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

(11) **EP 3 246 638 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
22.11.2017 Bulletin 2017/47

(51) Int Cl.:
F25B 3/00 *(2006.01)*

(21) Application number: **16170472.1**

(22) Date of filing: **19.05.2016**

(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:
MA MD

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(54) A PROCESS AND AN APPARATUS FOR TRANSFERRING HEAT

(57) A process of transferring heat from a first medium to a second medium is provided. The process comprises:
(a) rotating an amount of a compressible fluid about an axis of rotation such that the fluid is compressed in a direction away from the axis of rotation to provide a compressed fluid;
(b) during at least part of the compression of step (a), transferring heat from the fluid to the second medium;
(c) returning the compressed fluid towards the axis of rotation;
(d) expanding at least part of the compressed fluid to provide an expanded fluid; and
(e) conveying the expanded fluid to step (a);
wherein step (b) comprises condensing at least part of the fluid to a liquid and transferring heat of condensation from the fluid to the second medium and step (d) comprises transferring heat from the first medium to the fluid.

An apparatus associated with the process is also provided.

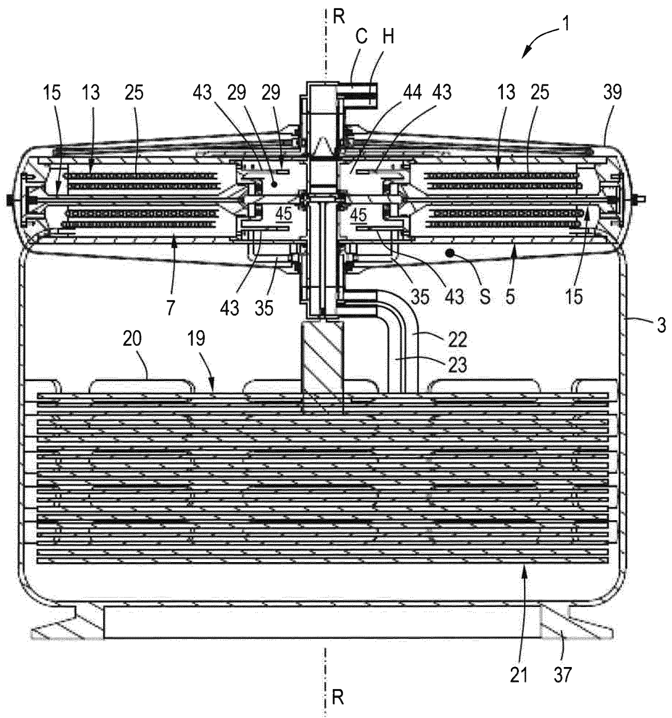

Fig.3A

EP 3 246 638 A1

Description

TECHNICAL FIELD

[0001] The present disclosure relates to a process and an apparatus for transferring heat from a first relatively cold medium to a second, relatively hot medium.

BACKGROUND

[0002] US 3, 470,704 discloses a refrigerator and/or heat pump comprising a rotor having conduits 37 attached thereto wherein a fluid having a relatively high initial pressure and density e.g. FREON gas, is rotated so as to move initially away from and then towards the axis of rotation in closed loops by a pump action utilizing the different densities and centrifugal forces of the fluid generated by a heat source and centrifugal action to pump the fluid through the conduits. The fluid may change between liquid and gaseous phases.

[0003] WO 2010/000840 discloses a process and an apparatus for transferring heat from a first medium to a second medium by rotating a working fluid, wherein heat exchange between compressed and expanded fluids is prevented and the working fluid remains a gas.

[0004] Improved efficiency of a process and of an apparatus for transferring heat from a first relatively cold medium to a second, relatively hot medium is still desired.

SUMMARY

[0005] In an aspect, a process according to the present disclosure comprises:

(a) rotating an amount of a compressible fluid about an axis of rotation such that the fluid is compressed in a direction away from the axis of rotation to provide a compressed fluid;
(b) during at least part of the compression of step (a), transferring heat from the fluid to the second medium;
(c) returning the compressed fluid towards the axis of rotation;
(d) expanding at least part of the compressed fluid to provide an expanded fluid; and
(e) conveying the expanded fluid to step (a);

wherein step (b) comprises condensing at least part of the fluid to a liquid and transferring heat of condensation from the fluid to the second medium and step (d) comprises transferring heat from the first medium to the fluid.

[0006] The velocity of rotation, e.g. expressed in revolutions per second, may determine the amount of compression and therewith the temperatures achieved in the fluid and by that the temperatures achieved in the second medium.

[0007] Thus, by transferring latent heat of condensation, isothermal and/or isobaric heat transfer may be provided, rendering the process efficient for transferring heat from the first medium to the second medium. Condensed fluid may flow away from the axis of rotation faster than gas under the influence of the rotation so that a pumping action on the working fluid may be provided.

[0008] The compression of the fluid in the compressor, at least up to the transfer of heat from the fluid to the second medium, may preferably comprise adiabatic compression, when not transferring heat to the second medium.

[0009] The fluid may be a saturated gas prior to the compression of step (a) and/or during the compression of step (a), and the temperature increase of the fluid by the compression of the fluid in the compressor, at least up to the transfer of heat from the fluid to the second medium, may follow the thermodynamic saturated vapour curve for the fluid.

[0010] In an embodiment, step (b) comprises heat transfer due to condensation from different portions of the fluid to the second medium at different temperatures and/or at different radial positions with respect to the axis of rotation, e.g. heat transfer from the fluid to the medium at different radial positions with respect to the axis of rotation wherein at each of the different radial positions the temperature of the fluid differs. Different radial positions relate to different degrees of compression of the fluid being compressed in a direction away from the axis of rotation which relate to different temperatures of the fluid. Thus, heat may be transferred at different temperatures. In a compressed saturated vapour latent heat of condensation may be absorbed or emitted at any temperature corresponding to the local pressure.

[0011] In an embodiment, step (b) comprises isothermal and/or isobaric heat transfer from the fluid to the medium. Thus, isothermal heat transfer is provided and in case of a saturated fluid the heat transfer may be both isothermal and isobaric.

[0012] In a particular embodiment, step (b) comprises condensing different parts of the compressed fluid to condensed fluid parts at different radial positions with respect to the axis of rotation and transferring heat of condensation from the fluid to the second medium at said different radial positions with respect to the axis of rotation. This allows the isothermal and/or isobaric heat transfer from the fluid to the medium at different isothermal temperatures.

[0013] Condensation of the fluid at different temperatures may be utilised to provide efficient heat exchange with little temperature difference between the heat source (e.g. here the fluid) and the heat receiver of the heat transfer (e.g. here the second medium) that is colder than the source. Incremental heat transfer in sequential steps with small temperature differences between source and receiver is considered more effective than a single step heat transfer from a source at a relatively high temperature to a receiver at a relatively low temperature. Further, heated second medium may be utilised at a particular temperature. In the present process the respective steps may be infinitesimal.

[0014] In an embodiment, heat transfer may be provided at different temperatures which vary with a constant temperature gradient over at least part of the heat transfer step (b). E.g., equal amounts of heat per amount of temperature increase across said part may be transferred from the fluid to the second medium. The gradient may also vary, e.g. a higher (lower) gradient over a particular part corresponds to a higher (lower) amount of heat transferred per amount of temperature increase across that part.

[0015] In view of the above, in a particular embodiment, step (b) comprises condensing at least part of the compressed fluid at one or more radial positions between first and second radial positions to provide an at least partially condensed fluid and transferring at least a fraction of the heat of condensation from the compressed fluid to the second medium at one or more radial positions between the first and second radial positions.

[0016] In an embodiment, between steps (b) and (c), heat is transferred from the condensed fluid to a further medium, which may be done in accordance with the thermodynamic saturated vapour curve for the fluid and/or which may be done at least substantially isobarically, e.g. at a constant radial position with respect to the axis of rotation. Also or alternatively, heat may be transferred from uncondensed compressed fluid at least substantially at a constant radial position with respect to the axis of rotation, which may be isobaric heat transfer.

[0017] Further, the process may comprise separating, at or near the outlet of the compressor, gaseous and liquid fractions of the compressed fluid. In an embodiment, step (c) comprises returning at least part of the condensed fluid towards the axis of rotation; and the process further comprises transferring heat from the condensed fluid to the second medium during step (c).

[0018] Thus, remaining heat stored in the condensed fluid is harvested and transferred to the second medium during return of the fluid towards the axis of rotation. Note that during compression of the fluid its temperature rises and liquid fluid at or near the circumference of the rotor may have the highest temperature which may be harvested during return of the condensed fluid towards the axis of rotation. This may obviate a heat transfer step to a further medium and provision of an associated heat exchanger.

[0019] In such embodiment, the condensed fluid may be maintained in condensed state during step (c). E.g. this may comprise applying pressure to the fluid along a route from a radial outward position to a radial inward position in the rotor, e.g. from a circumference of the rotor to a position at or near the axis of rotation of the rotor, such that along the route local temperature and pressure conditions of the fluid are maintained above the saturation pressure for each temperature.

[0020] In an embodiment, step (c) comprises conveying the condensed fluid towards the axis of rotation by pumping. Pumping the condensed fluid amounts to work done on the fluid but it may prevent loss of thermal energy to potential energy if the fluid is forced back towards the axis of rotation by expansion of the fluid and/or by possible evaporation of a portion of the fluid and/or by pressure of another portion of the fluid being compressed.

[0021] In an embodiment step (a) comprises rotating the amount of the compressible working fluid in a rotor, and the process further comprises after step (c) removing an amount of fluid from the rotor at or near the axis of rotation, heating the removed amount of fluid by heat transfer from the first medium to the fluid outside the rotor and returning the amount of fluid to the rotor.

[0022] In particular, this embodiment may comprise removing an amount of fluid in condensed state from the rotor at or near the axis of rotation, evaporating the amount of fluid by heat transfer from the first medium to the fluid outside the rotor and returning the amount of fluid in evaporated state to the rotor.

[0023] Thus step (d) may be performed on the removed amount of fluid, whether or not at least partly condensed, in a nonrotating situation of the amount of fluid, e.g. in a stationary heat exchanger.

[0024] Also or alternatively, heat may be transferred to the fluid from the first medium or another medium at least one of prior to, during and after the expansion of step (d) and prior to (re-)compression in step (a), which latter transfer may be done within the rotor and which may comprise evaporating condensed fluid.

[0025] In an embodiment, removing an amount of fluid from the rotor at or near the axis of rotation comprises separating an amount of condensed fluid from the fluid at or near the axis of rotation and removing the amount of condensed fluid from the rotor, retaining the non-removed fluid in the rotor. The thus removed amount of fluid may be replaced by the same amount of fluid but being in evaporated state.

[0026] In an aspect, the working fluid of a heat transfer process and/or apparatus as disclosed herein comprises, in particular consists of, a mono-atomic element having an atomic number $(Z) \geq 18$, e.g. $(Z) \geq 36$, and/or wherein the working fluid comprises, in particular consists of, one or more halogenated hydrocarbons, preferably perhalogenated hydrocarbons, more preferably perhalogenated alkanes, e.g. perfluoroalkanesThe latter molecule class is considered effective, nontoxic and non-flammable. The working fluid may be a pure substance or a mixture of substances, the substance or substances being selected from a list comprising at least C_3F_7, 1,1,1,2,3,3,3-heptafluoropropane, also known as "227EA"; C_2F_4, 1,1,1,2-tetrafluoroethane also known as "R134A"; C_3F_2, octafluoropropane also known as "R218"; C_2ClF_5, chloropentafluoroethane, also known as "R115"; C_4F_8, octafluorocyclobutane, also known as "RC318"; C_4F_{10}, perfluoprobutane and/or C_5F_{12}, perfluoropentane; CF_3I, trifluoroiodomethane. In particular C_4F_{10}, also known as perfluorobutane or decafluorobutane, has a boiling point just below 0 degrees Celsius at 1 atmosphere and thus is gaseous at Standard Temperature and Pressure (300 K, 1 atmosphere), and it is considered particularly useful as working fluid for any rotary heat pump and/or heat engine. CF_3I has a benefit of having a high condensation heat at a low molecular weight.

[0027] The presently provided process enables generating heat, cold and/or work at a relatively high efficiency compared to prior art, in particular due to the increased heat transfer efficiency from the state conversion of condensation.

[0028] In an embodiment, the first medium is taken from the surroundings and/or has a temperature at least substantially equal to that of the surroundings. Also or alternatively, the first medium may be a medium carrying waste heat of another process. Examples of the latter are exhaust gases and heated coolants of another process such as heated air, heated water and/or steam.

[0029] This enables use of the surroundings and/or waste heat as a source of low temperature heat to obtain higher temperature heat using the process.

[0030] The hot and cold media obtained by the presently provided process can be employed, e.g., for heating or cooling buildings or, on a larger scale, for generating electricity by means of e.g. a Carnot cycle or "steam cycle" and/or improving efficiency thereof.

[0031] In an aspect, and associated with the process described herein, an apparatus according to the present disclosure comprises: a frame; and a rotor rotatably mounted to the frame. The rotor comprises: a compressor having a low pressure side in a location relatively near the axis of rotation and a high pressure side in a location relatively far from the axis of rotation, for compressing a compressible fluid in a direction away from the axis of rotation to provide a compressed fluid; a first heat exchanger positioned within and/or in close thermal contact with the compressor between the low pressure side and the high pressure side of the compressor for transferring heat from the fluid to the second medium; at least one conduit, fluidly connected with the high pressure side of the compressor, configured and positioned for conveying fluid compressed by the compressor from the high pressure side towards the axis of rotation, e.g. being fluidly connected with the outlet of the compressor. The apparatus comprises, fluidly connected with the conduit, a second heat exchanger, e.g. comprising an evaporator and/or an expansion chamber, to provide expanded fluid from fluid conveyed towards the axis of rotation; and a channel for conveying the expanded fluid to the low pressure side of the compressor. The first heat exchanger comprises one or more heat exchanger elements spiralling relative to the axis of rotation; wherein the direction of outward spiralling may be in the direction of rotation of the rotor.

[0032] This facilitates, inter alia, isothermal and/or isobaric heat transfer from the fluid to the second medium at incremental temperatures. In the apparatus the fluid may circulate through the rotor then to and through the second heat exchanger and then back again to and through the rotor.

[0033] Further, such heat exchanger may be of relatively simple construction; one or more spiralling ducts may be attached to a carrier. It is noted that the heat exchanger and the compressor may be integrated and (a carrier of) the heat exchanger need not extend in a plane but it may be more or less curved relative to the axis of rotation such that a spiralling heat exchanger element also adopts a helical aspect about the axis of rotation. The low pressure side of the compressor may comprise one or more inlets for the compressible fluid and the high pressure side of the compressor may comprise one or more outlets for the compressible fluid.

[0034] The one or more heat exchanger elements may be integrated in one assembly, and/or they may be arranged adjacent each other in axial direction relative to the axis of rotation.

[0035] The compressor may comprise one or more vanes and/or be part of the rotor. The rotor may be gas tight other than dedicated entrances / exits for the fluid and/or for one or more of the first, second and further medium. The entrances / exits are preferably selectively closable, e.g. with valves.

[0036] The at least one conduit may be in direct thermal contact with one of the heat exchanger elements. This facilitates heat exchange from the fluid to the second medium during return of the fluid towards the axis of rotation. In embodiments, the conduit may have at least part of at least one wall in common with the respective heat exchanger element, improving thermal contact and heat exchange between the fluid and the second medium. In an embodiment, the conduit extends through and is arranged coaxially with at least part of the respective heat exchanger element.

[0037] Thus, the second medium may be sandwiched between fluid being compressed in a direction away from the axis of rotation on one side, e.g. an outside of the heat exchanger element, and fluid returning towards the axis of rotation on another side, e.g. on an opposite side and/or an inside of the heat exchanger element.

[0038] The apparatus may comprise at least one pump being fluidly connected to the high pressure side of the compressor and the conduit(s) and being configured and positioned for pumping fluid compressed by the compressor towards the axis of rotation through the at least one conduit, wherein preferably the rotor comprises a plurality of such pumps fluidly connected to the high pressure side of the compressor. Preferably the plurality of pumps are located substantially symmetrically with respect to the axis of rotation. The pump(s) may provide the aforementioned one or more outlets of the compressor.

[0039] The rotor may comprise the second heat exchanger. In an aspect the rotor comprises a plurality of pumps fluidly connected to the outlet of the compressor and being located substantially symmetrically with respect to the axis of rotation. This facilitates balancing the rotor and it increases pumping capacity.

[0040] The one or more pumps may have one or more movable elements such as pistons. At least one of the pumps may be a piston pump. In an embodiment with a piston pump, the piston may be driven by cam action against an axis; the axis may be stationary if the pump is rotating, e.g. by being comprised in the rotor.

[0041] The pump may be configured such that the piston is urged into a camming arrangement by fluid pressure or pressure differential of the compressed fluid. E.g. the piston may be floatable on the condensed fluid and/or the pump may be provided with one-way valves. Thus, a self-regulating system may be provided wherein the pump does not and/or need not operate when less than a predetermined amount of condensed fluid is available. Such system obviates a sensor and controller which may otherwise be provided for operating a pump in dependence of an amount of condensed fluid.

[0042] In an embodiment the apparatus comprises a further heat exchanger having (i) an inlet for the fluid fluidly connected with the high pressure side of the condenser and (ii) an outlet for the fluid fluidly connected with the conduit, the further heat exchanger preferably being located at a circumference of the rotor and preferably being a counter flow heat exchanger relative to the direction from the inlet to the outlet for the fluid with respect to a direction of a heat absorbing medium flowing through the second heat exchanger. This enables possible harvesting remaining heat energy from the compressed fluid after the heat transfer to the second medium.

[0043] The second heat exchanger may comprise one or more helical channels determining a helical flow path of at least the heat absorbing medium. This enables increasing heat absorption and closer adherence to a counter flow arrangement relative to rotating fluid.

[0044] In an embodiment the apparatus comprises a separator fluidly connected to the pump for separating liquid and gaseous fluid received from the pump and comprising a liquid outlet and a gas outlet at least one of the liquid outlet and a gas outlet being fluidly connected with the channel via the evaporator and/or the expansion chamber, wherein the gas outlet may be fluidly connected with the channel bypassing the evaporator and/or the expansion chamber.

[0045] Gaseous fluid may be kept in the process and/or reintroduced immediately into that and be (re-)compressed in the compressor, but it may also first be (re-)heated and/or further expanded by heat transfer from the first medium. Liquid working fluid should first be evaporated at least partly prior to reintroduction and recompression, e.g. by heat transfer from the first medium.

[0046] Efficiently, the separator operates on the basis of centrifugal separation about the axis of rotation with one or more liquid outlets being relatively from the axis of rotation and gas outlets being relatively close to or at least partly coincident with the axis of rotation.

[0047] In an embodiment the apparatus comprises a second heat exchanger for transferring heat from the first medium to the fluid, preferably being connected to/and or integrated in the evaporator and/or the expansion chamber, wherein the first medium may be taken from the surroundings and/or may have a temperature at least substantially equal to that of the surroundings.

[0048] The apparatus may comprise a casing enveloping the rotor, possibly maintaining a vacuum between the rotor and the casing, and in such case at least one of the second heat exchanger, the evaporator and the expansion chamber may be located outside the casing. A vacuum may reduce or prevent friction against air of the rotor and it may provide thermal insulation of the rotor from the casing and other surroundings.

[0049] In an embodiment, the axis of rotation is arranged vertical. This may reduce or prevent asymmetry in the rotary force field and it may facilitate operation and/or placement of the apparatus. Further, the second heat exchanger may be arranged below the rotor. This facilitates using normal gravity as a driving force for conveying condensed fluid into the second heat exchanger from the rotor for heating and/or evaporation and conveying evaporated expanded fluid out of the second heat exchanger and into the rotor for (re-)compression.

[0050] In an embodiment at least one of the heat exchangers is coupled to a heating system and/or an air conditioning system of a building, such as a house or an office.

[0051] In an aspect, typically when the invention is applied on an industrial scale, at least one of the heat exchangers may be coupled to a cycle for generating work. This cycle may comprise an evaporator or super-heater, which is thermally coupled to the high temperature heat exchanger, a condenser, thermally coupled to the low temperature heat exchanger, and a heat engine. The environment will typically serve as a heat sink, but may also serve a high temperature source, if the operating temperature of the cycle is sufficiently low. The apparatus may also be used for heating or cooling exhaust gases and/or waste steam.

[0052] In yet a further aspect, the compressible fluid is a gas and e.g. contains or consists essentially of a mono-atomic element having an atomic number (Z) $\geq$ 18, such as Argon, or $\geq$ 36, such as Krypton and Xenon. In another aspect, the working fluid comprises, in particular consists of, one or more perfluoroalkanes, in particular comprising or consisting of C_3F_8, C_4F_{10} and/or C_5F_{12}. Perfluoroalkanes are generally considered nontoxic and non-flammable. In particular C_4F_{10}, also known as perfluorobutane or decafluorobutane, has a boiling point just below 0 degrees Celsius at 1 atmosphere and thus is gaseous at Standard Temperature and Pressure (300 K, 1 atmosphere), and it is considered particularly useful as working fluid for any rotary heat pump and/or heat engine.

[0053] In accordance with at least some aspects of the present invention, the concept of artificial gravity, provided by the centrifugal force due to rotation, is employed to reduce the length of the column of the compressible fluid, in comparison with a column subjected merely to the gravity of the earth, and the atmosphere is replaced by a gas allowing a much higher temperature gradient in the fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0054] The above-described aspects will hereafter be more explained with further details and benefits with reference to the drawings showing a number of embodiments by way of example.

Figs. 1-2 are a top view and a side view, respectively, of an apparatus according to the present disclosure;
Fig. 3A is a cross section view along line AA of Fig. 1;
Fig. 3B is a partial perspective view of the of the apparatus with a cross section view along line AA of Fig. 2, cf. Fig. 3A;
Fig. 4 is a partial perspective view of the apparatus with a cross section view along line BB of Fig. 2;
Fig. 5 shows a detail of the first heat exchanger of Fig. 1;
Fig. 6 is an exemplary temperature-entropy diagram;
Fig. 7 is a schematic cross section view of a detail of another embodiment;
Fig. 8 is a schematic cross section view of a detail of yet another embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

[0055] It is noted that the drawings are schematic, not necessarily to scale and that details that are not required for understanding the present invention may have been omitted. The terms "upward", "downward", "below", "above", and the like relate to the embodiments as oriented in the drawings, unless otherwise specified. Further, elements that are at least substantially identical or that perform an at least substantially identical function are denoted by the same numeral, where helpful individualised with alphabetic suffixes or raised by 100, 200 etc..

[0056] Figs 1-4 show an apparatus 1 for transferring heat from a first medium to a second medium. The apparatus 1 comprises a frame 3 and a rotor 5 mounted to and in the frame 3 rotatably about an axis of rotation R.

[0057] The rotor 5 is gas tight and comprises a compressor 7, having radially inward with respect to the axis of rotation R a low pressure side 8 with a plurality of inlets 9 and radially towards the circumference of the rotor a high pressure side 10 with a plurality of outlets 11, for compressing a compressible fluid in a direction away from the axis R by rotating the fluid. Vanes 12 or other impellers facilitate imparting rotation of the rotor 5 to the fluid inside.

[0058] A first heat exchanger 13 is positioned within the rotor 5 and in the compressor 7 between the inlets 9 and the outlets 11 of the compressor 7 for transferring heat from the fluid to the second medium. The second medium may be a liquid such as water, glycol or another suitable substance. The second medium may enter the apparatus 1 at a cold medium channel C and exit the apparatus 1 at a hot medium channel H both fluidly connected with the first heat exchanger 13, see below, and in the shown embodiment both being arranged coaxially, although other arrangements are possible.

[0059] A plurality of pumps 15 provide conduits 17 which are fluidly connected with the high pressure side of the compressor 7 via the outlets 10, and which are configured and positioned for conveying fluid compressed by the compressor 7 towards the axis of rotation R.

[0060] The apparatus 1 comprises a second heat exchanger 19. The second heat exchanger 19 serves for transferring heat from the first medium to the fluid. In the shown embodiment, the first medium may be ambient air from the surroundings of the apparatus 1 via openings 20 in the frame 3. Such apparatus 1 is considered to be very well suited for domestic applications.

[0061] Here, the second heat exchanger 19 comprises a set of coiled tubes which form an evaporator 21 for condensed fluid having a boiling point at or below ambient temperature at the pressure level within the evaporator 21. The second heat exchanger 19 is configured to provide expanded fluid from fluid conveyed towards the axis of rotation R by the conduit, see below.

[0062] The second heat exchanger 19 is fluidly connected with the conduit 17 via a channel 22 (partly shown; see also below). The apparatus 1 further comprises a channel 23 for conveying the expanded fluid from the second heat exchanger 19 to the inlets 9 of the compressor 7.

[0063] The first heat exchanger 13 comprises a plurality of heat exchanger elements 25 in the form of tubes supported by the vanes and spiralling outward relative to the axis of rotation R (see Fig. 4 and 5). Fig 5 shows only the heat exchanger elements 25. In the shown embodiment the first heat exchanger 13 comprises four heat exchanger elements 25 adjacent each other in axial direction of the of rotation axis R. Each of the heat exchanger elements 25 has an inlet 25A on a radial inside fluidly connected with cold medium channel C and an outlet 25B on a radial outside. The outlets 25B are fluidly connected with the hot medium channel H. In the shown embodiment the connection is via an optionally common return manifold 26, here comprising a circumferential conduit 26A and radial conduits 26B which may be arranged symmetrically as shown. The direction of outward spiralling of the heat exchanger elements 25 and the direction of rotation of the rotor 5 may be in the same direction (e.g. both rotating clockwise or anticlockwise) or in opposite direction. In the former case the walls of the elements 25 may counteract centripetal forces on the fluid and the second medium to a certain extent and provide rather a circumferential force to the fluid and the second medium, and it may facilitate mixing of the fluid. In the latter case the walls of the elements 25 may increase a centripetal force on the fluid and the second medium e.g. for accelerating droplets outward. Thus, a particular mode of operation of the apparatus 1 may be selected.

[0064] The pumps 15 are located substantially radial and substantially symmetric with respect to the axis of rotation R.

[0065] Each shown pump 15 is a piston pump comprising a piston 27. The pistons 27 are hollow providing conduits 17 fluidly connected with the outlets 11 of the compressor 7, and being configured and positioned for conveying fluid compressed by the compressor 7 towards the axis of rotation R. Therewith, and explained in more detail below, the pumps 15 are configured and positioned for pumping fluid compressed by the compressor 7 towards the axis of rotation R through the conduits 17. , wherein preferably the rotor comprises a plurality of pumps fluidly connected to the outlet of the compressor and being

[0066] The apparatus 1, here integrated in the rotor 5, further comprises an optional separator 29 fluidly connected to at least some of the pumps 15 for separating liquid and gaseous fluid received from these pumps 15. The separator 29 comprises a plurality of liquid outlets 31 and optionally a plurality of gas outlets. The liquid outlets 31 are fluidly connected with the channel 22 via a liquid conduits 35 and 36 to the evaporator 21. The gas outlets may be fluidly connected with the channel 23 bypassing the evaporator 21 and/or an expansion chamber, as shown, so that a gaseous fraction of the fluid may circulate within the rotor 5.

[0067] Best seen in Figs. 2 and 3, frame 3 comprises a base 37. The base 37 facilitates to position the apparatus 1 stably on a flat surface. When standing on the base 37 on a horizontal surface, e.g. a building floor (not shown), the axis of rotation R is arranged vertical and the second heat exchanger 19 is arranged underneath the rotor 5.

[0068] The apparatus 1 comprises a casing 39 enveloping the rotor 5, wherein a vacuum may be maintained in a space S between the rotor 5 and the casing 39. The casing 39 is mounted to and may be at least partly integrated in the frame 3, as shown. The second heat exchanger 19 with its evaporator 21 are located outside the casing 39 within the frame. A power source 40 (schematically indicated at 40) is operably connected to the rotor 5 to drive the rotor 5 into rotation about the axis of rotation R within and with respect to the casing 39.

[0069] In operation, an amount of a compressible working fluid, in particular a saturated gas, is rotated about the axis of rotation R by rotating the rotor 5, such that the fluid is compressed in the compressor 7 of the rotor in a direction away from the axis of rotation R by the centrifugal force to provide a compressed fluid with increasing pressure in a radially outward direction, from the low pressure side to the high pressure side of the compressor 7.

[0070] With the compression the temperature of the fluid increases in outward direction. During at least part of the compression in the compressor 7 is transferred from the fluid to the second medium due to (thermal contact with) the first heat exchanger 13 and the second medium inside it. The radial position with respect to the axis of rotation of the transfer determines the local pressure and local temperature of the fluid and thus the temperature of the transferred heat. Heat transfer may therefore occur with a small temperature difference between heat source (the fluid) and heat sink (the second medium) at each position along the heat exchanger, providing heat transfer with significantly more effectivity than possible with a heat pump providing a heat source of constant temperature. Note that the heat exchanger 13 and the compressor 7 thus operate as a co-flowing heat exchanger in a direction from the axis of rotation towards the circumference of the rotor.

[0071] When the fluid in the low pressure side is a saturated gas, the pressure and temperature will normally follow the saturated vapour curve of the fluid. However, according to the present concepts, part of the fluid condenses in the compressor at a radial position and the heat of condensation is transferred from the (condensing) fluid to the second medium. The heat transfer may then be isothermal, in accordance with traversing a proportionality isotherm in a two-phase region of an entropy-temperature diagram (S-T diagram) of the working fluid; see the bold line A-C-B in Fig. 6. In point A the fluid is entirely in condensed state, in point B the fluid is entirely in a saturated gas state and in point C the fluid is partly gaseous and partly condensed; note that in point C the relative length AC/AB indicates the proportional amount of gas mass and the relative length CB/AB indicates the proportional amount of liquid mass.

[0072] Different parts of the compressed fluid condense to condensed fluid parts at different radial positions with respect to the axis of rotation, i.e. at different positions in the compressor. Thus heat of condensation is transferred from the fluid to the second medium at said different radial positions with respect to the axis of rotation and at the associated different temperatures. The different portions of the compressed fluid follow different proportionality isotherms in the T-S diagram (see Fig. 6). The line GA in Fig. 6 indicates the development of a saturated gas at a relatively lower temperature (at G) to a liquid at a relatively higher temperature (at A, see above).

[0073] The compressed fluid, in particular condensed liquid, is collected in the high pressure side of the compressor 7 at the circumference of the rotor 5. From there, the fluid is returned towards the axis of rotation R through the conduits 17 by the pumps 15. For this, the fluid exits the compressor 7 via the outlets 11 which serve as inlets for the pumps 15.

[0074] In an embodiment (not shown), at or near the circumference of the rotor 5 the first heat exchanger may comprise one or more further heat exchanger portions and/or a further heat exchanger may be provided, thus remaining heat in the fluid may be transferred from the fluid to the second medium and/or to a further medium. Such heat exchanger may take the form of one or more channels extending along the circumference of the rotor 5 in axial and/or helical direction, wherein the latter may determine a helical flow path of at least the heat absorbing medium, e.g. by accordingly shaping the heat exchanger outlets 25B of the first heat exchanger.

[0075] The pumps 15 pump the fluid from the circumference to the separator 29 via outlets 41. The inlets 11 and/or the outlets 41 of at least one of the pumps 15 may be provided with one-way valves which may assist the pumping. In the separator 29, liquid and gaseous fluid are separated into the liquid radially outside and the gas radially inside on the basis of their density difference due to the centrifugal force of the rotating rotor 5, much like in a cyclone separator.

[0076] A liquid fraction will flow out of the separator 29 by gravity via liquid outlets 31 in circumferential walls 43 and liquid conduit 35 via channels 33 and 22 to the second heat exchanger 19, however a pump may be provided to assist the liquid flow. A gaseous fraction may remain in the rotor 5 and may return directly from the separator 29 into the compressor 7 through central openings 44 in the walls 43 and through the inlets 9 so as to be compressed anew. The separator 29 with its central openings 44 thus providing a channel for conveying fluid expanded within the rotor 5 back to the low pressure side of the compressor.

[0077] In the second heat exchanger 19 at least part of the compressed fluid is heated and expanded into an expanded fluid, in particular by evaporation of the liquid fluid fraction, by heat transfer from the first medium (here: air) to the fluid.

[0078] The expanded fluid is returned to the rotor 5 via channel 23, channel 45 and outlets 47 of the latter. The channels 43 and 45 are coaxial in the shown embodiment. A driving force for the return flow of expanded fluid may be provided by a density and specific mass differential between the compressed fluid and the expanded fluid under gravity, but a pump may also be provided (not shown).

[0079] The pumps 15 rotate with the rotor 5. In the shown embodiment their pistons 27 are driven into reciprocating motion by interaction with a stationary cam axis against which the pistons 27 are urged radially inward. The inward force may e.g. be due to a spring and/or to fluid flow, e.g. the pistons being floatable on condensed working fluid. If the centrifugal force of the rotation outweighs the inward force the camming engagement may be lost. If the inward force depends on a radial liquid level in the rotor 5 a self-regulating system is provided. Pumps 15 opposite each other may act in phase, e.g. the pistons 27 simultaneously going outward or inward, so as to maintain balance of the rotor 5.

[0080] Fig. 7 shows a schematic detail of an apparatus 100 of another embodiment wherein reference numbers are as before but raised by 100. Fig. 7 indicates a rotor 105 having a circumferential wall 151, a pump 115, a heat exchanger element 125 of a first heat exchanger 113 and a cam axis 149. The rotor 105 is provided with a compressor as before (not shown).

[0081] The embodiment of Fig. 7 differs from the previous embodiment in that the conduit 117 is mounted extending through and being arranged coaxially with at least part of the tubing the respective heat exchanger element 125. Preferably, each heat exchanger element 125 is thus combined with a conduit 117.

[0082] The conduit 117 may exit the heat exchanger element 125 in or near the low pressure side of the compressor and it may have an outlet in or near a separator (not shown). The outer wall of conduit 117 forms an inner wall of a heat exchanger element 125 tube by virtue of the coaxial arrangement. Thus the conduit 117 is in direct thermal contact with the heat exchanger element 125. Further, the pump 115 has a piston 127 movably arranged in a pump chamber 153; the piston 127 is arranged for reciprocating being driven with the cam axis 149, similar to the previous embodiment. The pump 115 has an inlet 111 which forms an outlet of the compressor. Here, the inlet 111 is provided with a one-way valve. The pump 115 further has an outlet 141 (also provided with a one-way valve) donning to the conduit 117.

[0083] In operation of the apparatus 100 by rotation of the rotor 105 about the axis of rotation R a layer L of liquid condensed compressed working fluid is formed against the circumferential wall 151 in the high-pressure side of the compressor. By pumping action of the pump 151 the fluid is pumped out of the layer L and into the conduit 117, returning the compressed fluid towards the axis of rotation R through the conduit 117 and through the first heat exchanger. Thus, heat remaining in the fluid at the high pressure side of the compressor may be transferred from the fluid to first medium in a counter-flow heat exchanger arrangement during the return of the fluid towards the axis of rotation (see the arrows indicating flow direction of the fluid in conduit 117 and of the second medium in the heat exchanger element tube 125).

[0084] Fig. 8 shows a variant to the embodiment of Fig. 7, wherein in the rotor 105 an intermediate wall 251 is provided concentric with the rotor wall 151. The intermediate wall 251 effectively divides the rotor 105 in concentric compartments. A tube 161 provides a gas passage through the wall 251 but enables formation of a liquid layer L’ of condensed working fluid against the intermediate wall 251. One or more pumps 215, which may be of equal construction to the pumps 115 as shown here, pump the condensed fluid into a conduit 217 for return towards the axis of rotation R. Also in such case the conduit 217 may be coaxial with tubing of a heat exchanger element 125. The conduit 217 may join a conduit 117 and the respective heat exchanger element 125 may be shared. However, use of separate conduits 117, 217 and heat exchangers 113, 213 or heat exchanger elements 125, 225 is preferred, i.a. for the following reason: as explained before, in the apparatus (compression to) different radii correspond(s) to different temperatures of the compressed working fluid. By collecting condensed working fluid at different radial positions in one rotor and returning the respective condensed fractions in separate (first) heat exchangers, heat at different temperatures may be harvested with the different heat exchanger(s) (elements) at the same time with a single apparatus at a single operational configuration (e.g. running with a single rotational velocity). E.g., both warm water at about 30 degrees for domestic heating and hot water at about 60 degrees for washing and showering may be provided simultaneously. This can increase energy efficiency of a system comprising the apparatus even further.

[0085] The disclosure is not restricted to the above described embodiments which can be varied in a number of ways within the scope of the claims. E.g., the rotor 5 may be provided with an additional heater and/or heat exchanger (not shown) at or near the axis of rotation R to heat the fluid at or near the centre of the rotor 5 prior to entering the low pressure side of compressor. An impeller may be provided in the channel to enhance fluid flow through the channel. Different pumps may be provided. More or less heat exchanger elements may be provided, which may have different sizes and/or numbers of spiral turns. Instead of separating gaseous and liquid compressed fluid, e.g. with the shown separator, all compressed fluid may be conveyed after step (c) to and through the second heat exchanger for expansion. Also, elements and aspects discussed for or in relation with a particular embodiment may be suitably combined with elements and aspects of other embodiments, unless explicitly stated otherwise.

Claims

1. A process of transferring heat from a first medium to a second medium, comprising

(a) rotating an amount of a compressible working fluid, in particular a saturated gas, about an axis of rotation such that the fluid is compressed in a direction away from the axis of rotation to provide a compressed fluid;
(b) during at least part of the compression of step (a), transferring heat from the fluid to the second medium;
(c) returning the compressed fluid towards the axis of rotation;
(d) expanding at least part of the compressed fluid to provide an expanded fluid; and
(e) returning the expanded fluid to step (a);

wherein step (b) comprises condensing at least part of the fluid to a liquid and transferring heat of condensation from the fluid to the second medium and step (d) comprises transferring heat from the first medium to the fluid.

2. The process of claim 1, wherein step (b) comprises heat transfer from different portions of the fluid to the second medium at different temperatures and/or at different radial positions with respect to the axis of rotation, e.g. heat transfer from the fluid to the medium at different radial positions with respect to the axis of rotation wherein at each of the different radial positions the temperature of the fluid differs.

3. The process of any preceding claim, wherein step (b) comprises isothermal and/or isobaric heat transfer from the fluid to the medium and/or
wherein step (b) comprises condensing different parts of the compressed fluid to condensed fluid parts at different radial positions with respect to the axis of rotation and transferring heat of condensation from the fluid to the second medium at said different radial positions with respect to the axis of rotation.

4. The process of any preceding claim, comprising between steps (b) and (c), possibly after separating the condensed fluid and uncondensed compressed fluid, transferring heat from the condensed fluid to a further medium and/or transferring heat from the uncondensed compressed fluid at a constant radial position with respect to the axis of rotation.

5. The process of any preceding claim, wherein step (c) comprises returning at least part of the condensed fluid towards the axis of rotation; and wherein the process further comprises transferring heat from the condensed fluid to the second medium during step (c).

6. The process of any preceding claim, wherein step (a) comprises rotating the amount of the compressible working fluid in a rotor, and wherein the process further comprises after step (c) removing an amount of fluid from the rotor at or near the axis of rotation, heating the removed amount of fluid by heat transfer from the first medium to the fluid outside the rotor and returning the removed amount of fluid to the rotor,
wherein further step (d) may be performed on the removed amount of fluid.

7. The process of any preceding claim, wherein the working fluid comprises, in particular consists of, a mono-atomic element having an atomic number (Z) ≥ 18, e.g. (Z) ≥ 36, and/ or wherein the working fluid comprises, in particular consists of, one or more halogenated hydrocarbons, in particular perhalogenated hydrocarbons, e.g. comprising or consisting essentially of one or more substances selected from a list comprising C_3F_7, 1,1,1,2,3,3,3-heptafluoropropane; C_2F_4, 1,1,1,2-tetrafluoroethane; C_3F_8, octafluoropropane; C_2ClF_5, chloropentafluoroethane; C_4F_8, octafluorocyclobutane; C_4F_{10}, perfluoprobutane; C_5F_{12}, perfluoropentane; and CF_3I, trifluoroiodomethane.

8. The process of any preceding claim, wherein the first medium at least one of: is taken from the surroundings, has a temperature at least substantially equal to that of the surroundings, and is a medium carrying waste heat of another process.

9. An apparatus for transferring heat from a first medium to a second medium, the apparatus comprising:

a frame; and
a rotor rotatably mounted to the frame, the rotor comprising:

a compressor, having a low pressure side in a location relatively near the axis of rotation and a high pressure side in a location relatively far from the axis of rotation for compressing a compressible fluid in a direction away from the axis of rotation to provide a compressed fluid;
a first heat exchanger positioned within and/or in close thermal contact with the compressor between the low pressure side and the high pressure side of the compressor for transferring heat from the fluid to the second medium;
at least one conduit, fluidly connected with the high pressure side of the compressor, configured and positioned for conveying fluid compressed by the compressor from the high pressure side towards the axis of rotation,

the apparatus comprising, fluidly connected with the conduit, a second heat exchanger, e.g. comprising an evaporator and/or an expansion chamber, to provide expanded fluid from fluid conveyed towards the axis of rotation; and
a channel for conveying the expanded fluid to the low pressure side of the compressor,
wherein the first heat exchanger comprises one or more heat exchanger elements spiralling outward relative to the axis of rotation; wherein the direction of outward spiralling may be in the direction of rotation of the rotor.

10. The apparatus of claim 9, wherein the at least one conduit is in direct thermal contact with one of the heat exchanger elements, in particular having at least part of at least one wall in common with the respective heat exchanger element, preferably the conduit extending through and being arranged coaxially with at least part of the respective heat exchanger element.

11. The apparatus of any of claims 9-10, comprising at least one pump being fluidly connected to the high pressure side of the compressor and the conduit and being configured and positioned for pumping fluid compressed by the compressor towards the axis of rotation through the at least one conduit, wherein preferably the rotor comprises a plurality of such pumps fluidly connected to the high pressure side of the compressor and wherein preferably the plurality of pumps arelocated substantially symmetrically with respect to the axis of rotation.

12. The apparatus of any of claims 9-11, further comprising a separator fluidly connected to the pump for separating liquid and gaseous fluid received from the pump and comprising a liquid outlet and a gas outlet, at least one of the liquid outlet and a gas outlet being fluidly connected with the channel via the evaporator and/or the expansion chamber, wherein the gas outlet may be fluidly connected with the channel bypassing the evaporator and/or the expansion chamber.

13. The apparatus of any of claims 9-12, wherein the axis of rotation is arranged vertical and wherein the second heat exchanger may be arranged below the rotor.

14. The apparatus of any of claims 9-13,
wherein the apparatus comprises a casing enveloping the rotor, possibly maintaining a vacuum between the rotor and the casing, and wherein at least one of the second heat exchanger, the evaporator and the expansion chamber may be located outside the casing.

15. The apparatus of any of claims 9-14,comprising a further heat exchanger having (i) an inlet for the fluid fluidly connected with the a high pressure side of the compressor and (ii) an outlet for the fluid fluidly connected with the conduit, the further heat exchanger preferably being located at a circumference of the rotor and preferably being a counter flow heat exchanger relative to the direction from the inlet to the outlet for the fluid with respect to a direction of a heat absorbing medium flowing through the second heat exchanger, wherein the further heat exchanger may comprise one or more helical channels determining a helical flow path of at least the heat absorbing medium.

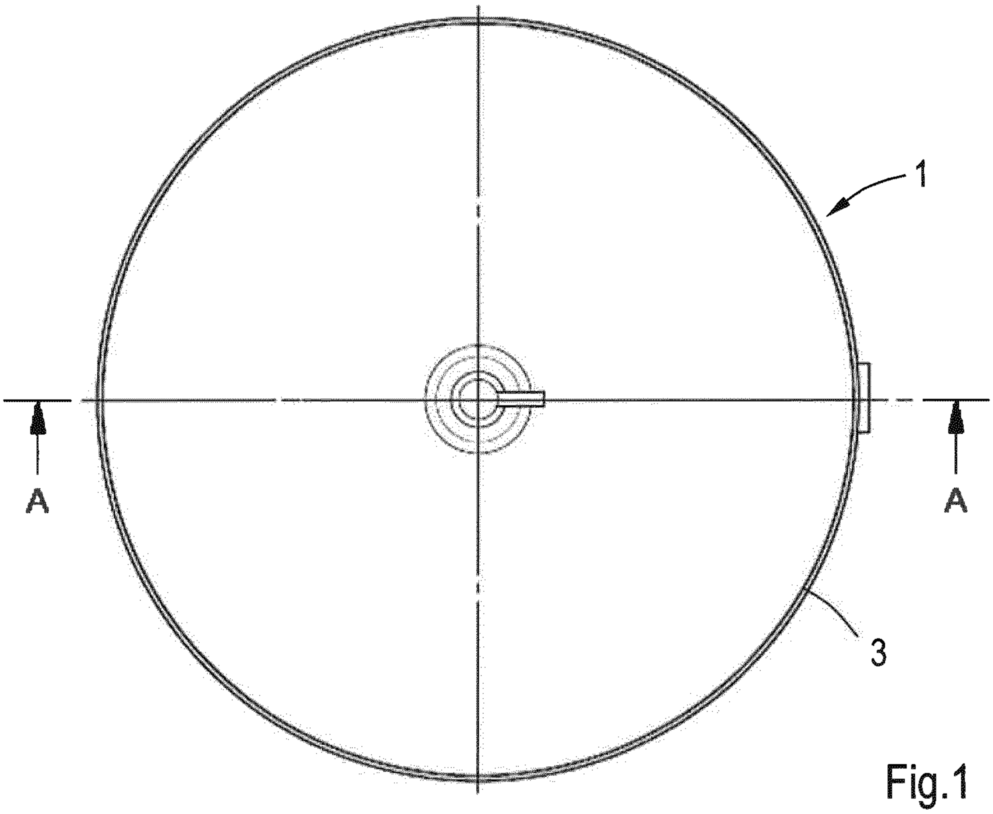

Fig.1

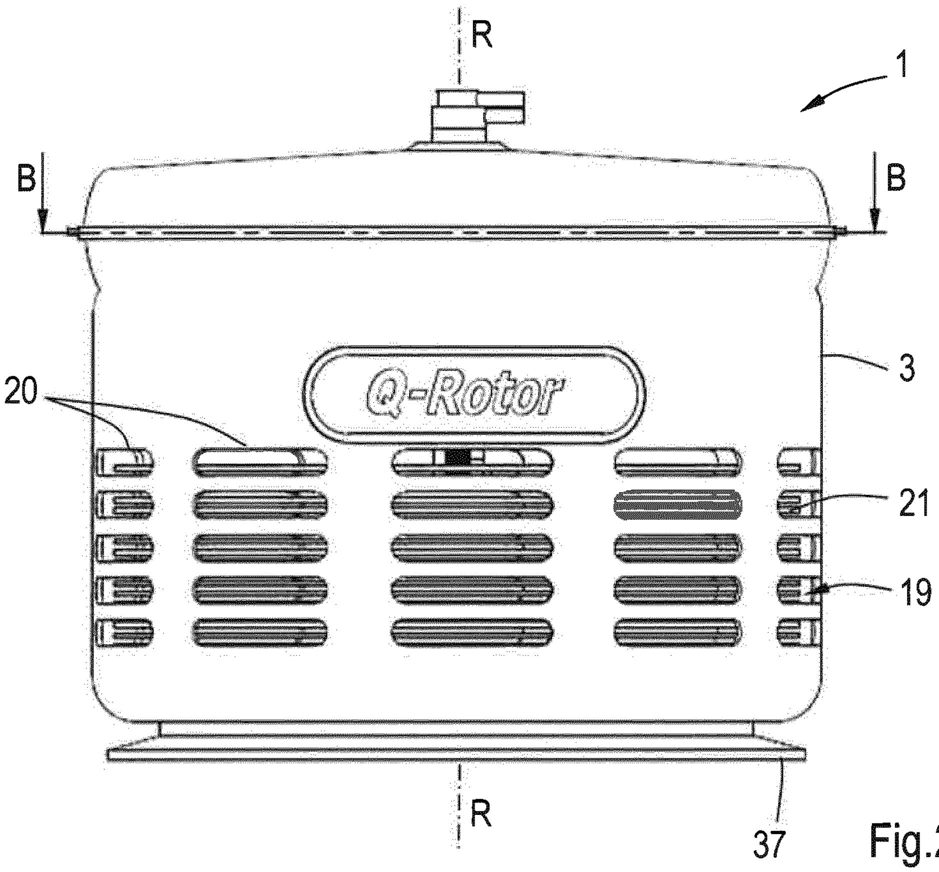

Fig.2

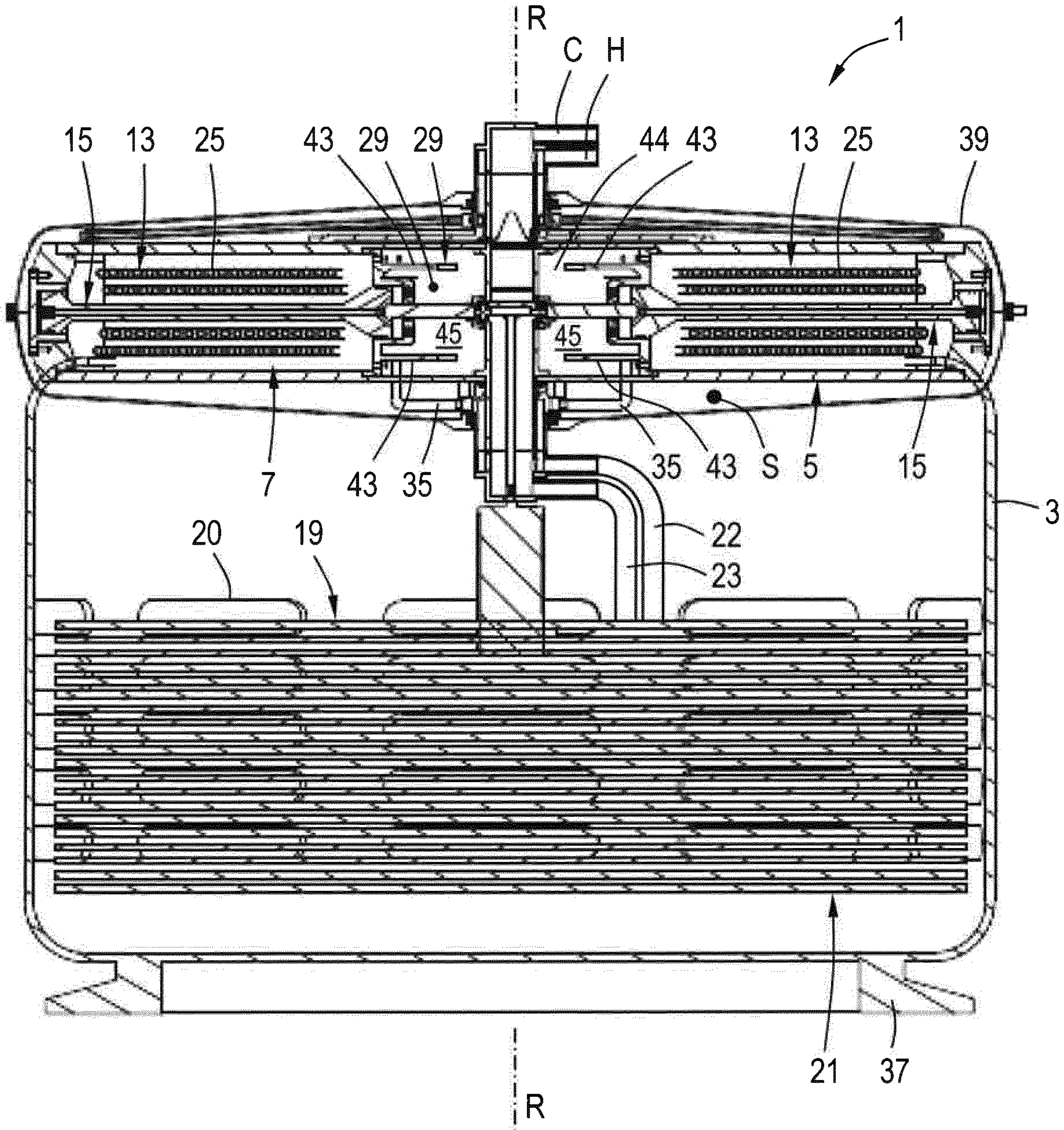
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Fig.3A

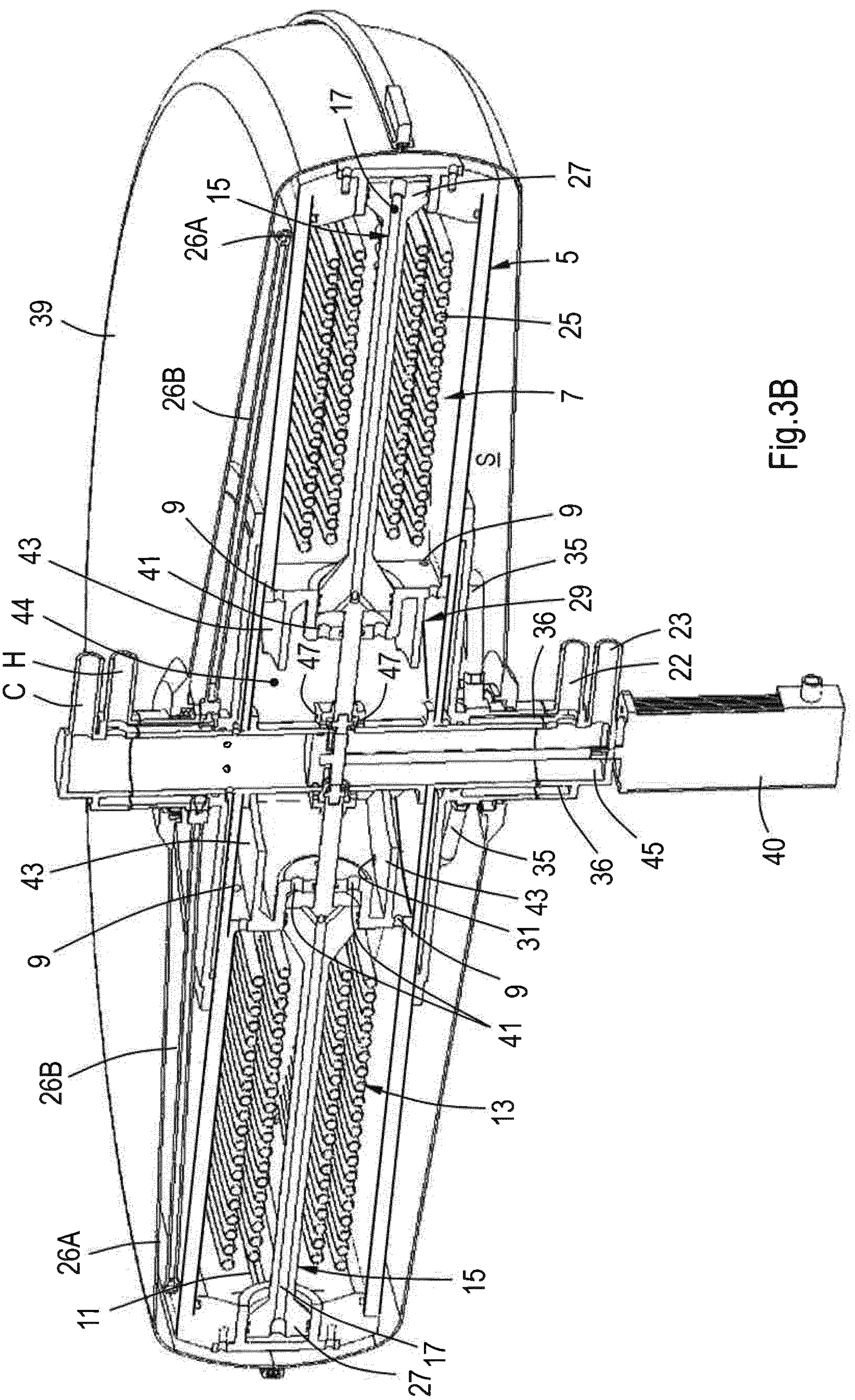
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Fig.3B

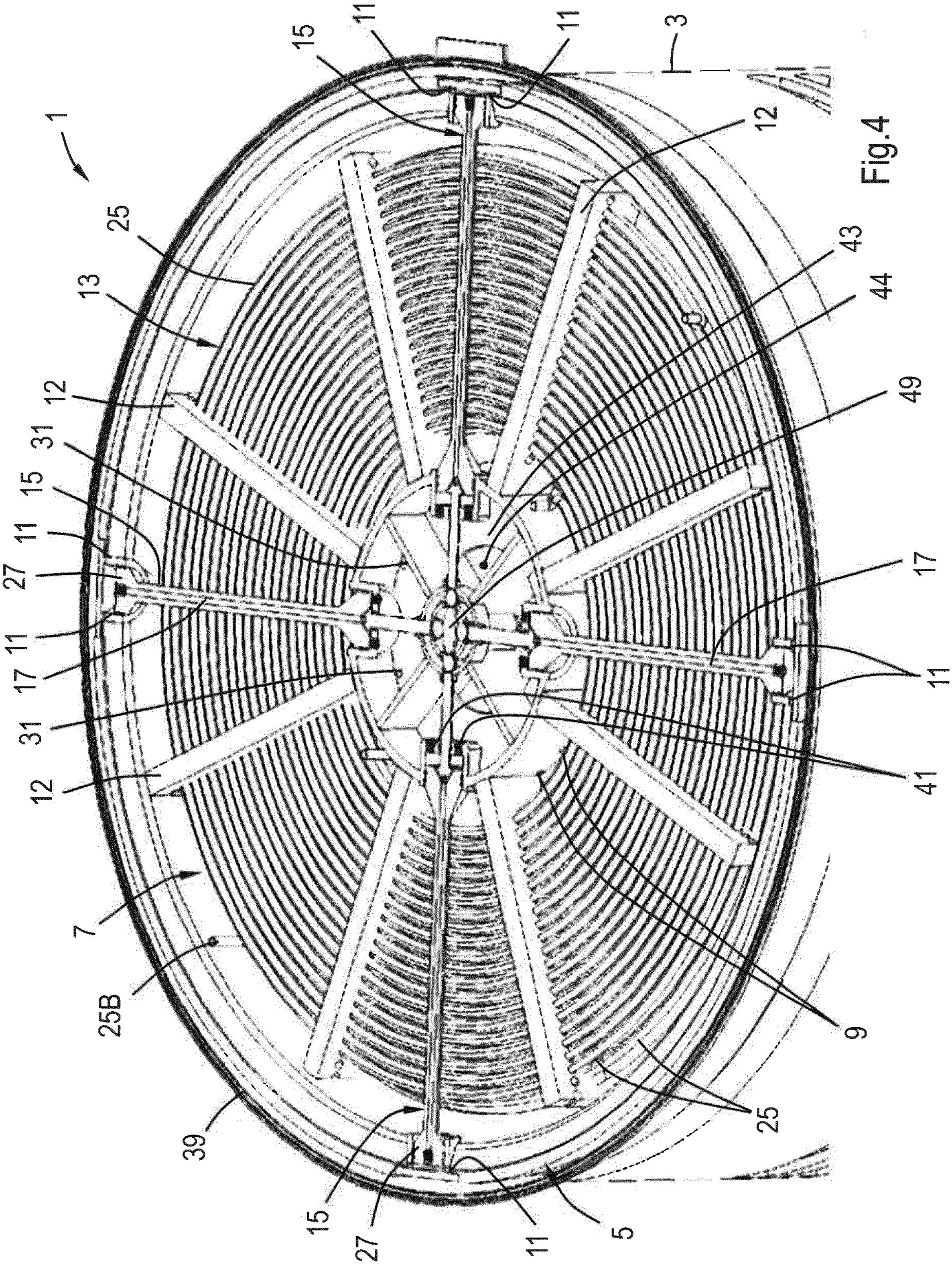

Fig.4

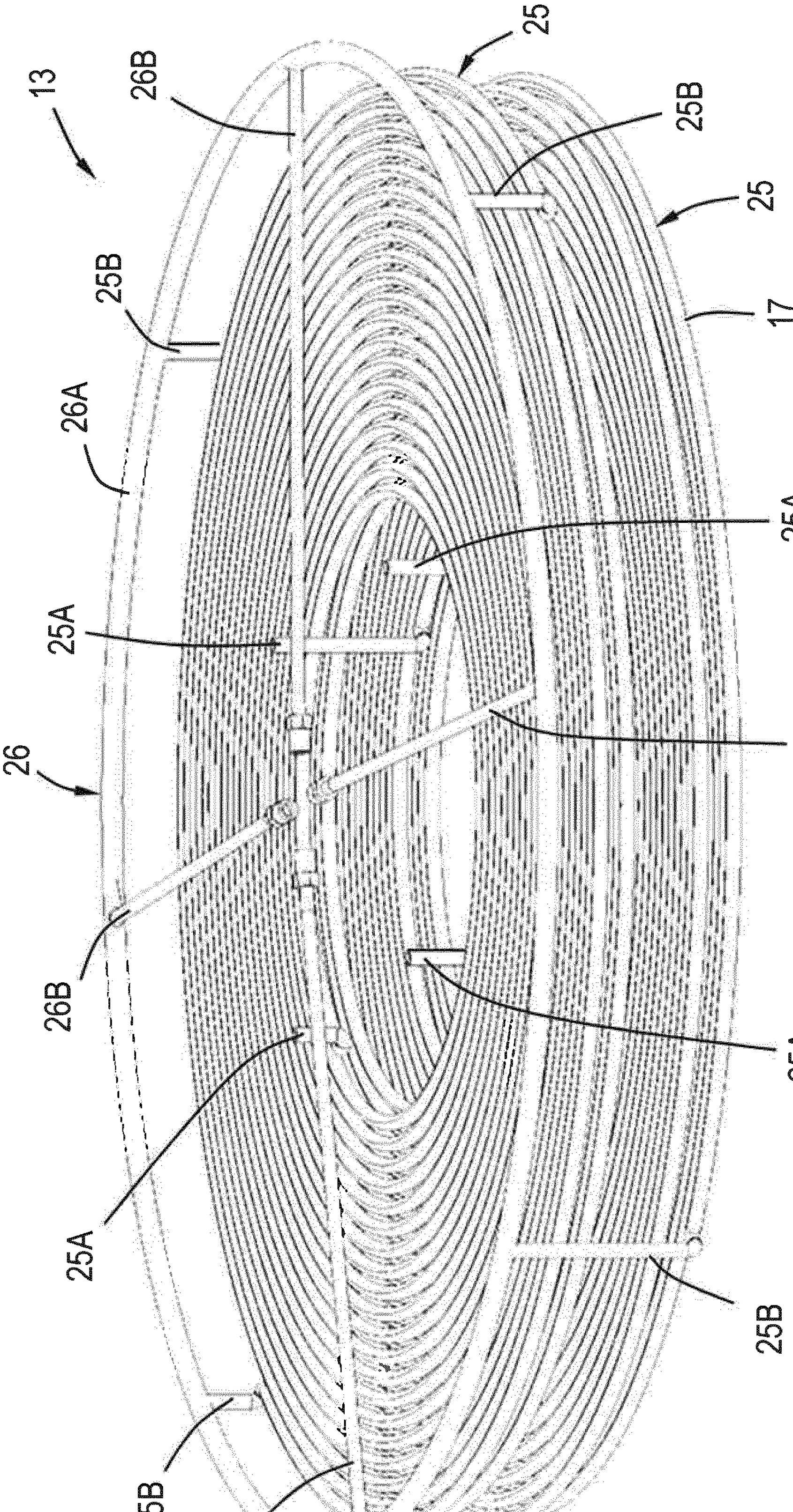

Fig.5

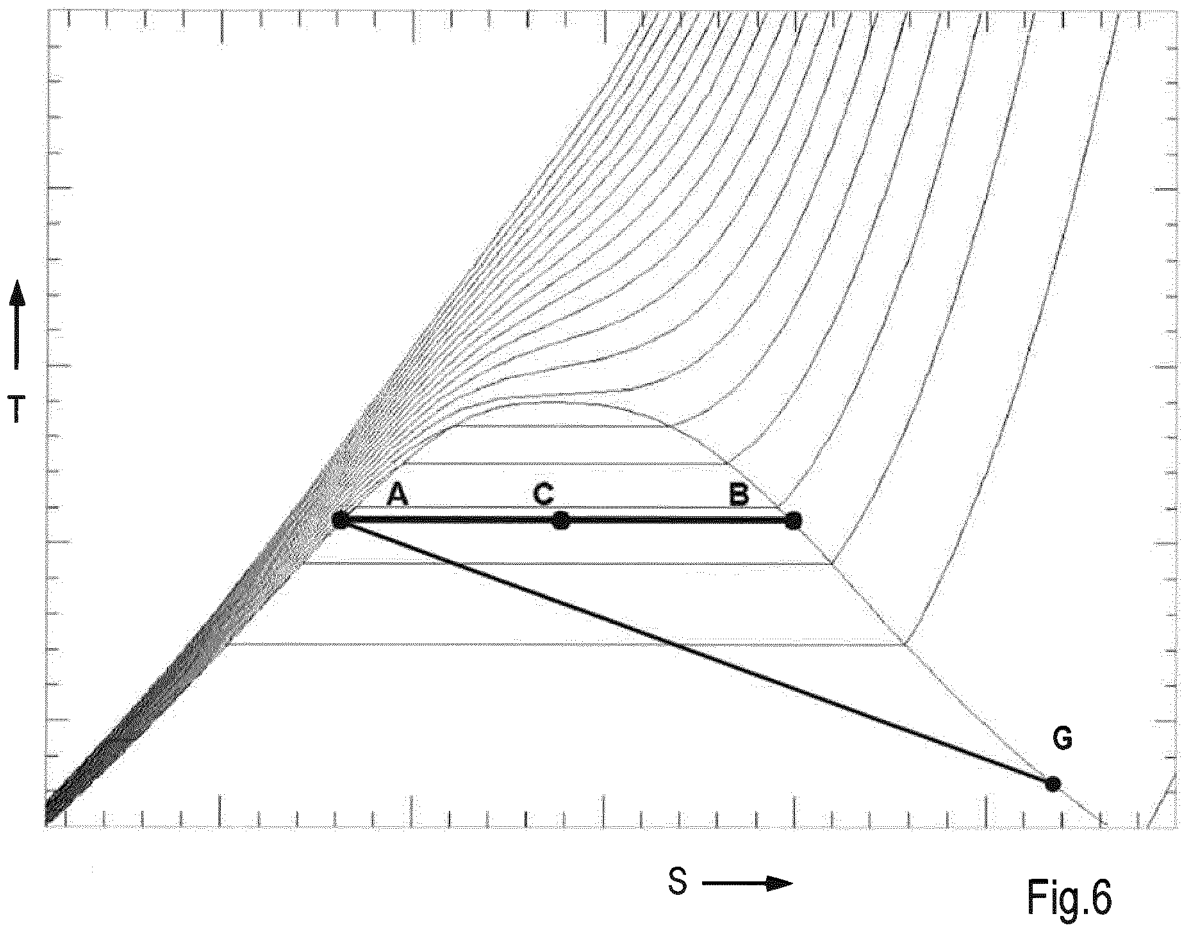

Fig.6

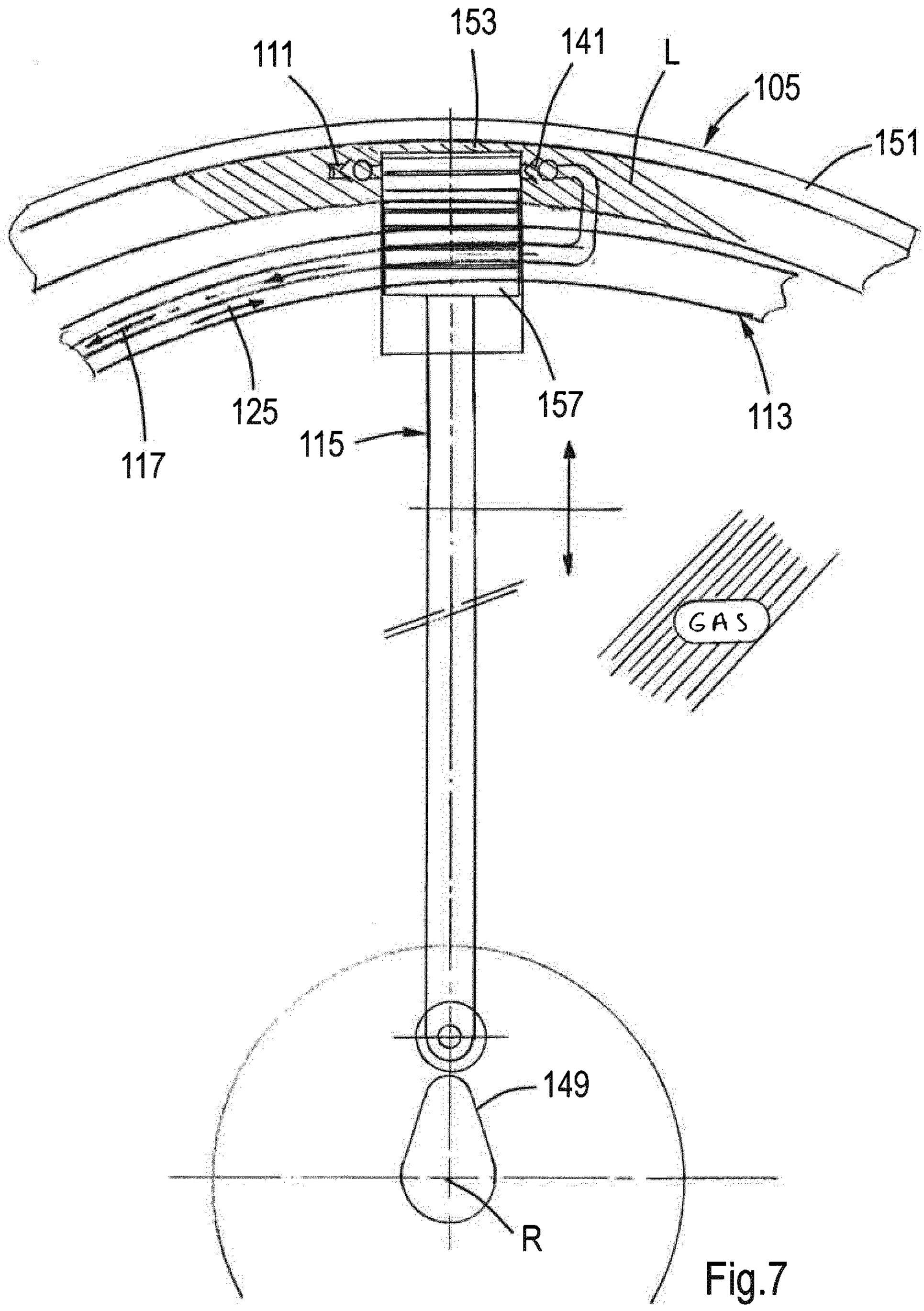

Fig.7

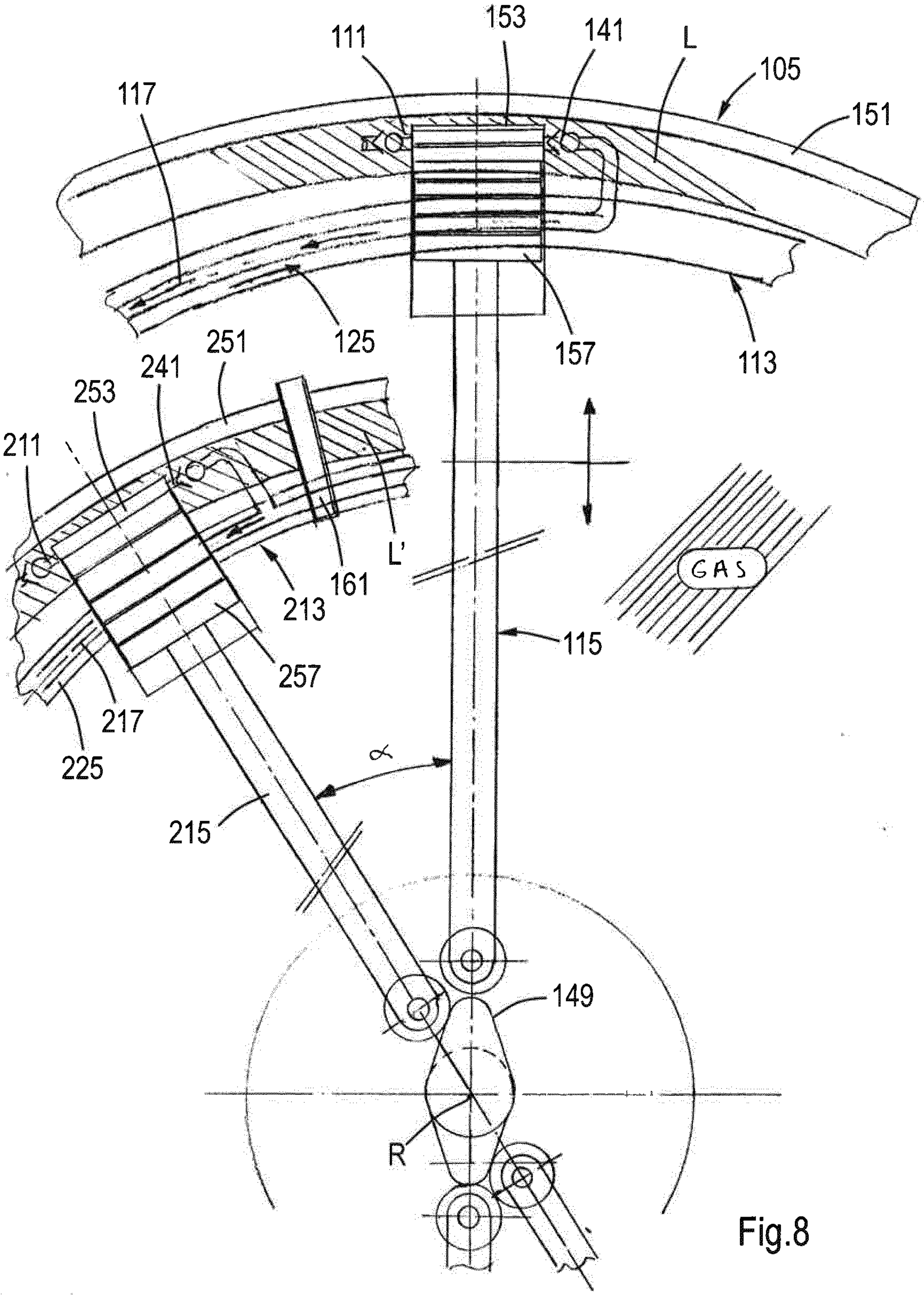
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Fig.8

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EUROPEAN SEARCH REPORT

Application Number
EP 16 17 0472

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F25B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	21 October 2016	Gasper, Ralf

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