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(73) Patenthaver: **Engie, 1, Place Samuel de Champlain, 92400 Courbevoie, Frankrig**

(72) Opfinder: **GUEDACHA, Hicham, 11 rue Yves Cariou, 92430 Marnes la Coquette, Frankrig**

(74) Fuldmægtig i Danmark: **NORDIC PATENT SERVICE A/S, Bredgade 30, 1260 København K, Danmark**

(54) Benævnelse: **ANORDNING, SYSTEM OG FREMGANGSMÅDE TIL TRYKREGULERING AF EN LAGERTANK TIL FLYDENDE NATURGAS**

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## TECHNICAL FIELD OF THE INVENTION

The present invention envisages a device, system and method for pressure regulation for a liquefied natural gas storage tank. It applies, in particular, to the field of liquefied natural gas transport by a vehicle or to any cryogenic storage tank, mobile or stationary, pressurized or unpressurized.

## STATE OF THE ART

Today, liquefied natural gas (hereinafter "LNG") is transported by road using pressurized cryogenic storage tanks. During this transportation phase, the LNG vaporizes as a result of heat entering along the outer wall of the tank.

The vaporized LNG is referred to as "evaporation gas" or "boil-off gas" (abbreviated to "BOG"). This evaporation gas is also referred to as the "vapor cloud" in an LNG tank. The accumulation of evaporation gas over time leads to the pressure inside the tank increasing as the LNG is transported.

If a maximum pressure threshold value, for which the tank has been sized, is exceeded, the evaporation gas contained in the tank, consisting of nitrogen and methane, is rejected into the atmosphere in order to avoid impairing the mechanical integrity of the tank.

These emissions are environmentally harmful, and pose a safety risk because of the flammability of the methane.

## SUBJECT OF THE INVENTION

The present invention aims to remedy all or part of these drawbacks.

To this end, according to a first aspect, the present invention envisages a pressure regulation device for a liquefied natural gas storage tank, which comprises:

- a pipe for transferring boil-off gas of liquefied natural gas configured to be attached to an outlet for boil-off gas from the tank, this transfer pipe being provided with a first discharging device that is activated when the boil-off gas pressure in the tank is greater than a first predetermined threshold value, referred to as "$P_1$",
- a heat exchanger for cooling and/or liquefying the boil-off gas discharged from the tank,
- between the transfer pipe and the heat exchanger:
    - a temporary storage volume of boil-off gas, and
    - between the storage volume and the heat exchanger:

- a second discharge device configured to be activated when the boil-off gas pressure in the tank is greater than a second predetermined threshold value, greater than the first threshold value, or
- an expander configured to be activated when the boil-off gas pressure at the exchanger and/or tank is less than a third predetermined threshold value, referred to as "$P_3$", $P_3$ being less than $P_1$, and

- a return pipe for liquefied boil-off gas connected to the heat exchanger, the return pipe being configured to be attached to an inlet for liquefied boil-off gas from the tank.

Thanks to these provisions, the boil-off gas can be cooled and/or liquefied by a heat exchanger instead of being dispersed in the atmosphere when the pressure of the tank is too high. This allows the tank to be kept close to a predefined pressure setpoint value.

In some embodiments, the device that is the subject of the present invention comprises, between the transfer pipe and the heat exchanger:

- a temporary storage volume of boil-off gas, and
- between the storage volume and the heat exchanger:
  - a second discharge device configured to be activated when the boil-off gas pressure in the tank is greater than a second predetermined threshold value, referred to as "$P_2$", greater than the first threshold value $P_1$, or
  - an expander configured to be activated when the boil-off gas pressure at the exchanger and/or tank is less than a third predetermined threshold value, referred to as "$P_3$", $P_3$ being less than $P_1$.

These embodiments allow the boil-off gas to be liquefied only when this boil-off gas at a given temperature has a sufficiently high pressure without in any way constraining the pressure in the tank from reaching a level likely to damage this tank.

In some embodiments, the boil-off gas acts as hot body in the heat exchanger, the cold body being formed of liquid nitrogen, the liquid nitrogen flow rate being dependent on the flow rate of boil-off gas entering the exchanger and/or a temperature of the boil-off gas on output from the exchanger.

These embodiments allow the evaporated nitrogen to be released into the atmosphere without greenhouse gas being created.

In some embodiments, the device that is the subject of the present invention comprises:

- a tank for storing liquid nitrogen, and

- a valve configured to supply the heat exchanger with liquid nitrogen as a function of a captured boil-off gas flow rate value and/or a captured boil-off gas temperature value, captured on output from the exchanger by a sensor on the outlet from the tank.

These embodiments make it possible to limit the supply to the heat exchanger solely to times when the boil-off gas is to be cooled and/or liquefied, and with a sufficient liquid nitrogen flow rate to cool and/or liquefy the boil-off gas.

In some embodiments, the device that is the subject of the present invention comprises an evaporation means configured to evaporate a portion of the liquid nitrogen in the tank so as to increase the pressure inside the tank in order to cause the liquid nitrogen to flow towards the heat exchanger.

These embodiments make it possible to cause the pressure to be increased inside the tank of liquid nitrogen without introducing an additional fluid in this tank.

In some embodiments, the device that is the subject of the present invention comprises an outlet for the evaporated liquid nitrogen into the atmosphere.

In some embodiments, the device that is the subject of the present invention comprises, downstream of at least one discharge device, a non-return valve.

These embodiments make it possible to avoid a reverse flow of the boil-off gas if the pressure in the tank drops.

In some embodiments, the device that is the subject of the present invention comprises, downstream of the first discharge device, a micro-compressor of the boil-off gas.

The micro-compressor makes it possible to ensure the flow of the gas towards the storage volume up to the maximum storage pressure of this volume, i.e. the set pressure of the second discharge device, $P_2$. The function of the storage volume is to temporarily store a volume of gas, making it possible to delay the use of the cold fluid and to limit the cooling, intermittently or by gas "buffer".

In some embodiments, the device that is the subject of the present invention comprises an auxiliary heat exchanger, downstream of the heat exchanger, on the path traversed by the cold fluid, configured to vaporize the cold fluid heated in the heat exchanger.

These embodiments make it possible to ensure the evaporation and the heating of the cold fluid vapor in order that this vapor, when released into the atmosphere, has no risk of contact with human operators near the device.

According to a second aspect, the present invention envisages a system for regulating the pressure inside a liquefied natural gas storage tank, which comprises:

- a liquefied natural gas storage tank, comprising:

- an outlet for boil-off gas from the liquefied natural gas, and
- an inlet for liquefied boil-off gas, and
- a regulation device that is a subject of the present invention, wherein:
    - the transfer pipe is attached to the outlet from the tank, and
    - the return pipe is attached to the inlet to the tank.

As the particular aims, advantages and features of the system that is the subject of the present invention are similar to those of the device that is the subject of the present invention, they are not repeated here.

According to a third aspect, the present invention envisages a method for regulating the pressure inside a liquefied natural gas storage tank, which comprises:

- a step of comparing the pressure inside the tank to a first predetermined threshold value,
- when the pressure inside the tank is greater than the first predetermined threshold value, referred to as "$P_1$":
    - a step of transferring boil-off gas from liquefied natural gas output from the tank,
    - a heat exchange step for cooling and/or liquefying the boil-off gas discharged from the tank,
    - between the transfer step and the heat exchange step:
        - a step of temporarily storing the boil-off gas, and
        - between the temporary storage step and the heat exchange step:
            - a second transfer step configured to be activated when the boil-off gas pressure in the tank is greater than a second predetermined threshold value, greater than the first threshold value or
            - an expansion step configured to be activated when the boil-off gas pressure at the exchanger and/or tank is less than a third predetermined threshold value, referred to as "$P_3$", $P_3$ being less than $P_1$, and
    - a step of returning liquefied boil-off gas to the tank.

As the particular aims, advantages and features of the method that is the subject of the present invention are similar to those of the device that is the subject of the present invention, they are not repeated here.

BRIEF DESCRIPTION OF THE FIGURES

Other advantages, aims and particular features of the invention will become apparent from the non-limiting description that follows of at least one particular embodiment of the device, system and method that are the subjects of the present invention, with reference to drawings included in an appendix, wherein:

- figure 1 represents, schematically, a particular embodiment of the device and system that are the subjects of the present invention;
- figure 2 represents, schematically and in the form of a logical diagram, a particular series of steps of the method that is the subject of the present invention; and
- figure 3 represents, schematically, a second particular embodiment of the device and system that are the subjects of the present invention.

DESCRIPTION OF EXAMPLES OF REALIZATION OF THE INVENTION

The present description is given in a non-limiting way, each characteristic of an embodiment being able to be combined with any other characteristic of any other embodiment in an advantageous way.

It is now noted that the figures are not to scale.

The term "discharge device" refers to a valve whose purpose is to reduce the pressure of a network to the target working pressure of the system. Such a discharge device is mounted in series between the pressure source and the operating position. An upstream discharge device or pressure reducing valve is intended to limit pressure in a pipe in the event of pressure variations. It has the same function as a relief valve.

Such a discharge device can be replaced by an assembly formed of a valve, a pressure sensor upstream of the valve, and a pressure sensor downstream of the valve, the valve being activated when the captured pressure is greater than the pressure limit value corresponding to the operating pressure of the equivalent discharge device and when the pressure captured downstream is less than the pressure captured upstream of the valve.

The term "cold fluid" refers to a fluid whose temperature is lower to the temperature of the liquefied natural gas at a given pressure and is able to cool or liquefy the boil-off gas of the liquefied natural gas partially or fully.

Figure 1, which is not to scale, shows a schematic view of an embodiment of the device 100 that is the subject of the present invention. This pressure regulation device 100 for a liquefied natural gas storage tank 200 comprises:

- a pipe 105 for transferring boil-off gas of liquefied natural gas configured to be attached to an outlet 205 for boil-off gas from the tank, this transfer pipe being provided with a first discharging device 110 that is activated when the boil-off gas pressure in the tank is greater than a first predetermined threshold value, referred to as "$P_1$",
- a heat exchanger 115 for cooling and/or liquefying the boil-off gas discharged from the tank, and
- a return pipe 120 for liquefied boil-off gas connected to the heat exchanger, the return pipe being configured to be attached to an inlet 210 for liquefied boil-off gas from the tank.

The transfer pipe 105 is attached, for example, by screwing attachment plates positioned in contact with each other and equipped with at least one thread for the passage of screws. In some variants, a sealing gasket is positioned between the two plates, this gasket having an annular structure. This attachment can be undone. This attachment is removable, which allows the device 100 to be removed from the tank 200.

This transfer pipe 105, and the attachment to the outlet 205, gives the device 100 modularity that is compatible with any type of tank 200.

The first discharge device 110 is configured to let the boil-off gas pass when the pressure in the tank 200 is greater than the first predetermined threshold value, $P_1$. This first predetermined threshold value is chosen so as to never exceed the maximum operating pressure for which the tank 200 has been sized, and varies according to the tank 200 to which the device 100 is attached.

This first predetermined threshold value can be set when the device 100 is manufactured or when the device 100 is attached to the tank 200, by an operator by means of a control interface of the first discharge device 110. This control interface can be mechanical or digital and, as a function of an interaction between the interface and the operator, varies the value of the first threshold value.

The tank 200 preferably comprises a standard vent 201 for any gas capacity in order to prevent overpressure likely to damage the tank 200. The first predetermined threshold value is less than the activation value of the vent 201.

The exchanger 115 is, for example, a plate exchanger in which the plate acts a medium for exchanging heat between the hot boil-off gas and a cold fluid, such as liquid nitrogen or a liquefied inert gas.

In some variants, the exchanger 115 is a tubular exchanger, plate exchanger or coil exchanger.

The exchanger 115 is sized, and the cold fluid chosen, such that at a given flow rate of boil-off gas in the exchanger 115, the boil-off gas will be liquefied on output.

The return pipe 120 is attached, for example, by screwing attachment plates positioned in contact with each other and equipped with at least one thread for the passage of screws. In some variants, a sealing gasket is positioned between the two plates, this gasket having an annular structure. This attachment can be undone. This attachment is removable, which allows the device 100 to be removed from the tank 200.

This return pipe 120, and the attachment to the inlet 210, gives the device 100 modularity that is compatible with any type of tank 200.

In some preferred embodiments, such as that shown in figures 1 and 3, the device, 100 or 600, comprises, between the transfer pipe 105 and the heat exchanger 115:

- a temporary storage volume 125 of boil-off gas, and
- between the storage volume and the heat exchanger:
  - a second discharge device 130 configured to be activated when the boil-off gas pressure in the tank is greater than a second predetermined threshold value, referred to as "$P_2$", greater than the first threshold value $P_1$, or
  - an expander 630 configured to be activated when the boil-off gas pressure at the exchanger and/or tank is less than a third predetermined threshold value, referred to as "$P_3$", $P_3$ being less than $P_1$.

The storage volume 135 of cold fluid is sized so as to have sufficient cold fluid for cooling/liquefying the boil-off gas coming from the volume 125 and ensure that there are no emissions throughout the total duration of a journey of the tank 200 as a minimum.

The second discharge device 130 is configured to let the boil-off gas contained in the storage volume 125 pass when the pressure in this volume 125 is greater than the second predetermined threshold value, $P_2$. This second predetermined threshold value is chosen such that it is greater than the sum of the first predetermined threshold value $P_1$, the pressure drop caused by the circulation of gas in the pipes, 105 and 120, and the pressure drop in the heat exchanger 115. Therefore, this second predetermined threshold value varies according to the tank 200 to which the device 100 is attached. A margin, corresponding to the estimated pressure drop of the circuit, must be added to this sum to ensure a sufficient injection flow rate inside the tank 200.

The volume 125 preferably comprises a standard vent 126 for any gas capacity in order to prevent overpressure likely to damage the volume 125. The second predetermined threshold value is less than the activation value of the vent 126.

This second predetermined threshold value can be set when the device 100 is manufactured or when the device 100 is attached to the tank 200, by an operator by means of a control interface of the second discharge device 130. This control interface can be mechanical or digital and, as a function of an interaction between the interface and the operator, varies the value of the second threshold value.

When the device 600 comprises an expander 630, this expander is actuated as a function of a boil-off gas pressure measured downstream of the expander 630, this pressure being representative of the pressure of the boil-off gas in the expander 115 or of the pressure of the gas in the tank 200.

In some preferred embodiments, such as that shown in figure 1, the boil-off gas acts as hot body in the heat exchanger, the cold body being formed of liquid nitrogen, the liquid nitrogen flow rate being dependent on the flow rate of boil-off gas entering the exchanger 115 and/or a temperature of the boil-off gas on output from the exchanger 115.

In some preferred embodiments, such as that shown in figure 1, the device 100 comprises:

- a tank for storing liquid nitrogen 135, and
- a valve 140 configured to supply the heat exchanger 115 with liquid nitrogen as a function of a captured boil-off gas flow rate value and/or a captured boil-off gas temperature value, captured on output from the exchanger 115 by a sensor 141 on the outlet from the tank.

This closed-loop control can be achieved by the addition to the device 100 of a sensor capturing:

- the boil-off gas flow rate on output from the tank 125 and/or
- the boil-off gas flow rate entering the pipe 105 and/or
- the pressure of the boil-off gas in the tank 125 and/or
- the temperature of the boil-off gas entering the pipe 105 and/or
- the temperature of the boil-off gas leaving the heat exchanger 115.

In some preferred embodiments, such as that shown in figure 1, the device 100 comprises an evaporation means 145 configured to evaporate a portion of the liquid nitrogen in the tank 135 so as to increase the pressure inside the tank in order to cause the liquid nitrogen to flow towards the heat exchanger.

The evaporation means 145 consists, for example, of a pipe for extracting liquid nitrogen contained in the tank 135, a exchanger of heat with a fluid that is hot relative to the liquid nitrogen, such as air, water or an electrical resistance for example, to vaporize the liquid nitrogen, and a pipe for injecting vaporized liquid nitrogen into the tank 135.

In some preferred embodiments, such as that shown in figure 1, the device 100 comprises an outlet 150 for the evaporated liquid nitrogen into the atmosphere.

In some preferred embodiments, such as that shown in figure 1, the device 100 comprises, downstream of at least one discharge device, 110 and/or 130, a non-return valve, 155 and/or 160.

In some preferred embodiments, such as that shown in figure 1, the device 100 comprises, downstream from the first discharge device 110, a micro-compressor 165 of the boil-off gas.

This micro-compressor 165 can be equipped with a recycling pipe to ensure, on input to the micro-compressor, a minimum flow rate allowing said micro-compressor to be utilized.

This micro-compressor is configured to bring the boil-off gas to a pressure between the activation pressure of the first discharge device 110 and the activation pressure of the second discharge device 130 or 630.

In some preferred embodiments, such as that shown in figure 3, the device that is the subject of the present invention comprises an auxiliary heat exchanger 116, downstream of the heat exchanger 115, on the path traversed by the cold fluid, configured to vaporize the cold fluid heated in the heat exchanger 115.

The purpose of the auxiliary heat exchanger 116 is to vaporize and heat the cold fluid residues on output from the exchanger 115.

Figure 1 also shows a particular embodiment of the system 300 that is the subject of the present invention. This system 300 for regulating the pressure inside a storage tank 200 for liquefied natural gas comprises:

- a liquefied natural gas storage tank 200, comprising:
    - an outlet 205 for boil-off gas from the liquefied natural gas, and
    - an inlet 210 for liquefied boil-off gas, and
- a regulation device 100 as described with regard to figure 1, wherein:
    - the transfer pipe 105 is attached to the outlet from the tank, and

- the return pipe 120 is attached to the inlet to the tank.

Figure 2 shows, in the form of a logical diagram, a particular series of steps of the method 400 that is the subject of the present invention. This pressure regulation method 400 for a liquefied natural gas storage tank comprises:

- a step 405 of comparing the pressure inside the tank to a first predetermined threshold value,
- when the pressure inside the tank is greater than the first predetermined threshold value, referred to as "$P_1$":
  - a step 410 of transferring boil-off gas from liquefied natural gas output from the tank,
  - a heat exchange step 415 for cooling and/or liquefying the boil-off gas discharged from the tank,
  - between the transfer step and the heat exchange step:
    - a step 411 of temporarily storing the boil-off gas, and
    - between the temporary storage step and the heat exchange step:
      - a second transfer step 412 configured to be activated when the boil-off gas pressure in the tank is greater than a second predetermined threshold value, greater than the first threshold value or
      - an expansion step 413 configured to be activated when the boil-off gas pressure at the exchanger and/or tank is less than a third predetermined threshold value, referred to as "$P_3$", $P_3$ being less than $P_1$, and
  - a step 420 of returning liquefied boil-off gas to the tank.

This method 400 is performed, for example, by utilizing the device 100 as described with regard to figure 1 or the device 600 as described with regard to figure 1.

**Patentkrav**

**1.** Anordning (100) til trykregulering af en lagertank (200) til flydende naturgas, **kendetegnet ved, at** den omfatter:

- en overføringsledning (105) til fordampningsgas fra flydende naturgas, der er konfigureret til at blive fastgjort til en udgang (205) til fordampningsgas fra tanken, hvilken overføringsledning er forsynet med en første udledningsanordning (110), der aktiveres, når fordampningsgassens tryk i tanken er højere end en første forudbestemt grænseværdi, betegnet "$P_1$",
- en varmeveksler (115) til afkøling og/eller flydendegørelse af fordampningsgassen fra tanken,
- en returledning (120) til flydende fordampningsgas forbundet med varmeveksleren, hvilken returledning er konfigureret til at blive fastgjort til en indgang (210) til flydende fordampningsgas fra tanken,

kendetegnet ved, at anordningen mellem overføringsledningen (105) og varmeveksleren (115) omfatter:

- et volumen (125) til midlertidig oplagring af fordampningsgassen og
- mellem oplagringsvolumenet og varmeveksleren:
- en anden udledningsanordning (130), der er konfigureret til at blive aktiveret, når fordampningsgassens tryk i tanken er højere end en anden forudbestemt grænseværdi, der er højere end den første grænseværdi, eller
- en trykregulator (630), der er konfigureret til at blive aktiveret, når fordampningsgassens tryk ved veksleren og/eller tanken er lavere end en tredje forudbestemt grænseværdi, betegnet "$P_3$", hvor $P_3$ er lavere end $P_1$

**2.** Anordning (100) ifølge krav 1, hvori fordampningsgassen virker som varmelegeme i varmeveksleren, hvilket varmelegeme er dannet af flydende nitrogen, hvor strømningsraten for flydende nitrogen afhænger af strømningsraten for fordampningsgas, der trænger ind i veksleren (115), eller af en udgangstemperatur for fordampningsgassen ved vekslerens udgang.

**3.** Anordning (100) ifølge krav 2, der omfatter:

- en beholder (135) til oplagring af flydende nitrogen og
- en ventil (140), der er konfigureret til at forsyne varmeveksleren med flydende nitrogen som en funktion af en registreret strømningsrateværdi for fordampningsgas

og/eller en temperaturværdi for fordampningsgassen ved vekslerens udgang, der er registreret af en føler (141) ved tankens udgang.

**4.** Anordning (100) ifølge et af kravene 2 eller 3, der omfatter et fordampningsmiddel (145), der er konfigureret til at fordampe en del af det flydende nitrogen i beholderen (135) for således at øge trykket inde i beholderen for at bevirke strømning af det flydende nitrogen mod varmeveksleren.

**5.** Anordning (100) ifølge et af kravene 2 til 4, der omfatter en udgang (150) til fordampet flydende nitrogen i atmosfæren.

**6.** Anordning (100) ifølge et af kravene 1 til 5, der, på nedstrømssiden af mindst én udledningsanordning (110, 130), omfatter en kontraventil (155, 160).

**7.** Anordning (100) ifølge et af kravene 1 til 6, der, på nedstrømssiden af den første udledningsanordning (110), omfatter en mikrokompressor (165) til fordampningsgassen.

**8.** Anordning (100) ifølge et af kravene 1 til 7, der, på nedstrømssiden af varmeveksleren (115) på den bane, som det kolde fluid tilbagelægger, omfatter en hjælpevarmeveksler (116), der er konfigureret til at fordampe det kolde fluid, der er opvarmet i varmeveksleren (115).

**9.** System (300, 500) til regulering af trykket inde i en lagertank (200) til flydende naturgas, **kendetegnet ved, at** det omfatter:

- en lagertank til flydende naturgas omfattende:
- en udgang (205) til fordampningsgas fra den flydende naturgas og
- en indgang (210) til flydende fordampningsgas og
- en reguleringsanordning (100) ifølge et af kravene 1 til 8, hvori:
- overføringsledningen (105) er fastgjort til udgangen fra tanken og
- returledningen (120) er fastgjort til indgangen til tanken.

**10.** Fremgangsmåde (400) til regulering af trykket for en opbevaringstank til flydende naturgas, **kendetegnet ved, at** den omfatter:

- et trin (405) med sammenligning af trykket inde i tanken og en forudbestemt grænseværdi, betegnet ”$P_1$”,

- når trykket inde i tanken er højere end den første forudbestemte grænseværdi:

- et trin (410) med overføring af fordampningsgas fra flydende naturgas fra tanken,

- et varmevekslingstrin (415) til afkøling og/eller flydendegørelse af fordampningsgassen, der er overført fra tanken,

- et trin (420) med returnering af flydende fordampningsgas i tanken,

**kendetegnet ved, at** fremgangsmåden mellem overføringstrinnet og varmevekslingstrinnet omfatter:

- et trin (411) med midlertidig oplagring af fordampningsgassen og

- mellem det midlertidige oplagringstrin og varmevekslingstrinnet:

- et andet overføringstrin (412), der er konfigureret til at blive aktiveret, når fordampningsgassens tryk i tanken er højere end en anden forudbestemt grænseværdi, der er højere end den første grænseværdi, eller

- et trykreguleringstrin (413), der er konfigureret til at blive aktiveret, når fordampningsgassens tryk ved veksleren og/eller tanken er lavere end en tredje forudbestemt grænseværdi, betegnet ”$P_3$”, hvor $P_3$ er lavere end $P_1$

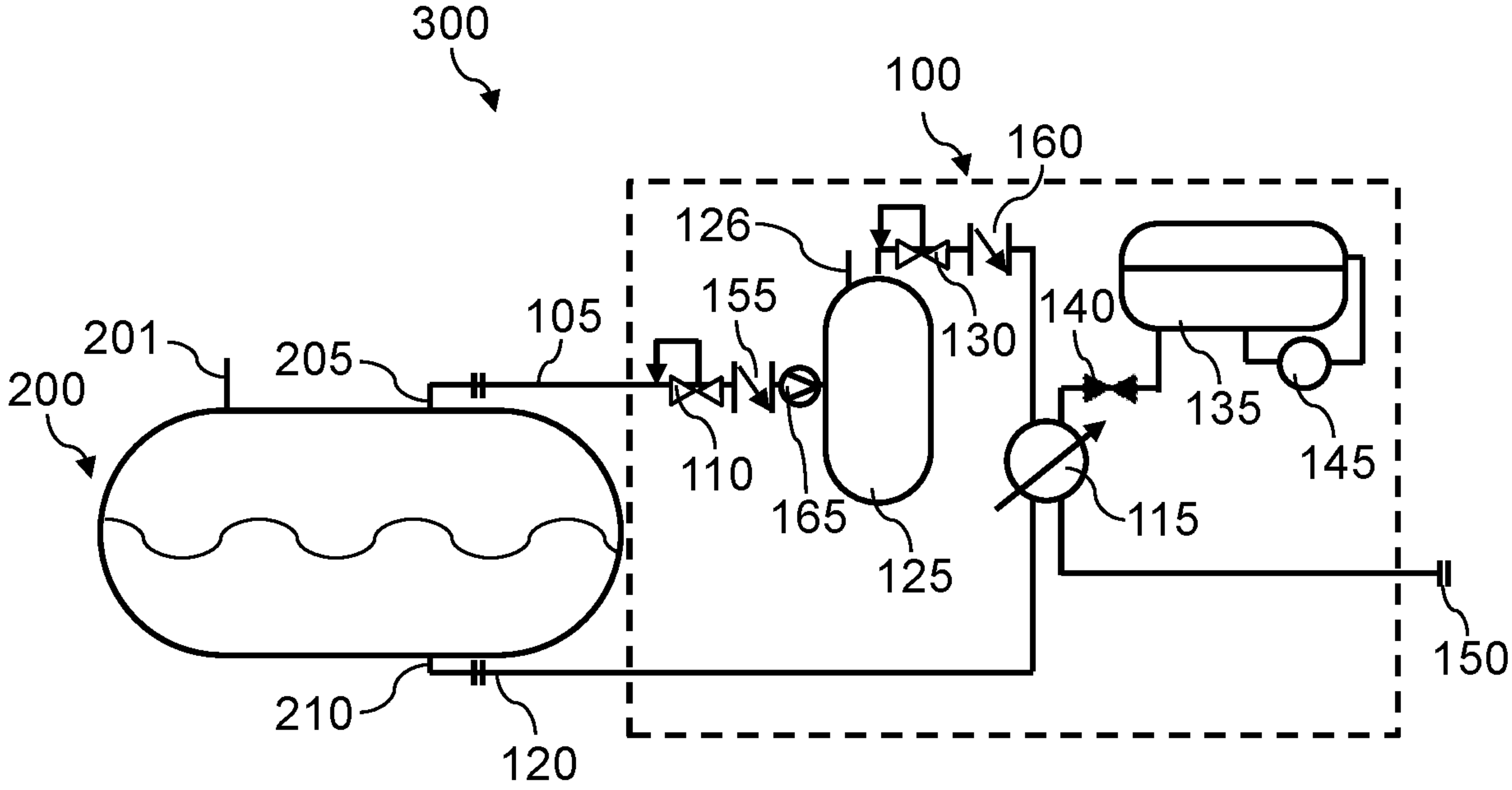


Figure 1

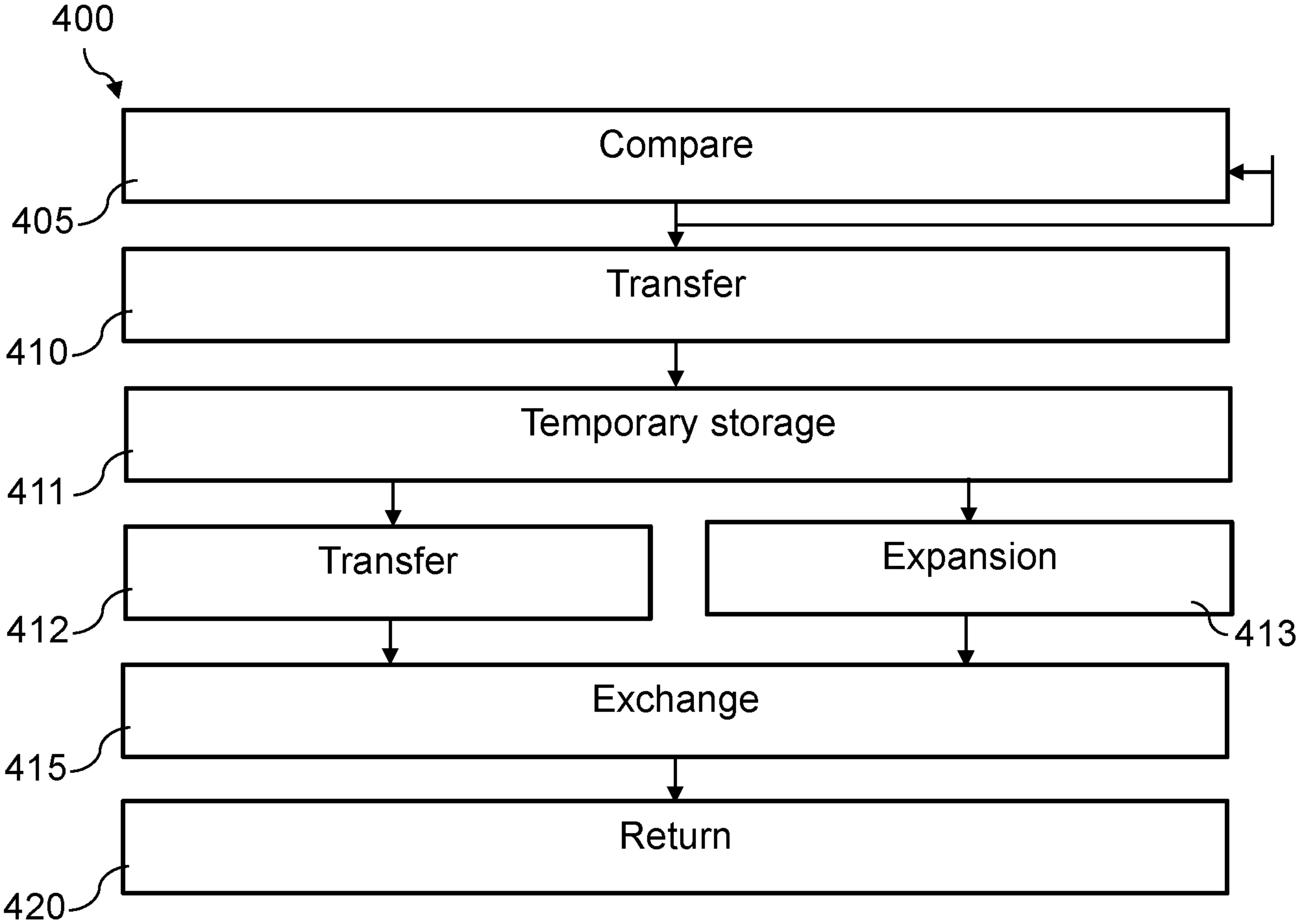


Figure 2

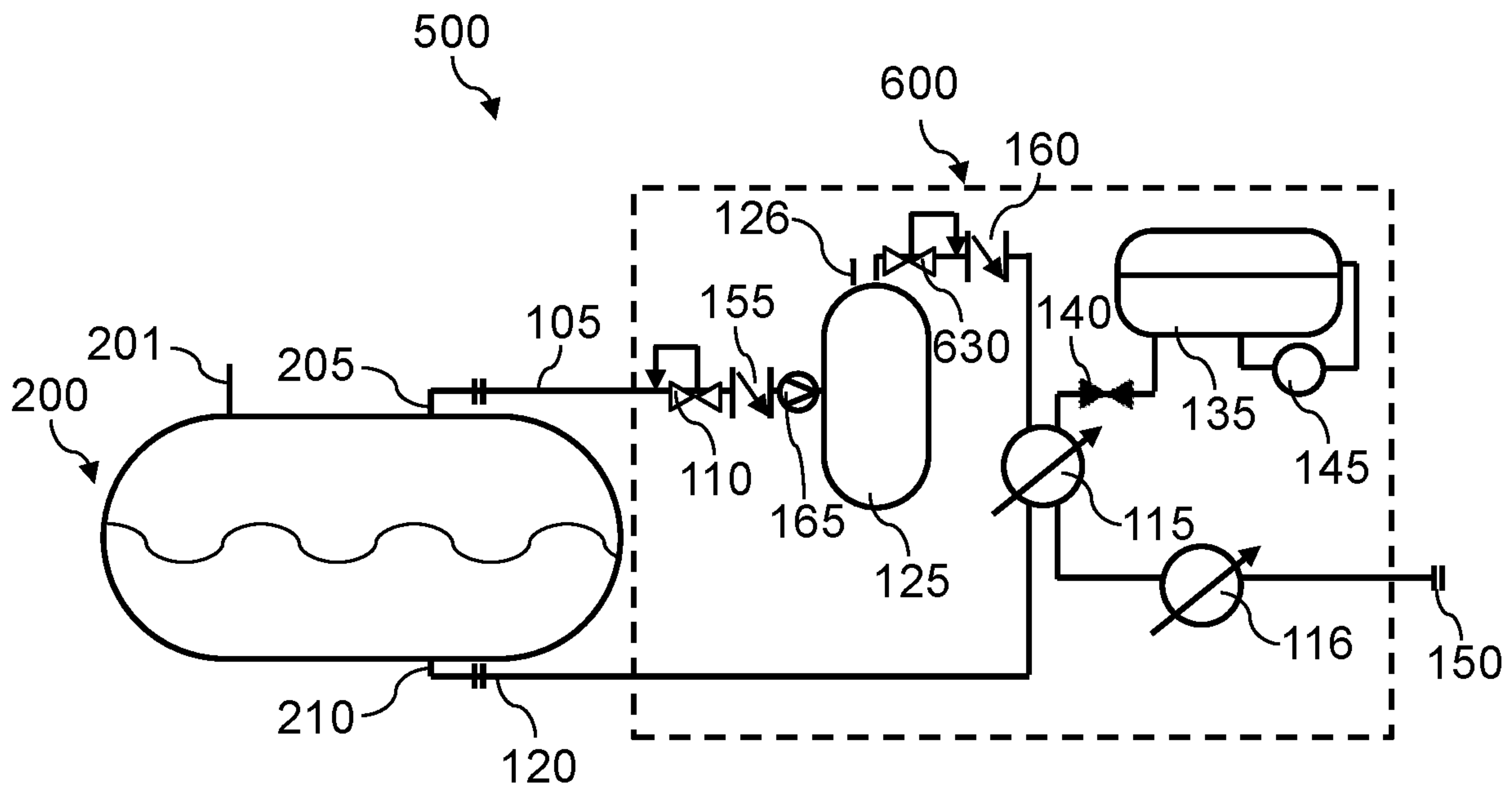
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Figure 3