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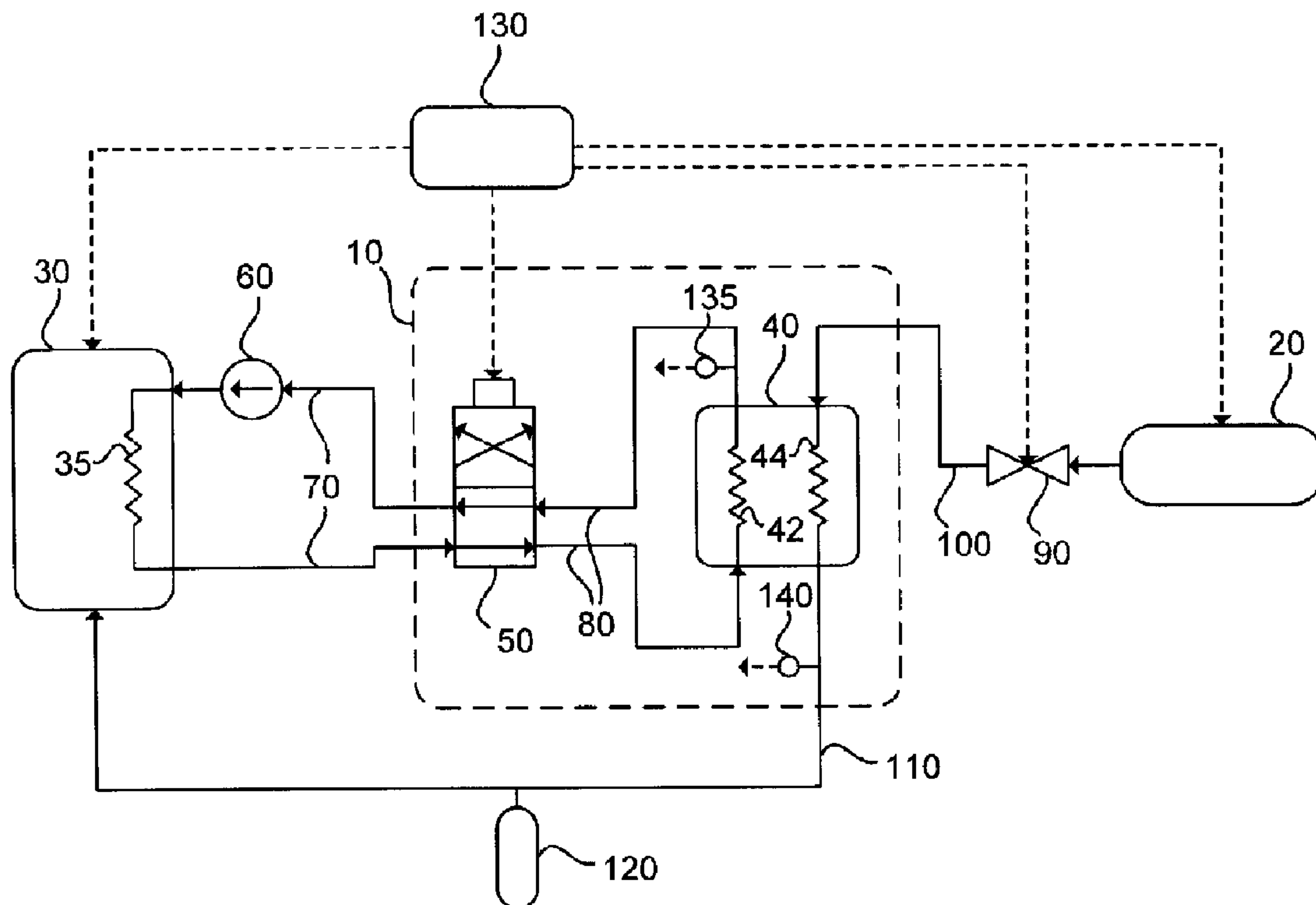
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(54) Title: VAPORIZER SYSTEM AND CONTROL STRATEGY



(57) Abrégé/Abstract:

During cold-start of an internal combustion engine, especially when ambient temperatures are low, a heat exchange medium can freeze in and around a heat exchanger that vaporizes a gaseous fuel. An improved method for vaporizing gaseous fuel stored in liquefied form for consumption by the internal combustion engine comprises counter flowing the gaseous fuel with the heat exchange medium through the heat exchanger during a first operating mode; and co-flowing the gaseous fuel with the heat exchange medium through the heat exchanger during a second operating mode. To reduce the risk of freezing the heat exchange medium the engine can be cold-started in the second operating mode.



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Abstract

During cold-start of an internal combustion engine, especially when ambient
10 temperatures are low, a heat exchange medium can freeze in and around a heat exchanger
that vaporizes a gaseous fuel. An improved method for vaporizing gaseous fuel stored in
liquefied form for consumption by the internal combustion engine comprises counter
flowing the gaseous fuel with the heat exchange medium through the heat exchanger
during a first operating mode; and co-flowing flowing the gaseous fuel with the heat
15 exchange medium through the heat exchanger during a second operating mode. To reduce
the risk of freezing the heat exchange medium the engine can be cold-started in the
second operating mode.

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VAPORIZER SYSTEM AND CONTROL STRATEGY**Field of the Invention**

[0001] The present application relates to a vaporizer system and a control strategy to operate the vaporizer system for an internal combustion engine.

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Background of the Invention

[0002] It is known to use engine coolant from an internal combustion engine as a heat exchange medium in a heat exchanger (also known as a vaporizer) that vaporizes a liquefied gaseous fuel, such as liquefied natural gas (LNG). The engine coolant circulates through what is commonly known as the water jacket of the engine and absorbs waste heat as the engine operates. The engine coolant is communicated outside the engine to the vaporizer where it and the liquefied gaseous fuel are routed through an arrangement of collocated passageways such that the waste heat in the engine coolant is transferred to the liquefied gaseous fuel, raising its temperature above the boiling point causing it to boil and change from a liquid state to a gas or supercritical state.

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[0003] To increase performance of the vaporizer, it is known to arrange the passageways such that the warmest engine coolant comes in contact with the coldest liquefied gaseous fuel, which is at respective inlets to the vaporizer for the engine coolant and the liquefied gaseous fuel. In this manner an increased amount of heat, relative to the overall performance characteristics of the vaporizer, gets transferred from the engine coolant to the liquefied gaseous fuel.

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[0004] When the engine cold-starts the temperature of the engine coolant can be much lower than the preferred operating temperature for the engine coolant. Depending on the ambient temperature, which is the temperature of the engine coolant on cold-start, and the temperature of the liquefied gaseous fuel, it is possible for the engine coolant to

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5 freeze in and around the vaporizer on cold-start. Similarly, when the engine is running at
a low engine speed, such as at idle or light load conditions, the flow rate of engine
coolant through the vaporizer relative to the heat transfer rate from the engine coolant to
the liquefied gaseous fuel in the vaporizer may result, again, in the engine coolant
freezing in and around the vaporizer. When the engine coolant freezes, the flow of engine
10 coolant through the vaporizer can be reduced, but not blocked. In these situations the
performance of the vaporizer is reduced and the downstream temperature of the
vaporized gaseous fuel decreases. Components downstream from the vaporizer may
experience increased thermal stress due to the cold temperatures, which decreases
servicing intervals and increases maintenance costs. When the flow of engine coolant
15 through the vaporizer is blocked, this could affect the flow of the engine coolant through
the water jacket, causing the engine temperature to increase until the engine is shutdown
due to overheating. A minimum amount of time is required after the engine coolant
freezes to allow it to melt, which is an inconvenience to the operator of the engine.

[0005] Previously, to prevent the engine coolant from freezing in the vaporizer, the
20 engine would operate with another fuel, such as Diesel, thereby reducing and possibly
eliminating the demand for liquefied gaseous fuel, for a predetermined amount of time
allowing the engine to warm up. The engine would switch to operating with liquefied
gaseous fuel after the engine coolant temperature was sufficient to reduce the likelihood
of the engine coolant from freezing. In other circumstances, there could be an
25 accumulator of vaporized gaseous fuel from which the engine could consume gaseous
fuel, allowing the engine to warm up, before beginning to vaporize liquefied gaseous
fuel. When operated in this manner, the pressure of the gaseous fuel in the accumulator
drops as fuel is consumed, which is not desirable if the pressure drops below the desired
injection pressure and/or the quantity of fuel that can be delivered to the engine is limited
30 on account of the available pressure.

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5 **[0006]** The state of the art is lacking in techniques for reducing the likelihood of engine coolant freezing, under certain operating conditions, when acting as a heat exchange medium through a vaporizer. The present system and control strategy provide a technique for reducing the likelihood of engine coolant from freezing.

Summary of the Invention

10 **[0007]** An improved method for vaporizing a gaseous fuel stored in liquefied form for consumption by an internal combustion engine comprises counter flowing the gaseous fuel with a heat exchange medium through a heat exchanger during a first operating mode; and co-flowing flowing the gaseous fuel with the heat exchange medium through the heat exchanger during a second operating mode. In a preferred embodiment, the heat
15 exchange medium is engine coolant from the internal combustion engine, which in a common heat exchange loop circulates through the heat exchanger and the engine water jacket. In those embodiments where the heat exchange loop is separate from the water jacket, the heat exchange medium can be glycol or other known heat exchange mediums.

20 **[0008]** There are several possible enabling conditions that determine which operating mode the engine is currently in. In a preferred embodiment, the internal combustion engine is in the second operating mode when at least one of heat exchange medium temperature is below a first predetermined value; and gaseous fuel temperature downstream from the heat exchanger is below a second predetermined value. When the heat exchange medium is engine coolant, the internal combustion engine can be in the
25 second operating mode when at least one of engine coolant temperature is below a first predetermined value; gaseous fuel temperature downstream from the heat exchanger is below a second predetermined value; engine speed is below a third predetermined value; engine coolant mass flow rate is below a fourth predetermined value; gaseous fuel mass flow rate is above a fifth predetermined value; and a differential mass flow rate between
30 the gaseous fuel and the engine coolant is above a sixth predetermined value. Alternatively, or additionally, the internal combustion engine is in the second operating

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5 mode when at least one of the internal combustion engine is starting, especially cold-starting; the internal combustion engine is idling; and the internal combustion engine is operating under a light load condition. The first operating mode can be entered after a predetermined time interval in the second operating mode. The internal combustion engine can be in the first operating mode when it is not in the second operating mode. In
10 another preferred embodiment there is a third operating mode where the heat exchange medium is made to by-pass the heat exchanger, such as when the engine is being fuelled with another fuel other than the gaseous fuel, such that the gaseous fuel does not need to be vaporized. When the internal combustion engine is not in both the second operating mode and the third operating mode, it is in the first operating mode.

15 **[0009]** In those embodiments where the heat exchange medium is not part of the engine water jacket heat exchange loop, the heat exchange medium can be heated in a variety of ways. For example, the heat exchange medium can be heated by at least one of heating the heat exchange medium with an electric heater; heating the heat exchange medium with a burner; and heating the heat exchange medium with a boiler.

20 **[0010]** In another preferred embodiment, when the internal combustion engine is in the second operating mode, the method further comprises one of by-passing an engine coolant radiator; and turning an engine coolant fan off.

[0011] An improved apparatus for vaporizing a gaseous fuel, stored in liquefied form in a fuel supply, for consumption by an internal combustion engine comprises a supply of
25 a heat exchange medium; a heat exchanger having a first passageway for the heat exchange medium and a second passageway for the gaseous fuel; a fluid switch fluidly connected to the heat exchanger and one of the supply of the heat exchange medium and the fuel supply; and a controller operatively connected with the fluid switch and programmed to command the fluid switch to a first position in a first operating mode
30 where the heat exchange medium counter flows with the gaseous fuel in the heat exchanger; and command the fluid switch to a second position in a second operating

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5 mode where the heat exchange medium co-flows flows with the gaseous fuel in the heat
exchanger. In a preferred embodiment the apparatus further comprises at least one of a
heat exchange medium temperature sensor arranged to measure at least one of heat
exchange medium temperature upstream from the heat exchanger and heat exchange
medium temperature downstream from the heat exchanger; and a gaseous fuel
10 temperature sensor arranged to measure at least one of gaseous fuel temperature upstream
from the heat exchanger and gaseous fuel temperature downstream from the heat
exchanger.

[0012] In another preferred embodiment, the apparatus further comprises a heater for
heating the heat exchange medium. The heater can comprise at least one of an electric
15 heater; a burner; and a boiler.

Brief Description of the Drawings

[0013] FIG. 1 is a schematic view of a vaporizer system illustrated in a first operating
mode according to a first embodiment.

[0014] FIG. 2 is a schematic view of the vaporizer system of FIG. 1 illustrated in a
20 second operating mode.

[0015] FIG. 3 is a schematic view of a vaporizer system illustrated in a first operating
mode according to a second embodiment.

[0016] FIG. 4 is a schematic view of the vaporizer system of FIG. 3 illustrated in a
second operating mode.

25 [0017] FIG. 5 is a schematic view of a vaporizer system illustrated in a first operating
mode according to a third embodiment.

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5 **[0018]** FIG. 6 is a schematic view of the vaporizer system of FIG. 5 illustrated in a second operating mode.

[0019] FIG. 7 is a schematic view of a vaporizer system illustrated in a third operating mode according to a fourth embodiment.

Detailed Description of Preferred Embodiment(s)

10 **[0020]** Referring to FIG. 1, vaporizer system 10 is shown according to a first embodiment in a first operating mode for vaporizing a gaseous fuel stored in liquefied form in fuel supply 20 for consumption by internal combustion engine 30. A gaseous fuel is any fuel that is in a gas state at standard pressure and temperature, which in the context of this application is defined as 1 atmosphere (atm) and 20 degrees Celsius (°C)
15 respectively. Vaporizer system 10 comprises heat exchanger 40, also known as a vaporizer, and fluid switch 50. Heat exchanger 40 has first passageway 42 for a heat exchange medium and second passageway 44 for gaseous fuel. Engine coolant from engine 30 is made to circulate by pump 60 through heat exchanger 40, where it operates as the heat exchange medium, by way of passageways 70, fluid switch 50 and
20 passageways 80. Within engine 30, the engine coolant circulates through water jacket 35 where it absorbs waste heat from the engine. Fuel supply 20 supplies liquefied gaseous fuel to heat exchanger 40 by way of shut-off valve 90 and passageway 100. As the gaseous fuel flows through heat exchanger 40, it vaporizes, and exits heat exchanger 40 in a gas or supercritical state, where it is then communicated to engine 30 through
25 passageway 110. Accumulator 120 is employed to provide a buffer of pressurized gaseous fuel, in the gas or supercritical state, to engine 30, and is shown in a t-connection to passageway 110 but can alternatively be in-line with the passageway in other embodiments. Instead of accumulator 120, passageway 110 can be sized to function as an accumulator.

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5 **[0021]** Controller 130 is operatively connected with fuel supply 20, engine 30, fluid switch 50 and shut-off valve 90, as indicated by the dashed lines therebetween, to command the operation of these components as will become evident in the course of this description. As used herein fluid switch 50 can be a single device and/or apparatus, or can be a collection of devices and/or components that operate together to achieve the specified functionality. Fuel supply 20 can be commanded by controller 130 to supply liquefied gaseous fuel at a predetermined pressure, for example by operating a cryogenic pump (not shown). Shut-off valve 90 is commanded to cut-off supply of liquefied gaseous fuel to downstream components, for example when engine 30 is shutdown, as well as during other circumstances. Temperature sensor 135 provides signals representative of engine coolant temperature to controller 130, and temperature sensor 140 provides signals representative of gaseous fuel temperature to the controller, both temperatures being measured downstream of the heat exchanger in the illustrated embodiment. In alternative embodiments temperature sensor 135 can be arranged upstream of heat exchanger 40 in the first operating mode, or can be integrated within the heat exchanger. Alternatively, or additionally, there can be a temperature sensor measuring engine coolant temperature within engine 30.

25 **[0022]** In the first operating mode, controller 130 commands fluid switch 50 into a first position illustrated in FIG. 1 such that engine coolant counter flows with gaseous fuel in heat exchanger 40. Counter flow with respect to fluid flow through heat exchanger 40 is defined to be that condition when the warmest engine coolant first delivers heat to the warmest gaseous fuel. As the engine coolant circulates through heat exchanger 40 it transfers heat to the liquefied gaseous fuel, such that the engine coolant drops in temperature and the liquefied gaseous fuel increases in temperature, which eventually begins to vaporize. That is to say, the warmest engine coolant is that engine coolant entering an inlet of heat exchanger 40, and the warmest gaseous fuel is that gaseous fuel exiting an outlet of the heat exchanger, as is illustrated schematically in FIG. 1. Counter flow occurs, generally, when the engine coolant and gaseous fuel flow in opposite

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5 forward directions. As a simplified example, when heat exchanger 40 comprises two parallel pipes, one for engine coolant and one for gaseous fuel, in the counter flow scenario the engine coolant and the gaseous fuel flow through their respective pipes in the opposite direction. In another example, heat exchanger 40 can comprise a helically wound pipe for gaseous fuel arranged in a chamber through which engine coolant flows,
10 in what is known as a 'bath'. In the counter flow scenario the gaseous fuel flows through the helically wound pipe such that it has the opposite forward direction as the engine coolant in the chamber. As can be appreciated, there are other configurations for heat exchangers 40, in which a counter flow scenario can be defined.

[0023] With reference to FIG. 2, vaporizer system 10 is illustrated in a second
15 operating mode, where controller 130 has commanded fluid switch 50 into a second position such that engine coolant co-flows with respect to gaseous fuel in heat exchanger 40. Co-flow with respect to fluid flow through heat exchanger 40 is defined to be that condition opposite to the counter-flow condition, which is when the warmest engine coolant first delivers heat to the coldest gaseous fuel. The coldest gaseous fuel is that
20 gaseous fuel entering an inlet of heat exchanger 40. Co-flow occurs, generally, when the engine coolant and gaseous fuel flow in the same forward direction through the heat exchanger. In the simplified example described above, when heat exchanger 40 comprises the two parallel pipes, in the co-flow scenario the engine coolant and the gaseous fuel flow through their respective pipes in the same direction. In the other
25 example described above, when heat exchanger 40 comprises the helically wound pipe for gaseous fuel arranged in the chamber (the "bath") through which engine coolant flows, in the co-flow scenario the gaseous fuel flows through the helically wound pipe such that it has the same forward direction as the engine coolant in the chamber. As can be appreciated, there are other configurations for heat exchangers 40, in which a co-flow
30 scenario can be defined.

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5 **[0024]** Under normal operating conditions, controller 130 commands vaporizer system 10 into the first operating mode where heat exchanger 40 counter flows engine coolant with gaseous fuel. Controller 130 commands vaporizer system 10 into the second operating mode when there is a risk of engine coolant freezing, such as when engine 30 is cold-started and the temperature of engine coolant is relatively low, or when engine 30 is idling or operating under a light load condition, when the mass flow rate of engine coolant through heat exchanger 40 is low. Controller 130 can monitor ambient temperature and/or engine coolant temperature, to determine whether under a cold-start condition or a light load condition there is a risk of engine coolant freezing. Alternatively, controller 130 can be programmed to command the second operating mode upon cold-start, for a predetermined amount of time, after which the controller commands the first operating mode. Similarly, controller 130 can command the second operating mode whenever engine 30 is operating under a light load condition, and when engine 30 transitions away from the light load condition the controller can command the first operating mode. Further, controller 130 can be programmed to command the second operating mode as function of gaseous fuel temperature downstream of heat exchanger 40. As gaseous fuel temperature drops below a predetermined temperature the controller commands the second operating mode (co-flow).

25 **[0025]** Engine 30 comprises a radiator (not shown) and a fan (not shown) employed to cool the engine coolant when its temperature rises above a predetermined value, as is known. In addition to being in the second operating mode, or alternatively, the engine coolant can be made to by-pass the radiator or the fan can be turned off when the engine coolant temperature is too low and there is a risk of freezing the engine coolant in and around heat exchanger 40. Techniques for by-passing the radiator are well known in the art.

30 **[0026]** Referring now to FIGS. 3 and 4, vaporizer system 12 is shown according to a second embodiment similar to the first embodiment where like parts to this and other

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5 embodiments have like reference numerals that may not be described in detail, if at all. Fluid switch 52 is fluidly connected with fuel supply 20, by way of valve 90 and passageway 100, and is commanded by controller 130 to switch the direction of flow of gaseous fuel through passageways 82 and passageway 44 of heat exchanger 40. Engine coolant from engine 30 is circulated through passageway 72 and passageway 42 of the
10 heat exchanger, always in the same direction. Vaporizer system 12 is illustrated in the first operating mode in FIG. 3 where gaseous fuel and engine coolant are counter flowed through heat exchanger 40, and in the second operating mode in FIG. 4 where gaseous fuel and engine coolant are co-flowed through the heat exchanger. Although the result of switching the direction of gaseous fuel instead of engine coolant is identical with respect
15 to the heat exchanger, it is preferred in general to switch the flow of the engine coolant instead of the gaseous fuel. The extremely low temperatures associated with liquefied gaseous fuels may require a more expensive version of fluid switch 52 and temperature sensor 142, which both must be able to operate both at extremely low temperatures, and over a wide temperature range, when the direction of the gaseous fuel is switched. As an
20 example, the temperature of LNG can be around -160°C and when vaporized its temperature can be between -20°C and as high as $+80^{\circ}\text{C}$ depending upon the operating conditions of the engine. Fluid switch 52 must direct the flow of the gaseous fuel when it is in the liquid state and the gas or supercritical state, and therefore has more stringent sealing requirements compared to fluid switch 50, which directs the flow of engine
25 coolant that is normally in the liquid state. Depending upon the application, gaseous fuel pressure can be very much higher than engine coolant pressure, which puts even further demands on fluid switch 52 for both sealing and switching under high pressure conditions.

[0027] Referring now to FIGS. 5 and 6, vaporizer system 13 is shown according to a
30 third embodiment. Heat exchange loop 25 is employed to provide heat exchanger 40 with a heat exchange medium instead of using the heat exchange loop from engine 30 (comprising water jacket 35). As an example, the heat exchange medium can be glycol,

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5 but as would be known to those familiar with the technology other types of heat exchange medium can be employed. Heater 45 elevates the temperature of the heat exchange medium that is circulated through heat exchanger 40. Examples of heater 45 can be an electric heater, a burner and a boiler, and other heater types are possible. The burner and boiler can burn a fuel, such as boil-off gas from a cryogenic vessel in fuel supply 20. In
10 other embodiments, waste heat in the engine coolant of engine 30 can be transferred to the heat exchange medium in loop 25 by way of a heat exchanger (not shown). Vaporizer system 13 is illustrated in the first operating mode in FIG. 5 where gaseous fuel and the heat exchange medium are counter flowed through heat exchanger 40, and in the second
15 operating mode in FIG. 6 where gaseous fuel and the heat exchange medium are co-flowed through the heat exchanger. In other embodiments, heat exchange loop 25 can be employed in those embodiments where the fluid switch is employed to switch the flow of the gaseous fuel, like fluid switch 52 in FIGS. 3 and 4, instead of the heat exchange medium.

[0028] Referring now to FIG. 7, vaporizer system 14 is shown according to a fourth
20 embodiment, illustrating vaporizer system 14 in a third operating mode, where fluid switch 54 redirects the heat exchange fluid (engine coolant in this embodiment) bypassing heat exchanger 40. This is advantageous when engine 30 is being fuelled with a fuel other than gaseous fuel from fuel supply 20, such as when the engine runs on diesel (ROD). Fluid switch 54 can be commanded by controller 30 such that vaporizer system
25 14 is in one of the first, second and third operating modes. Fluid switch 54 can be employed in the previously discussed embodiments, particularly those illustrated in FIGS. 1 through 4 where engine coolant must continue to be circulated regardless of which fuel engine 30 consumes. When engine 30 runs on a fuel other than the gaseous fuel, it is advantageous to reduce the heat transfer from the engine coolant to the gaseous
30 fuel, which if not reduced could cause the pressure of the gaseous fuel to increase excessively. In the embodiment of FIGS. 5 and 6, fluid switch 54 can be employed,

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5 alternatively, pump 60 can be stopped when engine 30 is fuelled with a fuel other than gaseous fuel from supply 20.

10 **[0029]** While particular elements, embodiments and applications of the present invention have been shown and described, it will be understood, that the invention is not limited thereto since modifications can be made by those skilled in the art without departing from the scope of the present disclosure, particularly in light of the foregoing teachings.

What is claimed is:

1. A method for vaporizing a gaseous fuel stored in liquefied form for consumption by an internal combustion engine comprising:

counter flowing the gaseous fuel with a heat exchange medium through a heat exchanger during a first operating mode; and

co-flowing the gaseous fuel with the heat exchange medium through the heat exchanger during a second operating mode.

2. The method of claim 1, wherein the internal combustion engine is in the second operating mode when at least one of:

heat exchange medium temperature is below a first predetermined value; and

gaseous fuel temperature downstream from the heat exchanger is below a second predetermined value.

3. The method of claim 1, wherein the heat exchange medium is engine coolant from the internal combustion engine.

4. The method of claim 3, wherein the internal combustion engine is in the second operating mode when at least one of:

engine coolant temperature is below a first predetermined value;

gaseous fuel temperature downstream from the heat exchanger is below a second predetermined value;

engine speed is below a third predetermined value;

engine coolant mass flow rate is below a fourth predetermined value;

gaseous fuel mass flow rate is above a fifth predetermined value; and

a differential mass flow rate between the gaseous fuel and the engine coolant is above a sixth predetermined value.

5. The method of claim 3, when in the second operating mode, further comprising one of:

by-passing an engine coolant radiator; and

turning an engine coolant fan off.

6. The method of claim 1, wherein the internal combustion engine is in the second operating mode when at least one of:

the internal combustion engine is starting;

the internal combustion engine is idling; and

the internal combustion engine is operating under a light load condition.

7. The method of claim 6, wherein the internal combustion engine is cold-starting.

8. The method of claim 1, wherein at least one of:

the first operating mode is entered after a predetermined time interval in the second operating mode; and

the internal combustion engine is in the first operating mode when it is not in the second operating mode.

9. The method of claim 1, further comprising a third operating mode wherein the heat exchange medium by-passes the heat exchanger.

10. The method of claim 1, further comprising at least one of:

heating the heat exchange medium with an electric heater;

heating the heat exchange medium with a burner; and

heating the heat exchange medium with a boiler.

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11. An apparatus for vaporizing a gaseous fuel, stored in liquefied form in a fuel supply, for consumption by an internal combustion engine comprising:

a supply of a heat exchange medium;

a heat exchanger having a first passageway for the heat exchange medium and a second passageway for the gaseous fuel;

a fluid switch fluidly connected to the heat exchanger and one of the supply of the heat exchange medium and the fuel supply; and

a controller operatively connected with the fluid switch and programmed to:

command the fluid switch to a first position in a first operating mode where the heat exchange medium counter flows with the gaseous fuel in the heat exchanger;
and

command the fluid switch to a second position in a second operating mode where the heat exchange medium co-flows flows with the gaseous fuel in the heat exchanger.

12. The apparatus of claim 11, further comprising at least one of:

a heat exchange medium temperature sensor arranged to measure at least one of heat exchange medium temperature upstream from the heat exchanger and heat exchange medium temperature downstream from the heat exchanger; and

a gaseous fuel temperature sensor arranged to measure at least one of gaseous fuel temperature upstream from the heat exchanger and gaseous fuel temperature downstream from the heat exchanger.

13. The apparatus of claim 11, wherein the internal combustion engine is in the second operating mode when at least one of:

heat exchange medium temperature is below a first predetermined value; and

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gaseous fuel temperature downstream from the heat exchanger is below a second predetermined value.

14. The apparatus of claim 11, wherein the heat exchange medium is engine coolant and the supply of the heat exchange medium is the internal combustion engine.

15. The apparatus of claim 14, wherein the internal combustion engine is in the second operating mode when at least one of:

engine coolant temperature is below a first predetermined value;

gaseous fuel temperature downstream from the heat exchanger is below a second predetermined value;

engine speed is below a third predetermined value;

engine coolant mass flow rate is below a fourth predetermined value;

gaseous fuel mass flow rate is above a fifth predetermined value; and

a differential mass flow rate between the gaseous fuel and the engine coolant is above a sixth predetermined value.

16. The apparatus of claim 14, wherein the internal combustion engine is in the second operating mode when at least one of:

the internal combustion engine is starting;

the internal combustion engine is idling; and

the internal combustion engine is operating under a light load condition.

17. The apparatus of claim 14, wherein the internal combustion engine is cold-starting.

18. The apparatus of claim 14, wherein the controller is further programmed to command at least one of:

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the first operating mode after a predetermined time interval in the second operating mode;

the first operating mode when the internal combustion engine is not in the second operating mode;

a third operating mode where the heat exchange medium by-passes the heat exchanger; and

the first operating mode when the internal combustion engine is not in both the second operating mode and the third operating mode.

19. The apparatus of claim 11, further comprising a heater for heating the heat exchange medium.

20. The apparatus of claim 19, wherein the heater is at least one of:

an electric heater;

a burner; and

a boiler.

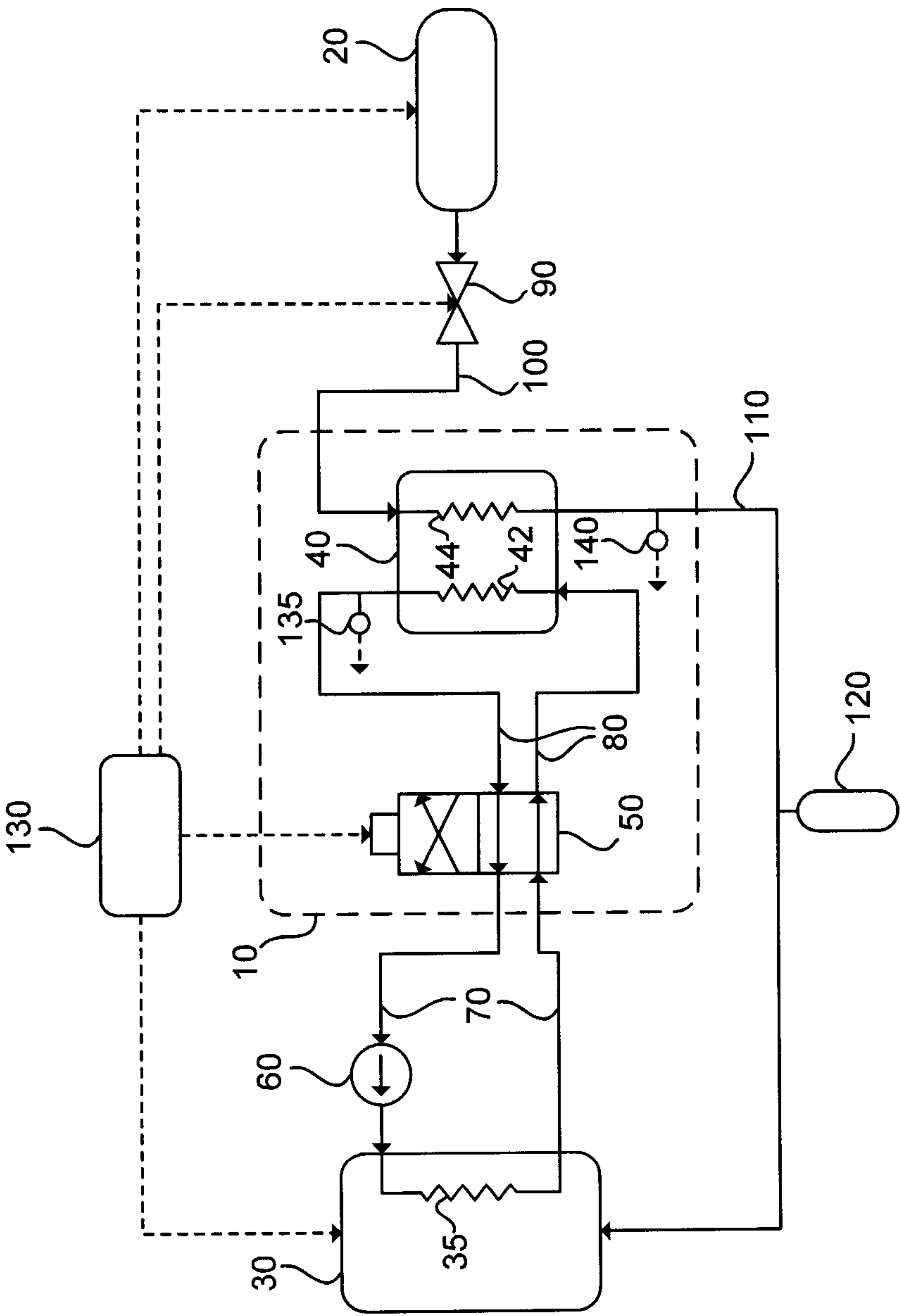


FIG. 1

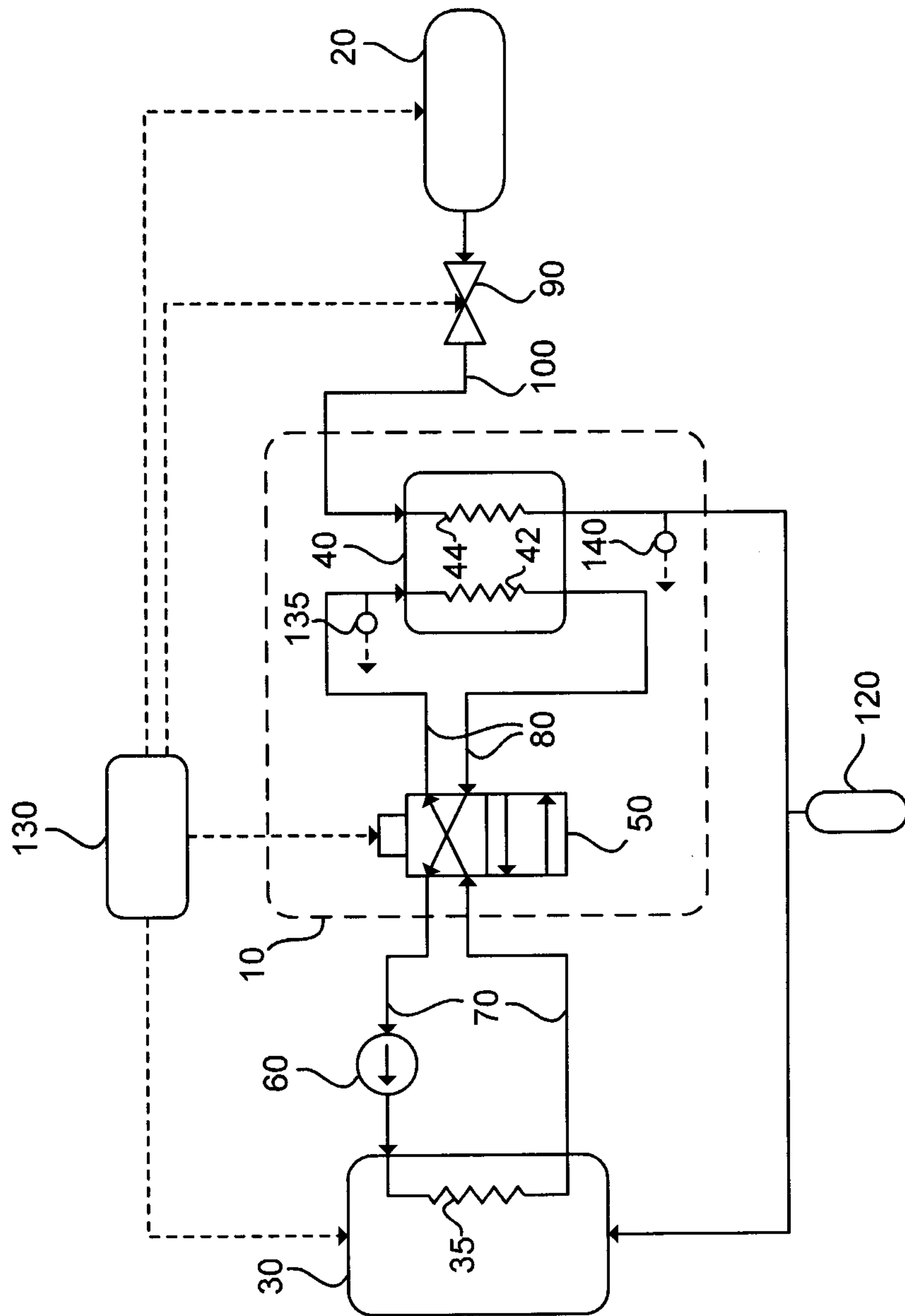


FIG. 2

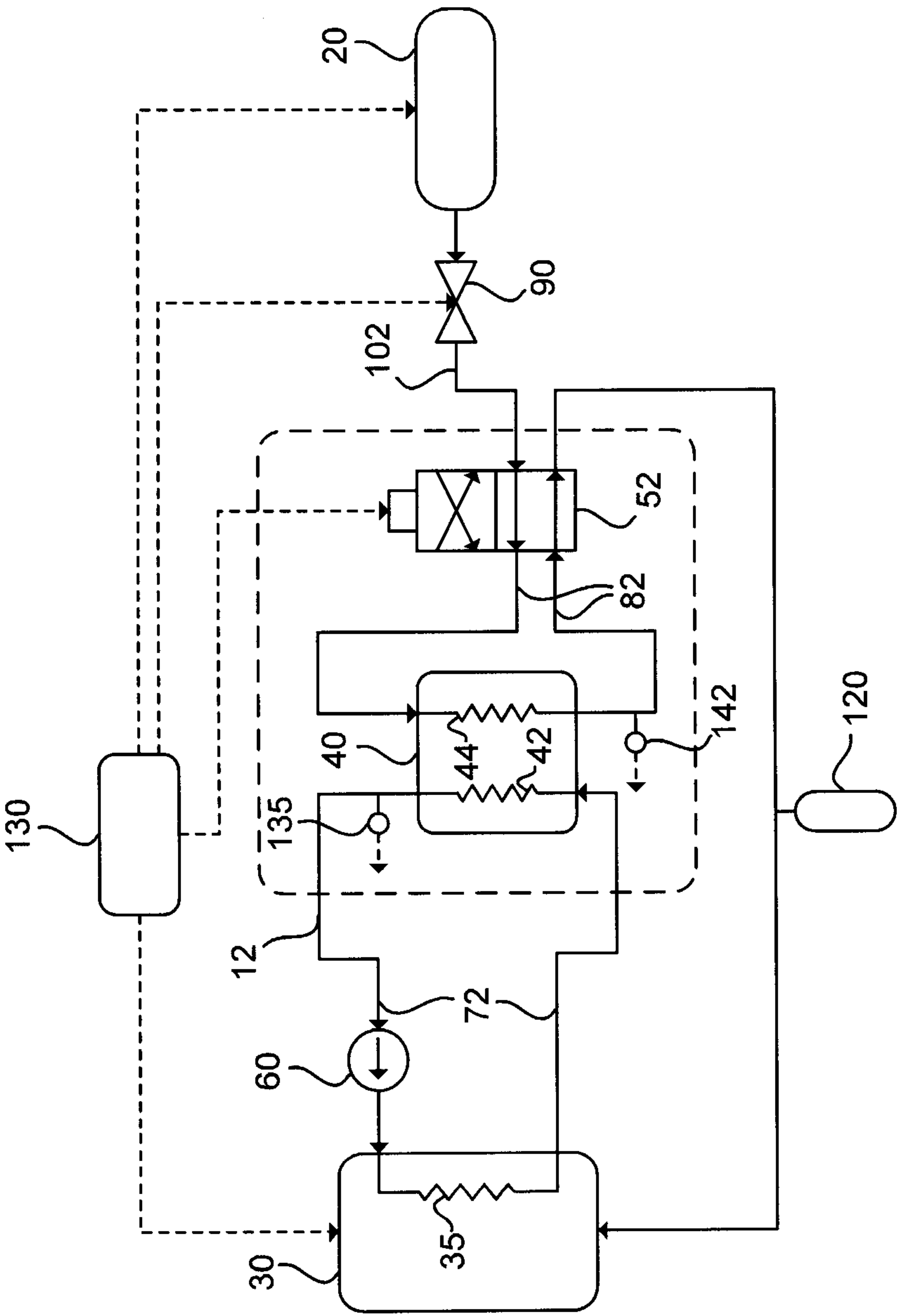


FIG. 3

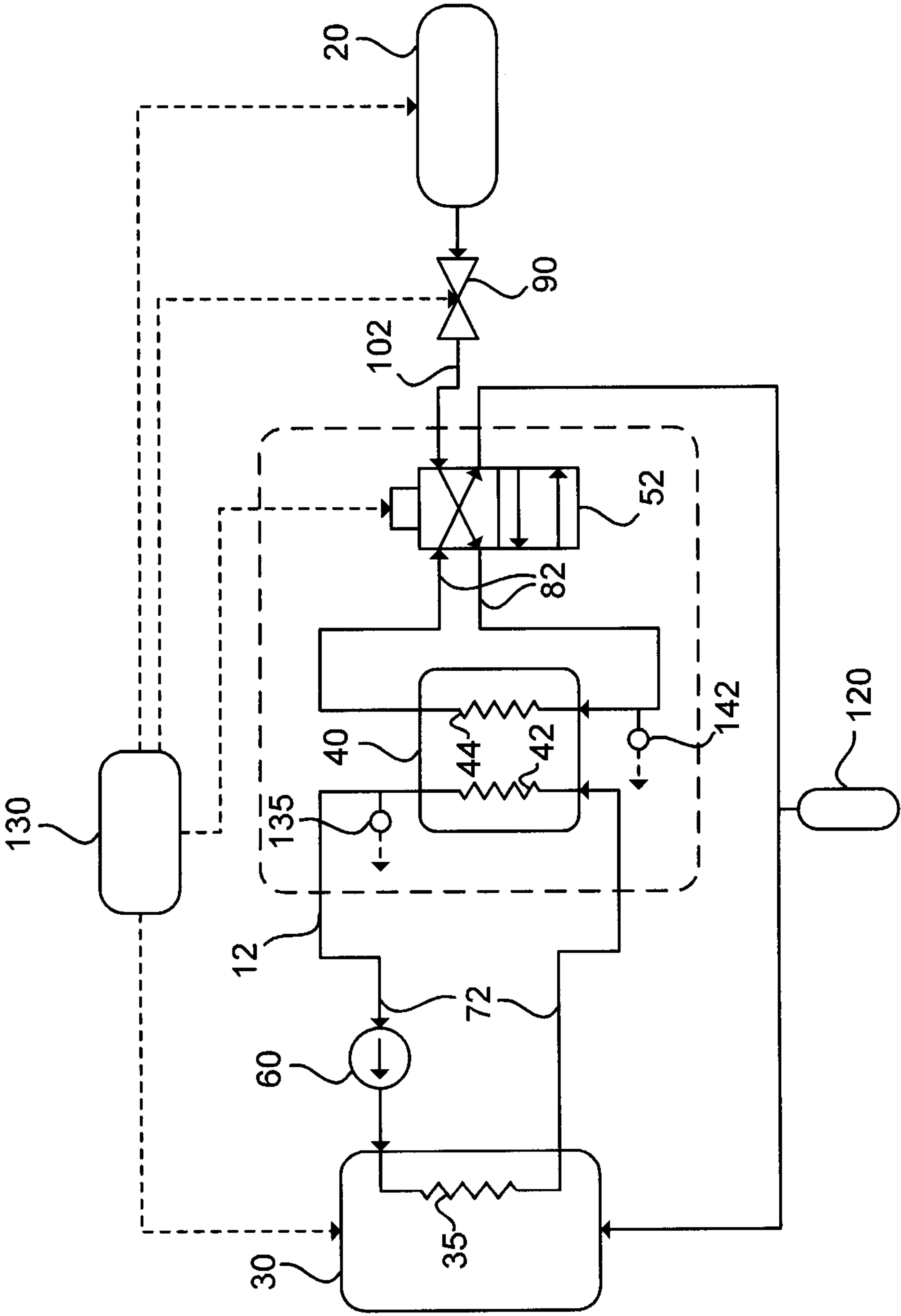


FIG. 4

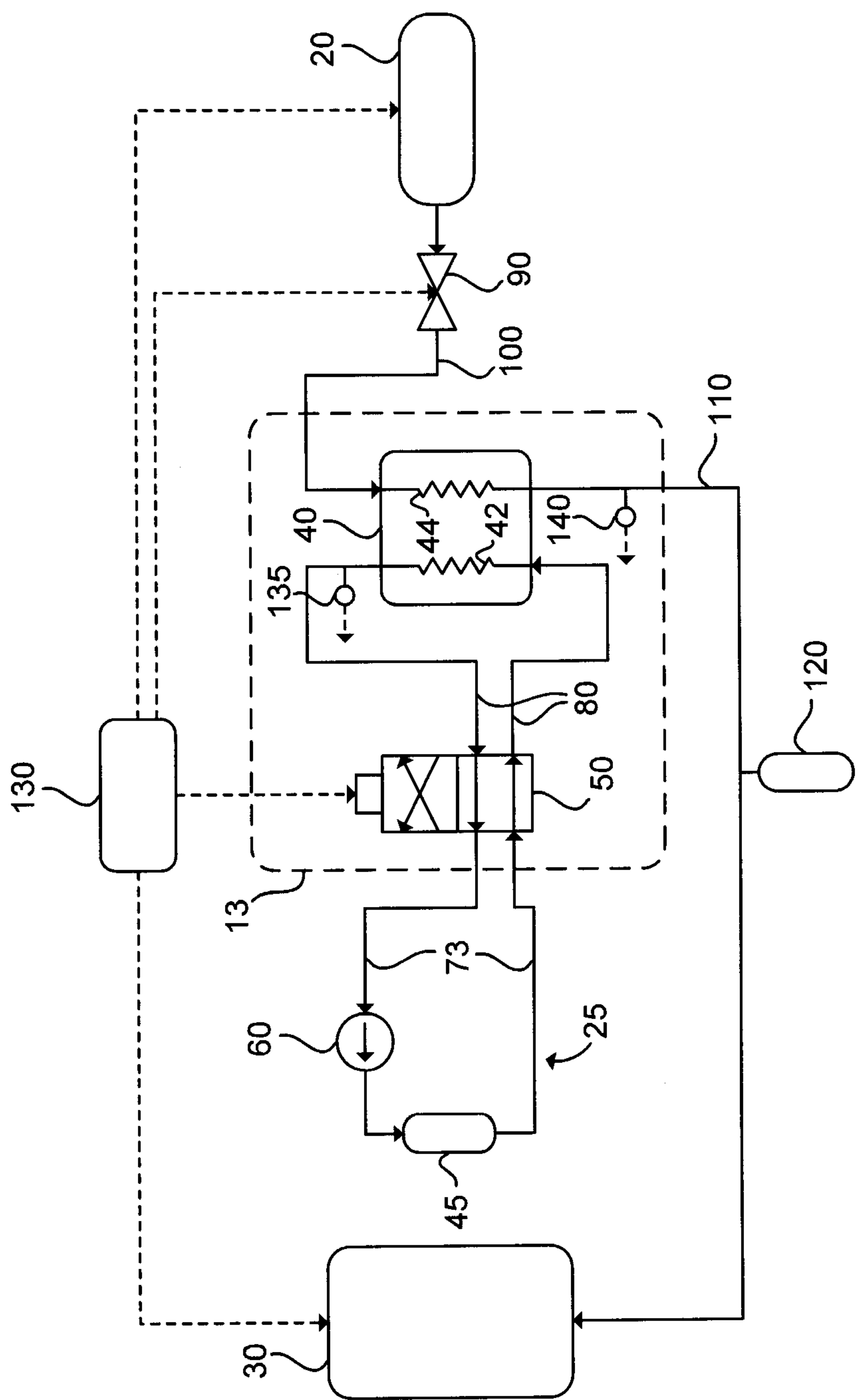


FIG. 5

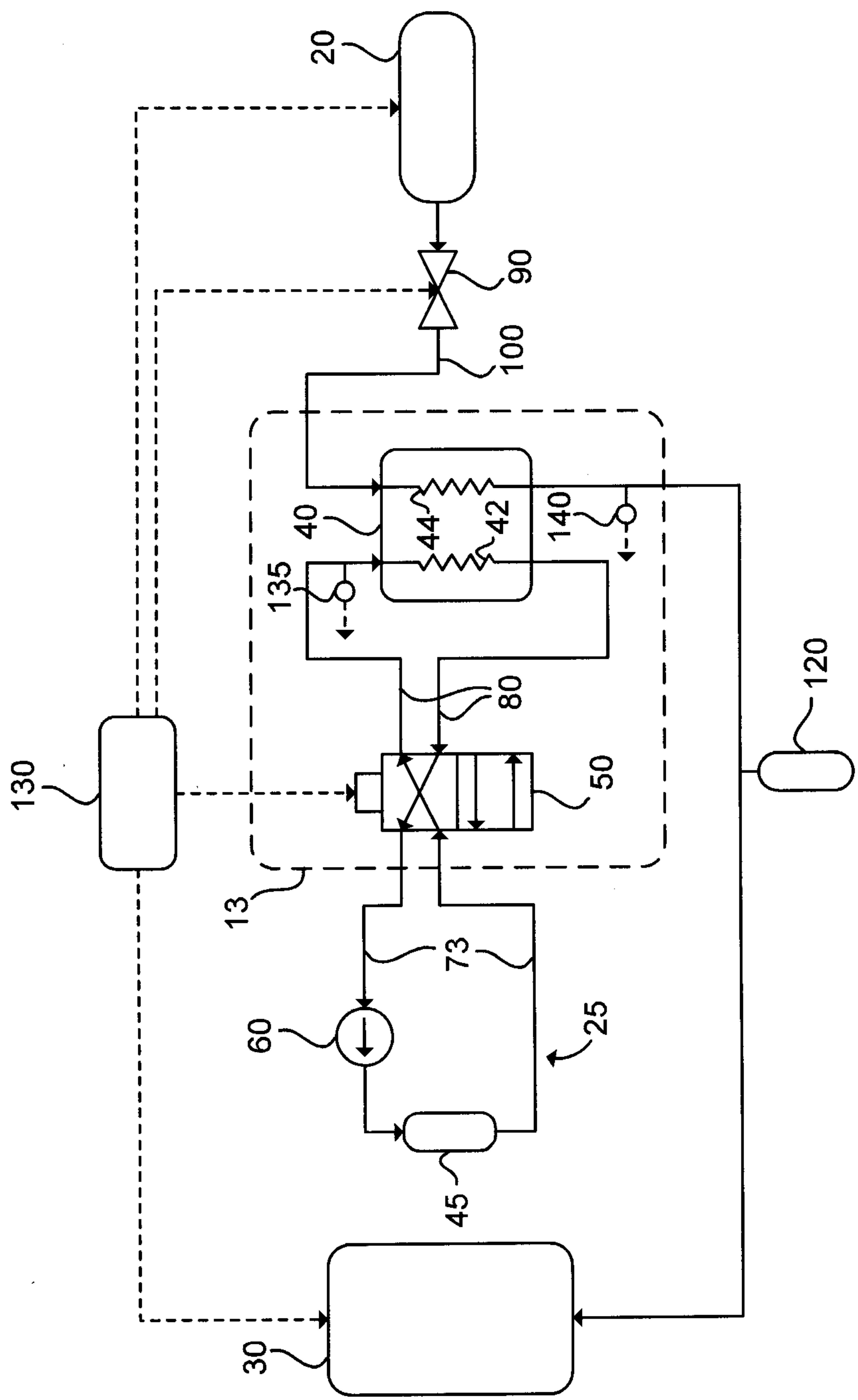


FIG. 6

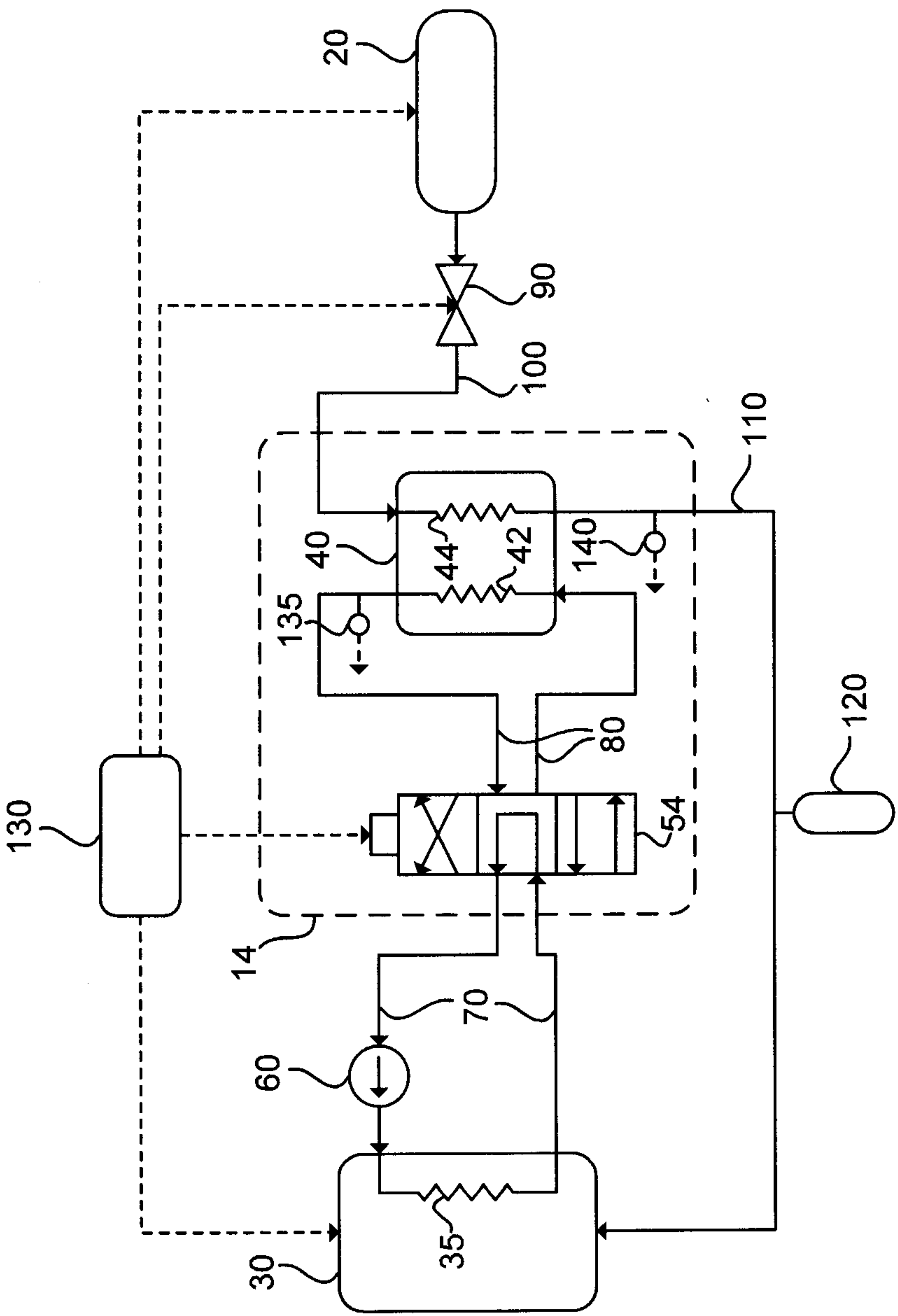


FIG. 7

