex socket parts 13 must allow the pipes 3 or alternatively the heating elements 4 to be tightly fitted into them.

[0064] The use of convex socket parts 13 is advantageous because it increases the length/surface area of the metallic contact between the heat supply/receiving element (pipe 3) and plate 1 of the exchanger, facilitates the installation of heating elements 5 and piping 10, and increases the contact of the part of plate 1 of the exchanger with the highest temperature with the working medium (water).

[0065] It is crucial to select the shape of the sheet metal extrusions (triangular, trapezoidal, etc.) and the dimensions of these extrusions in relation to the height of the water column above plate 1, to the diameter of the pipes 3 of the working medium, to the power of the heaters or other heat source and to the power of the exchanger.

[0066] The height of the protrusions 4 and the apex angle α should be selected so that the lower edge of the pipe 3, when mounted tangentially to both side walls of the protrusion 4, is not lower than ¼ of the height of the protrusion. It is permissible to truncate the apex 4' of the protrusion in order to obtain additional contact between the pipe 3 and the surface of the plate 1 of the exchanger.

Description of the physics of the solution:

[0067] In the process of heating the exchanger plate 1 in the form of the metal sheet in a sequence from the lower part of the plate to the upper part of the plate, asymmetric melting of the ice occurs (first at the edges in the lower part and then in the upper parts). A force moment favourable to ice detachment is then created, as the buoyancy force acting on the partially detached lump is not counterbalanced by adhesion to plate 1 of the exchanger, while the unmelted part of the ice lump strongly adheres to the surface of the metal sheet. The part of the ice detached by melting, on which the buoyancy force unbalanced by adhesion to the exchanger surface acts, tends to rotate around the axis determined by the lowest point of adhesion of the ice to the plate. This creates stresses in the ice structure, and these can lead to cracks. Asymmetric melting ensures that the ice detaches from the metal sheet faster than it would be possible for a given output of heaters heating the flat plate of the heat exchanger due to the hydrostatic pressure guaranteed by the water column above the ice block. This pressure causes the water to exert an additional force acting laterally on the spot where the ice adheres to the exchanger, which speeds up the process of separating the ice from the exchanger surface allowing energy savings.

Claims

1. Plate heat exchanger with phase change according to the invention comprises:

    a heat exchanger plate (1),
    a pipe assembly (10) which is located beneath the heat exchanger plate (1) and through which a working medium flows, comprising straight sections of pipes (3) for working medium, running parallel to each other and spaced apart, connected at both ends by connecting segments,
    wherein the pipes (3) of the pipe assembly (10) are made of a material with high thermal conductivity and a low thermal expansion coefficient,
    heating elements (5) located directly beneath the heat exchanger plate (1) or embedded within it, and
    a hydraulic system with a control system comprising a controller (8) connected to a set of sensors (7) for recording the parameters of the phase-change medium, a pump (9), and a heat receiver (6), with the pipe assembly (10) for the working medium being connected to this hydraulic system,
    wherein the heat exchanger plate (1) with the pipe assembly (10) and heating elements (5) is immersed in a tank (Z) filled with a liquid phase-change medium, preferably water,

    characterized in that

    the heat exchanger plate (1) is positioned near the bottom of the tank (Z) filled with the phase-change medium, preferably horizontally, such that a column of the phase-change medium, preferably water, of a height of no less than at least 20 cm or greater measured from the apex (4'), and preferably of a height that is a multiple - at least double - of the height of the protrusion (4), is located above the heat exchanger plate (1), wherein the phase-change medium (14) is **characterized by** a liquid density greater than its solid density, and the heat exchanger plate (1) is made of a material with high thermal conductivity and low thermal expansion coefficient and is profiled in the form of linearly extending, preferably along the length of the plate, protrusions (4) arranged side by side in parallel rows across the entire surface of the heat exchanger plate (1), wherein the protrusions (4) have a shape of elongated rectangular prisms with a base selected from: polygons or shapes formed by curved fragments, including shapes formed from elliptical fragments, and side walls (2) that converge at an angle in the apex region of the protrusion (4), wherein the apex region forms an apex (4') where the side walls (2) converge at an angle α ranging from 30° to 120°, preferably at an angle α between 45° and 90°, in a form selected from: a sharp-edged apex, a truncated apex, or an apex provided with a convex socket part (12) running along the apex region of the protrusion (4),
    moreover, in the regions of the heat exchanger plate (1) located directly beneath the apexes (4') of the protrusions (4), pipes (3) of the pipe assembly are arranged, running along the entire length of each protrusion (4), preferably tangentially adjacent to its side walls (5), wherein the height of the protrusions (4) and the apex angle α are selected such that the bottom edge of the pipe (3) is located no lower than ¼ of the height of the protrusion (4);
    and in the immediate vicinity, preferably directly on each of the side walls (5) of each protrusion (4), in areas located below and spaced apart from the apexes (4') of the protrusions (4), at least one heating element (5), and preferably more than one heating element (5), is situated, which is activated and controlled automatically by the control system with the controller (8) in response to a signal from a sensor (7), preferably a temperature sensor, located in the tank (Z) of the phase-change medium above the heat exchanger plate (1), indicating the formation of an ice layer of a predetermined maximum threshold value on the heat exchanger plate (1), and deactivated automatically by the control system with the controller (8) upon receiving a signal from the sensor (7) indicating detachment of the ice layer from the heat exchanger plate (1).

2. Plate heat exchanger according to claim 1, **characterized in that** the tank (Z) containing the phase-change medium is a hermetically sealed tank, insulated on all sides with insulation (11), preferably placed underground.

3. Plate heat exchanger according to claim 1 or 2, **characterized in that** the tank (Z) containing the phase-change medium is an insulated tank that can be opened from the top, and preferably open at the top, allowing for the collection of the formed solidified phase-change medium, preferably ice.

4. Plate heat exchanger according to any of claims 1-3, **characterized in that** in the immediate vicinity, pre-

ferably directly on each of the side walls (2) of each protrusion (4), at least two or more heating elements (5), preferably such as resistance wires, electric heaters, or inductive elements, are arranged at intervals, wherein these heating elements (5) are distributed starting from the lowest part of the heat exchanger plate (1) at areas of that plate (1) which are farthest from the individual apexes (4') of the protrusions (4) to higher areas, closer to the apexes (4') of the protrusions (4), but below the pipes (3) for the working medium and spaced apart from them, wherein the activation of the heating elements (5) closer to the apexes (4') of the protrusions (4) occurs later than the activation of the heating elements (5) located in the parts farthest from the apexes (4') of the protrusions (4), with time intervals preferably between 45s and 30s, more preferably every 30 seconds of delay, enabling ice detachment by buoyant force.

5. Plate heat exchanger according to any of claims 1-4, **characterized in that** multiple heat exchanger plates (1) are horizontally arranged in the insulated tank (Z) containing the phase-change medium, the exchanger plates (1) being spaced and placed one above the other, such that above each plate (1) a column of the phase-change medium (14) of the required height, at least twice the height of the protrusion (4), measured from the apex (4') of the protrusion (4) but not less than 20 cm, is ensured, wherein each heat exchanger plate (1) is isolated from the rest of the tank by an insulation layer (12) located directly beneath each exchanger plate (1), preferably integrated with the heat exchanger plate (1).

6. Plate heat exchanger according to any of claims 1-5, **characterized in that** the pipes (3) for the working medium of the pipe assembly (10) are connected to the side walls (2) of the protrusions (4) near the apexes (4') of these protrusions on the heat exchanger plate (1), and preferably follow a path selected from a meander or harp-like arrangement.

7. Plate heat exchanger according to any of claims 1-6, **characterized in that** the surface of the heat exchanger plate (1) is profiled such that in cross-section, it forms a series of adjacent triangles constituting protrusions (4) with a height of up to 10 cm, preferably between 5 and 3 cm, wherein the surface of the heat exchanger plate (1) is preferably structured.

8. Plate heat exchanger according to any of claims 1-7, **characterized in that** the protrusions (4) are equipped with convex socket parts (13) formed on the apexes (4') of the protrusions, having a cross-sectional shape of elliptical segments for tight mounting of the working medium pipes (3) of the pipe assembly (10) to ensure surface contact with the pipe (3) placed in them, wherein these convex socket parts (13) are located on the walls (2) of the protrusions (4) or preferably on straight metal sheet sections extending from the walls (2).

9. Plate heat exchanger according to any of claims 1-8, **characterized in that** the convex socket parts (13) have a cross-sectional shape of curve segments in the form of a Lissajous curve fragment, for tight mounting of the working medium pipes (3) of the pipe assembly (10) to ensure surface contact with the pipe (3) placed in them.

10. Plate heat exchanger according to any of claims 1-9, **characterized in that the** convex socket parts (13) are located on the side walls (2) of the protrusions (4) at points where heating elements (5) are mounted, for placement of the heating elements (5) in them.

11. Plate heat exchanger according to any of claims 1-10, **characterized in that** the exchanger with the exchanger plate (1) and the tank (Z) containing the phase-change medium has the form of a heat storage unit.

12. Plate heat exchanger according to any of claims 1-10, **characterized in that** the exchanger with the exchanger plate (1) and the tank (Z) containing the phase-change medium (14) has the form of an ice-making device.

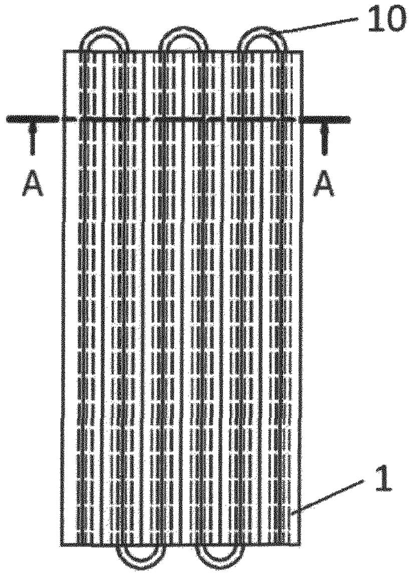

Fig.1

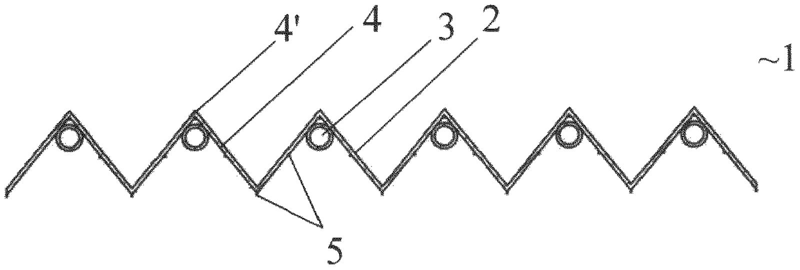

Fig. 2

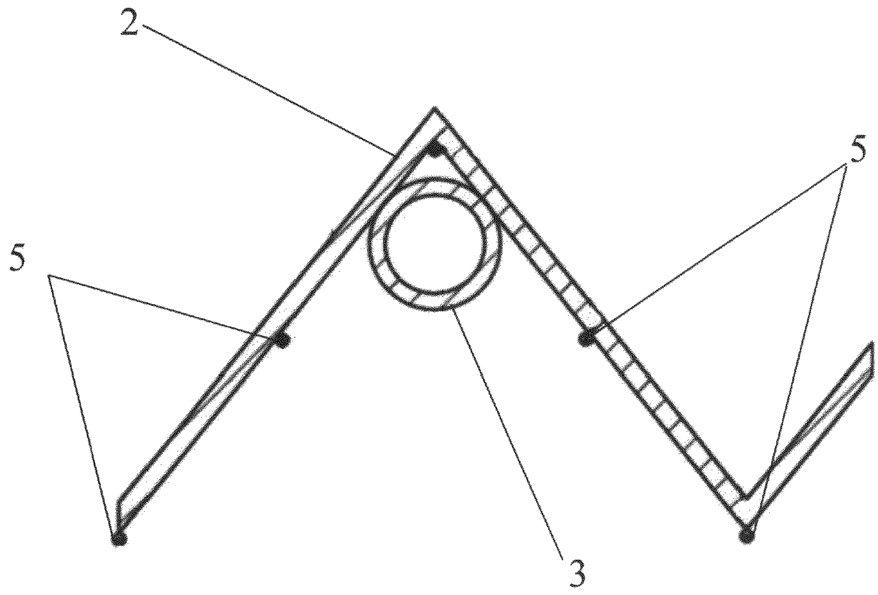

Fig. 3

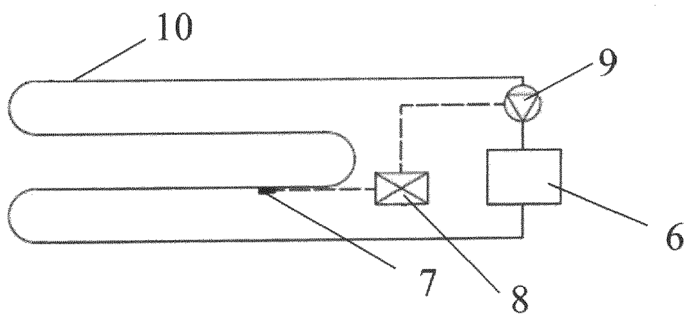

Fig. 4

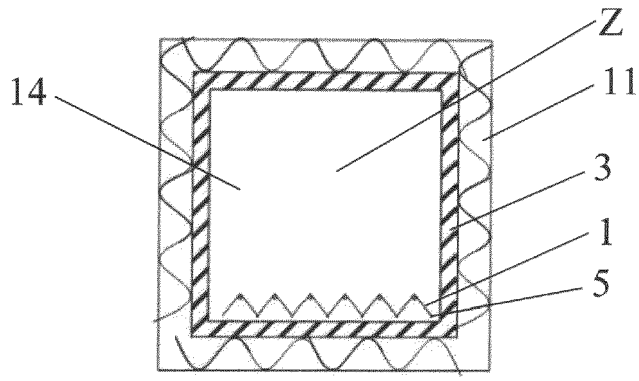

Fig. 5

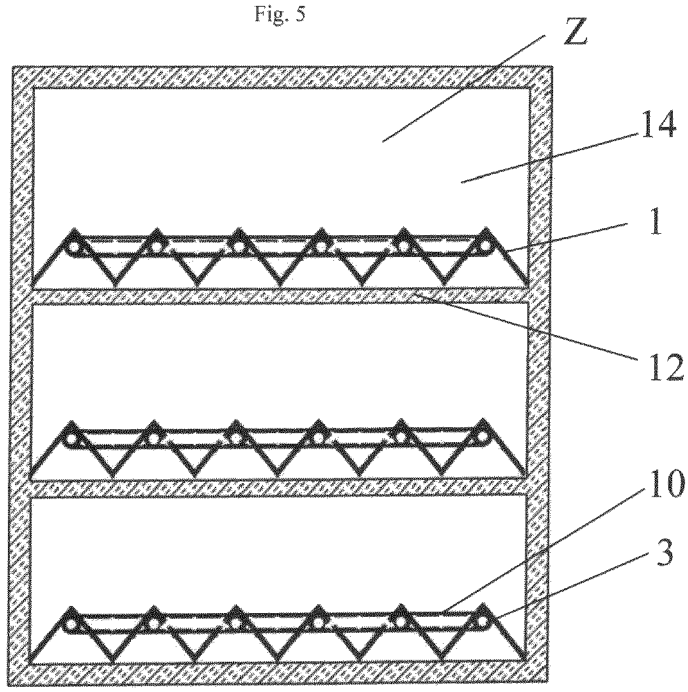

Fig. 6

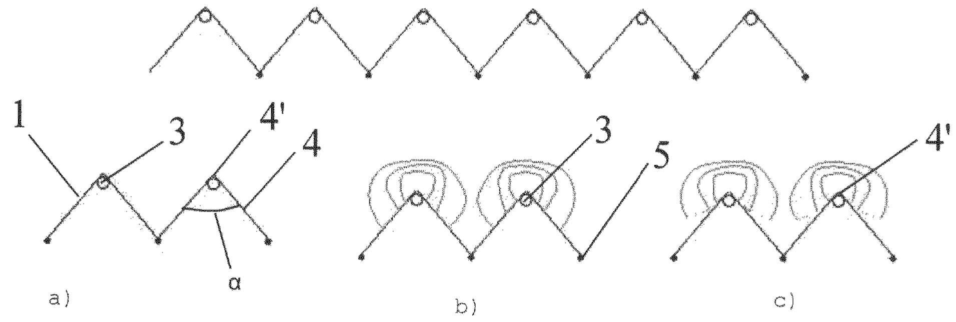

Fig. 7

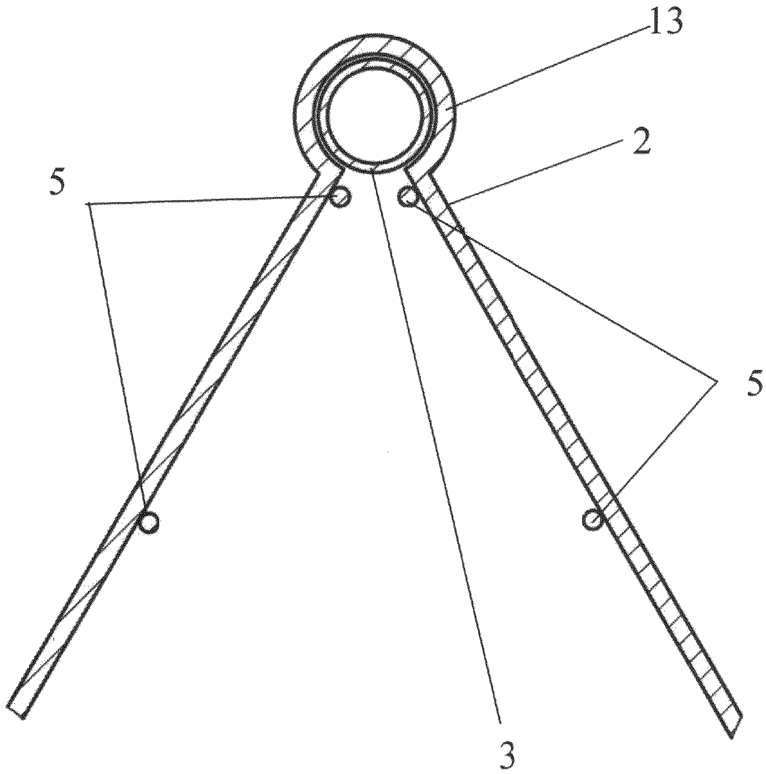

Fig. 8

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EUROPEAN SEARCH REPORT

Application Number
EP 24 21 9152

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3

Place of search	Date of completion of the search	Examiner
Munich	7 May 2025	Jessen, Flemming

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