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(54) **A SYSTEM FOR COOLING OF ELECTRONIC EQUIPMENT**

(57) A system for cooling of electronic equipment, comprising two heat transferring loops (1, 10) each of which including a heat dissipation unit (2; 20) for receiving heat from at least one electronic component (3; 30), a radiator (4; 40) receiving heat from the heat dissipation unit (2; 20) and a fluid loop (5a, 5b; 50a, 50b) connected to both ends of the heat dissipation unit (2; 20) and the radiator (4; 40), respectively, wherein pressurized fluid is arranged to flow in the fluid loop (5a, 5b; 50a, 50b) and

through the heat dissipation unit (2; 20) and the radiator (4; 40); and a fluid flow connection (100) between the dissipation units (2, 20) and between the fluid loops (5a, 5b; 50a, 50b) for oscillating fluid movement between the heat dissipation units (2, 20) and between the fluid loops for forcing generated vapour slug (6, 60) alternately from either heat dissipation unit (2, 20) to the respective radiator (4, 40).

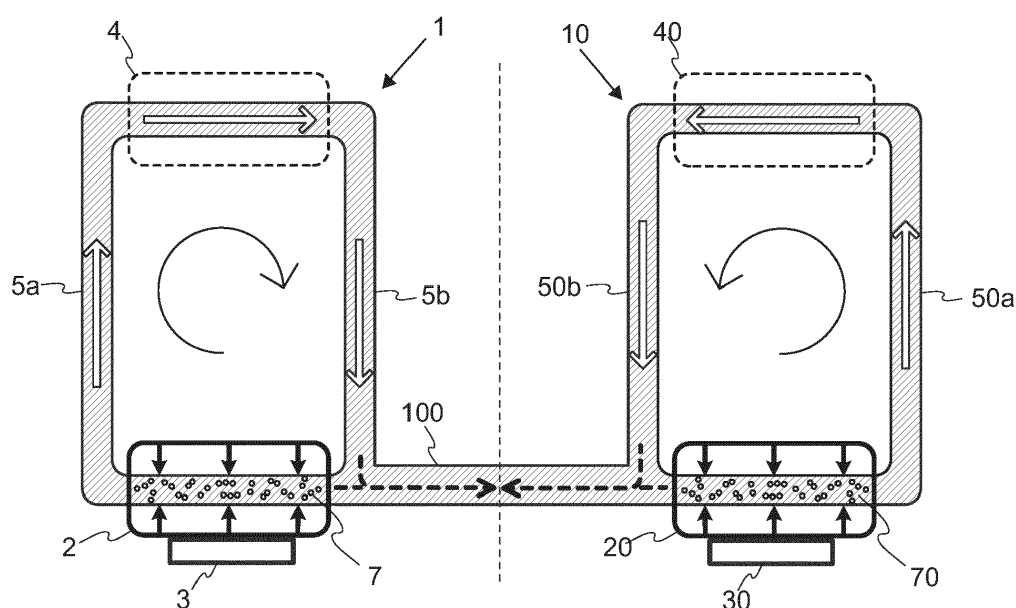


Fig. 1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a system for cooling of electronic equipment.

BACKGROUND OF THE INVENTION

[0002] At present, three different technologies can be identified for cooling of frequency converters or similar electric equipment suitable to cope with the cyclic loading combined with heavy duty under harsh environmental conditions. These are thermo-syphon cooling, pulsating heat pipes and conventional liquid cooling.

[0003] A thermo-syphon is a device used for passive heat-exchange based upon natural convection which circulates fluid without the necessity of mechanical pumps. It involves both base-to-air as well air-to-air versions and utilizes the phenomenon of density differences in the liquid causing heat transport from the source (evaporator) to the radiator (condenser). This allows for significant improvement in thermal resistance compared to traditional aluminium heatsinks, but still features the following technical downsides facing above job specification: It is gravity dependent and therefore has limited design freedom; it can be used only on one side of the radiator; it has limited mass flow (speed increment), whereby at a certain trigger velocity the internal heat flow is decreasing and thermal resistance is increasing, respectively; it has unique design, whereby no standardized components can be used; it is highly dependent with frequency converter thereby limiting design freedom and leading to e.g. unique cabinet designs for each application case; and it has inefficient heat dissipation in radiator (only gravity driven) leading to early risk of dry-out at increased/peak heat loads and leading further to restricted load operation range which is especially disadvantageous at cyclic loading profiles with great amplitudes.

[0004] Pulsating heat pipes are generally related to the thermosyphon principle previously described, however distinguish from one another by the arrangement of heat sources and condensers inside the system. Whereas a typical thermo-syphon is arranged in a parallel manner (many tubes in parallel), heat source and condenser are alternating in series in the case of pulsating heat pipes. This triggers different effects, the most important of which is the change in fluid flow direction and hence also against the direction of gravitational accelerations for which reason this is preferred in applications where an alignment with gravity as required from thermo-syphons is not guaranteed. However, following disadvantages involve: As a first major disadvantage there is low cooling efficiency as a result of limited fluid to ambient heat flow leading generally to a low base to fluid temperature difference. This effect is primarily caused by the short interaction time in the condenser section due to comparatively high mass flow or speed. This entails expensive and compar-

atively large radiators. As a second major disadvantage the high mass flow /fluid speed inside the piping is caused by competing expansion in the serial heat sources. Variations in the fluid state along the piping system consequently include an imbalance of forces that causes the fluid to set in motion in dependence on the resultant force. This happens unpredictably, for unknown length of time and non-periodical without exception. In short, the fluid flow inside the pipes is fast, the dissipated amount of heat losses is not, however. Though, the thermosyphon has a much lower fluid velocity in comparison to the pulsating heat pipes, its features a far better heat flux or fluid regeneration respectively, i.e. low fluid temperature back in the evaporator.

[0005] Liquid cooling is an established cooling technique where high cooling efficiency and compact design or remote heat dissipation (e.g. engine rooms) are required. Water is advantageous over air due to the higher specific heat capacity, density and thermal conductivity. Disadvantages are the higher costs, reduced reliability and lifetime due to the need of mechanical pumps and ambient temperature limitations (sub-zero temperatures) and possible need of start heaters (poor energy efficiency). Moreover, in drive business market often call for high fluid temperatures (combined diesel engine cooling in hybrid vehicles, mining etc.) leading to issues with electrical component cooling (70°C) whereas additives (alcohol) for frost protection significantly reduce thermal conductivity. Besides, bacterial growth is a major issue in water cooled devices.

BRIEF DISCLOSURE OF THE INVENTION

[0006] An object of the present invention is to create a system independent of gravitational accelerations enabling a much wider array of applications as with cooling regimes based upon gravitation as driving force.

[0007] A further object is to reduce and minimize high temperature gradients and chip temperatures for increasing lifetime of semiconductors in cyclic loading applications e. g. cranes and electric vehicles. Thermal management's function is to minimize total thermal resistance maximizing heat flow and dispose peaks.

[0008] Further, solution should be independent of direct air flow at or into the electric equipment for enclosed housing/harsh environment application. This comprises total thermal management. For e.g. electric vehicle or ship applications, heat dissipation shall take place remote of heat source using fluids other than ambient air.

[0009] External control like software or manual operation should be avoided.

[0010] High energy efficiency should be obtained by minimizing waste energy or turning losses into effective power output (heating, electric energy recovery).

[0011] High cooling efficiency is desirable to minimize space consumption for maximal power density.

[0012] Generally, the system should be decoupled from the electronic equipment for simple integration into

any electronic equipment to maximize backwards compatibility and electronic equipment reuse.

[0013] A general object should be maximizing simplicity of design for increased reliability and cost savings. This includes possibility to use standard components.

[0014] The objects of the invention are achieved by a system which is characterized by comprising:

a first heat transferring loop including a first heat dissipation unit for receiving heat from at least one electronic component, a first radiator receiving heat from the first heat dissipation unit and a first fluid loop connected to both ends of the first heat dissipation unit and the first radiator, respectively, wherein pressurized fluid is arranged to flow in the first fluid loop and through the first heat dissipation unit and the first radiator,

a second heat transferring loop including a second heat dissipation unit for receiving heat from at least one electronic component, a second radiator receiving heat from the second heat dissipation unit and a second fluid loop connected to both ends of the second heat dissipation unit and the second radiator, respectively, wherein pressurized fluid is arranged to flow in the second fluid loop and through the second heat dissipation unit and the second radiator, and

a fluid flow connection between the first and second heat dissipation units and between the first and second fluid loops for oscillating fluid movement between the first and second heat dissipation units and between the first and second fluid loops for forcing generated vapour slug alternately from either heat dissipation unit to the respective radiator.

[0015] The preferred embodiments of the invention are disclosed in the dependent claims 2 to 12.

[0016] The invention is based on the idea of alternately pressing in both heat dissipation loops hot vapour from heat dissipation units to the radiators using alternating increasing and decreasing fluid pressure in the fluid loops and pulsating fluid flow (fluid piston movement) generated thereby in the fluid flow connection. To ensure this, it is obvious that the first and second heat transferring loops should be essentially identical. Consequently, preferably all components in each heat transferring loops should be essentially identical.

[0017] The present invention has at least the following advantages:

The cooling system can be used independent of orientation and gravity field thanks to a pressure based operation compared to "bubble pump" drive in thermosiphon system. Gravity has no negative effect on cooling operation, because operation is based on thermodynamic work.

[0018] By using compression an efficient regeneration

of thermal fluid is guaranteed in every operation cycle. In auto-adaptive operation mode heat dissipation rate increases as heat load rises, significantly reducing risk of dry-out or chip overheating and expanding the range of application (cyclic load amplitudes).

[0019] The system has high overall efficiency and heat dissipation rate due to vapour compression for regeneration.

[0020] There is no need of moving components and mechanical systems such as pumps for the fluid, whereby high reliability is ensured.

[0021] Manufacturing is cheap and simple, wherein standard radiator components and piping can be used and mass production is possible.

[0022] Compression mechanism in radiator allows for compact total design due to high fluid to ambient temperature difference.

[0023] Local separation of heat sources and radiator for remote heat dissipation can be realized (e.g. in cars, ships).

[0024] The system is backwards compatible and simple to integrate in existing and future converter designs.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] In the following the invention will be described in greater detail by means of a preferred embodiment with reference to the attached drawings, in which

Figure 1 shows a system according to the invention for cooling of electronic equipment in a heavily schematic way illustrating the system behaviour during power-on mode; and

Figure 2 shows the system of Figure 1 illustrating one alternation during continuous operation mode.

DETAILED DESCRIPTION OF THE INVENTION

[0026] The system of Figures 1 and 2 for cooling of electronic equipment has "a first side" and "second side". "The first side" comprises a first heat transferring loop 1 including a first heat dissipation unit 2 for receiving heat from at least one electronic component 3 attached to it, a first radiator 4 receiving heat from the first heat dissipation unit 2 and a first fluid loop 5a, 5b connected to both ends of the first heat dissipation unit 2 and the first radiator 4, respectively, wherein pressurized fluid is arranged to flow in the first fluid loop 5a, 5b and through the first heat dissipation 2 unit and the first radiator 4.

[0027] "The second side" comprise a second heat transferring loop 10 including a second heat dissipation unit 20 for receiving heat from at least one electronic component 30 attached to it, a second radiator 40 receiving heat from the second heat dissipation unit 20 and a second fluid loop 50a, 50b connected to both ends of the second heat dissipation unit 20 and the second radiator 40, respectively, wherein pressurized fluid is arranged to flow in the second fluid loop 50a, 50b and through the

second heat dissipation unit 20 and the second radiator 40.

[0028] The system further comprise a fluid flow connection 100 between the "first side" and "the second side", i.e. between the first and second heat dissipation units 2, 20 and between the first and second fluid loops 5a, 5b; 50a, 50b for oscillating fluid movement between the first and second heat dissipation units 2, 20 and between the first and second fluid loops 5a, 5b; 50a, 50b for forcing generated vapour slug 6, 60 alternately from either heat dissipation unit 2, 20 to the respective radiator 4, 40. This fluid flow connection 100 is the most essential element of the invention.

[0029] The first and second heat transferring loops 2, 10 should be essentially identical as shown for a proper function of the system. In this disclosure they are symmetrical as well. Consequently, the first and second heat dissipation units 2, 20 are essentially identical and the first and second radiators 4, 40 are essentially identical. Also the first and second fluid loops 5a, 5b; 50a, 50b are essentially identical.

[0030] Typically, the first heat dissipation unit 2 and the first radiator 4 are remote from each other and second heat dissipation unit 20 and the second radiator 40 are remote from each other, and the first and second fluid loops 5a, 5b; 50a, 50b are fluid pipes, e.g. PTFE ("Teflon").

[0031] The fluid flow connection 100 between the first and second heat dissipation units 2, 20 and between the first and second fluid loops 5a, 5b; 50a, 50b is arranged directly between the first and second heat dissipation units 2, 20 for creating the most effective vapour slug 6, 60 movement.

[0032] Similar amount of essentially identical electronic components 3, 30 should be attached to each heat dissipation unit 2, 20 or the amount of heat generated by the electronic components 3, 30 attached to each heat dissipation unit 2, 20 should be essentially identical so that alternating vapour slug removing is possible.

[0033] The function of the illustrated system is the following:

Referring to Figure 1, as the electronic components 3, 30, e.g. semiconductors, commence switching operation, heat losses are generated resulting in a heat flow into the pressurized primary fluid inside the heat dissipation units 2, 20. Since this process takes place on both sides or both halves of the system likewise, pressure is building up on either side of the loops 1, 10 converting fluid outside of the heat dissipation units 2, 20 into liquid phase whereas fluid inside the heat dissipation units 2, 20 is transferred to vapour phase. Powered by the expanding vapour, liquid is diverging and consequently encountering a reverse liquid flow finally leading to an unstable equilibrium state. Ultimately, the previously described equilibrium state does collapse leading to a previously unknown and one-directional flow of liquid. The system

has entered continuous operation mode.

[0034] Referring to Figure 2, as a result of the previously described auto-start mechanism, fluid motion starts and removes the vaporized fluid such as liquid containing e.g. water from either of the heat dissipation units 2, 20. Due to a loop-type geometric arrangement, the vapour slug 6, 60 is transported into the built-in radiator 4, 40 where kinetic energy residing in the moving fluid piston is translated into heat by means of compression. A subsequent temperature gradient in-between the radiator 4, 40 chamber fluid and the ambient fluid such as air for instance, will cause an outward heat flow (heat exchange). Due to a dislocation of vapour slug from the heat dissipation unit 2, 20 to the radiator 4, 40 chamber, a permanent supply of liquid fluid in the heat dissipation unit 2, 20 is secured ready to take up heat from a source such as semiconductor modules for instance ("liquid cooling"). Simultaneous to the extinction of one vapour slug 6, 60 inside of the radiator 2, 20, another vapour slug 6, 60 is generated in the heat dissipation unit (illustrated by bubbles). Pressure is building up and momentum is transferred to the embracing liquid that is taking over the functional role of an engine's piston ("liquid piston drive"). A setting in reverse motion will repeat the process in the opposite direction. This reciprocation is continuing as long as heat is supplied into the heat dissipation unit 2, 20.

[0035] Thereby, the oscillation frequency is strictly related to the power losses and primary fluid temperature. Consequently, there is no system-inherent thermal resistance optimum, since the heat transmission is auto-adaptive. The overall heat dissipation performance is purely limited by the time constant of the radiator 4, 40, which is influenced by factors such as ambient fluid type and temperature or radiator surface area.

[0036] In Figures 1 and 2, arrows in the fluid loops 5a, 5b; 50a, 50b denote fluid movement, arrows in the heat dissipation units 2, 20 and in the radiators 4, 40 denote heat dissipation and heat radiation, whereas arrows in the heat transferring loops 1, 10 denote pressure building on "active side" of the system.

[0037] The first and second heat dissipation units 2, 20 which include first and second heat dissipation chambers 7, 70 are non-standard equipment used for transferring heat generated as power losses inside electronic components 3, 30 such as semiconductors into pressurized, primary fluid contained in the loops 1, 10 as described in Figures 1 and 2. The heat dissipation unit 2, 20 generally must allow for low thermal impedance, which may be realized by an increased internal surface (loops) in combination with good thermal conductive casing material such as aluminium. For power enhancement, secondary fluid loops with secondary fluids can be used for heat transmission. In any case, these both possible heat dissipation entities in each loop 1, 10 can be aggregated within one physical unit. This will guarantee that the heat dissipation unit 2, 20 won't run dry and function similar to a for instance water cooled heat exchanger

without the known downsides, of course.

[0038] As for the radiator 4, 40, the radiation of heat losses is based on standard radiator devices as to be found in the market today. The connection will take place as illustrated in Figures 1 and 2. For compactness purposes, e.g. two separate radiators can be combined in one physical entity to save fan devices. Another possibility would be the distribution of radiators when heat losses are requested for example to heat the passenger compartment in a vehicle. As a matter of course, the radiators 4, 40 are working independent of assembly orientation.

[0039] The fluid flow connection 100 between the first and second heat dissipation units 2, 20 and between the first fluid loop 5a, 5b and second fluid loop 50a, 50b is an essential functional entity for the invention. It guarantees the elementary operation mechanism involving momentum transfer, vapour slug 6, 60 dislocation, vapour compression/regeneration, "liquid piston" formation and heat absorption. It may be built using standard piping technologies that allow low friction in order to maximize the distance for remote cooling and high pressure withstand. A suitable material is for instance PTFE with 20 times reach of aluminium piping.

[0040] There are two regeneration loops, i.e. the first fluid loop 5a, 5b and second fluid loop 50a, 50b in the invention where only one of which is used for vapour slug regeneration purposes at a time depending on the phase of oscillation. The other one is for acceleration of the newly formed liquid piston. Though functionally different, the regeneration loops are an integral part of "the liquid piston drive system" created thereby and vital for embracing a vapour slug 6, 60 and transport it to the radiator 4, 40 for compression. Further, the loop-type geometry is securing the oscillation mechanism.

[0041] It is to be understood that the above description and the accompanying figures are only intended to illustrate the present invention. It will be obvious to a person skilled in the art that the invention can be varied and modified within the scope of the claims without departing from the scope of the invention.

Claims

1. A system for cooling of electronic equipment, **characterized by** comprising:

a first heat transferring loop (1) including a first heat dissipation unit (2) for receiving heat from at least one electronic component (3), a first radiator (4) receiving heat from the first heat dissipation unit (2) and a first fluid loop (5a, 5b) connected to both ends of the first heat dissipation unit (2) and the first radiator (4), respectively, wherein pressurized fluid is arranged to flow in the first fluid loop (5a, 5b) and through the first heat dissipation unit (2) and the first radiator (4), a second heat transferring loop (10) including a

second heat dissipation unit (20) for receiving heat from at least one electronic component (30), a second radiator (40) receiving heat from the second heat dissipation unit (20) and a second fluid loop (50a, 50b) connected to both ends of the second heat dissipation unit (20) and the second radiator (40), respectively, wherein pressurized fluid is arranged to flow in the second fluid loop (50a, 50b) and through the second heat dissipation unit (20) and the second radiator (40), and

a fluid flow connection (100) between the first and second heat dissipation units (2, 20) and between the first and second fluid loops (5a, 5b; 50a, 50b) for oscillating fluid movement between the first and second heat dissipation units (2, 20) and between the first and second fluid loops (5a, 5b; 50a, 50b) for forcing generated vapour slug (6, 60) alternately from either heat dissipation unit (2, 20) to the respective radiator (4, 40).

2. A system as claimed in claim 1, **characterized in that** the first and second heat transferring loops (1, 10) are essentially identical.
3. A system as claimed in claim 1 or 2, **characterized in that** the first and second heat transferring loops (1, 10) are essentially symmetrical.
4. A system as claimed in any one of the preceding claims, **characterized in that** the first and second heat dissipation units (2, 20) are essentially identical and the first and second radiators (4, 40) are essentially identical.
5. A system as claimed in any one of the preceding claims, **characterized in that** the first and second fluid loops (5a, 5b; 50a, 50b) are essentially identical.
6. A system as claimed in any one of the preceding claims, **characterized in that** the first heat dissipation unit (2) and the first radiator (4) are remote from each other and second heat dissipation unit (20) and the second radiator (40) are remote from each other, wherein the first and second fluid loops (5a, 5b; 50a, 50b) comprise fluid pipes.
7. A system as claimed in any one of the preceding claims, **characterized in that** the fluid flow connection (100) between the first and second heat dissipation units (2, 20) and between the first and second fluid loops (5a, 5b; 50a, 50b) is arranged directly between the first and second heat dissipation units (2, 20).
8. A system as claimed in any one of the preceding claims, **characterized in that** similar amount of essentially identical electronic components (3, 30) is

attached to each heat dissipation unit (2, 20) or the amount of heat generated by the electronic components (3, 30) attached to each heat dissipation units (2, 20) is essentially identical.

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9. A system as claimed in any one of the preceding claims, **characterized in that** the first and second heat dissipation units (2, 20) comprise first and second heat dissipation chambers (7, 70).

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10. A system as claimed in claim 9, **characterized in that** the first and second heat dissipation units (2, 20) comprise first and second secondary heat dissipation chambers isolated from the first and second fluid loops and filled with secondary fluid.

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11. A system as claimed in any one of the preceding claims, **characterized in that** the fluid in the first and secondary fluid loops (5a, 5b; 50a, 50b) is at least partially, preferably totally pressurized by the heat generated by the electronic components.

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12. A system as claimed in any one of the preceding claims, **characterized in that** the first and second radiators (4, 40) comprise several sub-radiators which are combined in one physical entity, respectively.

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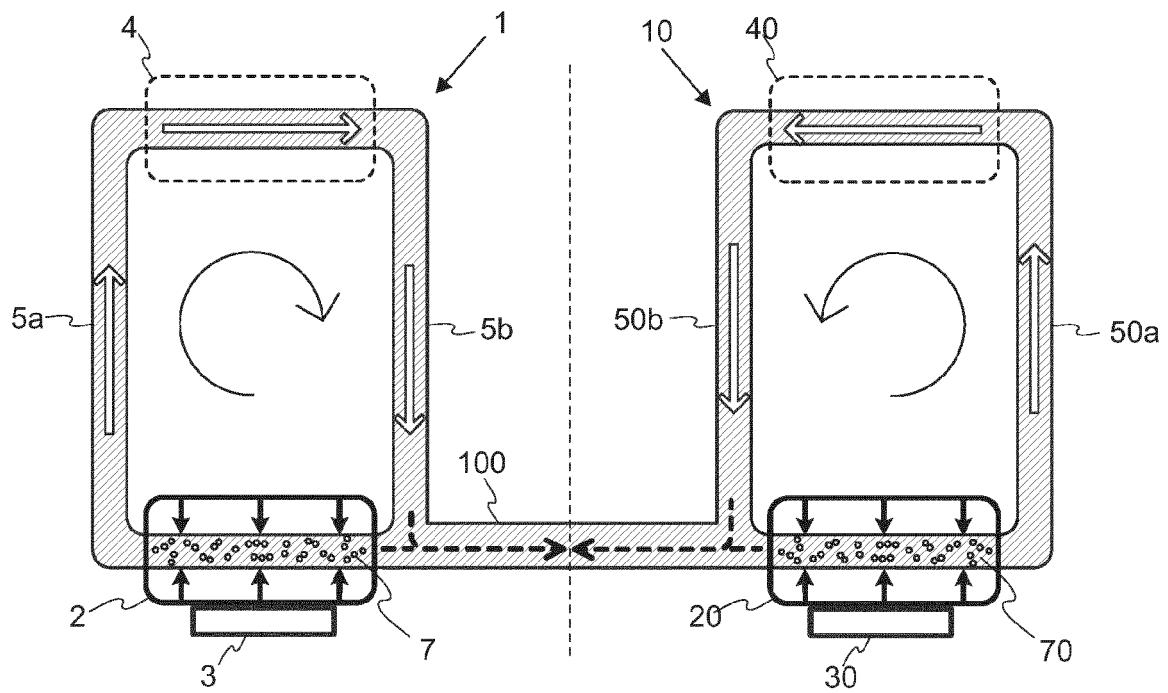


Fig. 1

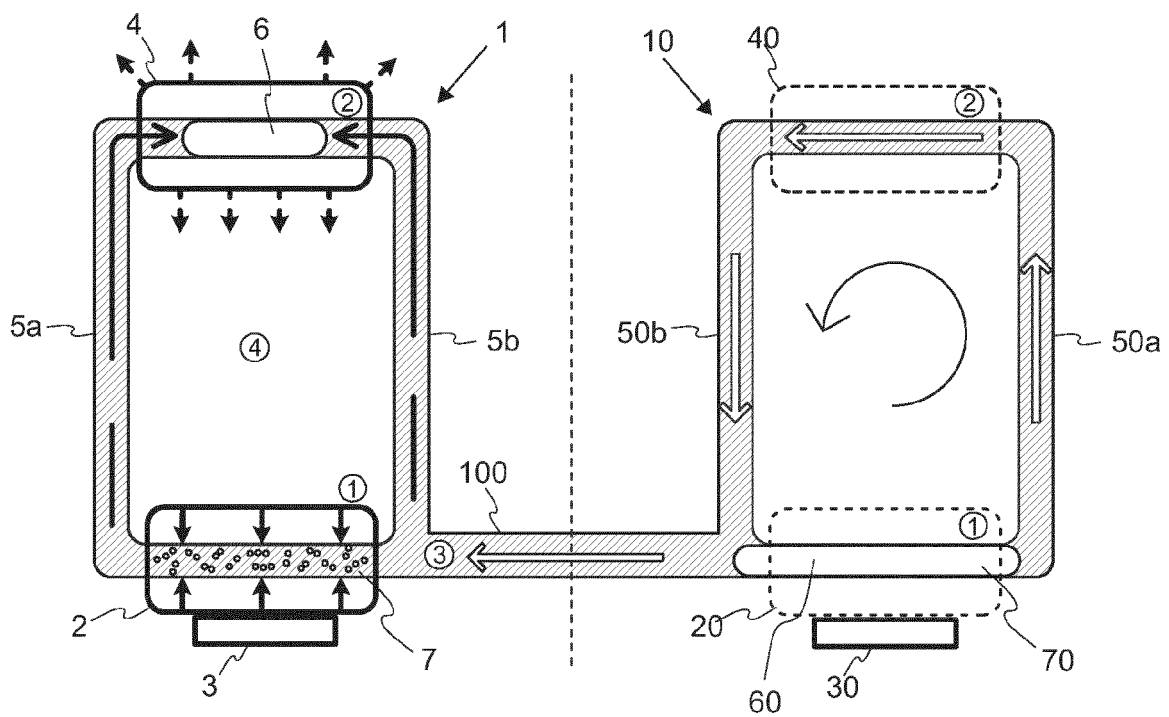


Fig. 2



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Place of search The Hague		Date of completion of the search 7 April 2016	Examiner Beltzung, Francis
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