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Amalfi et al.

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(54) **APPARATUS AND SYSTEM FOR COOLING**

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H05K 7/20 (2006.01)

(52) **U.S. Cl.**
CPC ***H05K 7/208*** (2013.01); ***H05K 7/20836*** (2013.01)

(58) **Field of Classification Search**
CPC H05K 7/20327; H05K 7/20336; H05K 7/20663; H05K 7/20518; H05K 7/208; H05K 7/20836; H05K 7/20381; H05K 7/20818
See application file for complete search history.

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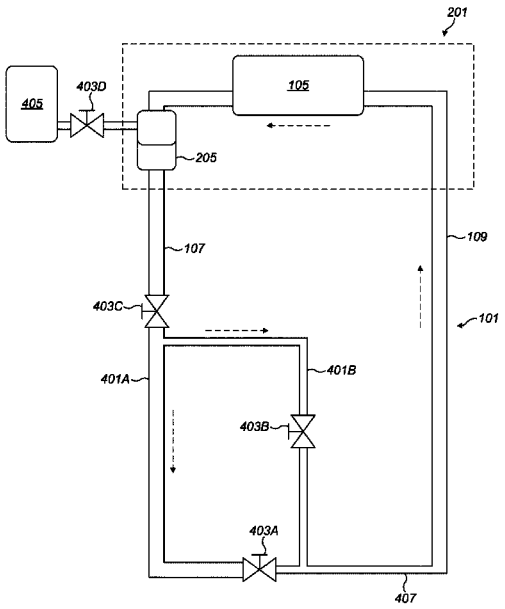
International Application No. PCT/EP2021/072211 Search Report; Completion Date: Nov. 9, 2021.

Primary Examiner — Jacob R Crum
(74) *Attorney, Agent, or Firm* — Geoffrey Lottenberg; Berger Singerman LLP

(57) **ABSTRACT**

A cooling apparatus includes thermosyphon loops for cooling multiple electronic devices. Each of the thermosyphon loops includes at least one evaporator and at least one condenser. Sensors within the thermosyphon loop measure can measure various parameters such as vapour quality within an inlet and outlet of at least one of the evaporators, total heat load of at least one of the evaporators; and the liquid level in a downcomer of the thermosyphon loop.

17 Claims, 10 Drawing Sheets



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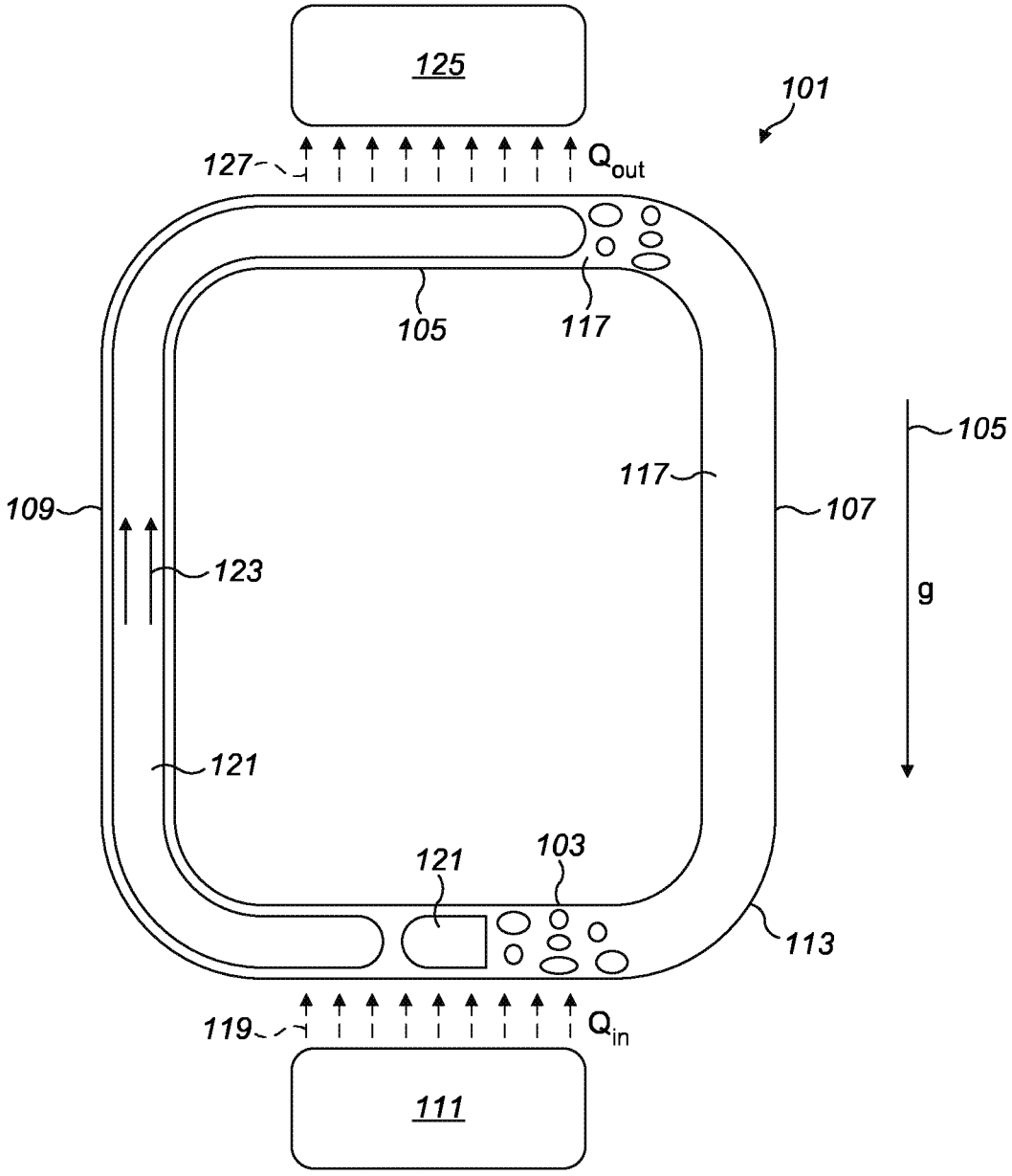

125
101
127
Q_{out}
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117
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107
123
g
121
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103
113
119
Q_{in}
111

FIG. 1

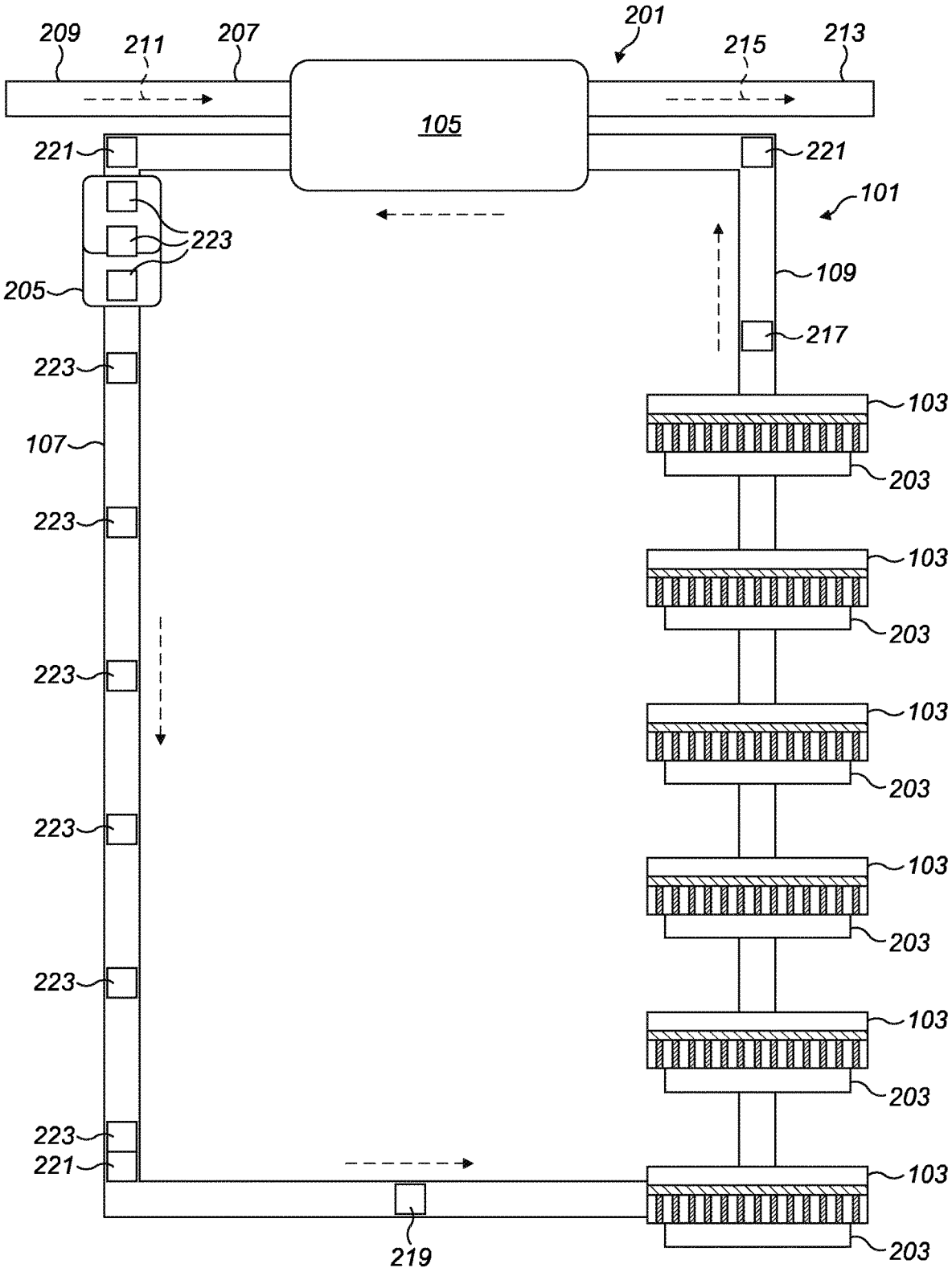

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FIG. 2

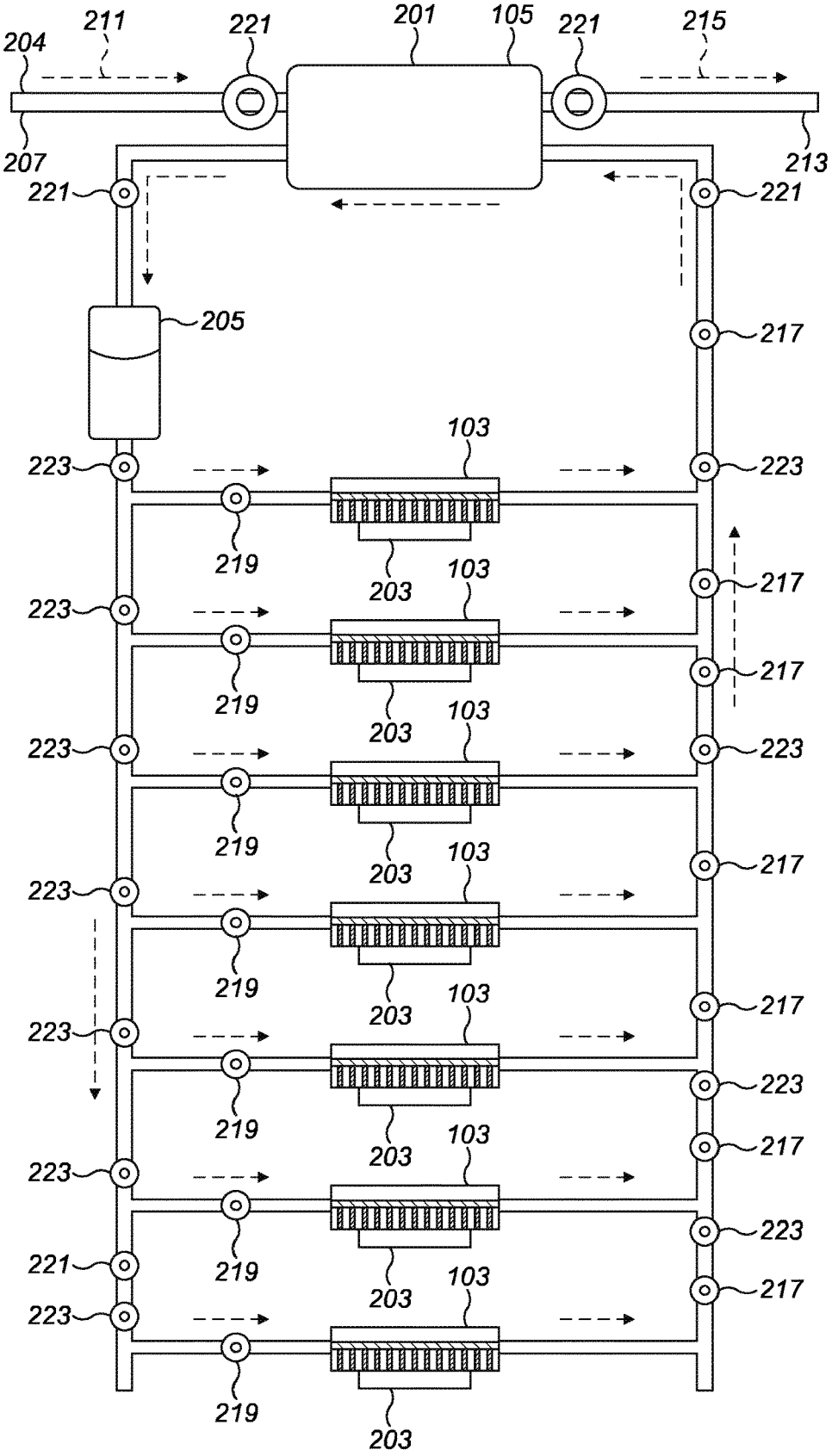

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FIG. 3

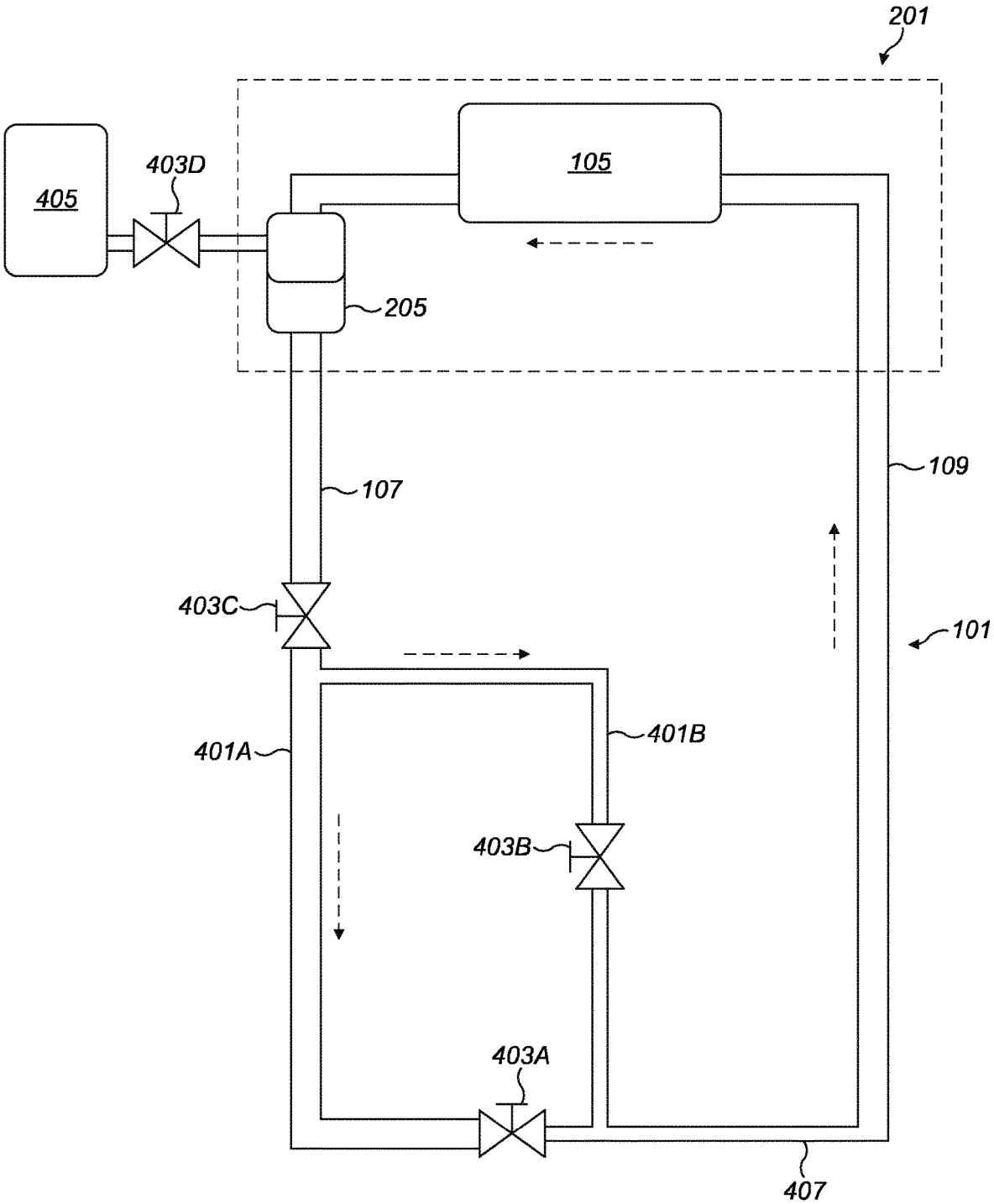


FIG. 4

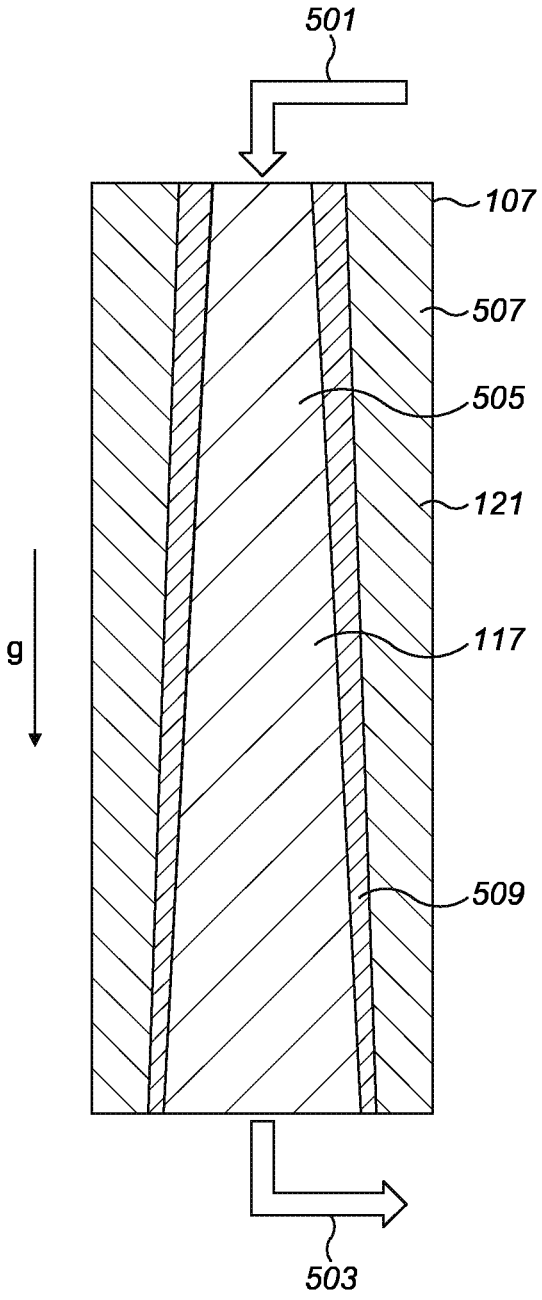


FIG. 5

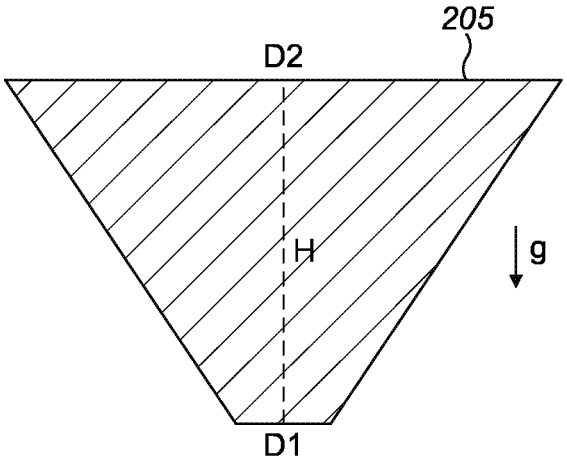

205
D2
H
g
D1

FIG. 6A

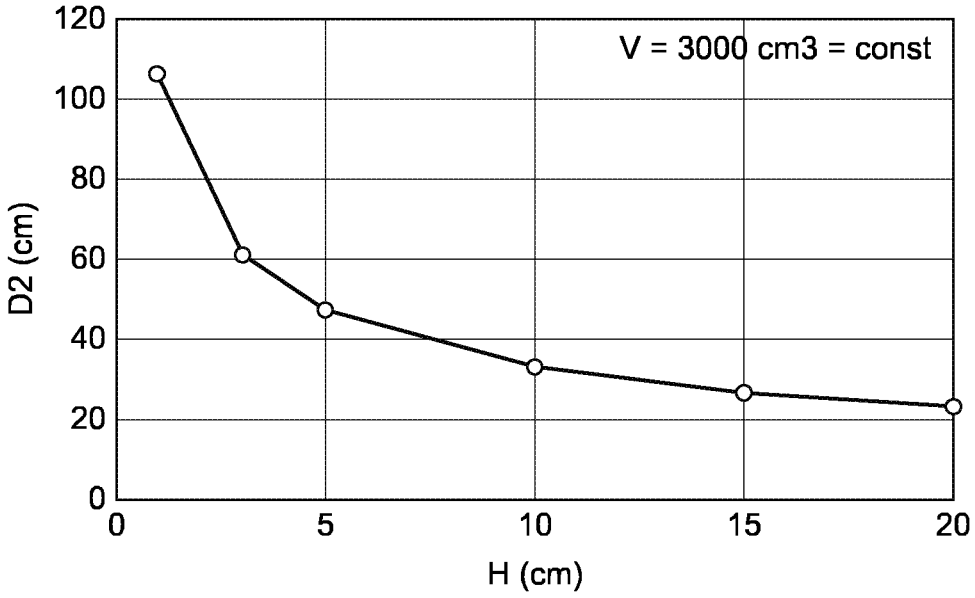

V = 3000 cm3 = const
120
100
80
60
40
20
0
D2 (cm)
0
5
10
15
20
H (cm)

FIG. 6B

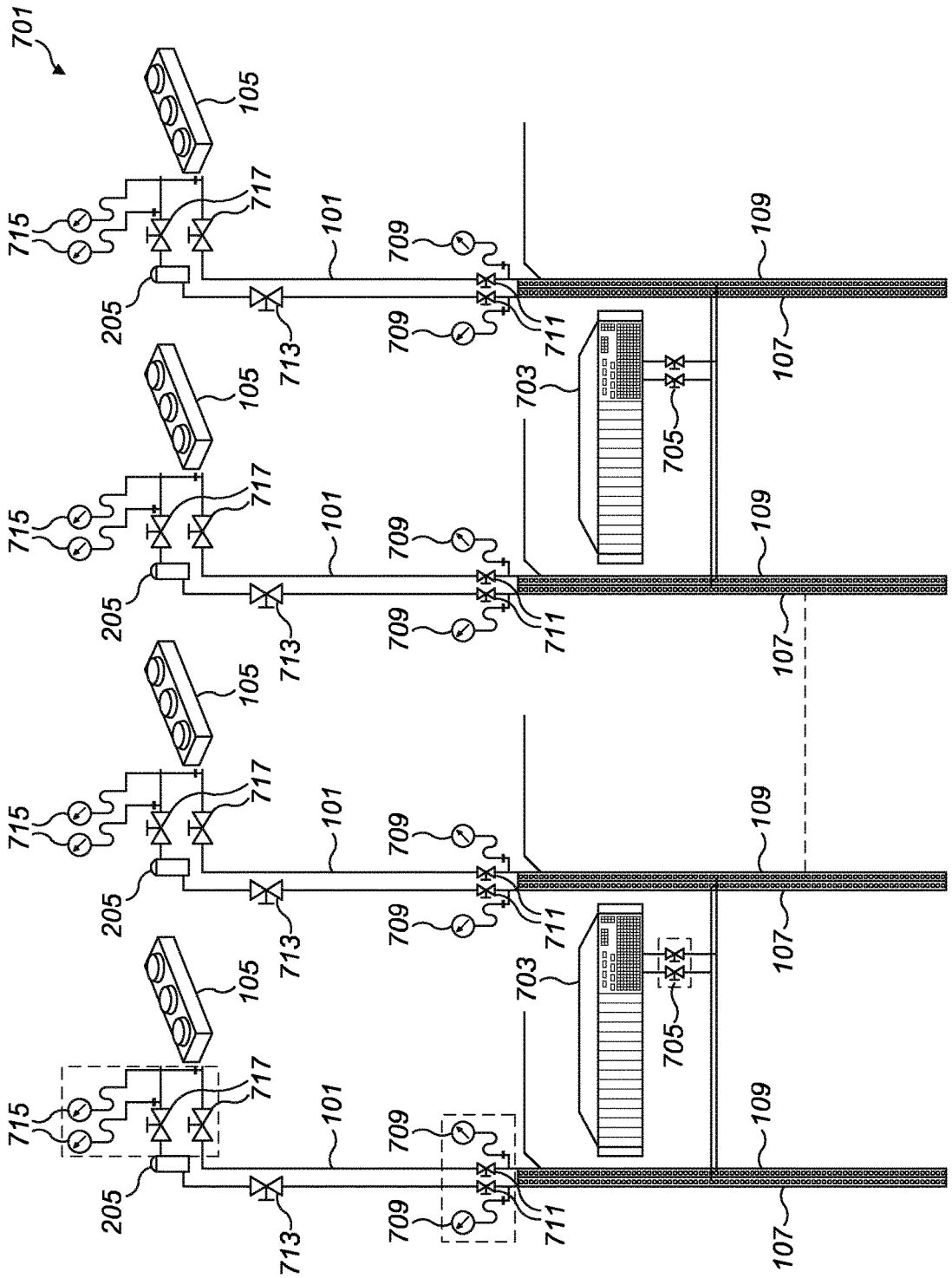


FIG. 7

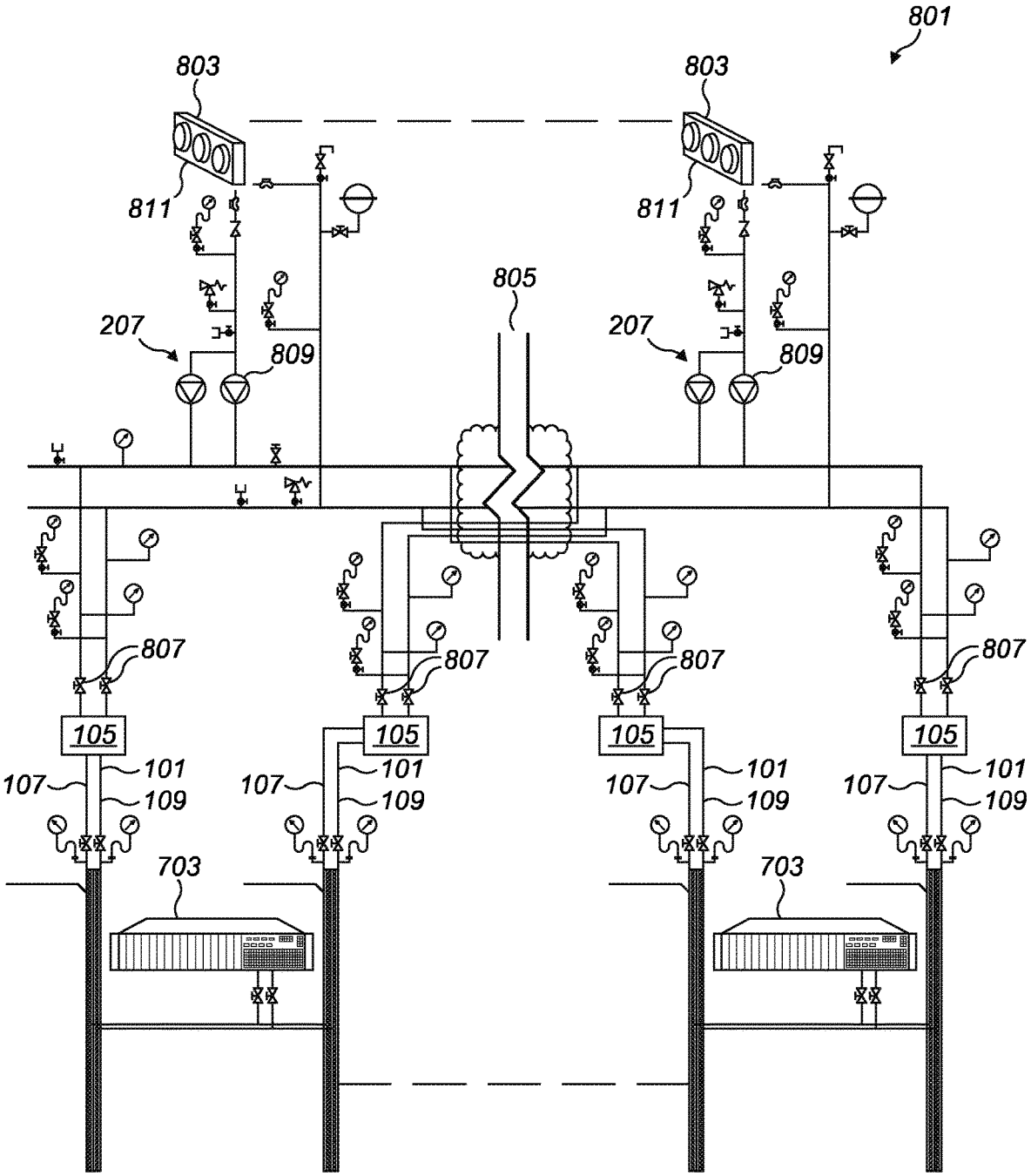

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FIG. 8

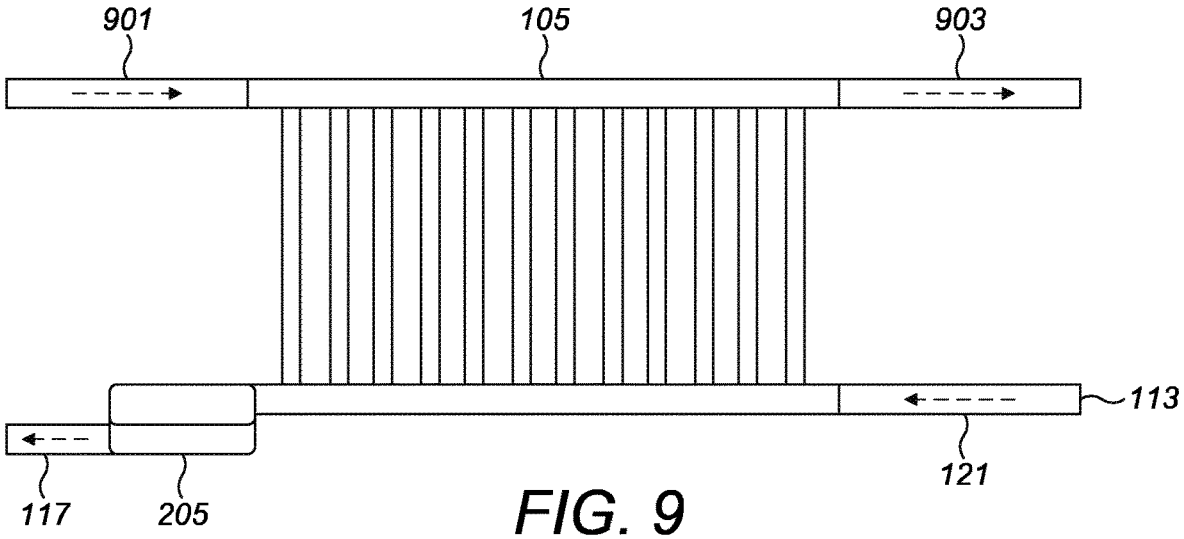

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903
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121
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205

FIG. 9

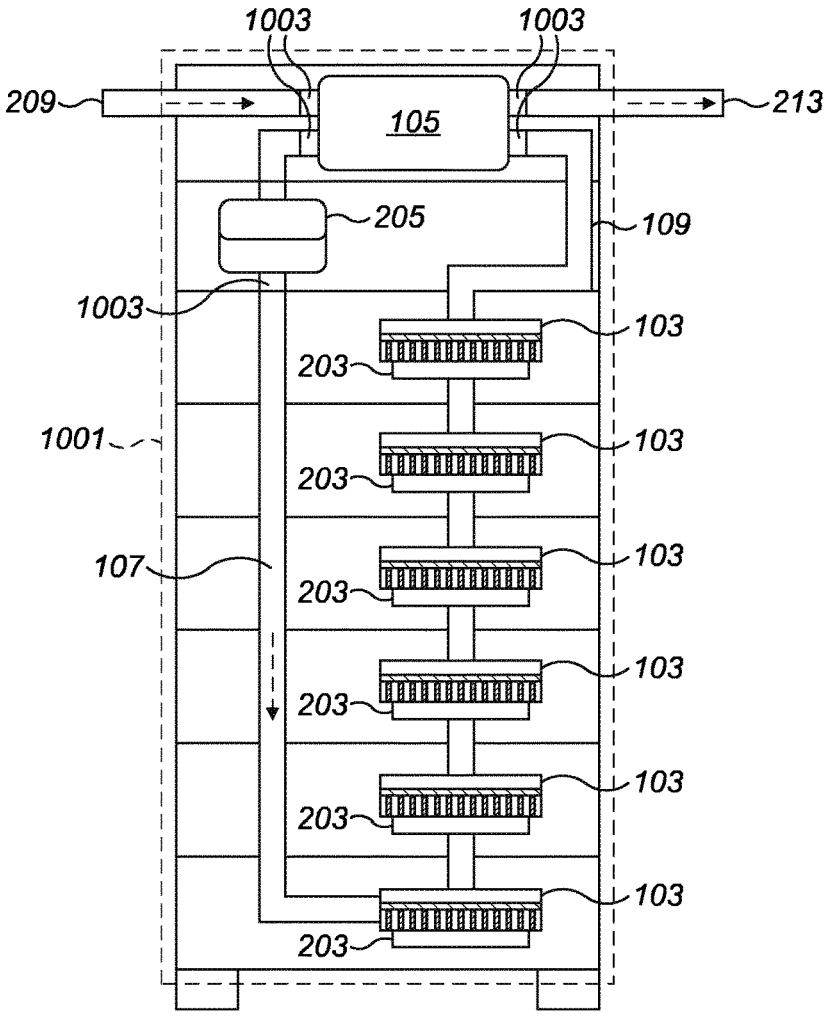

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FIG. 10

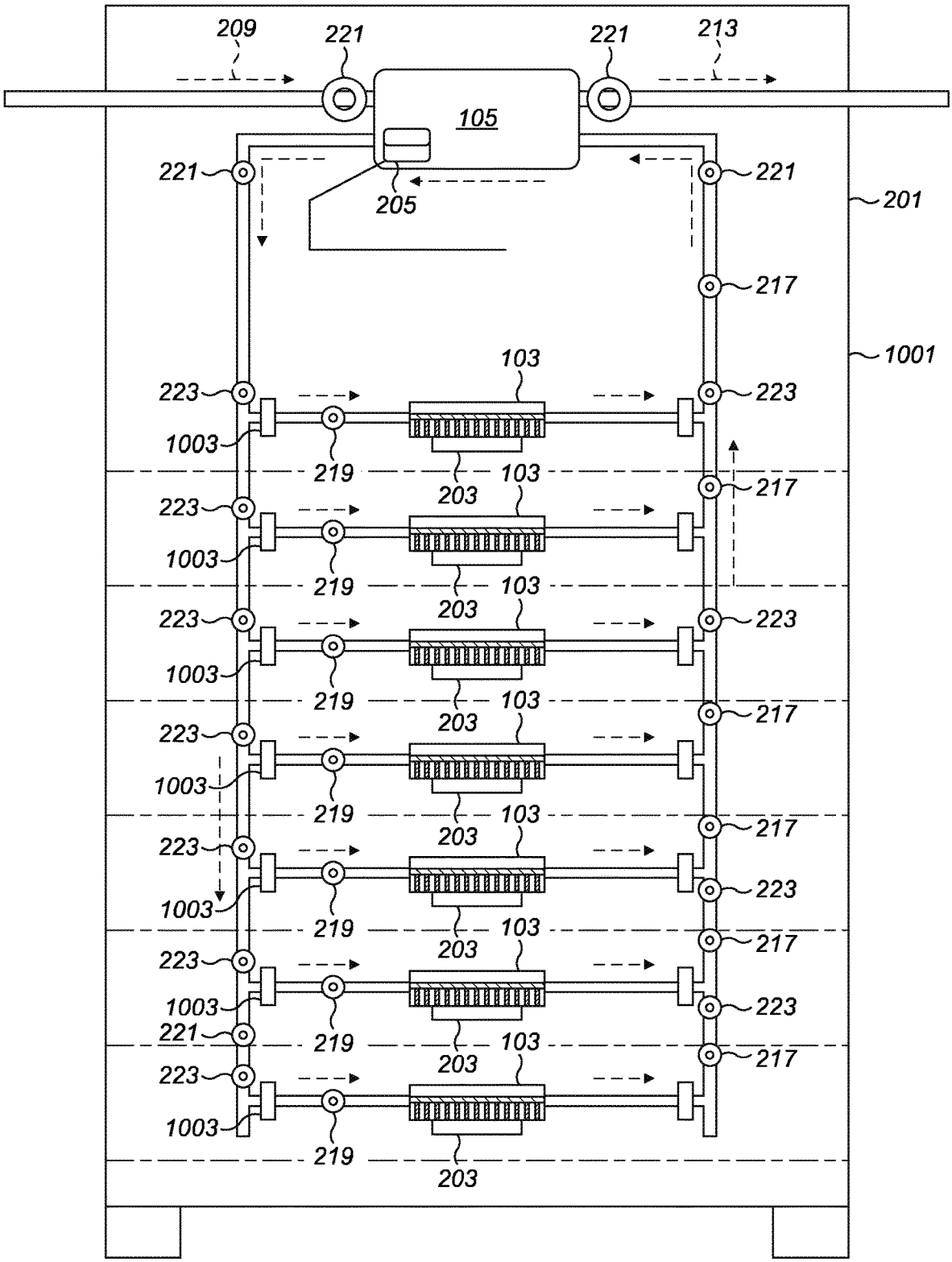

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FIG. 11

APPARATUS AND SYSTEM FOR COOLING

TECHNOLOGICAL FIELD

Examples of the disclosure relate to apparatus and systems for cooling. Some relate to apparatus and systems for cooling data centres comprising a plurality of electronic devices such as servers.

BACKGROUND

Cooling is essential to enable data centres to function. Efficient apparatus and systems for cooling data centres that consume less energy and reduce any active control are therefore advantageous.

BRIEF SUMMARY

According to various, but not necessarily all, examples of the disclosure there is provided an apparatus comprising: one or more thermosyphon loops for cooling a plurality of electronic devices wherein each of the one or more thermosyphon loops comprises at least one evaporator and at least one condenser; and a plurality of sensors within the thermosyphon loop wherein the sensors are configured to enable measurement of, one or more of; vapour quality within an inlet and outlet of at least one evaporator; total heat load of at least one evaporator; liquid level in a downcomer of the at least one thermosyphon loop.

The apparatus may comprise a thermosyphon loop comprising a plurality of evaporators.

The apparatus may comprise a plurality of thermosyphon loops and each thermosyphon loop comprises at least one evaporator.

The sensors may be configured to enable measurement of liquid level within an accumulator within the downcomer of the at least one thermosyphon loop.

The plurality of evaporators may be arranged in series within a thermosyphon loop. The sensors that are configured to enable measurements of the vapour quality may be provided at the outlet of the last evaporator in the series of evaporators.

The plurality of evaporators may be arranged in parallel within a thermosyphon loop. The sensors are configured to enable measurements of the vapour quality at the outlet of a plurality of the evaporators.

The apparatus may comprise at least one mass flow rate sensor configured to measure mass flow rate within the thermosyphon loop.

The apparatus may comprise at least one pressure sensor configured to measure pressure of working fluid within the at least one thermosyphon loop.

The apparatus may comprise a plurality of temperature sensors provided at different locations within a downcomer of at least one thermosyphon loop.

The apparatus may comprise a plurality of branches within a downcomer of at least one thermosyphon loop and one or more valves are configured to control flow through the different branches.

The different branches may have different diameters.

An expandable portion may be provided within a downcomer of at least one thermosyphon loop.

The downcomer of at least one thermosyphon loop may have a varying diameter along the length of the downcomer so that the downcomer is wider at the top than at the bottom.

The apparatus may be configured to enable one or more of the evaporators to be removed from the thermosyphon loop while the thermosyphon loop is in use.

The thermosyphon loop may be thermally coupled to a secondary cooling system.

The plurality of electronic devices cooled by the apparatus may comprise one or more of; servers, routers, switches, opto-electronic devices.

The plurality of electronic devices may be provided in one or more racks within at least one of: a data centre, a computer room, a telecommunications equipment room, a network room.

The evaporators may comprise one or more of: wick structures, microchannels, array of fins, serpentine arrangement of tubes.

The apparatus may be configured to be controlled by controller such that the controller can use outputs from the one or more sensors to increase efficiency of the apparatus.

According to various, but not necessarily all, examples of the disclosure there may be provided a cooling system comprising a plurality of thermosyphon loops configured so that the plurality of thermosyphon loops are isolated from each other such that no fluid path is provided between thermosyphon loops and wherein a plurality of thermosyphon loops are thermally coupled to a single electronic device so as to enable a first thermosyphon loop to be used to cool the electronic device independently of a second thermosyphon loop.

The cooling system may comprise a plurality of secondary cooling systems configured so that each thermosyphon loop can be thermally coupled to a plurality of secondary cooling systems so as to enable a first secondary cooling system to be used independently of a second secondary cooling system.

Each of the secondary cooling systems may be coupled to a plurality of thermosyphon loops.

The cooling system may be configured so that the secondary cooling systems are isolated from each other such that no fluid path is provided between secondary cooling systems.

BRIEF DESCRIPTION

Some examples will now be described with reference to the accompanying drawings in which:

FIG. **1** schematically shows a thermosyphon loop

FIG. **2** shows an example apparatus applied to a rack comprising a plurality of electronic devices cooled in series;

FIG. **3** shows an example apparatus applied to a rack comprising a plurality of electronic devices cooled in parallel;

FIG. **4** shows an example apparatus with flow control valves on the downcomer section;

FIG. **5** shows a section of a downcomer;

FIGS. **6**A and **6**B show an example accumulator with a profile designed to manage the liquid head variation with variations in dissipated power;

FIG. **7** shows an example apparatus for cooling a plurality of racks in data centres and/or Telco rooms and/or network/communication rooms;

FIG. **8** shows an example apparatus for cooling a plurality of racks comprising a primary rack-level cooling system and a secondary cooling system;

FIG. **9** shows an example condenser;

FIG. **10** shows an example apparatus applied to a rack comprising a plurality of electronic devices cooled in series and using an overhead rack condenser; and

FIG. **11** shows an example apparatus applied to a rack comprising a plurality of electronic devices cooled in parallel and using an overhead rack condenser.

DETAILED DESCRIPTION

The Figures illustrate an apparatus **201** comprising: one or more thermosyphon loops **101** for cooling a plurality of electronic devices **203** wherein each of the one or more thermosyphon loops **101** comprises at least one evaporator **103** and at least one condenser **105**; and a plurality of sensors within the thermosyphon loop **101** wherein the sensors are configured to enable measurement of, one or more of; vapour quality within an inlet and outlet of at least one evaporator **103**; total heat load of at least one evaporator, liquid level in a downcomer **107** of the at least one thermosyphon loop **101**.

FIG. **1** schematically shows a thermosyphon loop **101**. The thermosyphon loop **101** comprises a passive two-phase gravity driven cooling system. The thermosyphon loop **101** comprises an evaporator **103**, a condenser **105**, a downcomer **107** and a riser **109**. A working fluid **113** is provided within the thermosyphon loop **101**. When the thermosyphon loop **101** is in use the working fluid **113** circulates through the components of the thermosyphon loop **101**.

The evaporator **103** is provided at the bottom of the thermosyphon loop **101** so that the working fluid flows down the downcomer **107** into the evaporator **103** under the force of gravity as indicated by the arrow **115**. The height and inner diameter of the downcomer **107** can be selected so that the static head of the fluid within the downcomer **107** causes the fluid to flow through the evaporator **103**, riser **109** and condenser **105**. The working fluid **113** is in the liquid phase **117** when it is in the downcomer **107**.

The evaporator **103** comprises any means for transferring heat from a heat source **111** into the working fluid **113**. The evaporator **103** is thermally coupled to the heat source **111**. A thermal interface material could be used to enable the evaporator **103** to be thermally coupled to the heat source **111**. The heat source **111** could comprise an electronic device that generates unwanted heat during used. The electronic device could be an opto-electronic device. The electronic device could be a server, router, network switch, storage device or any other suitable type of device. In some examples the heat sources can comprise a plurality of electronic devices that could provide a data centre, telecommunication equipment room, or network, a communication room, a computer room, a network room or any other suitable arrangement.

Heat is transferred from the heat source **111** to the working fluid **113** in the evaporator **103** as indicated by the arrows **119**. This heat transfer causes a partial evaporation of working fluid **113** within the evaporator **103** and converts the working fluid **113** from a liquid phase **117** into a mixture of liquid and vapour phase. In particular, the evaporator **103** causes some of the working fluid **113** to be converted into the vapour phase **121** while some remains in a liquid phase **117** so that the fluid expelled from the outlet of the evaporator **103** is a two-phase mixture. The two-phase mixture can comprise droplets of vapour entrained within the liquid or other flow regimes depending on the design of the thermosyphon loop **101**, heat load, filling ratio and any other suitable factor.

The evaporator **103** is coupled to the riser **109** so that the working fluid expelled from the evaporator **103** flows from the evaporator **103** into the riser **109**. This working fluid comprises a two-phase mixture where the vapour phase **121** is less dense than the liquid phase **117**. The working fluid **113** within the thermosyphon loop **101** rises through the riser **109**, as indicated by the arrows **123**, as a result of the balance between the buoyancy force (associated with the two-phase mixture coming out from the evaporator **103**) and the gravity force (associated with the liquid coming out from the condenser **105**).

The evaporator **103** can comprise structures that enable efficient transfer of heat from the evaporator **103** into the working fluid **113**. For example the evaporator **103** could comprise wick structures, microchannels, arrays of fins, a serpentine arrangement of tubes or any suitable combination of such features.

The condenser **105** is provided at the top of the thermosyphon loop **101**. The condenser **105** is positioned above the evaporator **103** so that the working fluid **113** flows upwards from the evaporator **103** to the condenser **105**.

The condenser **105** is coupled to the riser **109** so that the working fluid **113** in the two-phase mixture (vapour phase **121** and liquid phase **117**) flows from the riser **109** into the condenser **105**. The condenser **105** can comprise any means for cooling the working fluid **113**.

The condenser **105** is thermally coupled to a coolant **125**. A thermal interface material could be used to enable the condenser **105** to be thermally coupled to the coolant **125**. In other examples the coolant **125** can be directly integrated in the condenser **105** with a wall interface separating the stream of thermosyphon working fluid **113** from the stream of coolant **125**. The wall interface can comprise a highly conductive metal or metal alloy, such as copper, aluminum, brass, or any other suitable metal. In some examples the wall interface can comprise highly conductive ceramics such as Aluminum Nitride (AlN), or polymers such as filled polymer composites. The condenser **105** could be a liquid-cooled condenser or any other suitable type of condenser. The condenser can comprise any suitable geometry that enables heat to be removed efficiently from the working fluid.

The condenser **105** enables heat to be transferred from the working fluid **113** to the coolant as indicated by the arrows **127**. This heat transfer causes the working fluid **113** to condense back into the liquid phase **117**. The working fluid **113** at the outlet of the condenser **105** is therefore in the liquid phase **117**.

The condenser **105** is coupled to the downcomer **107** so that the working fluid **113** in the liquid phase **117** can flow down the downcomer **107** by gravity and be returned to the inlet of the evaporator **103**.

Thermosyphon loops **101** such as the loop shown in FIG. **1** can be used in apparatus **201** according to examples of the disclosure.

FIG. **2** shows an example apparatus **201** according to examples of the disclosure. The apparatus **201** is configured to enable cooling of a plurality of electronic devices **203** in a data centre or in any other suitable environment. The apparatus **201** comprises a thermosyphon loop **101** and a plurality of sensors. The plurality of sensors are distributed throughout the thermosyphon loop **101** to enable different parameters of the thermosyphon loop **101** to be monitored.

In the example of FIG. **2** the thermosyphon loop **101** comprises a plurality of evaporators **103** where each of the evaporators **103** is thermally coupled to an electronic device **203**. The electronic device **203** could be a server, a router, a switch, or any other opto-electronic device. The evaporators **103** are coupled to the electronic devices **203** to enable heat from the electronic devices **203** to cause the working fluid **113** in the evaporators **103** to be evaporated. Six electronic devices **203** and corresponding evaporators **103** are shown

in FIG. **2**, however it is to be appreciated that other numbers of electronic devices **203** and evaporators **103** could be used in other examples of the disclosure.

In the example shown in FIG. **2** the evaporators **103** are arranged in series within the thermosyphon loop **101** so that working fluid **113** expelled from a first evaporator **103** is then provided to the inlet of the next evaporator **103** within the series. In this series arrangement the working fluid **113** passes through each of evaporators **103** sequentially. As the working fluid **113** passes through the evaporators **103** the amount of working fluid **113** in the vapour phase **121** increases, as more heat is absorbed during the evaporation process.

The example apparatus **201** of FIG. **2** comprises an accumulator **205** in the downcomer **107**. The accumulator **205** can be a liquid accumulator or a receiver. The accumulator **205** can comprise any means that can be configured to store working fluid **113** in the liquid phase **117**. The accumulator **205** stores the working fluid **113** in the liquid phase **117** and helps to prevent the working fluid **113** in the liquid phase **117** from entering the condenser **105** due to the larger cross sectional-area of the accumulator **205** relative to the downcomer. This avoids flooding of the condenser **105** that could result in a decrease in thermal performance of the thermosyphon loop **101**.

The condenser **105** comprises a compact heat exchanger. Other types of condenser **105** could be used in other examples of the disclosure. The type of condenser **105** that is used can be selected based on the expected amount of heat that is to be removed from the thermosyphon loop **101**. This can be dependent upon the number of electronic devices **203** that are to be cooled by the thermosyphon loop **101**.

In the example shown in FIG. **2** a secondary cooling system **207** is coupled to the condenser **105** to enable heat to be transferred out of the thermosyphon loop **101** and data centre environment. In this example water is the coolant and is provided at an inlet **209** as indicated by the arrow **211**. The condenser **105** is configured so that heat is then transferred from the working fluid **113** of the thermosyphon loop **101** to the water of the secondary cooling system **207**. The heated water is then expelled from the outlet **213** as indicated by the arrow **215**.

The apparatus **201** also comprises a plurality of sensors. The sensors are positioned within the thermosyphon loop **101** and are configured to enable measurement of one or more parameters of the thermosyphon loop **101** to be monitored. The parameters that are monitored can relate to the efficiency of the thermosyphon loop **101** and the amount of heat being transferred by the thermosyphon loop **101**.

The apparatus **201** comprises at least one sensor configured to obtain a vapour quality measurement **217** within an outlet of at least one evaporator **203**. In the example shown in FIG. **2** the plurality of evaporators **103** are arranged in series and the vapour quality measurement **217** is provided at the outlet of the last evaporator **103** in the series.

The vapour quality measurement **217** provides information on the mass of vapour within the outlet of the evaporator **103** and therefore gives a measure of the heat that is being removed by the thermosyphon loop **101**. The vapour quality can be calculated considering the sensible and latent contributions to the energy balance. The vapour quality can be calculated by using the following equations:

$$x_{inlet} = \frac{c_p(T_{fl} - T_{sat})}{H_v - H_l}$$

-continued

$$x_{outlet} = x_{inlet} + \frac{Q_{tot}}{m(H_v - H_l)}$$

where: c_p is the specific heat of the working fluid in the liquid phase at the constant pressure (J/kg/k), T_{fl} is the temperature in Kelvin of the working fluid in the liquid phase, T_{sat} is the saturation temperature in Kelvin of the working fluid, the difference between H_v and H_l represents the latent heat of vaporization (J/kg) of the working fluid, and m is the mass flow rate in kg/s.

A mass flow rate sensor **219** can be provided within the thermosyphon loop **101**. In the example shown in FIG. **2** the mass flow rate sensor **219** is provided at the inlet of the first evaporator **103** in the series of evaporators **103**. The mass flow rate sensor **219** is configured to measure the flow rate of the working fluid **113** upstream of the evaporators **103**. It is to be appreciated that the mass flow rate sensor **219** could be provided in other locations within the thermosyphon loop **101** in other examples of the disclosure.

In the example shown in FIG. **2** the mass flow rate sensor **219** could be an ultrasonic sensor that allows non-intrusive measurements. Other types of mass flow rate sensor **219** could be used in other examples of the disclosure. The type of mass flow rate sensor **219** that is used can depend on the design of the thermosyphon loop **101**, measurement location and any other suitable factor.

The apparatus **201** also comprises pressure sensors **221** configured to measure pressure of the working fluid **113** within the thermosyphon loop **101**. The apparatus **201** shown in FIG. **2** comprises three pressure sensors **221**. Other numbers of pressure sensors **221** could be used in other examples of the disclosure.

In the example shown in FIG. **2** a first pressure sensor **221** is provided in the downcomer **107** between the condenser **105** and the accumulator **205**, a second pressure sensor **221** is provided in the downcomer **107** upstream of the series of evaporators **103** and a third pressure sensor **221** is provided in the riser **109** downstream of the series of evaporators **103**. It is to be appreciated that other arrangements of the pressure sensors **221** could be used in other examples of the disclosure.

The pressure sensors **221** give a measurement of the pressure within the thermosyphon loop **101** which can be used to determine the latent heat of vaporization of the working fluid and the saturation temperature of the working fluid within the thermosyphon loop **101**.

The apparatus **201** also comprises a plurality of temperature sensors **223** that are positioned at a plurality of different positions within the downcomer **107** and the accumulator **205**. In the example of FIG. **2** the apparatus **201** comprises nine temperature sensors **223** at different locations within the downcomer **107** and the accumulator **205**. The temperature sensors **223** enable the temperature of the working fluid **113** to be measured. The temperature of the working fluid **113** close to the inlet of the first evaporator **103** can be used to determine the inlet vapour quality at the location of the pressure sensor **221**.

The vapour quality measurement **217** at the outlet of the evaporators **103** is calculated based on the inlet vapour quality at the location **221**, total power dissipated by the opto-electronic devices **203** and properties of the working fluid **113**.

The plurality of temperature sensors **223** also enables the determination of the height of the liquid level in the downcomer **107** of the thermosyphon loop **101** to be determined.

The measurement of the liquid level indicates at what point within the downcomer **107** the working fluid **113** is in the vapour phase. If too much heat is being transferred from the electronic devices **203** this leads to a decrease in the density of the working fluid **113** as more vapour is created, and more liquid is stored in the downcomer **107** If this excess of liquid reaches too far up the downcomer **107** this could lead to flooding of the condenser **105** and could prevent the thermosyphon loop **101** from functioning and so it is useful to monitor the liquid level within the downcomer **107**.

The plurality of temperature sensors **223** give an indication of the point at which the temperature of the working fluid **113** within the downcomer **107** reaches the saturation temperature of the working fluid. This indicates the point within the downcomer **107** at which the working fluid **113** is in vapour phase. The measurements provided by the plurality of pressure sensors **221** can be used to determine the saturation temperature for the working fluid **113** within the thermosyphon loop **101**.

The outputs of these sensors can be used to help to control the apparatus **201**. In some examples the outputs of the sensors can be provided to a controller device or other circuitry that can determine how much heat is being transferred into and out of the thermosyphon loop **101**.

In some examples the apparatus **201** can be configured to enable automatic control for the thermosyphon loop **101**. The controller can use outputs from the one or more sensors to increase efficiency of the thermosyphon loop **101** or any other part of a system. For instance, the controller can be configured to control parts of the apparatus **201** and to determine the amount of heat being transferred into and out of the thermosyphon loop **101**. The heat transfer could be controlled by controlling the function of one or more of the electronic devices **203**, by controlling the fluid flow through the thermosyphon loop **101**, by controlling the liquid level in the accumulator **205** or by any other suitable means.

In some examples the controller can be configured to enable manual control of the apparatus **201**. This could enable a user to receive a notification that then enables the user to decide how to control the system, for example by opening a valve or controlling one or more of the electronic devices **203**.

FIG. **3** shows another example apparatus **201** according to examples of the disclosure. The apparatus **201** is also configured to enable cooling of a plurality of electronic devices **203** in a data centre or in any other suitable environment. The electronic device **203** could be a server, a router, a switch, or any other opto-electronic device. The apparatus **201** also comprises a thermosyphon loop **101** and a plurality of sensors similar to those described in relation to FIG. **2**. However in the example of FIG. **3** the plurality of evaporators **103** of the thermosyphon loop **101** are arranged in parallel rather than in series.

The apparatus **201** of FIG. **3** comprises seven evaporators **103** configured to cool seven electronic devices **203**. It is to be appreciated that other numbers of electronic devices **203** and evaporators **103** could be used in other examples of the disclosure. The downcomer **107** comprises a branched manifold to provide different inlets for each of the evaporators **103**.

Each of the outlets of the evaporators **103** is provided to the riser **109**. As the working fluid **113** circulates through the thermosyphon loop **101** the working fluid **113** only passes through one of the evaporators **103**.

The example apparatus **201** of FIG. **3** also comprises an accumulator **205** in the downcomer **107**. The accumulator **205** can comprise any means that can be configured to store working fluid **113** in the liquid phase **117**. The accumulator **205** is positioned between the outlet of the condenser **105** and the inlet for the first evaporator **103**.

The condenser **105** in the example of FIG. **3** also comprises a compact heat exchanger. Other types of condenser **105** could be used in other examples of the disclosure. A secondary cooling system **207** is coupled to the condenser **105** to enable heat to be transferred out of the thermosyphon loop **101**. As in the example shown in FIG. **2** water is the coolant and it is provided at the inlet **209** as indicated by the arrow **211**. The condenser **105** is configured so that heat is then transferred from the working fluid **113** of the thermosyphon loop **101** to the water of the secondary cooling system **207**. The heated water is then expelled from the outlet **213** as indicated by the arrow **215**.

The apparatus **201** in the example of FIG. **3** also comprises a plurality of sensors. The sensors are positioned within the thermosyphon loop **101** and are configured to enable measurement of one or more parameters of the thermosyphon loop **101** to be monitored. The parameters that are monitored can relate to the efficiency of the thermosyphon loop **101** and the amount of heat being transferred by the thermosyphon loop **101**.

The apparatus **201** of FIG. **3** comprises one or more sensors that enable a plurality of vapour quality measurements **217**. The vapour quality measurements **217** are provided in the riser **109**. A vapour quality measurement **217** is provided after each outlet of an evaporator **103**. This can enable the vapour quality to be measured for each outlet of each evaporator **103**. The vapour quality can be calculated considering the sensible and latent heat contributions to the energy balance.

The apparatus **201** of FIG. **3** comprises a plurality of mass flow rate sensors **219**. The mass flow rate sensors **219** are provided within the inlets of each of the evaporators **103**. The mass flow rate sensors **219** are configured to measure the flow rate of the working fluid **113** upstream of each of the evaporators **103**.

The apparatus **201** also comprises pressure sensors **221** configured to measure pressure of the working fluid **113** within the thermosyphon loop **101**. The apparatus **201** shown in FIG. **3** comprises three pressure sensors **221** within the thermosyphon loop **101**. In the example shown in FIG. **3** a first pressure sensor **221** is provided in the downcomer **107** between the condenser **105** and the accumulator **205**, a second pressure sensor **221** is provided in a lower point of the downcomer **107** and a third pressure sensor **221** is provided in the riser **109** downstream of the evaporators **103**. It is to be appreciated that other arrangements of the pressure sensors **221** could be used in other examples of the disclosure.

In the apparatus **201** of FIG. **3** pressure sensors **221** are also provided within the secondary cooling system **207**. In particular a first pressure sensor **221** is provided at the inlet **209** to the condenser **105** and a second pressure sensor **221** is provided at the outlet **213**. Other numbers and arrangements of pressure sensors **221** could be used in other examples of the disclosure.

As with the example shown in FIG. **2** the pressure sensors **221** give a measurement of the pressure within the thermosyphon loop **101** which can be used to determine the latent heat of vaporization of the working fluid and saturation temperature within the thermosyphon loop **101**.

The apparatus **201** also comprises a plurality of temperature sensors **223** that are positioned at a plurality of different positions within the downcomer **107** and the riser **109**. In the example of FIG. **3** the apparatus **201** comprises eleven

temperature sensors **223** at different locations within the downcomer **107** and the accumulator **205**. Other numbers and arrangements of the temperature sensors **223** can be used in other examples of the disclosure. For example, two temperature sensors **223** can be located at the inlet and outlet of the secondary cooling system **207** in order to quantify the total heat dissipated by the opto-electronic devices **203**. The temperature sensors **223** enable the temperature of the working fluid **113** to be measured. The temperature measurements can be used to measure inlet vapour quality and also the liquid level in the downcomer **107**. The outputs of these sensors can be used to help to control the apparatus **201** either automatically or with some manual intervention.

FIG. **4** shows another example apparatus **201** according to examples of the disclosure. The evaporators **103** and electronic devices **203** are not shown in FIG. **4** for clarity. It is to be appreciated that in the example of FIG. **4** a plurality of evaporators **103** could be provided in series as shown in FIG. **2**, or in parallel as shown in FIG. **3**, or a combination of both. The secondary cooling system **207** and plurality of sensors are also not shown in FIG. **4**.

In the example apparatus **201** of FIG. **4** the downcomer **107** of the thermosyphon loop **101** is configured to provide for improved thermal performance and stability of flow of the working fluid **113**. The downcomer **107** comprises a plurality of branches **401**A, **401**B. Each of the branches **401**A, **401**B provides a conduit or pipe between the condenser **105** and the series of evaporators **103**. Each of the branches **401**A, **401**B is configured to provide a flow path for the working fluid **113**. The branches **401**A, **401**B are configured to provide a flow path for the working fluid **113** in the liquid phase **117**.

In the example shown in FIG. **4** two branches **401**A, **401**B are provided. It is to be appreciated that other numbers of branches **401**A, **401**B, with different diameters, could be provided in other examples of the disclosure.

A first valve **403**A is provided in the first branch **401**A. The first valve **403**A can be used to control fluid flow through the first branch **401**A. A second valve **403**B is provided in the second branch **401**B to control fluid flow through the second branch **401**B. In some examples the valves **403**A, **403**B can be controlled so that the working fluid **113** flows through either the first branch **401**A or the second branch **401**B. In the example shown in FIG. **4** the first branch **401**A has a larger diameter than the second branch **401**B. Controlling which of the branches **401**A, **401**B is used to provide working fluid **113** to the evaporators **103** enables adjustments of the liquid level in the downcomer **107**, which allows to control flow of the working fluid **113** through the thermosyphon loop **101**.

In some examples the thermosyphon loop **101** could be configured so that the working fluid **113** could flow through both of the branches **401**A, **401**B. This could enable three different configurations of the thermosyphon loop **101** to be used. In the first configuration just the first branch **401**A is used, in the second configuration just the second branch **401**B is used and in the third configuration both the first branch **401**A and the second branch **401**B are used. This enables three different configurations to control flow of the working fluid **113** through the thermosyphon loop **101**.

The apparatus **201** also comprises a third valve **403**C in the downcomer **107**. The third valve **403**C is positioned between the accumulator **205** and the branching point where the downcomer **107** splits into two, or more, branches **401**. The third valve **403**C can be used to control the amount of working fluid **113** that flows into the branched section of the downcomer **107**.

In the example shown in FIG. **4** the apparatus **201** also comprises a reservoir **405**. The reservoir **405** can comprise any means that can be configured to store working fluid **113**. The reservoir **405** can be configured to store the working fluid **113** in a liquid phase **117**.

The reservoir **405** is coupled to the accumulator **205** in the downcomer **107** so that the working fluid **113** can flow from the reservoir **405** to the accumulator **205**. A fourth valve **403**D is provided between the reservoir **405** and the accumulator **205** to enable flow from the reservoir **405** to the accumulator **205** to be controlled. The fourth valve **403**D can be closed when no additional working fluid **113** is needed within the thermosyphon loop **101** and can be opened when additional working fluid **113** is needed within the thermosyphon loop **101**.

It is to be appreciated that different variations of the apparatus **201** could have different configurations of the different branches **401**. For instance, in some examples more than two branches **401** could be provided. Also the branches **401** can have different diameters. In such examples the flow of working fluid **113** could be controlled by allowing the working fluid **113** to flow through one branch **401** or to flow through two different branches **401**.

In some examples the valves **403** can be operated in response to measurements made by the sensors as shown in FIG. **2**. For example, if the vapour quality measurements **217** indicate that the vapour quality is above a threshold then it can be determined that a high heat load is being transferred into the working fluid **113**. In such cases a high static head in the downcomer **107** is expected, which may flood the condenser **105**. In order to prevent this phenomenon, the first valve **403**A and the third valve **403**C are opened to enable the working fluid **113** to flow through the first branch **401**A.

If the vapour quality is below a threshold this indicates that there is a low heat load within the thermosyphon loop **101**. In such cases the static head for the liquid level in the downcomer **107** may be too low inducing intermittent flow in the evaporators **103**, and thus the second valve **403**B and the third valve **403**C are opened to enable the working fluid **113** to flow through the second branch **401**B. In this example the second branch **401**B with the smaller diameter provides for sufficient static head in low heat load cases. In other examples other configurations of the valves, branches, diameters of the branches or any other factors could be used.

In some examples the valves **403**A, **403**B, **403**C, **403**D could be operated automatically without any input from a user. For instance, the sensors within the thermosyphon loop **101** could detect whether or not the liquid level and/or the vapour quality is within a threshold range and provide a control signal to the valves **403**A, **403**B, **403**C, **403**D that causes the valves **403**A, **403**B, **403**C, **403**D to be opened or closed as needed. In some examples this could occur without any manual intervention and so could provide a passive system. In other examples one or more of the valves **403**A, **403**B, **403**C, **403**D could be operated manually.

The valves **403**A, **403**B, **403**C, **403**D could be any suitable types of valves **403**A, **403**B, **403**C, **403**D. In some examples the valves **403**A, **403**B, **403**C, **403**D could comprise spring constant valves **403**A, **403**B, **403**C, **403**D that can be opened and/or closed using an applied electric signal. Other types of valves **403**A, **403**B, **403**C, **403**D could be used in other examples of the disclosure.

In the example shown in FIG. **4** the inlet **407** to the evaporators **103** has a smaller diameter than the riser **109**. This is configured to provide a pressure force within the thermosyphon loop **101**. This provides for unidirectional

flow within the thermosyphon loop **101** and prevents bubble formation at the inlet **407** of the evaporators **103**.

FIG. **5** shows a cross section of part of a downcomer **107** that could be provided in some example apparatus **201**. The example downcomer **107** shown in FIG. **5** could be provided within thermosyphon loops **101** as shown in any of FIGS. **2** to **4**. Working fluid **113** from the condenser **105** flows into the downcomer **107** at the top, as indicated by the arrow **501**. The working fluid **113** flows down the downcomer **107** under the action of gravity and flows from the downcomer **107** into the one or more evaporators **103** as indicated by the arrow **503**.

In the example shown in FIG. **5** the downcomer **107** comprises an expandable portion **505**. The expandable portion **505** performs the function of a distributed accumulator **205** as it enables working fluid **113** in the liquid phase **117** to be stored within the downcomer **107**.

The downcomer **107** comprises a rigid outer portion **507**. The rigid outer portion **507** does not bend or contract during normal use of the thermosyphon loop **101**. The rigid outer portion **507** provides constraints on how much the expandable portion **505** can expand.

The expandable portion **505** is provided within the rigid outer portion **507**. The expandable portion **505** comprises an elastic wall **509** which is configured to expand or contract depending on the volume of working fluid **113** within the downcomer **107**. The elastic wall could be made of rubber or any other suitable material. In the example shown in FIG. **5** the expandable portion **505** is configured with a larger diameter at the bottom than at the top. Working fluid **113** in the liquid phase **117** is provided within the expandable portion **505** of the downcomer **107**.

In the example shown in FIG. **5** a spacing is provided between the elastic wall **509** and the rigid portion **507**. This provides a space into which the elastic wall **509** can expand. In the example shown in FIG. **5** working fluid **113** in the vapour phase **121** can be provided within the spacing provided between the elastic wall **509** and the rigid portion **507**. The vapour can be compressed when the elastic wall **509** expands into the spacing.

The expandable portion **505** of the downcomer **107** ensures that the static head is sufficiently high in cases where there is a low heat load within the thermosyphon loop **101**. It is important that the static head of the working fluid **113** is sufficiently high to avoid two phase instability within the working fluid **113** and to prevent intermittent flow within the evaporators **103**. When there is a low heat load the void fraction in the riser decreases **109** so that there is less vapour within the thermosyphon loop **101**. This causes a decrease in the liquid head of the downcomer **107**.

The expandable portion **505** of the downcomer **107** helps to maintain the position of the static head because the diameter of the expandable portion **505** can adjust to the pressure conditions within the thermosyphon loop **101**. The expandable portion **505** is configured so that as the pressure head within the thermosyphon loop **101** is reduced the diameter of the expandable portion **505** is also reduced. This enables a larger static head to be provided at lower heat loads.

The variation in the diameter of the expandable portion **505** is controlled by the mechanical properties and the stress-strain behaviour of the elastic walls **509**. These can be selected to ensure that the static head is sufficiently high for lower heat loads. In some examples different types of elastic walls **509** with different mechanical properties and stress strain behaviour can be used for different parts of the downcomer **107**. This can provide for greater control of the position of the static head within the downcomer **107**.

FIGS. **6**A and **6**B show an example accumulator **205** that could be provided in some example apparatus **201**. The accumulator **205** can be a liquid accumulator, a receiver or any other suitable means for storing working fluid **113** within the thermosyphon loop.

FIG. **6**A shows a cross section of the accumulator **205**. In this example the accumulator **205** has a varying diameter along the length of the accumulator **205**. The accumulator **205** has a smaller diameter D**1** at the bottom than at the top D**2** so that the accumulator is wider at the top than at the bottom. Although the accumulator **205** has been shown in cross section in FIG. **6**A it is to be appreciated that the accumulator/**205** forms a truncated cone.

FIG. **6**B is a plot that shows how the upper diameter of the accumulator **205** has to vary as a function of the height of the accumulator **205** in order to maintain a constant internal volume. In this example a volume of 3000 cm^3 has been selected. Other volumes could be used in other examples of the disclosure which would result in different values for the smaller diameter D**1** and for the larger diameter D**2**.

The plot shows that there is an inverse relationship between the upper diameter of the accumulator **205** and the height of the accumulator **205** to keep a constant volume as shown in FIG. **6**B. When the diameters and height of the accumulator **205** are being selected the performance considerations and spatial constraints must be taken into account.

The varying diameter of the accumulator **205** used in FIGS. **6**A and **6**B ensures that at low heat loads there is a sufficiently high liquid head so as to prevent intermittent flow through the evaporators **103**. This shape also ensures that at high heat loads the accumulator **205** has sufficient capacity to store the working fluid **113** and prevents flooding of the condenser **105**.

This type of accumulator **205** is beneficial as it can enable the liquid level in the accumulator **205** to be controlled without any active control.

FIG. **7** schematically shows a system **701** for cooling a plurality of racks **703**. Each of the racks **703** could comprise a plurality of electronic devices **203**. In this example the electronic devices **203** comprise servers. Other types of electronic devices could be used in other examples of the disclosure. The system **701** shown in FIG. **7** uses air-cooled condensers for the secondary cooling system **207** and could be used for smaller data centres of up to around five racks **703** of electronic devices **203**.

In the example two racks **703** comprising a plurality of electronic devices **203** are shown. It is to be appreciated that other numbers of racks **703** could be used in other examples of the disclosure.

The system comprises a plurality of thermosyphon loops **101**. The thermosyphon loops **101** can be as shown in FIGS. **2** and **3** and can comprise a plurality of evaporators **103** configured to cool a plurality of electronic devices **203** within each of the racks **703**. The plurality of thermosyphon loops **101** are isolated from each other such that no fluid path is provided between thermosyphon loops **101**. As shown in FIG. **7** plurality of thermosyphon loops **101** can be thermally coupled to a single electronic device so as to enable a first thermosyphon loop **101** to be used to cool the electronic device independently of a second thermosyphon loop **101**.

Each of the thermosyphon loops **101** comprises a downcomer **107** and a riser **109**. The thermosyphon loops **101** are independent of each of other so that working fluid **113** that flows in one of the thermosyphon loops **101** does not flow

into any other thermosyphon loops **101**. There is no fluid path provided between the thermosyphon loops **101**.

It is to be appreciated that the thermosyphon loops **101** can also comprise a plurality of sensors as shown in FIGS. **2** and **3**. In some examples the thermosyphon loops **101** can comprise branches and/or a variable accumulator **205** as shown in FIGS. **4** to **6**B.

In the example shown in FIG. **7** valves **705** are provided within the thermosyphon loops **101** at the inlet and the outlet of the evaporator **103**. These valves **705** can enable the fluid flow to the evaporator **103** to be closed which can enable the evaporator **103** to be removed from the thermosyphon loop **101**. The evaporator **103** could be removed for maintenance purposes or any other suitable reason.

In the example shown in FIG. **7** each of the racks **703** are thermally coupled to at least two independent thermosyphon loops **101**. The thermosyphon loops **101** are identical to each other so as to enable the total amount (equivalent) of heat to be transferred by any of the thermosyphon loops **101**. This can enable the server rack **703** to be cooled effectively by any of the available thermosyphon loops **101**. This arrangement enables one of the thermosyphon loops **101** to be closed for maintenance or could enable an auxiliary thermosyphon loop **101** to be used if a primary thermosyphon loop **101** fails. This can enable the electronic devices **103** to run continuously on the cooling system **701** without any break for maintenance and/or in case of failure of one of the thermosyphon loops **101**.

The valves **711** on the downcomer **107** and riser **109** can enable evaporators **203** and the thermosyphon loops **101** to be controlled. This can enable the thermosyphon loops **101** to be switched while the electronic device **203** is in operation which allows of continuous use of the electronic device **203** in the rack **703** even while the cooling system is being maintained.

In the example shown in FIG. **7** pressure sensors **709** and valves **711** are provided within the riser **109** and the downcomer **107** of each of the thermosyphon loops **101**. The pressure sensors **709** are configured to enable the pressure within the riser **109** and the downcomer **107** to be monitored during use.

The valves **711** can be configured to enable the thermosyphon loop **101** to be removed. In some examples the thermosyphon loop **101** could comprise a plurality of branches that are configured to be coupled to different electronic devices **203** within a rack. In such examples the valve **711** could enable one or more of the branches to be disconnected while other branches remain functioning. Therefore the valves **711** enable part of a branched thermosyphon loop **101** to be closed.

In the example of FIG. **7** each of the thermosyphon loops **101** also comprises a valve **713** provided in the downcomer **107** between the accumulator **205** and the pressure sensor **709** and valves **711**. This valve **713** is an on/off valve that is always open when the thermosyphon loop **101** is in use but can be closed to allow for maintenance of the thermosyphon loop **101**.

The example system **701** also comprises pressure sensors **715** and valves **717** within the riser **109** and the downcomer **107** of each of the thermosyphon loops **101** close to the condenser **105**. The pressure sensors **715** and valves **717** are provided close to the tops of the riser **109** and the downcomer **107**. In the downcomer **107** the pressure sensor **715** and valve **717** are provided between the condenser **105** and the accumulator **205**. The pressure sensors **715** are configured to enable the pressure close to the top of the riser **109** and the downcomer **107** to be monitored during use.

The valves **717** can be configured to enable the condenser **105** to be removed. This could enable maintenance of the condenser **105** or any other part of the thermosyphon loop **101**. Therefore, the valves **717** enable an entire thermosyphon loop **101** to be closed.

In the example shown in FIG. **7** the system **701** comprises an air-cooled condenser **105**. Other types of condenser **105** could be used in other examples of the disclosure. For example, if a larger number of racks **703** are to be cooled then the condenser **105** can be coupled to secondary cooling system **207**. The secondary cooling system **207** could be a water-cooled cooling system as shown in FIG. **8** or any other suitable type of heat removal system.

FIG. **8** schematically shows another system **801** for cooling a plurality of racks **703**. Each of the racks **703** could comprise a plurality of electronic devices **203** such as servers. The system **801** shown in FIG. **8** uses a plurality of water-cooling systems **803** for the secondary cooling system **207** and could be used for larger data centres comprising more than five racks **703** of electronic devices **203**.

The example system **801** shown in FIG. **8** comprises a plurality of thermosyphon loops **101**. These can be branched thermosyphon loops **101** that are thermally coupled to the racks **703** of electronic devices **203**. The thermosyphon loops **101** in the system **801** of FIG. **8** can be similar to the thermosyphon loops **101** in FIG. **7**. The thermosyphon loops **101** can comprise branches and valves that enable thermosyphon loops **101** or parts of thermosyphon loops **101** to be closed for maintenance or other purposes.

The system **801** of FIG. **8** differs from the system of FIG. **7** in that the condensers **105** used in the thermosyphon loops **101** in FIG. **8** comprise water cooled condensers **105**. This can enable higher heat loads to be removed from the thermosyphon loops **101** and so can enable the system **801** to be used to cool larger data centres.

In the example shown in FIG. **8** each of the thermosyphon loops **101** is coupled to at least two water cooling systems **803**. Each water-cooling system **803** provides an independent secondary cooling system for the thermosyphon loops **101**. The water-cooling systems **803** are independent of each other in that water from a first water-cooling system **803** does not flow into any other of the water-cooling systems **803**. FIG. **8** schematically shows that a path separation **805** is provided between the different water-cooling systems **803** so that there is no fluid flow between the different water-cooling systems **803**.

In the example shown in FIG. **8** of the water-cooling systems **803** each water-cooling systems **803** is capable of removing the same heat loads from the thermosyphon loops **101**. This means that the amount of heat that can be removed from the thermosyphon loops **101** is not dependent upon which of the water-cooling systems **803** is used for the secondary cooling.

One or more valves **807** can be provided within the water-cooling systems **803**. In the example of FIG. **8** the valves **807** can be provided at the inlets and outlets of the condenser **105** of the thermosyphon loop **101**. These valves **807** can be configured to control the flow of water to the condensers **105**. These valves **807** can enable the water-cooling system **803** that is coupled to the thermosyphon loop **101** to be swapped. This could be used if one of the water-cooling systems **803** needs to be maintained or is faulty.

Each of the water-cooling systems **803** also comprises one or more pumps **809**. The pumps **809** can comprise any means that can be configured to pump the water through the water-cooling systems **803**. Each of the water-cooling sys-

tems **803** has its own pumping system as the water flow in one water-cooling system **803** is independent of the water flow in another water-cooling system **803**.

The water-cooling systems **803** also comprise secondary condensers **811**. The secondary condensers **811** can comprise air-cooled dry coolers or any other suitable type of condensers.

The system of FIG. **8** therefore comprises a plurality of secondary water-cooling systems **803** configured so that each thermosyphon loop **101** can be thermally coupled to a plurality of secondary water-cooling systems **803** so as to enable a first secondary water-cooling system **803** to be used independently of a second secondary water-cooling system.

FIG. **9** shows an example condenser **105** that can be provided within thermosyphon loops **101** in examples of the disclosure. In the example condenser **105** of FIG. **9** the accumulator **205** is provided within the condenser **105**. The condenser **105** of FIG. **9** could be used within the thermosyphon loops **101** of any of the example apparatus **201** and systems **801** described above.

In this example the condenser **105** is a water-cooled condenser. Water flows in the inlet **901** and heated water flows out of the outlet **903** into a secondary cooling system **207**. The flow within the condenser **105** is not shown in FIG. **9** but could be in a counter-flow, parallel flow or cross flow configuration with respect to the working fluid **113** of the thermosyphon loop **101**.

The condenser **105** can be any suitable type of condenser **105**. For example, the condenser **105** could comprise a micro-scale heat exchanger, plate heat exchanger, tube-in-tube heat exchanger or shell-and-tube heat exchanger or any other suitable type of heat exchanger.

The amount of heat that can be dissipated can be controlled by changing the design and/or the size of the condenser **105**. For example, the number of plates in a plate heat exchanger can be selected based on the heat dissipation needed, overall dimensions to accommodate larger heat exchanger, etc.

The total internal volume of the condenser **105** can be between two to five times the internal volume of the accumulator **205**. The relative volumes of the condenser **105** and the accumulator **205** can be dependent upon the volumes of other components within the thermosyphon loop **101**.

FIG. **10** shows an example apparatus **201** according to examples of the disclosure. In this example the thermosyphon loop **101** is located within a server cabinet **1001**. The thermosyphon loop **101** can be as shown in FIG. **2** and comprises six evaporators **103** connected in series and configured to cool six electronic devices **203**. In this example the electronic devices **203** comprise servers. The thermosyphon loop **101** can also comprise a plurality of sensors that are not shown in FIG. **10**.

In this example the condenser **105** is a water-cooled condenser **105**. Water flows in the inlet **209** and heated water flows out of the outlet **213** into a secondary cooling system **207**. It is to be appreciated that the overhead condenser can be also air-cooled if the data centre does not have a room-level pump-driven loop for the secondary cooling system **207**.

In the example of FIG. **10** a plurality of quick couplings **1003** are provided within the thermosyphon loop **101**. In particular the quick couplings **1003** are provided either side of the accumulator **205** to enable the accumulator **205** to be removed for maintenance or other purposes.

Quick couplings **1003** are also provided in the downcomer **107** and the riser **109** on either side of the condenser **105** to enable the condenser **105** to be removed from the thermosyphon loop **101**. Quick couplings **1003** are also provided in the inlet **209** and the outlet **213** to the condenser **105** for the secondary cooling system **207**. This can enable the thermosyphon loop **101** to be disconnected from the secondary cooling system **207**. Also, the valves **705** can be quick couplings, not shown in FIG. **10**, in order to connect the electronic devices **203** to the thermosyphon loop **101** for maintenance or other purposes.

FIG. **11** shows an example apparatus **201** according to another example of the disclosure. In this example the thermosyphon loop **101** is located within a server cabinet **1001**. The thermosyphon loop **101** can be as shown in FIG. **3** and comprises seven evaporators **103** connected in parallel and configured to cool seven electronic devices **203**. In this example the electronic devices **203** comprise servers. The thermosyphon loop **101** can also comprise a plurality of sensors such as mass flow rate sensors **219**, temperature sensors **223**, pressure sensor **221**, including vapour quality measurements. These can be configured as described in relation to FIG. **3** or in any other suitable configuration.

In this example of FIG. **11** the condenser **105** is a water-cooled condenser **105**. Water flows in the inlet **209** and heated water flows out of the outlet **213** into a secondary cooling system **207**.

In the example of FIG. **11** a plurality of quick couplings **1003** are provided within the thermosyphon loop **101**. In particular the quick couplings **1003** are provided either side of each of the evaporators **103** to enable the evaporators **103** to be removed for maintenance or other purposes.

Examples of the disclosure therefore provide cooling systems that can be used to cool data centres or severs or other similar devices. The use of the plurality of sensors distributed throughout the thermosyphon loops **101** enables different parameters of the cooling systems to be monitored. This can allow for these apparatus **201** and systems to be passively controlled.

The systems can also be compartmentalized so that parts of the systems and apparatus **201** can be removed without affecting the functioning of other parts of the systems and apparatus. This makes the system and apparatus "hot swappable" so that the electronic devices **203** and data centres can continue to function while parts of the cooling system are maintained or closed down for any other purposes.

In the above description the term coupled means operationally coupled. In some examples the component can be coupled so as to enable a fluid such as working fluid to flow between components. In some examples coupled can mean thermally coupled so as to enable transfer of heat between the components.

The term 'comprise' is used in this document with an inclusive not an exclusive meaning. That is any reference to X comprising Y indicates that X may comprise only one Y or may comprise more than one Y. If it is intended to use 'comprise' with an exclusive meaning then it will be made clear in the context by referring to "comprising only one . . . " or by using "consisting".

In this description, reference has been made to various examples. The description of features or functions in relation to an example indicates that those features or functions are present in that example. The use of the term 'example' or 'for example' or 'can' or 'may' in the text denotes, whether explicitly stated or not, that such features or functions are present in at least the described example, whether described as an example or not, and that they can be, but are not necessarily, present in some of or all other examples. Thus 'example', 'for example', 'can' or 'may' refers to a particular instance in a class of examples. A property of the instance

can be a property of only that instance or a property of the class or a property of a sub-class of the class that includes some but not all of the instances in the class. It is therefore implicitly disclosed that a feature described with reference to one example but not with reference to another example, can where possible be used in that other example as part of a working combination but does not necessarily have to be used in that other example.

Although examples have been described in the preceding paragraphs with reference to various examples, it should be appreciated that modifications to the examples given can be made without departing from the scope of the claims.

Features described in the preceding description may be used in combinations other than the combinations explicitly described above.

Although functions have been described with reference to certain features, those functions may be performable by other features whether described or not.

Although features have been described with reference to certain examples, those features may also be present in other examples whether described or not.

The term 'a' or 'the' is used in this document with an inclusive not an exclusive meaning. That is any reference to X comprising a/the Y indicates that X may comprise only one Y or may comprise more than one Y unless the context clearly indicates the contrary. If it is intended to use 'a' or 'the' with an exclusive meaning then it will be made clear in the context. In some circumstances the use of 'at least one' or 'one or more' may be used to emphasis an inclusive meaning but the absence of these terms should not be taken to infer any exclusive meaning.

The presence of a feature (or combination of features) in a claim is a reference to that feature or (combination of features) itself and also to features that achieve substantially the same technical effect (equivalent features). The equivalent features include, for example, features that are variants and achieve substantially the same result in substantially the same way. The equivalent features include, for example, features that perform substantially the same function, in substantially the same way to achieve substantially the same result.

In this description, reference has been made to various examples using adjectives or adjectival phrases to describe characteristics of the examples. Such a description of a characteristic in relation to an example indicates that the characteristic is present in some examples exactly as described and is present in other examples substantially as described.

Whilst endeavoring in the foregoing specification to draw attention to those features believed to be of importance it should be understood that the Applicant may seek protection via the claims in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not emphasis has been placed thereon.

We claim:

1. An apparatus comprising:

one or more thermosyphon loops for cooling a plurality of electronic devices wherein each of the one or more thermosyphon loops comprises at least one evaporator and at least one condenser;

a plurality of sensors within the thermosyphon loop wherein the sensors are configured to enable measurement of, one or more of;

vapour quality within an inlet and outlet of at least one evaporator;

total heat load of at least one evaporator;

liquid level in a downcomer of the at least one thermosyphon loop; and

a plurality of branches within a downcomer and one or more valves configured to control flow through different branches of the plurality of branches.

2. The apparatus of claim **1**, wherein the apparatus comprises a thermosyphon loop comprising a plurality of evaporators.

3. The apparatus of claim **2**, wherein the apparatus comprises a plurality of thermosyphon loops and each thermosyphon loop comprises at least one evaporator.

4. The apparatus of claim **1**, wherein the sensors are configured to enable measurement of liquid level within an accumulator within the downcomer of the at least one thermosyphon loop.

5. The apparatus of claim **2**, wherein the plurality of evaporators are arranged in series within a thermosyphon loop and the sensors that are configured to enable measurements of the vapour quality are provided at the outlet of a last evaporator in the series of evaporators.

6. The apparatus of claim **2**, wherein the plurality of evaporators are arranged in parallel within a thermosyphon loop and the sensors are configured to enable measurements of the vapour quality at the outlet of a plurality of the evaporators.

7. The apparatus of claim **1**, comprising at least one mass flow rate sensor configured to measure mass flow rate within at least one of the thermosyphon loops, at least one pressure sensor configured to measure pressure of working fluid within at least one of the thermosyphon loops, a plurality of temperature sensors provided at different locations within the downcomer, or combinations thereof.

8. The apparatus of claim **1**, wherein the downcomer of at least one thermosyphon loop has a varying diameter along a length of the downcomer so that the downcomer has a wider top than bottom.

9. The apparatus of claim **1**, wherein the thermosyphon loop is thermally coupled to a secondary cooling system.

10. The apparatus of claim **1**, wherein the plurality of electronic devices cooled by the apparatus comprise a server, a router, a switches, an opto-electronic device, or combinations thereof.

11. The apparatus of claim **1**, wherein the plurality of electronic devices are provided in one or more racks within a data center, a computer room, a telecommunications equipment room, a network room, or combinations thereof.

12. The apparatus of claim **1**, wherein the apparatus is configured to be controlled by controller such that the controller can use outputs from the one plurality of sensors to increase efficiency of the apparatus.

13. An apparatus comprising:

one or more thermosyphon loops for cooling a plurality of electronic devices wherein each of the one or more thermosyphon loops comprises at least one evaporator and at least one condenser;

one or more sensors within the thermosyphon loop configured to take one or more measurements within the one or more thermosyphon loops, and

a plurality of branches within a downcomer and one or more valves configured to control flow through different branches of the plurality of branches.

14. An apparatus comprising:

one or more thermosyphon loops for cooling a plurality of electronic devices wherein each of the one or more thermosyphon loops comprises at least one evaporator and at least one condenser; and

one or more sensors within the thermosyphon loop configured to take one or more measurements within the one or more thermosyphon loops, and

wherein an expandable portion is provided within a downcomer of at least one thermosyphon loop.

15. The apparatus of claim **14**, comprising at least one mass flow rate sensor configured to measure mass flow rate within at least one of the thermosyphon loops, at least one pressure sensor configured to measure pressure of working fluid within at least one of the thermosyphon loops, a plurality of temperature sensors provided at different locations within the downcomer, or combinations thereof.

16. The apparatus of claim **14**, wherein the thermosyphon loop is thermally coupled to a secondary cooling system.

17. The apparatus of claim **14**, wherein the apparatus is configured to be controlled by controller such that the controller can use outputs from the one or more sensors to increase efficiency of the apparatus.

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