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(54) **METHOD, FUELING SYSTEM AND SUBCOOLING AND CONDENSING UNIT FOR FILLING TANKS WITH A FUEL SUCH AS LNG**

(57) Subcooling and condensing unit (4) for a fueling system (1) for a fuel having methane as its primary component, wherein the subcooling and condensing unit (4) comprises a temperature controller (24) for controlling the temperature of fuel inside the subcooling and condensing unit (4), a first section (5), a second section (6), a separating plate (19) between the first section (5) and the second section (6), and a tube (20) having a first opening (21) in the first section (5) and a second opening (22) in the second section (6) of the subcooling and condensing unit (4), wherein the first section (5), the second section (6), the separation plate (19) and the tube (20) are arranged in such a way that a separation layer (45) and a thermal isolation layer (38) can be generated, wherein the separation layer (45) comprises gaseous fuel for thermally isolating liquid fuel being evaporated in the first section (5) from subcooled liquid fuel in the second section (6), and wherein the thermal isolation layer (38) comprises liquid fuel for thermally isolating the gaseous fuel forming the separation layer (45) from the subcooled liquid fuel in the second section (6).

A fueling system is proposed, wherein only one sin-

gle device can be used for both subcooling and condensing fuel, while no specialized fuel storage tank or additional pump is required.

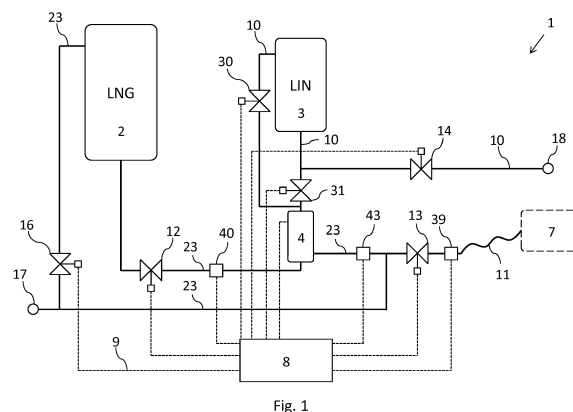


Fig. 1

Description

[0001] The present invention is directed to a fueling system for a fuel having methane as its primary component, in particular liquid natural gas (LNG). The invention also relates to a subcooling and condensing unit for the fueling system and a method for operating the fueling system.

[0002] The use of methane and methane comprising gas mixtures like liquid natural gas (LNG) as fuels for internal combustion engines, e. g. in cars, is known as are storage tanks for such fuels. Losses during storing or transporting of such fuels can be minimized by subcooling the fuel. The term subcooling means within this document that the fuel is treated such that it is not in its phase equilibrium but mainly in its liquid phase. That is, the temperature of the fuel is lower than the equilibrium temperature at the respective pressure. This can be obtained, e.g., by increasing the pressure at constant temperature, or by lowering the temperature at constant pressure - called subcooling. Apparatuses for subcooling are known. Subcooled fuel is advantageous compared to liquid fuel in phase equilibrium because it remains liquid even if warmed moderately. Therein, moderately means that the fuel may be warmed to that extent that it is kept cooled below the equilibrium temperature. Having the fuel in its liquid state can minimize losses because, compared to a gas, a liquid is less likely to penetrate through leakages of the system it is stored in.

[0003] Maintaining the liquid state of the fuel may require a frequent cooling and especially a frequent condensing of evaporated fuel. This can be necessary especially because a thermal isolation from the environment inevitably is non-ideal and heat intake will lead to some amount of evaporation. Apparatuses for condensing LNG and comparable fuels are known. An example is given in EP 2 617 587 A1, which discloses condensing LNG by a cooling means within an LNG storage tank or by a thermal connection of an LNG storage tank to a liquid nitrogen (LIN) tank. However, within this LNG storage tank, subcooling of the fuel is not possible.

[0004] From EP 2 569 176 B1, a fueling system is known, wherein LNG can be cooled by a heat exchanger within an LNG storage tank. However, this has the disadvantage that a special tank is required including an internal heat exchanger.

[0005] It is therefore an object of the present invention to overcome at least in part the disadvantages known from prior art and in particular to provide a method and a fueling system for filling tanks with a fuel having methane as its primary component with a simplified and improved hardware. Especially, according to the present invention a simplified and improved hardware for subcooling and condensing fuel shall be provided.

[0006] These objects are solved by the features of the independent claims. Preferred embodiments according to the invention, which can be separately or jointly applied as technically feasible are described in the respective

dependent claims.

[0007] The subcooling and condensing unit according to the present invention is described for a fueling system for a fuel having methane as its primary component. The subcooling and condensing unit comprises

- a temperature controller for controlling the temperature of fuel inside the subcooling and condensing unit,
- a first section,
- a second section, and
- a separating plate between the first section and the second section, and
- a tube having a first opening in the first section and a second opening in the second section of the subcooling and condensing unit,

wherein the first section, the second section, the separation plate and the tube are arranged in such a way that a separation layer and a thermal isolation layer can be generated. The separation layer comprises gaseous fuel for thermally isolating liquid fuel being evaporated in the first section from subcooled liquid fuel in the second section. The thermal isolation layer comprises liquid fuel for thermally isolating the gaseous fuel forming the separation layer from the subcooled liquid fuel in the second section.

[0008] Liquid fuel in the second section is preferably pressurized highly enough so that it can flow into the target tank at any pressure conditions in the target tank or back into the fuel storage tank.

[0009] The fueling system is preferably used to provide fuel to a target tank of, e. g., a vehicle such as a car, a truck or a ship. More generally, any target tank can be filled using the fueling system. The fueling system is not limited to be used for mobile target tanks. For example, the fueling system could also be installed on a truck. Thereby, it could be used to fill stationary target tanks. The fuel that is used in the fueling system is usually, but not necessarily, LNG. Generally, any fuel that has methane (CH₄) as its primary component could be used. Methane being the primary component means that the methane fraction of the fuel is at least 50%. Wherever the term LNG is used in the following, this is by way of example only and does not limit the invention to LNG. Any fuel having methane as its primary component is equally suitable and will be denoted by the term fuel in the following. Further, gaseous natural gas will be referred to as NG, in order to distinguish gaseous (NG) and liquid (LNG) natural gas. For a mixture of NG and LNG the abbreviation NG/LNG will be used. The further relevant liquid nitrogen will be referred to as LIN, while gaseous nitrogen will be referred to as GAN.

[0010] In the subcooling and condensing unit, fuel can be subcooled and condensed. In prior art, there is no fueling system for filling a target tank with a fuel such as LNG, wherein both subcooling and condensing of the fuel can be readily performed in the same apparatus, and

wherein a standard LNG storage tank can be used rather than a specialized one comprising, e.g. a heat exchanger. With the subcooling and condensing unit being designed both for subcooling and condensing fuel, only one single device is required instead of two, while a standard LNG storage tank is sufficient. This is in particular advantageous as it is possible to retrofit existing systems having a standard LNG storage tank with the subcooling and condensing unit according to the present invention.

[0011] Energy consumption for storing and filling fuel can be reduced because only a single device has to be cooled. An apparatus used for condensing fuel according to prior art is required to be ready for use, i.e. cold, whenever fuel has to be condensed. The less frequently the fueling system is used, the more often it is necessary to condense fuel, e.g. to reduce the pressure in a fuel storage tank. An apparatus used for subcooling fuel according to prior art is supposed to be ready for use, i.e. cold, whenever the fueling system is used, e.g. for filling the target tank. That is, depending on how frequently the fueling system according to prior art is used, either the apparatus used for condensing or the apparatus used for subcooling has to be kept ready for use permanently. The other apparatus can either be warmed up after each usage or it can be kept cold permanently as well. Both is inefficient.

[0012] Initially the fueling system according to the present invention can be in a standby mode, which is a kind of idle mode in which the fueling system is driven, unless a different mode is activated. In the standby mode, the subcooling and condensing unit may be kept at a predefined standby temperature. The standby temperature is a trade-off between energy consumption and time required for cooling down the subcooling and condensing unit. At least at the time the fueling system changes into the standby mode, there is preferably no significant amount of liquid fuel in the subcooling and condensing unit to reduce losses.

[0013] The subcooling and condensing unit preferably comprises a tank that can be filled with fuel. It may have a volume of e.g. 50 l, where the first section may have a volume of e.g. 20 l and the second section of 30 l.

[0014] The temperature controller of the subcooling and condensing unit can be realized by any means suitable for cooling and/or warming fuel within a tank. Means required for supplying and controlling a flow of e.g. a refrigerant are preferably included in the fueling system. Preferably, the temperature controller is able to cool fuel below the equilibrium temperature. The temperature controller may be used both for subcooling and condensing the fuel. Further, it may be used in order to increase or decrease the pressure in the subcooling and condensing unit by increasing or decreasing the temperature, respectively.

[0015] Due to the separation of the subcooling and condensing unit into the first section and the second section, the increase or decrease of the temperature, and, consequently, of the pressure, can be restricted locally.

This is enhanced by the separation layer and by the thermal isolation layer, which can be formed because of the separating plate.

[0016] The separating plate is preferably designed in such a way that liquid fuel cannot penetrate the separating plate and flow from the first section into the second section other than by flowing through the tube. The separating plate is preferably a steel plate mounted tightly to the walls of the subcooling and condensing unit.

[0017] The tube can in particular be designed in such a way that both liquid and gaseous fuel may flow through the tube. The tube may be made of a material which is suitable for the low temperatures relevant in the given context, such as steel, e. g. in the range of the boiling temperature of methane being 112 K at atmosphere pressure.

[0018] In a preferred embodiment, where the subcooling and condensing unit is divided horizontally with the separating plate being arranged horizontally, the tube might have the first opening in the first section spaced apart from the separating plate. Thereby, the fact that the subcooling and condensing unit is divided horizontally is to be understood in a way that the first section is situated above the second section, provided the subcooling and condensing unit is oriented in its intended orientation. In this embodiment, an amount of liquid fuel, which is limited by the vertical spacing between the first opening and the separating plate, can remain on the separating plate without being able to enter the tube.

[0019] Increasing the pressure of fuel in the first section can cause gaseous fuel to flow through the tube from the first section into the second section. This may provide the gaseous fuel that forms the separation layer in the second section.

[0020] Gaseous fuel that adjoins the separating plate can form the separation layer. Generally, a gas has a much lower thermal conductivity and a much higher volume than a liquid. That is why, the separation layer can pressurize NG in the second section. There, NG can condense into the subcooled liquid. This leads to a warming up of the surface of the LNG. LNG for example exhibits a significant thermal expansion, which facilitates the formation of the isolation layer.

[0021] The thermal isolation layer can enhance a thermal separation between the separation layer and the liquid subcooled fuel in the second section, thus maintaining the state of subcooling in the latter. In particular, if the pressure is increased, the state of subcooling is more likely to be maintained because the equilibrium temperature of, e.g. LNG, increases with increasing pressure. The thermal isolation layer may be formed by liquid fuel, the temperature of which is higher than of the liquid subcooled fuel in the second section. For LNG, in particular, the density decreases with increasing temperature.

[0022] In a preferred embodiment, where the subcooling and condensing unit is divided horizontally with the separating plate being arranged horizontally, a lower part of the second section may be filled with subcooled liquid

fuel and an upper part of the second section may be filled with gaseous fuel forming the separation layer. In between the subcooled fuel in the lower part and the gaseous fuel in the upper part, the thermal isolation layer can be formed by warmer liquid fuel. This may enhance a thermal separation of the subcooled fuel in the lower part from the gaseous fuel in the upper part. In this preferred embodiment, the thermal isolation layer is a horizontal layer. The subcooled fuel in the lower part may not or only sparsely mix with the warmer fuel that forms the thermal isolation layer due to different densities.

[0023] In a preferred embodiment the subcooling and condensing unit further comprises at least one sieve plate in the second section.

[0024] The sieve plate preferably is a perforated plate or a sieve made of metal, e.g. steel (in particular stainless steel). The size and further details of the perforation are preferably chosen depending on the properties of the fuel that is supposed to be used. The sieve plate is preferably oriented parallel to the separating plate. Further, the sieve plate preferably is arranged in such a way that fuel that enters the second section has to penetrate the sieve plate before proceeding, e.g. further into the second section. Hence, the sieve plate is preferably situated close to the separating plate. The sieve plate reduces turbulences in fuel that penetrates the sieve plate. The above mentioned thermal separation between liquid subcooled fuel in the second section and warmer liquid fuel forming the thermal isolation layer could be reduced by such turbulences. Such turbulences could especially cause a state of subcooling to be lost.

[0025] In a further preferred embodiment of the subcooling and condensing unit, the temperature controller comprises at least one of the following

- a first part for controlling the temperature of fuel inside the first section of the subcooling and condensing unit, and
- a second part for controlling the temperature of fuel inside the second section of the subcooling and condensing unit.

[0026] The temperature controller is preferably divided into at least two parts. The separation of the temperature controller into parts enhances the above described effect of dividing the subcooling and condensing unit into sections, where liquid fuel in the first section and liquid fuel in the second section can be treated thermally in different ways.

[0027] In a further preferred embodiment of the subcooling and condensing unit, the first part of the temperature controller comprises a first heat exchanger, and the second part of the temperature controller comprises a second heat exchanger. The first heat exchanger and the second heat exchanger each can be flown through by a refrigerant, preferably at least temporarily consecutively by the same refrigerant. The temperature controller preferably further comprises at least

- an inlet, through which the refrigerant can enter the first heat exchanger,
- a first outlet, through which the refrigerant can leave the temperature controller after having flown through the first heat exchanger, and
- a second outlet, through which the refrigerant can leave the temperature controller after having flown through the first heat exchanger and through the second heat exchanger.

[0028] The subcooling and condensing unit further comprises at least one shut-off device for switching between different refrigerants and for opening and closing the first outlet and the second outlet of the temperature controller.

[0029] The first heat exchanger and the second heat exchanger are preferably tubes that are formed as to provide a favorable thermal coupling between fuel in the subcooling and condensing unit and the refrigerant. That means that the first heat exchanger and the second heat exchanger preferably span across the whole of the first section and the second section of the subcooling and condensing unit, respectively. The first heat exchanger and the second heat exchanger are preferably connected in such a way that a refrigerant may flow through the first heat exchanger and, optionally, subsequently through the second heat exchanger. The first heat exchanger and the second heat exchanger both are preferably made of a material that can withstand the relevant low temperatures when flown through by the refrigerant. This can be e.g. steel.

[0030] As a refrigerant preferably a liquefiable gas is used with an equilibrium temperature, depending on the respective pressure, lower than the respective equilibrium temperature of the fuel. In particular, LIN and/or GAN is used as the refrigerant. If LIN is used, fuel in the subcooling and condensing unit can be cooled and/or condensed because the equilibrium temperature of LIN is, depending on the respective pressures, usually lower than that of e.g. LNG. With GAN at a suitable temperature, LNG in the subcooling and condensing unit can be evaporated. Means for warming GAN might be included into the fueling system. In order to avoid congestions, freezing of the fuel has to be prevented. E.g., the freezing temperature of LNG is between 90.7 K and 91 K for pressures between 1 bar and 20 bar, respectively. To ensure a sufficiently high temperature of the LNG, LIN can be provided as the refrigerant at significantly high temperatures. For example, the equilibrium temperature of LIN is 94 K at 5 bar.

[0031] The inlet, the first outlet and the second outlet are arranged as to allow the refrigerant to flow either through the first part of the temperature controller, i.e. through the first heat exchanger, or to flow through both the first part and the second part of the temperature controller, i.e. the first heat exchanger and the second heat exchanger. Thereby, the temperature in the first section of the subcooling and condensing unit only and the tem-

perature in the whole subcooling and condensing unit can be controlled, respectively. For example, with the first heat exchanger being used with sufficiently warm GAN, fuel in the first section of the subcooling and condensing unit can be evaporated. This can cause an increase of the pressure in the first section, whereby gaseous fuel can preferably flow through the tube into the second section, forming the separation layer. Using LIN in the first heat exchanger combined with the second heat exchanger, fuel in the whole subcooling and condensing unit can be cooled and/or condensed. The second heat exchanger preferably comprises a cyclone, which is a device for preventing a liquid from exiting the heat exchanger towards the exhaust so that only a gas can be let out into the exhaust. This may save valuable LIN.

[0032] The temperature controller is preferably connected to supply means for the at least one refrigerant, e.g. to a LIN storage tank and/or a means for warming and/or evaporating LIN to GAN. Preferably, GAN is extracted from the top of the LIN storage tank. GAN is preferably warmed up by heat transfer from the environment. With the shut-off devices, it can be controlled, which of the available refrigerants is let into the temperature controller. Further, a flow rate of the refrigerant might be controlled. The shut-off devices are preferably valves that can be controlled electronically. Preferably, one or more of the shut-off devices is situated between the subcooling and condensing unit and the supply means for the at least one refrigerant. Further, the shut-off devices might be used in order to switch between using the first heat exchanger only and the first heat exchanger combined with the second heat exchanger. In a preferred example, the refrigerant can be let into the first heat exchanger via the inlet controlled by one of the shut-off devices. After having flown through the first heat exchanger, the refrigerant can either be let out of the temperature controller via the first outlet or let into the second heat exchanger. This might be controlled by another shut-off device, which is situated at the first outlet. If the refrigerant is let into the second heat exchanger, it might be let out of the temperature controller via the second outlet. At the second outlet, a further shut-off device can be situated.

[0033] Regarding energy consumption, an estimation is given for the example of LNG being cooled by LIN. The required amount of LIN is given for exemplary assumed values. The enthalpy of evaporation of LIN at 5 bar is ca. 172 J/g. Lowering the vapor pressure of LNG from 15 bar to 8 bar while maintaining the pressure above the liquid requires 2.09 J/g. That is, under the given assumptions, 1 g LIN is required for 82.5 g LNG. Further, condensing methane, which is the primary component of NG, from a gas into a liquid from a pressure level of 15 bar to a pressure level of 8 bar, requires 648 J/g. That is, under the given assumptions, 3.8 g LIN are required for condensing 1 g methane.

[0034] According to a further aspect of the present invention a method is provided for operating a fueling sys-

tem for managing the fuel content in a target tank that can be connected to the fueling system via a filling hose for a fuel having methane as its primary component is disclosed. The fueling system comprises a fuel storage tank and a subcooling and condensing unit. The method comprises at least one of the following steps that are performed in the subcooling and condensing unit:

- a) condensing fuel from the gaseous phase into the liquid phase, and
- b) subcooling fuel that is in the liquid phase.

[0035] Depending on a mode of operation of the fueling system, steps a) and b) can be performed in any suitable combination. That is, steps a) and b) especially do not have to be performed in the order given here.

[0036] Operating the fueling system relates to all conceivable actions a user or operator of the fueling system might perform in regular use of the fueling system. This might include interacting with the fueling system in order to initiate a process as well as observing and terminating the process. Especially, managing the fuel content of the target tank can be included in the operation of the fueling system. This preferably comprises filling and/or depressurizing the target tank. Below, this will be described in more detail.

[0037] The filling hose can be any hose suitable for the fuel that is supposed to be used. This means especially, that the filling hose has to be able to withstand the relevant low temperatures. The fuel is preferably stored in the fuel storage tank at a pressure high enough to allow a filling of the target tank. That is, the pressure in the fuel storage tank is supposed to be higher than the pressure in the target tank, and, therefore, higher than usual pressures in the target tank. The fuel in the fuel storage tank preferably is in or near phase equilibrium. That is, there is a liquid phase of the fuel coexisting with a gaseous phase of the fuel. Preferably, the filling hose terminates in a dispenser such as a filling gun.

[0038] The subcooling and condensing unit fulfills the dual function of both subcooling and condensing fuel. As with the subcooling and condensing unit only a single device is required for these two functions, this is both cost and energy efficient as described above. Preferably, the subcooling and condensing unit is one according to the present invention. It is preferably situated at the same or at a lower level than the target tank. After e.g. a filling of the target tank is completed, the filling hose is supposed to no longer contain liquid fuel. Otherwise, this fuel in the filling hose could warm up, causing losses. Situating the subcooling and condensing unit below the fuel storage tank further ensures that the pressure in the subcooling and condensing unit is higher than in the fuel storage tank, given there is no closed valve in between.

[0039] In step a), fuel is preferably condensed by lowering the temperature in the subcooling and condensing unit with a temperature controller, preferably by a temperature controller as described above. Preferably, a

condensation rate of e.g. 0.5 l liquid per minute or more is achieved, which is equal to 30 l liquid / hour plus the condensation in the first part being used to pressurize the second part / the 30 l LNG to press it back into the storage to avoid boil off. Reducing the pressure of the target tank can consume less time. That is because the target tank is nearly empty when being filled so that only gas should be condensed and very low liquid should be cooled down.

[0040] For step b), the temperature controller can be used as well. Step b) might be considered an extension of step a).

[0041] In a further preferred embodiment, a method is provided that further comprises extracting liquid sub-cooled fuel from the subcooling and condensing unit by increasing the pressure of gaseous fuel in the subcooling and condensing unit by locally increasing the temperature of fuel in the first section of the subcooling and condensing unit.

[0042] Liquid fuel can be extracted from the subcooling and condensing unit by increasing the pressure inside the subcooling and condensing unit. Increasing the pressure of the fuel can be especially achieved by increasing the temperature of the fuel. Preferably, the fuel that is extracted is not warmed, but rather remains sufficiently cold, i.e. subcooled, as to remain liquid even when transferred through pipes. However, an increasing pressure likely coincides with an increasing temperature. Therefore, the increasing of the temperature is preferably limited locally, e.g. to the first section, while liquid fuel from the second section can be extracted.

[0043] According to a further preferred embodiment, a method is proposed that further comprises generating a separation layer between subcooled liquid fuel in the second section of the subcooling and condensing unit and fuel with a temperature that is increased due to the step of locally increasing the temperature in the first section of the subcooling and condensing unit, so that the liquid subcooled fuel that is extracted from the subcooling and condensing unit remains subcooled during the extraction process.

[0044] The temperature of fuel in the first section can be increased locally, while the separation layer thermally decouples this fuel from liquid subcooled fuel in the second section. That is, the pressure in the subcooling and condensing unit can be increased, while at least the liquid subcooled fuel in the second section may remain subcooled while being extracted.

[0045] Even if the subcooling and condensing unit is situated below the fuel storage tank, it can be used to condense fuel in order to lower the pressure in the fuel storage tank without using any pump. Therefore, the fuel is condensed in the subcooling and condensing unit, subsequently subcooled in the subcooling and condensing unit and finally extracted from the subcooling and condensing unit and moved back into the storage tank due to the pressure created by increasing the temperature of fuel in the first section of the subcooling and condensing

unit.

[0046] According to a further preferred embodiment the separation layer is generated by evaporating fuel in the first section of the subcooling and condensing unit.

5 [0047] Especially if the subcooling and condensing unit is filled with liquid fuel completely or almost completely, the gas that is supposed to form the separation layer can be obtained by evaporating liquid fuel that is already inside the subcooling and condensing unit. The separation layer is hence generated from the fuel itself with no external source of a gas being required.

10 [0048] According to a preferred embodiment the fuel storage tank is refilled with fuel from an external fuel supply tank, wherein the fuel from the external supply tank is subcooled in the subcooling and condensing unit before it is filled into the fuel storage tank.

15 [0049] Once the fuel storage tank needs to be refilled, an external supply tank can be connected to the fueling system. Preferably, this external supply tank is that of a tank truck. The preferred process described in the following can be initiated, e.g., by the identification of the tank truck. Then, the subcooling and condensing unit is cooled down. Once it is sufficiently cold, fuel can be moved from the external supply tank into the fuel storage tank while slowly passing the subcooling and condensing unit. Thereby, the fuel preferably is let into the fuel storage tank at the bottom of the fuel storage tank. Alternatively, e.g. if the fuel in the external supply tank is already sufficiently cold, the fuel can be moved from the external supply tank into the fuel storage tank directly, i.e. without passing the subcooling and condensing unit. Preferably, in this case the fuel is let into the top of the fuel storage tank via a respective intake. After the filling of the fuel storage tank the subcooling and condensing unit preferably is emptied to minimize losses.

20 [0050] According to a preferred embodiment the method further comprises at least one of the following steps:

- 40 α) reducing the pressure in the fuel storage tank or in the target tank,
- β) depressurizing the target tank to a remaining minimum pressure,
- γ) filling the target tank with fuel stored in the fuel storage tank, and
- 45 δ) reducing the temperature in the target tank by performing steps β) and γ) alternately.

[0051] Depending on a mode of operation of the fueling system, steps α), β) and γ) can be performed in any suitable combination. That is, steps α), β) and γ) especially do not have to be performed in the order given here.

50 [0052] The subcooling and condensing unit can be used for condensing gaseous fuel to liquid fuel, e.g. to reduce the pressure in the fuel storage tank and/or in the target tank (boil off condensation) according to step α). Therefore, gaseous fuel preferably is filled into the subcooling and condensing unit, where it can be condensed. After condensing, the liquid fuel can be extracted from

the subcooling and condensing unit by the method described above. If the subcooling and condensing unit volume is insufficiently small, step α) can be performed repeatedly. Regarding the fuel storage tank, this process is preferably performed at times the fueling system is less likely to be used, e.g. at night. The process can be triggered automatically, e.g. once the pressure in the fuel storage tank exceeds a predefined limit. If the fueling system is used frequently, this process does not have to be performed very often. If the fueling system is used less frequently, there is enough time for this process. Preferably, a possibility is provided for switching from step α) to step γ) immediately.

[0053] Besides the filling of a target tank, it can be advantageous to have a method provided for depressurizing it according to step β). For example, if a vehicle is expected to be put out of service for some time, fuel losses can be avoided by depressurizing the tank of the vehicle. Further, vehicles parked e.g. in a garage must not emit NG as this would be dangerous. An increased pressure in a vehicle tank could e.g. be reduced by burning NG/LNG. However, this would be inefficient and would cause the undesired emission of carbon dioxide. Further, depressurizing the target tank can be useful for maintenance purposes.

[0054] Depressurizing the target tank to a remaining minimum pressure can be achieved by extending the above described step α). Thereby, the pressure in the target tank is lowered until a predetermined minimum pressure is reached that remains in the target tank.

[0055] Further, the fueling system can be used to fill the target tank with fuel from the fuel storage tank according to step γ), which is preferably initiated by a user or operator of the fueling system. This can be done, e.g., by taking the filling hose out of a holder or by interacting with the fueling system via a user interface. Then, the subcooling and condensing unit can be cooled down. Preferably, all sections of the temperature controller are thereby used simultaneously. If necessary, the subcooling and condensing unit can be filled with fuel from the fuel storage tank. The target tank can be connected to the filling hose of the fueling system. A predetermined minimum pressure assigned to the fuel in the target tank may be required in order to ensure that such a target tank is actually connected to the system. If the pressure in the target tank is too high, i.e. higher than a predetermined maximum value, it can be lowered by the previously described step α). As the pressure in the subcooling and condensing unit and in the fuel storage tank can be higher than in the target tank, the target tank can be filled with preferably subcooled fuel from the subcooling and condensing unit. Preferably, a filling rate of e.g. 80 l/min or more is achieved. The fueling process can be terminated if the target tank is full, a manual stop (e.g. pressing a button) or an emergency stop is performed, or if any other predetermined trigger causes a stop. The fact that the target tank is full may be detected, e.g., by detecting that the flow rate of fuel flowing into the target tank is lower

than a predetermined minimal value, or by detecting a pressure surge (so called Chart technology). After the filling of the target tank is completed, the subcooling and condensing unit preferably is emptied to minimize losses.

[0056] With step δ) the temperature in the target tank can be lowered. Therefore, fuel is extracted from the target tank according to step β), cooled (preferably subcooled) in the subcooling and condensing unit, and subsequently filled into the target tank according to step γ). Performing steps β) and γ) alternately means that after having performed steps β) and γ) a first time, steps β) and γ) may be performed a second time or even more times for an enhanced effect of lowering the temperature in the target tank.

[0057] According to a preferred embodiment the method further comprises deciding, which of the multitude of steps α), β) and γ) is performed once the target tank is connected to the fueling system. The decision is obtained in a control unit. The decision is based at least on information obtained by gauges in the fueling system that provide measurement values of

- a first pressure in the filling hose,
- a second pressure in the subcooling and condensing unit,
- a first temperature in the first section of the subcooling and condensing unit,
- a second temperature in the exhaust, and
- a flow between the subcooling and condensing unit and the filling hose.

[0058] This facilitates the usage of the fueling system because the status of the target tank that is connected to the system can be detected and an adequate process can be initiated automatically. The decision can be made by the control unit. The control unit preferably has at least access to information obtained by the gauges and is, therefore, preferably connected to at least one of the gauges. According to this information, the control unit determines, e.g., which valves have to be opened or closed. This opening and closing of valves is preferably performed automatically, e.g., by magnetic valves being connected to the control unit. The gauges can be any instruments that are suitable for measuring the respective quantities.

[0059] The first pressure in the filling hose is, e.g., used to detect if the pressure in the target tank is too high. If this is the case, the above described step α) might be initiated. The second pressure in the subcooling and condensing unit is preferably used to monitor the effect of valve regulation. Further, it can be taken into account to ensure that in the above described step α), condensed fuel only enters the fuel storage tank once the fuel pressure is sufficiently high, e.g. 1 bar above the pressure at the bottom of the fuel storage tank.

[0060] The first temperature in the first section of the subcooling and condensing unit is preferably measured at the top of the subcooling and condensing unit. There-

by, it can be detected if liquid fuel is at the top of the subcooling and condensing unit and hence, if the subcooling and condensing unit is filled with liquid fuel completely or almost completely. Therefore, the first temperature can be used to initiate the above introduced step of extracting fuel from the subcooling and condensing unit. The second temperature can be regarded as an indication for the state of the refrigerant that exits the temperature controller. Especially, if LIN/GAN is used as the refrigerant, it can be distinguished if LIN or GAN exits the temperature controller. In order to control the second temperature to a predetermined set point, the control unit may adjust the temperature controller, e.g. by adjusting a flow of a refrigerant.

[0061] The measurement of the flow can be performed in terms of a mass measurement. With the flow gauge the amount of fuel entering or leaving the target tank can be monitored. This information may be used, e.g. to invoice the amount of fuel delivered to a user of the fueling system.

[0062] Further, a fueling system is provided for managing the fuel content in a target tank that can be connected to the fueling system via a filling hose for a fuel having methane as its primary component. The fueling system comprises a fuel storage tank, a control unit and a subcooling and condensing unit as described. The fueling system may be operated by a method as described.

[0063] Those features of the described method that involve gauges can be performed preferably with a fueling system of a preferred embodiment that comprises at least one gauge that is connected to the control unit. The details and advantages disclosed for the method according to the present invention can be applied to the subcooling and condensing unit of the invention and the fueling system according to the invention and vice versa.

[0064] It should be noted that the individual features specified in the claims may be combined with one another in any desired technological reasonable manner and form further embodiments of the invention. The specification, in particular in connection with the figures, explains the invention further and specifies particularly preferred embodiments of the invention. Particularly preferred variants of the invention and also the technical field will now be explained in more detail on the basis of the enclosed figures. It should be noted that the exemplary embodiments shown in the figures are not intended to restrict the invention. The figures are schematic and may not be to scale. The figures display

1 and 2 in a first state;

Fig. 4 a schematic drawing of the example according to Fig. 3 in a second state;

Fig. 5 a schematic drawing of the example according to Figs. 3 and 4 in a third state; and

Fig. 6 a schematic drawing of a further embodiment of a subcooling and condensing unit.

[0065] Fig. 1 displays a fueling system 1 for LNG. LNG can be stored in an LNG storage tank 2. Further, there is a subcooling and condensing unit 4 that is shown in more detail in Fig. 2. A LIN storage tank 3 is provided for storing LIN. LIN pipes 10 and LNG pipes 23 connect elements of the fueling system 1. The LIN pipes 10 and the LNG pipes 23, the LNG storage tank 2, the LIN storage tank 3 and the subcooling and condensing unit 4 are thermally isolated, e.g. by vacuum isolation. The operation of the fueling system 1 is controlled by a control unit 8, which has access to the information obtained by several gauges that are described in more detail below. The control unit 8 controls magnetic valves that are described in more detail below as well. The connection between the control unit 8 and the gauges and the valves is realized by respective wires 9, which are depicted by dotted lines and/or wireless. The dotted line from the control unit 8 to the subcooling and condensing unit 4 summarizes, for simplicity, all connections between the control unit 8 and gauges and valves in and near the subcooling and condensing unit 4. These are not shown in Fig. 1, but are included in the more detailed depiction of the subcooling and condensing unit 4 in Fig. 2.

[0066] An LNG pipe 23 including a first valve 12 connects the bottom of the LNG storage tank 2 and the subcooling and condensing unit 4. An LNG pipe 23 including a second valve 13 connects the subcooling and condensing unit 4 and a target tank 7 via a flexible filling hose 11, which is indicated by a curvy line. The target tank 7 is detachable. The filling hose terminates in a dispenser (not shown). The target tank 7 is situated at the same or at a higher level than the subcooling and condensing unit 4. A LIN pipe 10 including a third valve 14 connects the LIN storage tank 3 and a LIN junction 18, where an external LIN supply tank or a LIN/dispenser (both not shown) can be connected to the fueling system 1 for either filling the LIN storage tank 3 or a separate target tank for LIN (also not shown). A LIN pipe 10 including a LIN supply valve 31 connects a bottom part of the LIN storage tank 3 and the subcooling and condensing unit 4. A LIN pipe 10 including a GAN supply valve 30 connects the subcooling and condensing unit 4 with an upper part of the LIN storage tank 3. An LNG pipe 23 including a fifth valve 16 connects the top of the LNG storage tank 2 and the bottom of the subcooling and condensing unit 4. Further, there is an LNG junction 17, where an external LNG supply tank (not shown) can be connected, e.g., in

Fig. 1 a schematic overview of a fueling system with a subcooling and condensing unit;

Fig. 2 a schematic detailed view of the subcooling and condensing unit according to Fig. 1;

Fig. 3 a schematic drawing of an example of the subcooling and condensing unit according to Figs.

order to refill the LNG storage tank 2.

[0067] The pressure can be monitored by a first pressure gauge 39 between the second valve 13 and the filling hose 11 as well as by a second pressure gauge 40 between the subcooling and condensing unit 4 and the first valve 12. The NG/LNG flow can be measured by a flow gauge 43 between the subcooling and condensing unit 4 and the filling hose 11.

[0068] Fig. 2 is a detailed drawing of the subcooling and condensing unit 4 of Fig. 1. The subcooling and condensing unit 4 can be filled with NG/LNG. It is divided horizontally into a first section 5 and a second section 6. The first section 5 and the second section 6 are separated by a separating plate 19. The separating plate 19 fits tightly into the subcooling and condensing unit 4, i.e. there is no gap between the separating plate 19 and walls of the subcooling and condensing unit 4 through which NG or LNG could penetrate. A sieve plate 44 is arranged in the second section 6 parallel to the separating plate 19. The sieve plate 44 also fits tightly into the subcooling and condensing unit 4. A tube 20 with a first opening 21 in the first section 5 and a second opening 22 in the second section 6 connects the first section 5 and the second section 6 of the subcooling and condensing unit 4. The temperature in the first section 5 of the subcooling and condensing unit 4 is measured by a first temperature gauge 41.

[0069] A temperature controller 24 comprising a first part 25 and a second part 26 is integrated into the subcooling and condensing unit 4. The first part 25 of the temperature controller 24 is realized by a first heat exchanger 27 situated in the first section 5 of the subcooling and condensing unit 4. The second part 26 of the temperature controller 24 is realized by a second heat exchanger 28 situated in the second section 6 of the subcooling and condensing unit 4. For reasons of clarity, the second heat exchanger 28 is depicted by dotted lines, while the first heat exchanger 27 is depicted by solid lines. The first heat exchanger 27 is connected to an inlet 29, which, via the fourth valve 15, is connected to the GAN supply valve 30 and the LIN supply valve 31, through which the refrigerants GAN and LIN can be supplied, respectively. Further, the first heat exchanger 27 is connected to a first outlet 32, where the refrigerant can be directed out of the first heat exchanger 27 via a GAN exhaust valve 35 and an exhaust 34. The first heat exchanger 27 is also connected to the second heat exchanger 28. The second heat exchanger 28 comprises a cyclone 37. The second heat exchanger 28 is connected to a second outlet 33, which is connected to the exhaust 34 via a LIN exhaust valve 36. The temperature of the LIN or GAN in the exhaust can be measured by a second temperature gauge 42.

[0070] Not included in Fig. 2 are especially the wires 9 that connect the valves and gauges to the control unit 8. However, all valves and gauges included in Fig. 2 are connected to the control unit 8 by wires 9. A method of extracting fuel from the subcooling and condensing unit

4 is described with reference to Figs. 3 to 5. Therein, the subcooling and condensing unit 4 from Fig. 1 and Fig. 2 is shown, whereby features less relevant for the explanation (such as the sieve plate 44) are omitted in Figs. 3 to 6 for reasons of clarity.

[0071] Fig. 3 depicts a first state of the subcooling and condensing unit 4 during a first stage of the method for extracting fuel from the subcooling and condensing unit 4. The subcooling and condensing unit 4 is assumed to be filled with LNG up to a level within the first section 5 indicated by an area filled with a dashed pattern. The remainder of the subcooling and condensing unit 4 is filled with NG. The temperature in the first section 5 of the subcooling and condensing unit 4 can be increased by guiding a suitable refrigerant, e.g. warmed GAN, through the first heat exchanger 27. The second heat exchanger 28 is not shown, as it is not involved at this stage of the method. With increasing temperature, the LNG in the first section 5 of the subcooling and condensing unit 4 vaporizes in part to NG, increasing the pressure in the subcooling and condensing unit 4.

[0072] Fig. 4 depicts the subcooling and condensing unit 4 in a second state corresponding to a second stage of the method of extracting fuel from the subcooling and condensing unit 4. The subcooling of LNG in the second section 6 of the subcooling and condensing unit 4 is maintained, even while the temperature of NG/LNG in the first section 5 is increased. A separation layer 45 is introduced between LNG in the first section 5 and LNG in the second section 6 of the subcooling and condensing unit 4 by guiding NG from the first section 5 through the tube 20 into the second section 6. A thermal isolation layer 38 is formed as a layer of warmer LNG between the subcooled LNG in the second section 6 and the separation layer 45. The thermal isolation layer 38 is formed by LNG and is indicated by a dotted line.

[0073] Fig. 5 displays the subcooling and condensing unit 4 in a third state corresponding to a third stage of the method of extracting fuel from the subcooling and condensing unit 4. At this stage, there is only a small amount of LNG left at the bottom of the subcooling and condensing unit 4. At this stage, the process may be terminated, ensuring that no NG is extracted from the subcooling and condensing unit 4.

[0074] Fig. 6 is an alternative embodiment of the subcooling and condensing unit 4, wherein the tube 20 is not arranged inside the subcooling and condensing unit 4. Instead, the tube 20 is arranged at the outside. It is referred to the description of Figs. 1 to 5 regarding the further features of this subcooling and condensing unit 4.

[0075] A fueling system is proposed, wherein only one single device can be used for both subcooling and condensing fuel, while no specialized fuel storage tank or additional pump is required.

List of reference numerals

[0076]

1	fueling system		- a second section (6),
2	fuel storage tank		- a separating plate (19) between the first section
3	LIN storage tank		(5) and the second section (6), and
4	subcooling and condensing unit		- a tube (20) having a first opening (21) in the
5	first section	5	first section (5) and a second opening (22) in the
6	second section		second section (6) of the subcooling and condensing unit (4),
7	target tank		
8	control unit		
9	wires		
10	LIN pipes	10	wherein the first section (5), the second section (6),
11	filling hose		the separation plate (19) and the tube (20) are ar-
12	first valve		anged in such a way that a separation layer (45)
13	second valve		and a thermal isolation layer (38) can be generated,
14	third valve		wherein the separation layer (45) comprises gase-
15	fourth valve	15	ous fuel for thermally isolating liquid fuel being evap-
16	fifth valve		orated in the first section (5) from subcooled liquid
17	LNG junction		fuel in the second section (6), and wherein the ther-
18	LIN junction		mal isolation layer (38) comprises liquid fuel for ther-
19	separating plate		mally isolating the gaseous fuel forming the separa-
20	tube	20	tion layer (45) from the subcooled liquid fuel in the
21	first opening		second section (6).
22	second opening		
23	LNG pipes		2. Subcooling and condensing unit (4) according to
24	temperature controller		claim 1, further comprising at least one sieve plate
25	first part	25	(44) in the second section (6).
26	second part		
27	first heat exchanger		3. Subcooling and condensing unit (4) according to
28	second heat exchanger		claim 1 or 2, wherein the temperature controller (24)
29	inlet		comprises at least one of the following
30	GAN supply valve	30	
31	LIN supply valve		- a first part (25) for controlling the temperature
32	first outlet		of fuel inside the first section (5) of the subcool-
33	second outlet		ing and condensing unit (4), and
34	exhaust		- a second part (26) for controlling the temper-
35	GAN exhaust valve	35	ature of fuel inside the second section (6) of the
36	LIN exhaust valve		subcooling and condensing unit (4).
37	cyclone		
38	thermal isolation layer		4. Subcooling and condensing unit (4) according to
39	first pressure gauge		claim 3, wherein the first part (25) of the temperature
40	second pressure gauge	40	controller (24) comprises a first heat exchanger (27),
41	first temperature gauge		wherein the second part (26) of the temperature
42	second temperature gauge		controller (24) comprises a second heat exchanger (28),
43	flow gauge		wherein the first heat exchanger (27) and the second
44	sieve plate		heat exchanger (28) each can be flown through by
45	separation layer	45	a refrigerant, and wherein the temperature controller
			(24) further comprises at least

Claims

1. Subcooling and condensing unit (4) for a fueling sys- 50
tem (1) for a fuel having methane as its primary com-
ponent, wherein the subcooling and condensing unit
(4) comprises
 - a temperature controller (24) for controlling the 55
temperature of fuel inside the subcooling and
condensing unit (4),
 - a first section (5),

- an inlet (29), through which the refrigerant can
enter the first heat exchanger (27),
- a first outlet (32), through which the refrigerant
can leave the temperature controller (24) after
having flown through the first heat exchanger
(27), and
- a second outlet (33), through which the refrig-
erant can leave the temperature controller (24)
after having flown through the first (27) and
through the second heat exchanger (28),

wherein the subcooling and condensing unit (4) fur-

ther comprises at least one shut-off device (30, 31, 35, 36) for switching between different refrigerants and for opening and closing the first outlet (32) and the second outlet (33) of the temperature controller (24).

5. Method for operating a fueling system (1) for managing the fuel content in a target tank (7) that can be connected to the fueling system (1) via a filling hose (11) for a fuel having methane as its primary component, wherein the fueling system (1) comprises a fuel storage tank (2) and a subcooling and condensing unit (4), and wherein the method comprises at least one of the following steps that are performed in the subcooling and condensing unit (4):

- a) condensing fuel from the gaseous phase into the liquid phase, and
- b) subcooling fuel that is in the liquid phase.

6. Method according to claim 5, further comprising extracting liquid subcooled fuel from the subcooling and condensing unit (4) by increasing the pressure of gaseous fuel in the subcooling and condensing unit (4) by locally increasing the temperature of fuel in the first section (5) of the subcooling and condensing unit (4).

7. Method according to claim 6, further comprising generating a separation layer (38) between subcooled liquid fuel in the second section (6) of the subcooling and condensing unit (4) and fuel with a temperature that is increased due to the step of locally increasing the temperature in the first section (5) of the subcooling and condensing unit (4), so that the liquid subcooled fuel that is extracted from the subcooling and condensing unit (4) remains subcooled during the extraction process.

8. Method according to claim 7, wherein the separation layer (38) is generated by evaporating fuel in the first section (5) of the subcooling and condensing unit (4).

9. Method according to one of claims 5 to 8, further comprising refilling the fuel storage tank (2) with fuel from an external fuel supply tank, wherein the fuel from the external supply tank is subcooled in the subcooling and condensing unit (4) before it is filled into the fuel storage tank (2).

10. Method according to one of claims 5 to 9, further comprising at least one of the following steps:

- α) reducing the pressure in the fuel storage tank (2) or in the target tank (7),
- β) depressurizing the target tank (7) to a remaining minimum pressure,
- γ) filling the target tank (7) with fuel stored in the

fuel storage tank (2), and

δ) reducing the temperature in the target tank by performing steps β) and γ) alternately.

11. Method according to claim 10, further comprising deciding, which of the multitude of steps α), β) and γ) is performed once the target tank (7) is connected to the fueling system (1), wherein the decision is obtained in a control unit (8), and wherein the decision is based at least on information obtained by gauges (39, 40, 41, 42, 43) in the fueling system (1) that provide measurement values of

- a first pressure in the filling hose (11),
- a second pressure in the subcooling and condensing unit (4),
- a first temperature in the first section (5) of the subcooling and condensing unit (4),
- a second temperature in the exhaust (34), and
- a flow between the subcooling and condensing unit (4) and the filling hose (11).

12. Fueling system (1) for managing the fuel content in a target tank (7) that can be connected to the fueling system (1) via a filling hose (11) for a fuel having methane as its primary component, wherein the fueling system (1) comprises a fuel storage tank (2), a control unit (8) and a subcooling and condensing unit (4) according to one of claims 1 to 4, and wherein the fueling system (1) can be operated by a method according to one of claims 5 to 10.

13. Fueling system (1) according to claim 12, further comprising at least one gauge (39, 40, 41, 42, 43) that is connected to the control unit (8), wherein the fueling system (1) further can be operated by a method according to claim 11.

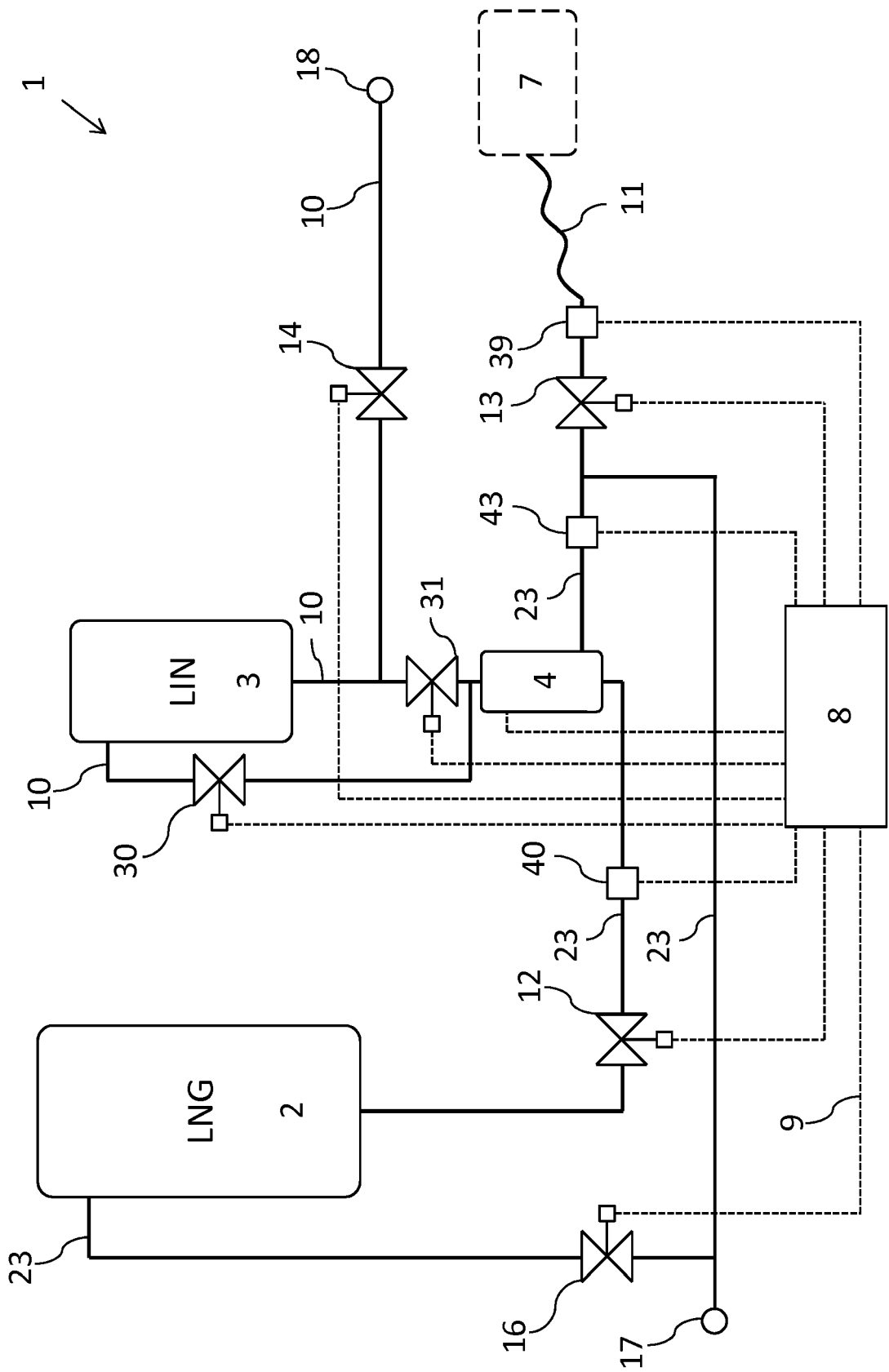
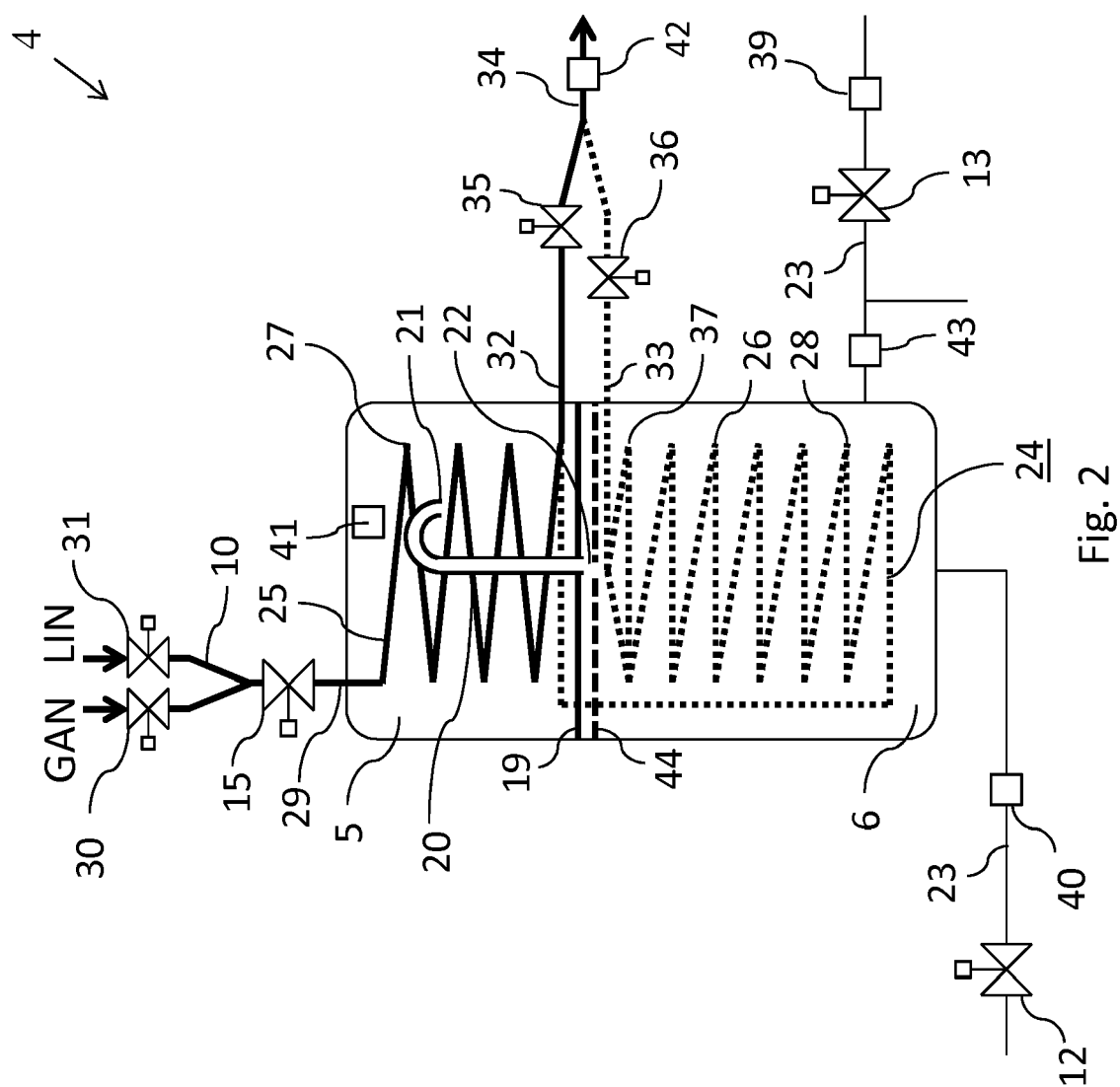


Fig. 1



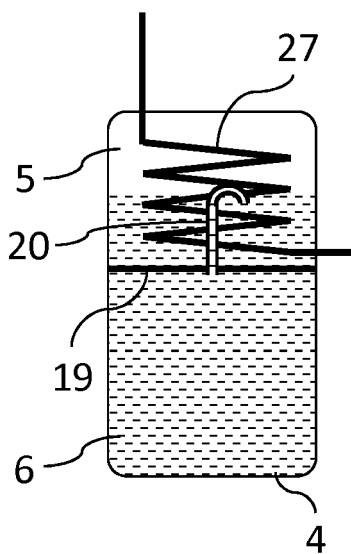


Fig. 3

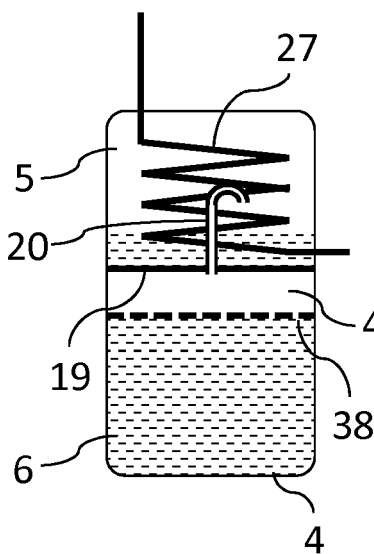


Fig. 4

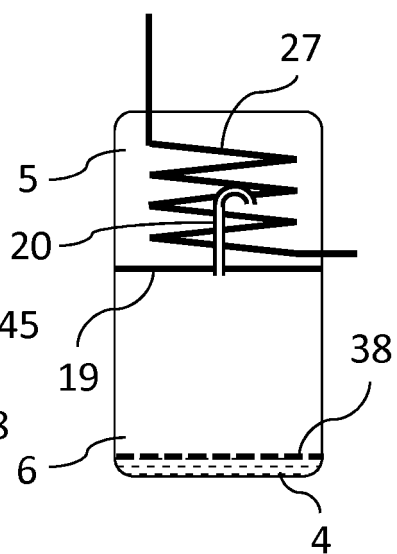


Fig. 5

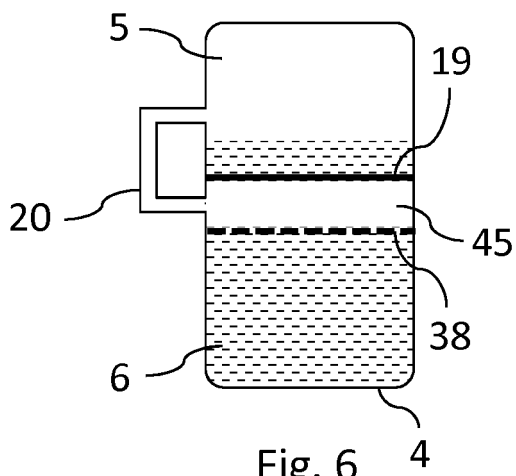


Fig. 6



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