

Process for controlling a methane number of a liquefied natural gas and corresponding control system

The field of the present invention is that of systems for controlling a methane number of a liquefied natural gas, notably in order to be able to use said liquefied natural gas as an engine fuel.

Liquefied natural gas, commonly referred to by the abbreviation "LNG", is an important energy source, composed of about 90% methane. More particularly, LNG is stored in the liquid state in a heat-insulated tank at a temperature close to -160°C, the LNG then occupying 1/600 of the volume that it would occupy in gaseous state, making it possible to facilitate transportation between an extraction site and a destination site of the LNG.

LNG may also be used as fuel for a vehicle, and notably for a ship, such as a cargo ship, for example an oil tanker, a methane tanker or a container ship. For ecological and economic reasons, the use of LNG as fuel is thus advantageous when compared with conventional fuels, notably petroleum-based fuels.

In order to be used as engine fuel, LNG must have a methane number between a minimum target value and a maximum target value tolerated by the engine. The methane number is a value corresponding to the methane content of the LNG, reflecting the quality of the LNG and in particular its capacity for resistance to engine auto-ignition. The use of an LNG having a methane number that is not between the minimum target value and the maximum target value tolerated by the engine would run the risk of causing a decrease in the engine performance, or even mechanical degradation of the engine, notably due to the appearance of a phenomenon known as "pinking", resulting from abnormal combustion.

Furthermore, the methane number of a liquefied natural gas is dependent on several parameters, such as the initial composition of the LNG, the duration of storage or the storage conditions. More particularly, due to the preferential evaporation of LNG components with a high methane number, notably methane, and despite the heat insulation of the tank in which the LNG is stored, the methane

number has a tendency to decrease over time, thus imposing constraints on the monitoring of the methane number, and also on the fuel supply of the engine. Thus, ships incorporating systems for measuring the methane number of LNG and for adjusting it if necessary by means of a phase separator separating light LNG hydrocarbons, on the one hand, such as methane and ethane, which have a high methane number, and heavy LNG hydrocarbons, on the other hand, such as butane and propane, which have a negative impact on the methane number of the cargo, are known. Thus, via a known system, a ship propulsion engine can use LNG as fuel.

Such known systems have the drawback of requiring heavy technical means. Moreover, these known systems do not make it possible to slow down or even to prevent the preferential evaporation of the LNG stored in the tank, and thus do not prevent the reduction of the methane number of the LNG over time.

The aim of the present invention is to at least partly address the drawbacks mentioned previously and also to lead to other advantages. Thus, the aim of the invention is to maintain the methane number of a liquefied natural gas above a determined threshold. An aim of the present invention is also to slow down the reduction of the methane number of LNG over time, so that the LNG can be used as engine fuel throughout its transportation.

The invention achieves this, according to a first aspect, by means of a process for controlling a methane number of a liquefied natural gas stored in a tank, the control process comprising:

- a step of estimating the methane number of the liquefied natural gas;
- a step of comparison between the methane number estimated in the estimation step and a target methane number;
- a step of active adjustment of the pressure of a tank headspace as a function of the comparison between the estimated methane number and the target methane number.

This configuration according to the invention makes it possible to prevent, or at least to reduce, the variations in the methane number of the LNG stored in the tank. Specifically, when the methane number changes, the pressure in the tank headspace is adjusted so as to keep the estimated methane number at the required level. The pressure in the tank headspace may be understood as being a stable value over a period of time or as a value, measured in millibar per hour, which changes over time, for example 10 millibar per hour, notably due to the evaporation of the LNG stored in the tank, said LNG then passing from the liquid state to the gaseous state.

The pressure adjustment performed by the active adjustment step is between 20 millibar and 400 millibar, more particularly between 20 millibar and 100 millibar and even more particularly between 20 millibar and 50 millibar, so that this adjustment remains compatible with the mechanical properties of the tank, notably in the case of a tank with an insulated primary membrane and an insulated secondary membrane. More particularly, when the LNG evaporates, passing from the liquid state to the gaseous state, the pressure inside the tank increases, the LNG in the gaseous state occupying a greater volume than in the liquid state. The gas thus formed then occupies a volume, known as the tank headspace, located between the LNG in the liquid state and a ceiling of the tank.

The LNG component which evaporates first is nitrogen, this component having a lower evaporation temperature than the other constituent components of LNG, for instance methane. Since nitrogen generally represents less than 1% of the volume of LNG, it evaporates very rapidly. The preferential evaporation of nitrogen leads to an increase in the methane number of the LNG, and more particularly of the LNG present in the liquid state in the tank. The evaporation of nitrogen is followed by an evaporation of methane, which has a boiling point of about -161°C at atmospheric pressure, methane representing about 90% of the volume of LNG. The evaporation of methane has the consequence of bringing about a reduction in the methane number of the LNG, and more particularly of the LNG present in the liquid state in the tank. In other words, the methane number of the LNG decreases over time inside the tank according to particular kinetics. Thus,

the methane number estimation step makes it possible to evaluate, directly or indirectly, the methane number of the LNG at a given moment.

The comparison step makes it possible to compare the methane number thus estimated with a target methane number, which represents a minimum value to be
5 respected in order to ensure optimum functioning of an engine intended to use LNG as fuel, the engine notably being intended for propelling a ship. Thus, the target methane number may be a minimum target value tolerated by the engine, the estimated methane number then needing to be greater than said minimum target value in order to avoid damaging the engine. The target methane number
10 may also be a range of values between which the methane number must be maintained, thus defining a minimum target value and a maximum target value, the target methane number then being between the minimum target value and the maximum target value. Thus, when the estimated methane number is below the minimum target value of the target methane number, the control process is
15 directed towards increasing the estimated methane number so that it becomes greater than the minimum target value. Similarly, when the estimated methane number is above the maximum target value of the target methane number, the control process may be directed towards reducing the methane number so that it becomes less than the maximum target value.

20 Finally, the step of active adjustment of the pressure in the tank headspace as a function of the comparison between the estimated methane number and the target methane number makes it possible to modify the estimated methane number, by acting on the pressure present in the tank headspace. As mentioned hereinabove, once the nitrogen has evaporated, the evaporation of the LNG brings
25 about a reduction in the methane number of the LNG over time. The active adjustment step notably comprises a step of adjusting the pressure in the tank headspace, making it possible to increase or decrease, if necessary, the pressure in the tank headspace. Thus, the increase in pressure in the tank headspace during the active adjustment step slows down or stops the process of natural
30 evaporation of the LNG stored in the tank, which is reflected by blocking of the change in the methane number of the LNG. In contrast, the decrease in pressure in the tank headspace during the active adjustment step, which accelerates the

process of natural evaporation of the LNG stored in the tank, makes it possible to reduce the methane number of the LNG.

It is understood that the step of active adjustment of the pressure in the tank headspace differs from the passive change in pressure in the tank headspace, notably due to the natural evaporation of the LNG in the liquid state, then passing into the gaseous state. Thus, the step of active adjustment of the pressure in the tank headspace is notably performed by means of a device for adjusting the pressure in the tank headspace, making it possible, if necessary, to bring about an increase or a decrease in the pressure in this tank headspace.

Thus, the control process in accordance with the first aspect of the invention makes it possible to control the methane number of an LNG stored in a tank and intended to be used as fuel for an engine, mainly using liquid LNG as fuel, the control of the methane number of the LNG being performed by active adjustment of the pressure in the tank headspace.

The control process in accordance with the first aspect of the invention advantageously comprises at least one of the improvements below, the technical characteristics forming these improvements possibly being taken separately or in combination:

- the methane number estimation step comprises a step of direct determination of the methane number by analysis of the composition of the liquefied natural gas present in the tank. For example, the direct determination step involves an analysis by chromatography, or an analysis by spectrometry, making it possible to precisely determine the composition of the LNG in situ and at a given moment. Thus, by making it possible to precisely determine the composition of the LNG stored in the tank, the direct determination step makes it possible to calculate the methane number of the LNG stored in the tank, in situ and at a precise moment, the analysis of the composition of the LNG possibly being performed, advantageously, on a pipe for feeding the engine with LNG, the LNG being used as fuel for the engine, thus allowing determination of the composition of the LNG and thus direct determination of the methane number of the LNG directly before it is used as fuel for the engine. Specifically, the methane

number depends on the composition of the LNG and more particularly on the respective proportions of the components of the LNG and notably of the nitrogen, methane, ethane, butane, propane and carbon dioxide of which the LNG is composed. Thus, this step of direct determination of the methane number makes it possible, in conjunction with other steps, such as steps for measuring the pressure in the tank headspace and the temperature of the LNG stored in the tank, to determine the saturation pressure of the LNG, the saturation pressure of the LNG being the minimum pressure at and above which the passage of the LNG from the liquid phase to the gaseous phase is stopped. Thus, by knowing the saturation pressure of the LNG stored in the tank, the step of active adjustment of the pressure in the tank headspace makes it possible to increase the pressure of the gaseous phase of the LNG so that said pressure is greater than the saturation pressure of the LNG, then stopping the LNG evaporation process and thus inhibiting the reduction in the methane number of the LNG present in the liquid state stored in the tank. The active adjustment step increases the pressure in the tank headspace above the saturation pressure of the LNG stored in the tank, notably by a value of between 20 millibar and 400 millibar and more particularly between 20 millibar and 100 millibar.

- the methane number estimation step comprises a step of indirect determination of the methane number. More particularly, and according to a first alternative, the methane number is determined, during the indirect determination step, from the composition of the liquefied natural gas at the time of filling of the tank. Specifically, the initial composition of the LNG depends notably on its site of extraction. Thus, the initial composition of the LNG extracted from a particular extraction site is known. Since the methane number changes according to known kinetics involving various parameters, such as the initial composition of the LNG or the volume of LNG stored in the tank, it is possible to determine indirectly the composition of the LNG and thus the methane number, at a given moment, as a function of the initial composition of the LNG. According to a second alternative, the methane number is determined during the indirect determination step, at least partly, from indications coming from a pressure sensor in the tank headspace. Specifically, an increase in the pressure in the tank headspace, detected by the

pressure sensor, indicates that the process of evaporation of the LNG in the liquid state is taking place, and thus that the pressure in the tank headspace is less than the saturation pressure of the LNG stored in the tank, leading to a decrease in the methane number over time. Similarly, when the pressure in the tank headspace remains constant, the pressure in the tank headspace is greater than or equal to the LNG saturation pressure, the methane number then remaining stable over time.

- the active adjustment step is a step of increasing the pressure in the tank headspace when a decrease in the estimated methane number is detected. Thus, increasing the pressure in the tank headspace makes it possible to slow down, or even to stop, the evaporation of the LNG stored in the tank, and thus to slow down, or even to stop, the decrease in the methane number of the LNG stored in the tank. The pressure increase may be achieved, for example, by withdrawing, using a pump, LNG in the liquid phase and injecting it into the storage tank or else by stopping or slowing down the output of LNG in the gaseous phase out of the storage tank. Stopping or slowing down the output of LNG in the gaseous phase out of the storage tank may be obtained, firstly, by stopping or slowing down the functioning of a compressor which sucks in the tank headspace, and/or, secondly, by totally or partially closing a valve which places the tank headspace in communication with a pipe outside the tank.

- the active adjustment step comprises a step of determining the saturation pressure of the liquefied natural gas, a step of measuring the pressure in the tank headspace, a step of comparison between the pressure in the tank headspace and the determined saturation pressure, and a step of adjusting the pressure in the tank headspace. Thus, this configuration makes it possible notably to be able to adjust the pressure in the tank headspace so that this pressure is above the LNG saturation pressure, thus preventing evaporation of the liquid phase of the LNG so as to stop the decrease in the methane number of the LNG over time, when it has been determined that the methane number is about to pass below the minimum target value.

- the active adjustment step comprises a plurality of intermediate

adjustments of the pressure in the headspace. Thus, the pressure adjustments in the tank headspace are performed one after the other, i.e. in stages. The active adjustment step thus takes place in a stepwise, progressive manner over time. In other words, the pressure in the tank headspace is adjusted in several steps
5 between an initial pressure and a final pressure. This configuration makes it possible notably to adjust the pressure in the tank headspace, in several steps, each step being performed as soon as a reduction in the methane number is determined. Advantageously, the intermediate adjustments are increases in stages of the pressure in the tank headspace, so that, at each step, the pressure
10 in the tank headspace is slightly greater than the saturation pressure of the LNG stored in the tank. This configuration makes it possible to control the pressure in the tank headspace, and thus to maintain the methane number of the LNG stored in the tank, while at the same time limiting the heating of the LNG stored in the tank, in comparison with a configuration in which the pressure of the tank
15 headspace is modified by a single adjustment between the initial pressure and the final pressure. This configuration also makes it possible to conserve a safety margin relative to a maximum pressure tolerated by the tank, or else relative to an operational safety pressure, the process of natural evaporation of the LNG stored in the tank producing an increase in the pressure in the headspace.
20 Advantageously, the plurality of intermediate adjustments comprises between two and fifty adjustments each performed in stages. These intermediate adjustments form steps of the pressure control step.

- it will be noted that the step of estimating the methane number of the liquefied natural gas, the step of comparison between the estimated methane
25 number and the target methane number, and the active adjustment step are steps that may be performed iteratively, notably in the case of a pressure adjustment in stages.

- the control process comprises, following the step of determining the saturation pressure of the liquefied natural gas, a step of informing an operator
30 when the determined saturation pressure is greater than the pressure in the tank headspace. Thus, the operator is informed that the process of evaporation of the LNG stored in the tank is liable to take place, which may then potentially lead to a

decrease in the methane number, notably below the minimum target value tolerated by the engine, the operator then being able, for example, to take the necessary measures in order to increase the methane number of the LNG stored in the tank, or to reduce the load, and notably its rotation speed, of the engine
5 using the LNG as fuel in order to reduce the risk of deteriorating said engine.

- in one embodiment, the process is performed during a final period of the ship's journey, such a period corresponding, for example, to a second half of the ship's journey. The reason for this is that, since the liquid phase of the LNG decreases over time, notably due to the consumption of LNG by the ship's engine
10 during the journey, the decrease in the methane number of the LNG accelerates in the course of the ship's journey. This configuration of the invention thus makes it possible to slow down, or even to stop, the reduction in the methane number of the liquid LNG stored in the tank, when this reduction tends to be the fastest. Similarly, the process may be performed as a function of the amount of LNG in the liquid
15 state in the tank. Thus, the process may be performed when the LNG in the liquid state represents less than 50% of the volume of the tank, or else less than 60%, or else less than 70%, or less than 80%, or less than 90% of the volume of the tank.

- the process that is the subject of the invention may be performed over a period of between 7 days and 15 days, thus making it possible to conserve or at
20 least to slow down the decrease in the methane number of the LNG stored in the tank over time.

- irrespective of the case of implementation of the process that is the subject of the invention, it is estimated that the methane number of the LNG stored in the tank can be maintained in the order of 1 to 5 points, in comparison with a
25 configuration in which the process that is the subject of the invention is not implemented.

According to a second aspect, a subject of the invention is also a system for controlling a methane number of a liquefied natural gas, the control system comprising at least one calculator and a means for estimating the composition of
30 the liquefied natural gas (LNG) communicating with the calculator, the calculator driving a device for adjusting the pressure in the tank headspace as a function of

the information transmitted by the estimation means.

Thus, the control system makes it possible to modify the methane number of the LNG stored in the tank to maintain the methane number of the LNG intended to be used as engine fuel, above the minimum target value of the methane number tolerated by said engine, and optionally below the maximum target value of this methane number.

Moreover, this configuration has the advantage of being able to be performed easily on existing ships, this configuration not requiring any substantial structural modifications.

The control system in accordance with the second aspect of the invention advantageously comprises at least one of the improvements below, the technical characteristics forming these improvements possibly being taken separately or in combination:

- the pressure adjustment device comprises at least one compressor and/or one valve and/or one pump. More particularly, an inlet of the compressor communicates with the tank headspace, whereas an outlet of the compressor communicates with the engine which propels the ship. Thus, the compressor makes it possible to adjust the pressure in the tank headspace. Specifically, the rotation speed of the compressor, or the modification of its displacement, for example, acts directly on the pressure in the tank headspace, increasing the rotation speed of the compressor promoting the reduction of the pressure in the tank headspace, whereas reducing the rotation speed of the compressor brings about an increase in the pressure in the tank headspace, the pressure increase in the tank headspace then being due to the evaporation of the LNG stored in the tank until the saturation pressure is reached. Furthermore, the compressor makes it possible to heat the LNG in the gaseous state that is in the tank headspace, promoting its combustion in the engine. Preferably, the compressor is a six-stage compressor, thus allowing a high compression ratio of the gas between the compressor inlet and the compressor outlet. When the pressure adjustment device comprises a valve, said valve is connected to a pipe communicating with the tank headspace, the valve also being connected to a vent or else to a combustion

system, such as a boiler. Thus, the valve makes it possible to evacuate the gas that is in the tank headspace, thus making it possible to reduce the pressure prevailing in the storage tank. The gas thus evacuated is then advantageously directed towards a boiler, making it possible to burn the gas occupying the tank headspace, said gas notably being methane, so as to produce energy from its combustion. Optionally, before being conveyed to the boiler, the gas may circulate through a heat exchanger in order to be heated to promote its combustion. Alternatively or cumulatively, the gas present in the tank headspace is directed, after circulation through the valve, to a ventilation circuit in order to be released into the atmosphere via a ventilation tower. Thus, total or partial closure of the valve allows the pressure in the tank headspace to be increased. When the pressure adjustment device comprises a pump, the pump communicates fluidly with the LNG in the liquid state stored in the storage tank. Alternatively, the pump can function so as to pump LNG in the liquid state in order to reinject it in the liquid state into the tank headspace, thus bringing about an increase in the pressure in the tank headspace. Specifically, during the pumping of liquid LNG, it undergoes heating, notably due to its circulation through the pump, or else through the pipes connecting a part of the tank communicating with the liquid LNG to the tank headspace, or else due to pressurization of the LNG required for circulation of the LNG in said pipes. Thus, the saturation pressure of the LNG which is pumped by the pump is greater than the saturation pressure of the LNG stored in the tank. Thus, reinjection of the LNG pumped by the pump into the tank brings about an increase in the pressure in the tank headspace.

- the estimation means comprises a pressure sensor in the tank headspace and/or a chromatograph and/or a spectrometer configured to analyse the LNG in the liquid state, the estimation means comprising a calculating member which analyses the data from the pressure sensor, from the chromatograph and/or from the spectrometer. Thus, this configuration allows the calculator, driving the adjustment device, to adjust the pressure in the tank headspace as a function of the data coming from the pressure sensor, from the chromatograph and/or from the spectrometer, in order to modify the methane number of the LNG stored in the tank. Specifically, since the initial composition of the LNG is known, notably as a

function of the LNG extraction site, and the evaporation kinetics over time of the LNG stored in the tank are also known, as a function notably of the storage conditions, the tank headspace pressure data supplied by the pressure sensor make it possible to estimate, indirectly, the methane number of the LNG stored in the tank. Alternatively, the chromatograph and/or the spectrometer make it possible to determine the in situ composition of the LNG at a given moment, thus making it possible to estimate, directly, the methane number of the LNG stored in the tank.

According to a third aspect, a subject of the invention is a ship propulsion system comprising a control system in accordance with the second aspect of the invention, the propulsion system comprising an internal combustion engine using as fuel the liquefied natural gas stored in the tank to ensure, at least partially, the propulsion of the ship.

Thus, the propulsion system ensures the propulsion of the ship. More particularly, the internal combustion engine ensures the propulsion of the ship, the control system making it possible to adjust the methane number of the LNG used as fuel by the internal combustion engine above the minimum target value tolerated by the internal combustion engine, thus enabling the engine to function optimally, and with a reduced risk of mechanical deterioration.

According to a fourth aspect, a subject of the invention is a ship comprising a control system in accordance with the second aspect of the invention and/or a propulsion system in accordance with the third aspect of the invention.

Thus, this configuration ensures the propulsion of the ship by means of the control system and/or of the propulsion system, the ship using the LNG, the estimated methane number of which is greater than the minimum target value tolerated by the engine, as fuel. Advantageously, the ship is a methane tanker, the main cargo of which is LNG. Alternatively, the ship is an oil tanker, the main cargo of which is a petroleum-based product, such as liquefied petroleum gas, known by the abbreviation LPG, a container ship or any other type of ship.

Other characteristics, details and advantages of the invention will emerge

more clearly on reading the description that follows, on the one hand, and several implementation examples given as a nonlimiting guide with reference to the attached schematic drawings, on the other hand, in which:

- 5 - figure 1 is a schematic representation of an implementation example of a control process in accordance with the first aspect of the invention;
- figure 2 is a representation of the kinetics of change of the pressure in the tank headspace as a function of time during the application of an implementation example of a control process in accordance with the invention;
- 10 - figure 3 is a schematic representation of an implementation example of a propulsion system in accordance with the third aspect of the invention and comprising a control system in accordance with the second aspect of the invention;
- figure 4 is a schematic representation of a first mode of functioning of an implementation example of a propulsion system in accordance with the third
15 aspect of the invention;
- figure 5 is a schematic representation of a second mode of functioning of an implementation example of a propulsion system in accordance with the third aspect of the invention;
- figure 6 is a schematic representation of a third mode of functioning of an
20 implementation example of a propulsion system in accordance with the third aspect of the invention;
- figure 7 is a schematic illustration of an implementation example of a ship in accordance with the fourth aspect of the invention.

25 The characteristics, the variants and the various embodiments of the invention may be combined together, in various combinations, provided that they are not mutually incompatible or exclusive. Variants of the invention comprising only a selection of characteristics described hereinbelow in isolation from the other described characteristics, if this selection of characteristics is sufficient to give a

technical advantage or to differentiate the invention from the prior art, may notably be imagined.

In particular, all the variants and all the embodiments described may be combined together if there is nothing technically opposing this combination.

5 Figure 1 is a schematic representation of an implementation example of a process 1 for controlling a methane number of a liquefied natural gas (LNG hereinbelow) stored in a tank, the control process being in accordance with the first aspect of the invention.

10 Thus, the control process 1 schematically represented comprises a step 10 of estimating the methane number of the LNG followed by a step 20 of comparison between the methane number estimated in the estimation step 10 and a target methane number. The control process 1 comprises, following the comparison step 20, a step 30 of active adjustment of the pressure of a tank headspace as a function of the comparison between the estimated methane number and the target methane number, performed during the comparison step 20. Finally, the control process may comprise a step 40 of informing an operator.

20 More particularly, the estimation step 10 comprises a step 12 of direct determination or a step 14 of indirect determination of the methane number of the LNG stored in the tank. Thus, the direct determination step 12 makes it possible to know the composition of the LNG stored in the tank at a given moment. The direct determination step 12 notably involves a step of analysis by chromatography or by spectrometry. The composition of the LNG measured at a given moment and in situ makes it possible to determine, directly, the methane number of the LNG stored in the tank. Thus, the methane number of the LNG may be calculated using
25 the following formula:

$$MN = 1.445 \times (MON) - 103.42$$

where MON is the motor octane number, the MON being calculated from the formula:

$$MON = (137.78x_{\text{methane}}) + (29.948x_{\text{ethane}}) + (-18.193x_{\text{propane}}) + (-167.062x_{\text{butane}})$$

$$+ (181.233x_{\text{CO}_2}) + (26.994x_{\text{N}_2})$$

where x is the mole fraction of the corresponding methane, ethane, propane, butane, carbon dioxide and dinitrogen components, these components generally being included, in various contents, in the composition of an LNG.

- 5 The indirect determination step makes it possible, for its part, to indirectly estimate the methane number of the LNG, notably from the initial composition of the LNG, for example known as a function of the LNG extraction site.

- 10 The comparison step 20 makes it possible to compare the methane number estimated, directly or indirectly, in the estimation step 10 with a target methane number. The target methane number corresponds to a minimum methane number value in order for the LNG to be usable, safely, as fuel by the engine. Thus, the target methane number is notably greater than a minimum target value tolerated by said engine so as to ensure optimum functioning of the engine, i.e. without any risk of damaging the engine and/or without the need to reduce the engine
- 15 performance.

- 20 The active adjustment step 30 makes it possible to adjust the pressure in the tank headspace as a function of the comparison between the methane number estimated in the estimation step 10 and the target methane number. The LNG stored in the tank is present in the liquid state and in the gaseous state. The LNG in the gaseous phase, which has a lower density than in the liquid phase, is located at the surface of the LNG in the liquid phase, the gaseous phase thus occupying a volume known as the tank headspace and delimited, on the one hand, by the liquid phase of the LNG and, on the other hand, by the walls of the tank.

- 25 Specifically, the tank is delimited by walls, each wall comprising, for example, a leaktight primary membrane and a leaktight secondary membrane, between which is inserted an insulator promoting the thermal insulation of the tank. Thus, the increase in the pressure prevailing in the tank headspace must be particularly monitored, i.e. of the order of a few millibar above atmospheric pressure, in order
- 30 to ensure the integrity of the structure of the primary membrane and/or of the

secondary membrane.

Advantageously in the illustrated example, the active adjustment step 30 comprises a step of determining the saturation pressure 32 of the LNG stored in the tank according to the pressure, temperature and composition conditions of the LNG at the time of performing this step, followed by a step 34 of measuring the pressure in the tank headspace, and then a step 36 of comparison between the saturation pressure and the pressure in the tank headspace. The saturation pressure of the LNG corresponds to the pressure above which evaporation of the LNG is stopped. The step of measuring the pressure in the tank headspace is notably performed using a pressure sensor. Step 36 of comparison between the saturation pressure and the pressure in the tank headspace thus makes it possible to order a step 38 of correction, if necessary, of the pressure in the tank headspace as a function of the determined saturation pressure, notably in the case where the estimated methane number is different from the target methane number. More particularly, when the saturation pressure is greater than the pressure in the tank headspace, the LNG evaporation process takes place, leading to a reduction of the methane number. Thus, increasing the pressure in the tank headspace, so that said pressure is above the saturation pressure, makes it possible to stop the evaporation of the LNG, bringing about stoppage of the reduction of the methane number, the pressure in the tank headspace notably being from 20 millibar to 400 millibar above the saturation pressure.

Finally, the control process 1 example illustrated in figure 1 comprises a step 40 of informing an operator, notably when the saturation pressure, determined during step 32 of determining the saturation pressure, is greater than the pressure in the tank headspace, indicating that the LNG evaporation process is taking place inside the tank, potentially leading to a reduction in the methane number of the LNG. The operator thus informed can then take the necessary measures in order to stop the evaporation process, for example by increasing the pressure in the tank headspace so that said pressure is greater than the saturation pressure of the LNG stored in the tank, thus stopping the reduction in the methane number.

Thus, the control process 1 makes it possible to control the methane number

of the LNG stored in the tank by acting on the pressure in the tank headspace, and more particularly by authorizing the evaporation of the LNG when the estimated methane number is greater than the target methane number or else for as long as the estimated methane number is increasing, notably due to the preferential
5 evaporation of nitrogen. According to an alternative, the control process makes it possible to prohibit the evaporation of the LNG when the estimated methane number is less than the target methane number.

Figure 2 is a representation of the kinetics of change of the pressure P_a in the tank headspace as a function of time during the application of an
10 implementation example of a control process in accordance with the invention.

Thus, it is seen that the kinetics of change of the pressure P_a in the tank headspace takes place, in the illustrated implementation example, via several intermediate increases, in other words step by step, between an initial pressure P_i in the tank headspace, for example at the start of a phase of transportation of the
15 LNG stored in the tank between an extraction site and a use site, and a final pressure P_f in the tank headspace at the end of the transportation phase. Thus, the step-by-step increase in the pressure in the tank headspace is achieved by means of a plurality of intermediate increases P_a of the pressure in the tank headspace. More particularly, figure 2 illustrates a first pressure P_1 corresponding
20 to the maximum pressure that may be tolerated by the tank storing the LNG, and above which said tank might undergo damage putting its structural integrity at risk. Thus, the tank advantageously cooperates with an exhaust valve, the calibration adjustment of which is equal to the first pressure P_1 , the exhaust valve thus making it possible for the pressure in the tank headspace to not exceed the first
25 pressure P_1 .

Figure 2 also illustrates a second pressure P_2 , below the first pressure P_1 , and which corresponds to an operational safety pressure, also known by the abbreviation MOP meaning Maximum Operating Pressure, corresponding, for
30 example, to 90% of the first pressure P_1 . Specifically, due to the evaporation of the LNG stored in the tank over time, the pressure in the tank headspace has a tendency to increase naturally over time, making it necessary to use a second

pressure P2 whose value is below the first pressure P1 in order to prevent losses of the LNG by excessively frequent actuating of the exhaust valve. In one embodiment, the first pressure P1 is equal, for example, to 2 bar, the second pressure P2 being equal to 1.8 bar. Step-by-step increase in the pressure in the tank headspace over time makes it possible to stop the process of natural evaporation of the LNG stored in the tank while at the same time limiting the heating of said LNG due to the increase in pressure in the tank headspace.

A first time period T1 is noted during which the pressure Pa in the tank headspace is not affected by the process that is the subject of the invention, the first time period T1 taking place at the start of the period of change of pressure in the tank headspace illustrated in figure 2. In other words, the process in accordance with the first aspect of the invention is not performed during the first period T1, notably due to the fact that this is a period in which nitrogen evaporates, which contributes towards increasing the methane number.

The control process in accordance with the first aspect of the invention is performed at a time Ta, the time Ta allowing the definition of a second time period T2 during which the control process is performed. The time period T2 comprises a plurality of steps of increasing the pressure Pa in the tank headspace over time, enabling the pressure in the tank headspace to be slightly greater than the saturation pressure of the LNG stored in the tank, so as to stop the evaporation of the liquid phase of the LNG.

Other kinetics may be imagined, notably kinetics during which a phase of constant pressure in the tank headspace takes place after a period during which the pressure in the tank headspace has been increased by means of the invention, or else kinetics free of a specific period during which the pressure in the tank headspace remains constant.

In the kinetics illustrated in figure 2, it is noted that, during the second period T2 during which the control process is performed, the pressure increase over time takes place such that a first increase A1, for example of the order of 400 millibar, of the pressure in the tank headspace at the start of the second period T2 is greater than a second increase A2, for example 20 millibar, of the pressure in the

tank headspace at the end of the second period T2. In other words, the interval of increase in the pressure in the tank headspace decreases gradually as the control process in accordance with the invention is performed. This configuration makes it possible to slow down the increase in the pressure P in the tank headspace as this pressure approaches the second pressure P2 corresponding to an operational safety pressure of the tank, thus making it possible to perform the control process in accordance with the first aspect of the invention for a longer period of time. Without departing from the context of the invention, the increase in pressure in the tank headspace over time may be constant, provided that it is performed by the process that is the subject of the invention.

Figure 3 is a schematic representation of an implementation example of a propulsion system 55 in accordance with the third aspect of the invention and comprising a control system 50 in accordance with the second aspect of the invention. The control system 50 makes it possible to control a methane number of a natural gas stored in a tank 80.

The propulsion system 55 also comprises an internal combustion engine 52 which can notably ensure the propulsion of a ship comprising the propulsion system 55, the internal combustion engine 52 using the LNG stored in the tank 80 as fuel. Alternatively or cumulatively, the internal combustion engine 52 may also be coupled to an electrical energy storage device, the internal combustion engine 52 then functioning as the generator of an electrical machine. Thus, the control system 50 makes it possible to provide to the internal combustion engine 52 with an LNG as fuel, said LNG having a methane number between a minimum target value and a maximum target value tolerated by the internal combustion engine 52.

The control system 50 comprises a calculator 60 and a means 70 for estimating the pressure of a tank headspace 82 of an LNG storage tank 80. The tank headspace corresponds to the volume occupied by a gaseous phase 83 of the LNG, said gaseous phase being located at the surface of a liquid phase 84 of the LNG stored in the tank 80. The estimation means 70 comprises a pressure sensor 72 in the tank headspace, the pressure sensor 72 transmitting data relating to the pressure in the tank headspace to a calculating member 74 communicating

with the calculator 60 so that said calculator drives the device 90 for adjusting the pressure in the tank headspace 82 as a function of the data from the pressure sensor 72.

5 The control system 50 also comprises the device 90 for adjusting the pressure in the tank headspace 82 driven by the calculator 60, the device 90 for adjusting the pressure in the tank headspace comprising, in the illustrated embodiment, a compressor 92, a pump 94 and/or a valve 96. The adjustment device 90 makes it possible to act on the pressure in the tank headspace, by increasing or decreasing said pressure, so as to modify the methane number of
10 the LNG stored in the tank, and more particularly to stop the decrease in the methane number of the LNG stored in the tank, so as to feed LNG to the internal combustion engine 52 which ensures the propulsion of the ship and which uses the LNG stored in the tank 80 as fuel.

Specifically, due to the preferential evaporation of certain compounds of the
15 LNG stored in the tank, the methane number of the LNG changes over time. Thus, during the evaporation of nitrogen, the methane number increases over time. Then, during the evaporation of methane, the methane number decreases over time. It is thus necessary to control the methane number of the LNG in order to ensure that said number is between a minimum target value and a maximum
20 target value tolerated by the internal combustion engine 52.

Thus, the estimation means 70 makes it possible to estimate or to measure, directly or indirectly, the methane number of the LNG stored in the tank 80. The pressure sensor 72 makes it possible to detect changes in the pressure in the tank headspace 82, the pressure sensor then transmitting information relating to the
25 pressure in the tank headspace to the calculating member 74, thus making it possible to know whether the LNG stored in the tank has or has not undergone an evaporation process potentially leading to a modification of the methane number of said LNG.

As a function of the information received by the pressure sensor 72, the
30 estimation means 70 drives the adjustment device 90 so that said device modifies, if necessary, the pressure in the tank headspace, in order for the LNG stored in

the tank to have a methane number tolerated by the internal combustion engine 52. More particularly, the increase in pressure in the tank headspace 82 such that it is greater than a saturation pressure of the LNG makes it possible to stop the LNG evaporation process, thus making it possible to prevent the reduction of the methane number of the LNG over time.

Modes of functioning of the control system 50 making it possible to modify the pressure in the tank headspace 82 so as to modify, if necessary, the methane number of the LNG, are detailed in figures 4, 5 and 6. In order to facilitate comprehension, only the elements required for each illustrated mode of functioning are represented in these figures. These modes of functioning may notably be used independently of each other, or may be combined together in various combinations, as illustrated by figure 3.

Figure 4 is a schematic representation of a first mode of functioning of an implementation example of a propulsion system 55 in accordance with the third aspect of the invention.

Thus, figure 4 illustrates the functioning of the compressor 92 of the device 90 for adjusting the pressure in the tank headspace 82.

The compressor 92 communicates with the tank headspace 82. More particularly, an inlet of the compressor communicates with the tank headspace, whereas an outlet of the compressor communicates with the internal combustion engine 52. The LNG in the gaseous state, entering the compressor, is compressed between the compressor inlet and the compressor outlet. Thus, increasing the rotation speed or the displacement of the compressor brings about a decrease in the pressure in the tank headspace, whereas decreasing the rotation speed or the displacement of the compressor brings about an increase in the pressure in the tank headspace, notably leading to lowering of the methane number or stabilization of the methane number of the LNG stored in the tank, respectively, thus allowing feeding as a fuel for an internal combustion engine 52 compatible with the minimum required by the internal combustion engine 52. More particularly, the compressor 92 notably makes it possible to adjust the pressure in the tank headspace 82 relative to the saturation pressure of the LNG, so as to authorize or

prohibit the evaporation of the LNG, and thus to adapt the methane number as a function of the indications from the estimation means 70. Moreover, the compressor 92 makes it possible to heat the LNG intended to be used as fuel by the internal combustion engine 52, thus promoting its combustion.

- 5 Advantageously, the internal combustion engine 52 may be coupled to an electrical energy storage device 87, such as an electric battery, via a device, not shown, for converting mechanical energy into electrical energy, such as an alternator, thus enabling the internal combustion engine 52 to provide electrical supply to at least one peripheral of the ship requiring electrical energy to function.
- 10 The internal combustion engine 52 may thus be an engine for propelling the ship, but the invention also covers the case where the internal combustion engine 52 is dedicated to ship accessories, notably for forming an electrical generator.

Figure 5 is a schematic representation of a second mode of functioning of an implementation example of a propulsion system 55 in accordance with the third
15 aspect of the invention.

Thus, figure 5 illustrates the functioning of the pump 94 of the device 90 for adjusting the pressure in the tank headspace. The pump 94 communicates, on the one hand, with the liquid phase 84 of the LNG stored in the tank 80 and, on the other hand, with the tank headspace 82, a stopping device 85 being located
20 between the pump 94 and the tank headspace 82 and making it possible to authorize or to prohibit the circulation of the LNG between the pump and the tank headspace. The stopping device 85 may notably be a two-way valve. Thus, activation of the pump 94 brings about pumping of the liquid phase of the LNG which is then reinjected into the gaseous phase present in the tank headspace 82,
25 thus leading to an increase in pressure in the tank headspace, notably due to the increase in the saturation pressure of the LNG consecutive to its heating following its pumping by the pump 94, the saturation pressure of the pumped LNG thus being greater than the saturation pressure of the LNG stored in the tank. The reinjection of the LNG pumped into the tank headspace 82 then brings about an
30 increase in pressure in the tank headspace, as desired by the process according to the invention. The increase in pressure in the tank headspace 82 thus brought

about therefore allows stabilization of the methane number by stopping or slowing down the process of evaporation of the LNG stored in the tank, by adjusting the pressure in the tank headspace as proposed by the invention.

Moreover, the pump 94 also communicates with the internal combustion engine 52. Thus, the pump allows the internal combustion engine 52 to be fed with LNG, the LNG then being used as fuel for the internal combustion engine 52. Advantageously, an evaporation device 99 is inserted between the pump 94 and the internal combustion engine 52, making it possible to pass the LNG, in the liquid state, pumped by the pump 94, to the gaseous state in order to transfer it to the internal combustion engine 52.

The propulsion system 55 may also comprise a boiler 86 configured to use the LNG stored in the tank as fuel, in order to produce energy. In the implementation example illustrated, the evaporation device 99 is inserted between the pump 94 and the boiler 86, thus allowing the boiler to use the LNG, in the gaseous state, as fuel.

The internal combustion engine 52 and the boiler 86 may be coupled to an electrical energy storage device 87, thus making it possible, for example, to electrically supply a peripheral of the ship. Advantageously, the internal combustion engine 52 and the boiler 86 are arranged in parallel, each thus being able to supply the electrical energy storage device 87 independently.

Figure 6 is a schematic representation of a third mode of functioning of an implementation example of a propulsion system 55 in accordance with the third aspect of the invention.

Thus, figure 6 illustrates the functioning of the valve 96 which forms an implementation example of the device 90 for adjusting the pressure in the tank headspace 82. The valve communicates with the tank headspace 82. Thus, opening the valve 96, or increasing the opening of the valve 96, makes it possible to promote the outlet of the gaseous phase of the LNG in the tank headspace 82, leading to a reduction in the pressure prevailing in the tank headspace 82. Thus, the valve 96 allows adjustment of the pressure in the tank headspace 82 as a

function of the methane number estimated by the estimation means 70. The valve 96 also makes it possible to reduce the pressure in the tank headspace 82 in the case where said pressure in the tank headspace is greater than a safety pressure in the tank headspace that is tolerated by the tank, thus making it possible to
 5 preserve the structural integrity of the tank 80.

The valve 96 can communicate with the internal combustion engine 52 ensuring the propulsion of the ship, thus enabling said engine to be fed with LNG, the LNG being used as fuel by this engine. The valve 96 thus makes it possible, by acting on the pressure in the tank headspace, to control the methane number of
 10 the LNG intended to be used as fuel by the internal combustion engine 52.

In the implementation example illustrated, the valve 96 can communicate with a boiler 86. Thus, the valve 96 allows the boiler to be fed with LNG, this boiler being used to burn the LNG in order to produce energy, for example in order to produce electrical energy, intended notably to be stored in an electrical energy
 15 storage device 87, electrically supplying a peripheral of the ship. An evaporation device 99 is advantageously inserted between the valve and the boiler, the evaporation device 99 making it possible to heat the LNG coming from the tank 80 and intended for the boiler 86, in order to promote the combustion of the LNG by the boiler, the LNG being stored at about -160°C in the tank.

According to the example illustrated in figure 6, the valve, known as the first valve 96, is connected to a ventilation tower 98 communicating with the environment external to the tank 80. A valve, known as the second valve 97, is inserted between the first valve 96 and the ventilation tower 98. Thus, the ventilation tower 98 allows the evacuation of the gaseous phase of the LNG
 25 present in the tank headspace 82 so as to reduce the pressure in the tank headspace, for example in the case of an excess pressure which runs the risk of damaging the tank 80, or alternatively so as to reduce the pressure in the tank headspace 82, thus authorizing the process of evaporation of the liquid phase of the LNG to take place, in the case where the methane number of the LNG is
 30 higher than the maximum target value tolerated by the engine. The second valve 97 makes it possible to authorize or to prohibit the circulation of the LNG from the

first valve 96 in the direction of the ventilation tower 98.

Figure 7 schematically illustrates an implementation example of a ship 100 in accordance with the fourth aspect of the invention.

The ship 100 thus comprises an LNG storage tank 80, a propulsion system
5 55 comprising a system 50 for controlling the methane number of the LNG stored in the tank 80, the propulsion system 55 also comprising an internal combustion engine 52 ensuring the propulsion of the ship, the internal combustion engine 52 being coupled to at least one propeller 53 via a transmission shaft, the placing in rotation of the propeller 53 by the internal combustion engine 52 being responsible
10 for the propulsion of the ship 100.

In the implementation example illustrated, the ship 100 is a methane tanker, i.e. the main cargo of the ship is the LNG stored in the tank 80, said LNG thus being intended, on the one hand, to be conveyed to a destination site, and, on the other hand, to be used as fuel to at least partly ensure the propulsion of the ship
15 100. In another implementation example, the ship might notably be, without departing from the scope of the invention, a container ship, or any other type of ship, the ship comprising a tank for storing LNG, as main or secondary cargo or as a reservoir, and a propulsion system 55 comprising a control system and an engine using the LNG stored in the tank as fuel, the control system allowing the
20 methane number of the LNG to be modified in order to allow risk-free use, by the engine, of the LNG as fuel.

Alternatively or cumulatively, and without departing from the scope of the invention, the internal combustion engine 52 may be an engine dedicated to an electrical energy storage device, the internal combustion engine then functioning
25 as the generator of an electrical machine in order to electrically supply a peripheral of the ship.

Needless to say, the invention is not limited to the examples that have just been described and numerous amendments may be made to these examples without departing from the scope of the invention.

The invention, as has just been described, does indeed achieve the aims that were set, and makes it possible to propose a process and a system for controlling a methane number, making it possible to control the methane number of an LNG intended to be used as fuel for an engine, by adjusting the pressure in the tank
5 headspace of the tank in which the LNG is stored. The invention also makes it possible to slow down or even prevent the decrease in the methane number of the LNG over time, notably during transportation of the LNG, by controlling the pressure in the tank headspace. Variants that have not been described here may be applied without departing from the context of the invention, provided that, in
10 accordance with the invention, they comprise a control process in accordance with the first aspect of the invention and/or a control system in accordance with the second aspect of the invention.

CLAIMS

1. Process (1) for controlling a methane number of a liquefied natural gas stored in a tank (80), the control process (1) comprising:

- 5 - a step (10) of estimating the methane number of the liquefied natural gas;
- a step (20) of comparison between the methane number estimated in the estimation step (10) and a target methane number;
- a step (30) of active adjustment of the pressure of a tank headspace (82) as a function of the comparison between the estimated methane number and the
- 10 target methane number.

2. Control process (1) according to the preceding claim, in which the methane number estimation step (10) comprises a step (12) of direct determination of the methane number by analysis of the composition of the liquefied natural gas present in the tank (80).

- 15 3. Control process (1) according to Claim 1, in which the methane number estimation step (12) comprises a step (14) of indirect determination of the methane number.

 4. Control process (1) according to the preceding claim, in which the methane number is determined, during the indirect determination step (14), from

20 the composition of the liquefied natural gas at the time of filling of the tank.

5. Control process (1) according to Claim 3, in which the methane number is determined during the indirect determination step (14), at least partly, from indications coming from a pressure sensor (72) in the tank headspace (82).

 6. Control process (1) according to any one of the preceding claims, in which

25 the active adjustment step (30) is a step of increasing the pressure in the tank headspace (82) when a decrease in the estimated methane number is detected.

7. Control process (1) according to any one of the preceding claims, in which the active adjustment step (30) comprises a step (32) of determining the saturation pressure of the liquefied natural gas, a step (34) of measuring the pressure in the tank headspace (82), a step (36) of comparison between the pressure in the tank headspace (82) and the determined saturation pressure, and a step (38) of adjusting the pressure in the tank headspace (82).

8. Control process (1) according to any one of the preceding claims, in which the active adjustment step (30) comprises a plurality of intermediate adjustments (Pa) of the pressure in the tank headspace (82).

9. Control process (1) according to either of Claims 7 and 8, comprising, following step (32) of determining the saturation pressure of the liquefied natural gas, a step (40) of informing an operator when the determined saturation pressure is greater than the pressure in the tank headspace (82).

10. System (50) for controlling a methane number of a liquefied natural gas, the control system (50) comprising at least one calculator (60) and a means (70) for estimating the composition of the liquefied natural gas communicating with the calculator (60), characterized in that the calculator (60) drives a device (90) for adjusting the pressure in the tank headspace (82) as a function of the information transmitted by the estimation means (70).

11. Control system (50) according to the preceding claim, in which the device (90) for adjusting the pressure in the tank headspace (82) comprises at least one compressor (92) and/or one valve (96) and/or one pump (94).

12. Control system (50) according to either of Claims 10 and 11, in which the estimation means (70) comprises a pressure sensor (72) in the tank headspace (82) and/or a chromatograph (73) and/or a spectrometer (75) configured to analyse the LNG in the liquid state, the estimation means (70) comprising a calculating member (74) which analyses the data from the pressure sensor (72), from the chromatograph (73) and/or from the spectrometer (75).

13. System (55) for propelling a ship (100) comprising a control system (50) according to one of Claims 10 to 12, the propulsion system (55) comprising an internal combustion engine (52) using as fuel the LNG stored in the tank (80) to
5 ensure, at least partially, the propulsion of the ship (100).

14. Ship (100) comprising a control system (50) according to any one of Claims 10 to 12 and/or a propulsion system (55) according to Claim 13.