

DESCRIPTION**Title of the Invention: Method for estimating and adjusting an energy balance of a gas in liquid form contained in a tank**

5 The present invention relates to the field of transporting natural gas, and more particularly to the field of regulating the temperature of said natural gas during such transport.

10 In order to more easily transport and/or store gas in liquid form, such as natural gas in liquid form, over long distances, the gas is usually liquefied by cooling it to cryogenic temperatures, for example -163°C at atmospheric pressure, in order to obtain liquefied natural gas, commonly known by the acronym "LNG." This liquefied natural gas is then loaded into specialized storage tanks in the floating structure.

15 However, such tanks are never perfectly thermally insulated, such that boil-off of the gas is inevitable, this phenomenon being called BOG, an acronym for Boil-Off Gas. The storage tanks of the floating structure thus comprise both natural gas in liquid form and natural gas in gaseous form, the gas phase of the natural gas forming the top of the tank.

20 In known manner, at least part of the natural gas present in the tank in gaseous form can be used to supply an engine designed to meet the operating energy needs of the floating structure, in particular for its propulsion and/or its production of electricity for on-board equipment. To this end, it is in particular known to circulate natural gas in the gaseous state through at least one natural gas treatment system, so as to allow heating and compression thereof, said system comprising a heat exchanger used as a superheater and a compressor, both placed upstream of the engine.

25 It is also known to configure the natural gas treatment system so that it can allow the condensation of a part taken from the natural gas in the gaseous state.

30 Condensation of the natural gas may in particular be required when the quantity of natural gas boiled off in the tank is too great compared to the operating energy needs of the floating structure; the natural gas treatment system then makes it possible to condense the boil-off gas present in the tank in order to return it there in the liquid state. Such a liquefaction system can in particular be implemented when

the floating structure is stopped and the consumption of gaseous natural gas by its engine(s) is zero, or almost zero.

An essential piece of data to take into account for this type of transport is the state of the natural gas in liquid form when the floating structure arrives at its destination to unload its cargo. In fact, stations for receiving natural gas in liquid form have requirements as to the characteristics of the delivered natural gas in liquid form, such as the temperature or the saturation pressure of said natural gas in liquid form. The facility manager at the place of destination can therefore refuse to unload the cargo of natural gas in liquid form if it does not comply with the requirements of the place of destination. Since temperature is a variable factor that changes significantly during transport, the major risk taken during this type of transport is that the natural gas in the liquid state may arrive at its destination at a saturation pressure and/or a temperature that does not correspond to the criteria expected by the facility manager of the place of destination, thus implying a potential refusal or downgrading of the cargo.

Managing the temperature of the cargo raises two problems directly related to a fuel supply system for a consumer of the floating structure. The first problem concerns the cooling function of the supply system. Lowering the temperature and/or the saturation pressure of the natural gas in liquid form is superfluous if this leads to a very high deviation from the requirements of the place of destination. In this situation, the cooling function of the supply system is overused and leads to unnecessary energy consumption.

The second problem concerns the condensation function of the supply system. When the condensation function is active, the excess gas phase generated from the gas in liquid form returns to the liquid phase and returns to the transport tank. However, the gas in condensed liquid form may have a higher temperature than the gas in liquid form present in the tank. The return of the condensed gas in liquid form to the tank can therefore lead to a general increase in the temperature of the gas in liquid form present in the tank, thus leading to the risk that the cargo of gas in liquid form no longer complies with the requirements of the place of destination and resulting in a refusal of delivery. In contrast, the inactivity of the condensation function of the supply system leads to the elimination of the surplus gas phase

generated from the gas in liquid form, for example by combustion or by release into the air, and therefore a waste of cargo.

The general problem is therefore to find a balance between the condensation and cooling functions of the supply system so that the cargo meets the requirements of the place of destination, but while limiting the energy consumption due to the elimination of the gas phase generated from the gas in liquid form and/or to the overconsumption of the cooling function of the supply system. The present invention therefore proposes to optimize the use of the liquefaction system so as to guarantee that on delivery, the cargo will be below the acceptance criterion of the place of destination, but without deviating too much from this criterion so as to avoid any overconsumption linked to the cooling function of the supply system.

As such, the invention consists of a method for estimating and adjusting an energy balance of a gas in liquid form contained in at least one tank of a floating structure intended to deliver said gas in liquid form to a given place of destination, the floating structure comprising a system for supplying fuel to a consumer of the floating structure capable of carrying out a function of condensation of a gas phase generated from the gas in liquid form and/or a function of cooling the gas in liquid form, characterized in that the estimating and adjusting method comprises the following steps:

- a step A of calculating the maximum authorized temperature of the gas in liquid form contained in the tank on arrival at the place of destination, based on the maximum saturation pressure requirements of gas in liquid form of the place of destination and the characteristics of the gas in liquid form contained in the tank,
- a step B of establishing a first operating plan for the condensation function of the gas phase generated from the gas in liquid form carried out by the supply system until the arrival at the place of destination, said first operating plan being established from an estimate of an excess gas phase generated from the gas in liquid form in the tank during a journey,
- a step C of establishing a second operating plan for the cooling function of the gas in liquid form carried out by the supply system until arrival at the place of destination, said second operating plan being established from the estimate of the excess gas phase generated from the gas in liquid form during the journey,

- a step D of calculating an energy balance of the gas in liquid form at a time t from the temperature of the gas in liquid form contained in the tank and the properties of the gas in liquid form contained in the tank,

- a step E of calculating a maximum energy balance from the maximum authorized temperature of the gas in liquid form, calculated in step A, and the characteristics of the gas in liquid form contained in the tank,

- a step F of estimating the energy balance of the gas in liquid form contained in the tank on arrival from the journey from the operating plans of the condensation and cooling functions determined in steps B and C and from the energy balance of the gas in liquid form at time t, determined in step D,

- a step G of adjusting the first operating plan and/or the second operating plan,

- a step H of implementing the supply system according to the operating plans of the condensation and cooling functions of the gas in liquid form adjusted in step G.

The floating structure can for example be a transport ship capable of storing and/or transporting gas in liquid form, for example natural gas in liquid form, or LNG. The fuel supply system of a consumer of the floating structure ensures the management of the gas phase generated from the gas in liquid form that forms in the tank by using it wisely to supply one or several consumers, such as a propulsion engine of the floating structure or an electric generator thereof. At the same time, the fuel supply system of a consumer of the floating structure is able to manage a state of the gas in liquid form contained in the tank, owing to its cooling function and its condensation function. The term "fuel supply system of a consumer of the floating structure" is subsequently simplified to "supply system."

The estimating and adjusting method regulates the characteristics of the liquid gas so that a cargo of liquid gas is delivered to the place of destination with a saturation pressure of the liquid gas according to the requirements of the place of destination, while minimizing the energy consumption necessary for temperature regulation. The term "energy balance" is used to designate numerical data obtained by a calculation that may derive from a plurality of physical constants of the gas, such as the saturation pressure of the gas in liquid form or the temperature of the gas in liquid form, or even from the energy supplied or taken by the cooling or condensation

functions of the supply system. The estimating and adjusting method can be initiated before a departure from the floating structure and/or during the journey between a starting point of the floating structure, for example a gas liquefaction terminal, and the place of destination where the liquid gas cargo is delivered. The tank containing the gas in liquid form is a compliant tank suitable for transporting such cargo, and it can for example be a tank with primary and secondary membranes, each of the membranes being thermally insulated.

The estimating and adjusting method begins with step A, which generally consists in determining the conditions for acceptance of the cargo of gas in liquid form by the place of destination, more particularly the maximum authorized temperature of the gas in liquid form contained in the tank on arrival. It is, however, possible to reason in terms of the saturation pressure of the gas in liquid form or another value linked to the pressure and/or the temperature. The calculation of such a target value not to be exceeded depends on the saturation pressure requirements of the gas in liquid form and the temperature of the gas in liquid form of the place of destination and constant characteristics of the gas. Thus, it is clear that the requirement of the terminal receiving the gas in liquid form aims to avoid massive vaporization of the natural gas during its transfer between the ship and the terminal by imposing conditions for acceptance of the cargo.

The maximum authorized temperature of the gas in liquid form contained in the tank on arrival depends on the properties of the transported gas in liquid form, which are the total mass of gas in liquid form and the specific heat capacity of the gas in liquid form. These two pieces of data can for example be provided by any document relating to the cargo, such as a technical data sheet, and can be taken into account by the supply system, for example by means of a control monitor.

The maximum authorized temperature of the gas in liquid form contained in the tank on arrival calculated by the estimating and adjusting method also depends on the maximum saturation pressure requirements of the gas in liquid form determined by the facility manager of the place of destination. Such data is also known through any information source provided by the place of destination and can also be recorded in the supply system in a manner identical to what has been described above.

Steps B and C consist in setting up an operating plan for each of the functions of the supply system. "Operating plan" must be understood as progress of the activity of each of the functions during the journey allowing the place of destination to be reached. Each of the functions, namely the condensation function and the cooling function, is either active or inactive and the supply system can switch from one mode to the other. The operating plan for each of the functions therefore determines active and inactive sequences of each of the functions during the journey, which result in heating or cooling of the cargo, as the case may be.

When the condensation and cooling functions are qualified as active, it means that the supply system is authorized to perform its condensing and/or cooling functions. Conversely, when the condensation and cooling functions are qualified as inactive, it means that the supply system is not authorized to perform its condensing and/or cooling functions. When the cooling function is active, the supply system is authorized to cool the gas in liquid form provided that gas phase generated from the gas in liquid form is present. When the condensation function is active, the supply system is able to cool the gas in liquid form provided that an excess gas phase generated from the gas in liquid form is also present.

When the condensation function is active, the temperature of the gas in liquid form contained in the tank may tend to increase. The cooling function leads to a lowering of the temperature when it is activated. The temperature varies differently when the two functions act simultaneously, or may vary naturally depending on the environmental conditions during the journey. It is, however, understood that the major temperature variations occurring during the journey depend on the activation of the operating plans implemented during steps B and C of the estimating and adjusting method.

The operating plans for the condensation or cooling functions of the power supply system are therefore flowcharts determining at which time t of the journey each of the functions must be activated or deactivated. It is also possible that the operating plan consists of keeping one or the other of the functions active or inactive during the entire journey.

Each of these operating plans is determined from the estimate of the excess gas phase generated from the gas in liquid form during the journey. The gas phase

generated from the gas in liquid form emanates from the transport tank naturally or else in a forced way. This gas phase can subsequently be used to supply the floating structure, for example the engine allowing the propulsion of the floating structure, or else a generator supplying the floating structure with electricity. The gas phase generated from the gas in liquid form that is not used to supply the floating structure represents the excess gas phase generated from the gas in liquid form. When the condensation function and the cooling function act simultaneously, this means that there is an excess gas phase generated from the gas in liquid form circulating within the supply system.

The presence of excess gas phase generated from the gas in liquid form can be detected by a system outside the management system of the invention or directly by means of the estimating and adjusting method according to the invention.

Step D of the estimating and adjusting method consists in calculating the energy balance of the gas in liquid form at time t, that is to say, from data measured at time t. Step D is independent of steps B and C and can therefore take place simultaneously or before steps B and C. The calculation of the energy balance during step D depends on the total mass of gas in liquid form and the specific heat capacity of the gas in liquid form, constants used during step A, as well as the average temperature of the gas in liquid form contained in the tank at time t. More specifically, the energy balance of the gas in liquid form is calculated from the following formula:

$$Be = m_{Gas} \times C_p \times T$$

Be being the energy balance of the gas in liquid form at time t, m_{Gas} being the total mass of the gas in liquid form, C_p being the specific heat capacity of the gas in liquid form and T being the temperature of the gas in liquid form at time t.

The temperature of the gas in liquid form can be measured by at least one temperature sensor arranged in the tank. Said temperature is then taken into account during the calculation of step D. The temperature can be addressed in the form of an average, for example if several temperature sensors are placed in the tank, or if the floating structure comprises several tanks, each being provided with one or more temperature sensors. The energy balance of the gas in liquid form at

time t calculated during this step D is used during the rest of the estimating and adjusting method.

Step E consists in calculating an energy balance similar to the energy balance calculated in step D, but the energy balance of step E is the maximum energy balance, relating to the maximum authorized temperature of the gas in liquid form calculated in step A. The calculation of the maximum energy balance calculated during step E is independent of the energy balance of the gas in liquid form at time t calculated in step D. Steps D and E can therefore be carried out simultaneously or else one after the other in any order. The maximum energy balance is calculated from the total mass of gas in liquid form of the gas in liquid form, the specific heat capacity of the gas in liquid form, and the maximum authorized temperature of the gas in liquid form. Thus, the calculation carried out in step E is similar to the calculation carried out in step D, with the maximum authorized temperature of the gas in liquid form instead of the temperature measured in the tank of the floating structure.

During step F, the estimating and adjusting method calculates an estimated energy balance of the gas in liquid form contained in the tank on arrival. In other words, the estimating and adjusting method makes it possible to predict the characteristics of the gas in liquid form contained in the tank on the arrival of the floating structure at its place of destination, in particular the energy balance thereof. To estimate the energy balance of the gas in liquid form contained in the tank on arrival from the journey, the estimating and adjusting method uses the energy balance of the gas in liquid form at time t calculated during step D, as well as the operating plans for the supply system cooling and condensation functions calculated in steps B and C. The energy balance of the gas in liquid form at time t calculated during step D constitutes a starting point for the estimation in terms of saturation pressure of the gas in liquid form and temperature of the gas in liquid form. The operating plans for the cooling and condensation functions calculated in steps B and C are also part of the estimate, since they influence the temperature of the gas in liquid form contained in the tank as mentioned above. From these three data, the estimating and adjusting method is able to determine the energy balance of the gas in liquid form once the floating structure has arrived at the place of destination, taking into account the operating

plans of the cooling and condensation functions established previously. Since the energy balance of the gas in liquid form encompasses a plurality of characteristics, it is also possible to reason in terms of saturation pressure of the gas in liquid form, temperature, or quantity of heat exchanges. By estimating the energy balance of the cargo on arrival in this way, it is possible to adjust the operating plans so that the saturation pressure of the gas in liquid form on arrival makes it acceptable.

Step G then consists in adjusting the operating plans based on a comparison between the maximum energy balance calculated in step E and the estimate of the energy balance of the gas in liquid form contained in the tank on arrival from the journey calculated in step F. Depending on said comparison, the first operating plan of the condensation function and/or the second operating plan of the cooling function can be adjusted. The adjustment may consist in stopping one and/or the other of the functions, the stopping possibly being instantaneous or programmed after a certain period of time. One and/or the other of the functions can also be put into operation or restarted, also instantaneously or in a scheduled manner. Thus, the first operating plan of the condensation function and/or the second operating plan of the cooling function are modified from the data calculated or estimated during steps E and F.

Step H consists in implementing the adjusted operating plans. In other words, the supply system no longer takes into account the operating plans established during steps B and C, which are replaced by the operating plans adjusted during step G. The adjusted operating plans are transmitted to the supply system after the estimating and adjusting method has been completed. The supply system can therefore implement the cooling and/or the condensation of the gas in liquid form, keep them active or deactivate them, according to the respective adjusted operating plans transmitted to it.

According to one feature of the invention, step G consists in activating the condensation function as long as the estimated energy balance of the gas in liquid form contained in the tank on arrival from the journey, calculated in step F, is less than the maximum energy balance calculated in step E. When the estimated energy balance of the gas in liquid form contained in the tank on arrival from the journey is less than the maximum energy balance, this means that on arrival from the journey, the cargo of gas in liquid form will for example be at a gas saturation pressure in

liquid form lower than the prerequisites defined by the place of destination. If this situation arises during the journey, there is no disadvantage in adjusting the operating plans for the functions of the supply system so as to authorize and control a rise in the temperature of the gas in liquid form contained in tank. Thus, if this is not already the case, the adjustment of the first operating plan of the condensation function can consist in keeping the latter active throughout the entire journey. The excess gas phase generated from the gas in liquid form is therefore fully condensed instead of possibly being eliminated. There is therefore no loss of gas in liquid form contained in the tank, except for the gas phase generated from the gas in liquid form and used to supply the floating structure.

In this situation, the condensation function is active. In other words, the supply system is authorized to condense the excess gas phase generated from the gas in liquid form if the latter is present. The condensation of the gas in liquid form can vary in terms of activity based on a need to manage the excess gas phase generated from the gas in liquid form. The condensation of the gas in liquid form can for example take place in a more sustained manner in the event of excess gas phase generated from the gas in liquid form in the tank, in order to reduce the pressure within the latter.

According to one feature of the invention, step G consists in stopping the cooling function at an estimated time dt that guarantees that the estimated energy balance of the gas in liquid form contained in the tank on arrival from the journey, calculated in step F, is less than the maximum energy balance calculated in step E. After the adjustment of the first operating plan for the condensation function consisting in maintaining it throughout the entire journey, it is possible for the estimated energy balance of the gas in liquid form on arrival always to be less than the requirements of the place of destination. It is therefore possible to adjust the second operating plan for the cooling function so that the latter is deactivated at the estimated time dt . Such an adjustment makes it possible to save the energy consumed by the cooling function during the period of time when the latter is deactivated. This leads to a rise in the temperature of the gas in liquid form contained in the tank, due to the fact that the gas in liquid form is no longer cooled by the cooling function. This is why the estimated time dt when the cooling function is stopped is established such that the

gas in liquid form contained in the tank increases in temperature, but such that this increase does not cause the requirements to be exceeded at the moment when the gas in liquid form will be delivered to the place of destination on arrival from the journey.

5 To do this, the estimating and adjusting method will successively repeat the adjustment of the second operating plan for the cooling function and step F, i.e. the step of estimating the energy balance of the gas in liquid form contained in the tank on arrival. The adjustment of the second operating plan for the cooling function consists in determining the estimated time dt , taking the arrival at the place of
10 destination as the target. The estimated time dt is then determined as being prior to a certain amount of time with respect to the arrival, for example several days or hours. The estimating and adjusting method then recalculates the estimated energy balance of the gas in liquid form contained in the tank on arrival, this time taking into account the new adjustment of the second operating plan for the cooling function,
15 that is to say, stopping it for example several days or hours before arrival at the place of destination. If the estimated energy balance of the gas in liquid form contained in the tank on arrival is no longer less than the maximum energy balance calculated in step E, then the estimating and adjusting method continues normally with step H. If the estimated energy balance of the gas in liquid form contained in the
20 tank on arrival is still lower than the maximum balance, the estimating and adjusting method then repeats the adjustment of the second operating plan for the cooling function by further anticipating the estimated time dt by, for example, several days or hours before arrival at the place of destination. Then, the estimated energy balance of the gas in liquid form contained in the tank on arrival is calculated again by taking
25 the new adjustment into account. Thus, as long as the estimated energy balance of the gas in liquid form contained in the tank on arrival is less than the maximum energy balance, the estimated time dt is delayed. This loop makes it possible to determine the estimated time dt closest to the current time t , and thus to deactivate the cooling function as soon as possible in order to save as much energy as
30 possible. Once the final estimated time dt has been determined, the estimating and adjusting method continues with step H.

According to one feature of the invention, step G consists in stopping the condensation function as long as the estimated energy balance of the gas in liquid form contained in the tank on arrival from the journey, calculated in step F, is greater than the maximum energy balance calculated in step E. When the estimated energy balance of the gas in liquid form contained in the tank on arrival from the journey is greater than the maximum energy balance, this means that the cargo of gas in liquid form will be at a saturation pressure of the gas in liquid form that is too high in relation to the requirements of the place of destination on arrival of the floating structure. In order to avoid such a situation, it is advisable to limit any action leading to a rise in temperature of the gas in liquid form contained in the tank. Thus, the first operating plan for the condensation function is adjusted in order to bring about a shutdown of the condensation function of the supply system at a given time d't where the energy balance of the gas in liquid form contained in the tank exceeds the maximum energy balance. The condensation function may possibly be reactivated if the estimated energy balance of the gas in liquid form contained in the tank on arrival from the journey again becomes lower than the maximum energy balance thereafter.

According to one feature of the invention, step G consists in activating the cooling function as long as the estimated energy balance of the gas in liquid form contained in the tank on arrival from the journey, calculated in step F, is greater than the maximum energy balance calculated in step E. In this situation, it is essential to reduce the temperature of the gas in liquid form contained in the tank. Thus, at the same time as the first operating plan of the condensation function is adjusted so that it is deactivated at the given time d't, the second operating plan of the cooling function is also adjusted so that the cooling function is active until the arrival of the floating structure at the place of destination so that the saturation pressure of the gas in liquid form meets the requirements of the place of destination.

In this situation, the cooling function is therefore active. In other words, the supply system is authorized to cool the gas in liquid form contained in the tank. The supply system cools the gas in liquid form according to the highest possible activity with respect to a configuration of said supply system.

According to one feature of the invention, the estimating and adjusting method is repeated by iteration starting from step B and during the journey of the floating structure. The journey time of the floating structure between its point of departure and the place of destination is variable according to the delivery, but the journey can last several days, even several weeks. The estimate may for example be distorted in the medium or long term by environmental conditions, such as the weather or the state of the sea for maritime transport. Thus, in order to achieve the desired objective, the estimating and adjusting method must be repeated regularly during the journey. As a result, the estimating and adjusting method can for example be parameterized to launch at a regular time interval, for example every six hours.

Step A is based on a calculation dependent on fixed values. It is therefore not necessary to repeat this step after launching the estimating and adjusting method for the first time. The estimating and adjusting method is therefore repeatable by iteration starting from the step of establishing the first operating plan for the condensation function of the supply system.

According to one feature of the invention, the estimating and adjusting method comprises an additional step D', carried out simultaneously with step D, of calculating the energy balance of the gas in liquid form at time t from the execution of the condensation and cooling functions from the departure of the floating structure until time t and from an energy balance of the gas in liquid form at time t calculated during an earlier iteration. The calculation of the energy balance of the gas in liquid form at time t carried out in step D' no longer takes into account the temperature of the gas in liquid form contained in the tank at time t noted for example by the temperature sensor, but an energy balance of the gas in liquid form at time t calculated previously. In other words, step D' is only executed if the estimating and adjusting method has already been implemented a first time. Advantageously, the energy balance of the gas in liquid form at time t is calculated from the energy balance of the gas in liquid form at a previous time t, i.e. the energy balance of the gas in liquid form from the previous iteration of the estimating and adjusting method, which may have been calculated during step D or D'.

The calculation of the energy balance of the gas in liquid form at time t during step D' also takes into account the execution of the condensation and cooling functions from

the departure of the floating structure until time t. For the condensation function, this corresponds to data relating to the heat transmitted to the tank and leading to a general increase in its temperature, illustrated for example by a temperature differential at the inlet and at the outlet of a heat exchanger performing the condensation function. For the cooling function, this corresponds to data relating to the cold transmitted to the tank and resulting in a general drop in its temperature, illustrated for example by a temperature differential at the inlet and outlet of a heat exchanger performing the cooling function.

According to one feature of the invention, the energy balance of the gas in liquid form at time t conserved for step F is the highest among the energy balance of the gas in liquid form at time t calculated in step D and the energy balance of the gas in liquid form at time t calculated in step D'. In other words, when subsequently the estimating and adjusting method reaches step F, i.e. the step of estimating the energy balance of the gas in liquid form contained in the tank estimated on arrival, it is the energy balance of the gas in liquid form contained in the tank at time t having the highest value among the result obtained in step D and the result obtained in step D' that is used for the estimation of step F. The energy balance of the gas in liquid form at time t having the highest value is considered to be the most pessimistic result. Since the objective is not to exceed the maximum energy balance of the place of destination, it is advisable to keep the energy balance of the gas in liquid form at the highest time t as a safety measure.

According to one feature of the invention, the estimating and adjusting method comprises an additional step A' of selecting a safety margin for the maximum energy balance of the gas in liquid form as a function of the characteristics of the journey of the floating structure, step E being performed taking said safety margin into account. In order to be certain that the floating structure does not arrive at the place of destination with a cargo of gas in liquid form whose energy balance is higher than the requirements of said place of destination, it is possible to take a safety margin into account in order to virtually decrease the value of the maximum energy balance. Thus, during step E, the maximum energy balance is always calculated according to the maximum authorized temperature of the gas in liquid form calculated in step A, but also taking the safety margin into account. A secure maximum energy balance is

then obtained, with a value lower than the real maximum energy balance. During the rest of the estimating and adjusting method, the first operating plan for the condensation function and the second operating plan for the cooling function are adjusted according to the comparison between the estimated energy balance of the gas in liquid form contained in the tank on arrival from the journey and a virtual maximum energy balance, that is to say, which takes the safety margin into account. The safety margin thus guarantees the certainty of remaining below the real maximum energy balance.

The safety margin can be chosen according to different parameters. For example, the longer the journey, the better to select a high safety margin. A high safety margin is also recommended in case of lack of weather information during the journey. The safety margin can for example be entered manually via the control monitor, or can even be programmed to be variable over time.

Since the safety margin is used for the calculation of step E, step A' therefore precedes step E during the estimating and adjusting method.

According to one feature of the invention, step A' is repeated by iteration during the journey of the floating structure. The repetition of step A' can be independent of the repetition of the estimating and adjusting method, or else form part of the latter. Step A' can also be triggered manually, for example following the appearance of an unforeseen meteorological phenomenon. It may then be wise to manually increase the value of the safety margin to overcome the uncertainty caused by said meteorological phenomenon.

According to one feature of the invention, the safety margin decreases as the floating structure approaches the place of destination. In other words, the closer the floating structure comes to its place of destination, the lower the safety margin needs to be. It is therefore possible to program a decreasing safety margin over time.

According to one feature of the invention, the floating structure is equipped with at least one engine powered at least partially by the gas phase generated from the gas in liquid form, the estimation of the excess gas phase generated from the gas in liquid form liquid during the journey being established from an image value of the heat inputs into the tank and an estimate of the consumption of the engine. As previously stated, the floating structure may be able to use the gas phase generated

from the gas in liquid form, or even to create it, for example to power its propulsion engine and/or its electricity generator. The gas phase generated from the gas in liquid form that is not used for these various functions corresponds to the excess gas phase generated from the gas in liquid form. The latter needs to be estimated in quantity so that steps B and C of the estimating and adjusting method, i.e. the steps for establishing operating plans for the condensation and cooling functions of the supply system, can take place. The image value of the heat inputs into the tank can for example depend on the tank model used and therefore be available as a technical characteristic of the tank. The image value of the heat inputs into the tank can also be estimated using sensors.

The engine consumption can be estimated if the floating structure is equipped with a module making it possible to define a route plan for the journey to the place of destination. If this is not the case, the engine consumption can be estimated from the average speed of the floating structure on the remaining journey, the latter depending on the distance remaining to be covered and the time remaining to reach the place of destination.

The excess gas phase generated from the gas in liquid form can thus be estimated by means of a source external to the estimating and adjusting method, and for example be entered by means of the control monitor in order to be taken into account during the estimating and adjusting method. This surplus can then be quantified in tons/hour.

The invention also covers a system for managing an energy balance of a gas in liquid form contained in at least one tank of a floating structure, implementing the estimating and adjusting method as described previously, said management system comprising at least one fuel supply system for a consumer of the floating structure and at least one computer having the function of estimating a quantity of excess gas phase generated from the gas in liquid form during a journey of the floating structure.

Such an energy balance management system comprises the fuel supply system for a consumer of the floating structure implementing the condensation and cooling functions, and allows the estimating and adjusting method to run.

In order to ensure the smooth running of the estimating and adjusting method, in particular steps B and C respectively establishing the first operating plan for the

condensation function of the gas phase generated from the gas in liquid form and the second operating plan for the cooling function of the gas in liquid form carried out by the supply system, the computer can transmit the estimated quantity of excess gas phase generated from the gas in liquid form, which is essential to carry out steps B and C. The energy balance management system can also comprise the control monitor mentioned above.

The invention also covers a floating structure for transporting gas in liquid form comprising a system for managing the energy balance of said gas as described above.

Other features and advantages of the invention will appear both from the description which follows and from several exemplary embodiments, which are given for illustrative purposes and without limitation with reference to the appended schematic drawings, in which:

[Fig. 1] is a schematic representation of a floating structure loaded with gas in liquid form and making a journey to a place of destination,

[Fig. 2] is a schematic representation of an embodiment of a system for managing the temperature of the gas in liquid form according to the invention,

[Fig. 3] is a schematic representation of a sequence of a method for estimating and adjusting an energy balance of the gas in liquid form according to the invention, when the latter is launched for the first time,

[Fig. 4] is a schematic representation of a sequence of the method for estimating and adjusting the energy balance of the gas in liquid form according to the invention, when the latter is launched by iteration,

[Fig. 5] is a general diagram illustrating a fuel supply system for a consumer of the floating structure capable of executing a plurality of commands according to the estimating and adjusting method,

[Fig. 6] is a diagram of the supply system according to a first specific embodiment,

[Fig. 7] is a diagram of the supply system according to a second specific embodiment,

[Fig. 8] is a curve representing the change in the energy balance of the gas in liquid form as a function of time as well as the operating plans for the condensation and cooling functions, in a situation where said energy balance of the gas in liquid form is estimated to be too low on arrival,

5 [Fig. 9] is a curve representing the change in the energy balance of the gas in liquid form as a function of time as well as the operating plans adjusted for the condensation and cooling functions, to overcome the situation mentioned in Fig. 8,

10 [Fig. 10] is a curve representing the change in the energy balance of the gas in liquid form as a function of time as well as the operating plans for the condensation and cooling functions, in a situation where said energy balance of the gas in liquid form is estimated to be too high on arrival,

[Fig. 11] is a curve representing the change in the energy balance of the gas in liquid form as a function of time as well as the operating plans adjusted for the condensation and cooling functions, to overcome the situation mentioned in Fig. 10,

15 [Fig. 12] is a curve representing a first example of the change in a value of a safety margin as a function of time,

[Fig. 13] is a curve representing a second example of the change in the value of the safety margin as a function of time.

20 In order to visualize the context in which the invention fits, Fig. 1 shows a floating structure 1 heading toward a place of destination 2 by following a journey 3. The floating structure 1 shown here is a transport ship, for example an LNG carrier. The floating structure 1 transports a cargo of gas in liquid form with the aim of delivering the latter to the place of destination 2. In order to ensure such transport, the floating structure 1 comprises at least one tank 9.

25 The place of destination 2 is a terminal intended to receive the gas in liquid form contained in the tank 9 of the floating structure 1. When the latter reaches the place of destination 2, the gas in liquid form is discharged, for example, into a reservoir 40. The place of destination 2, however, imposes requirements concerning the characteristics of the gas in liquid form. The requirements of the place of
30 destination 2 may vary according to the manager of the facility to which the place of

destination 2 is attached, and mainly relate to the characteristics of the gas in liquid form, for example its saturation pressure and/or its temperature.

If the gas in liquid form contained in the tank 9 of the floating structure 1 does not meet these saturation pressure requirements for the gas in liquid form, the cargo of gas in liquid form can potentially be refused by the facility manager of the place of destination 2.

In order to avoid this, the cargo of gas in liquid form must be closely monitored throughout the journey 3. The journey 3 has a variable distance and can last several days, even several weeks depending on the distance between a loading location and the place of destination 2 as well as the speed of the floating structure 1.

Fig. 2 schematically shows a system 4 for managing an energy balance of the gas in liquid form contained in the tank of the floating structure. The energy balance of the gas in liquid form corresponds to data encompassing various characteristics of said gas, such as its temperature, its saturation pressure, its total mass of gas in liquid form or its specific heat capacity, for example. The management system 4 comprises a control box 41 having in memory a method for estimating and adjusting the energy balance of the gas in liquid form contained in the tank of the floating structure. The control box 41 is thus capable of initiating the estimating and adjusting method 5 in a regular and automated manner and/or following a manual control exercised for example by means of a control monitor 6. It is also possible to manually enter data via the control monitor 6, for example the characteristics of the transported gas in liquid form, or any other information useful for the progress of the estimating and adjusting method 5 as this will be clarified later.

The management system 4 also comprises a fuel supply system 8 for a consumer of the floating structure. The supply system 8 has the function of condensing and/or cooling the gas in liquid form contained in the tank and is able to adjust one or the other of these functions by activating or deactivating them. The adjustment of the condensing and cooling functions of the supply system 8 depends on the result of the estimating and adjusting method 5. Thus, when the latter ends, the control box 41 sends a signal to the supply system 8, said signal indicating the adjustments to be made by the supply system 8.

The management system 4 also comprises a computer 7. The function of the computer 7 is to estimate a quantity of excess gas phase generated from the gas in liquid form during the journey of the floating structure. The gas phase generated from the gas in liquid form occurs naturally within the tank of gas in liquid form, or else can be forced. The estimated excess gas phase generated from the gas in liquid form is calculated using an estimate of the consumption of the engine of the floating structure and an image value of the heat inputs into the tank. The computer 7 and the control box 41 can be part of the same control unit or be independent of each other.

The consumption of the engine of the floating structure can be estimated owing to the entry of a route plan into the control monitor 6, which transmits the information to the computer 7, or else by calculating an average speed of the floating structure from the remaining distance between a position of the floating structure and the place of destination and the time remaining to reach it. The average speed of the floating structure can also be calculated by entering data into the control monitor 6, which transmits the information to the computer 7.

The image value of the heat inputs into the tank can correspond to a design value of the heat inputs into the tank, or also to an estimate of the heat inputs into the tank. The design value of the heat inputs into the tank depends on the model of tank used for transport and can be given to the computer 7 via the control monitor 6. The estimate of the heat inputs into the tank can also be communicated by sensors included in said tank.

Once the excess gas phase generated from the gas in liquid form during the journey is estimated by the computer 7, the latter transmits the result to the control box 41.

The excess gas phase generated from the gas in liquid form during the journey is a datum allowing the estimating and adjusting method 5 to run, as will be described below.

Fig. 3 is a schematic representation of the method for estimating and adjusting the energy balance of the gas in liquid form according to the invention. This diagram shows the progress of the estimating and adjusting method 5 when the latter is launched for the first time during the journey to the place of destination. The estimating and adjusting method 5 can be launched a first time before the departure

or on departure from the floating structure. In Fig. 3, the solid arrows represent the progress of each of the steps of the estimating and adjusting method 5, and the dotted arrows correspond to a transmission of data between two steps of the estimating and adjusting method 5 or between an element of the system for managing the energy balance of the gas in liquid form and a step of the estimating and adjusting method 5.

When the estimating and adjusting method 5 is launched for the first time, it begins with a step A that makes it possible to calculate the maximum authorized temperature of the gas in liquid form contained in the tank on arrival at the place of destination. The calculation of step A depends on certain constant characteristics of the gas in liquid form, such as the total mass of gas in liquid form and the specific heat capacity thereof. Such characteristics depend on the type of gas in liquid form being transported and are known in one way or another by the personnel of the floating structure. Thus, the total mass of gas in liquid form and the specific heat capacity of the gas in liquid form can be entered or can be preselected through the control monitor 6 and transmitted for the calculation of step A of the estimating and adjusting method 5. The calculation of step A also depends on the maximum saturation pressure requirements of the gas in liquid form of the place of destination. Since these requirements vary according to the place of destination, the value of the maximum saturation pressure required of the gas in liquid form is known when the place of destination is known. The saturation pressure requirements of the gas in liquid form can be entered via the control monitor 6 or can be known, for example via a database listing all the destination locations authorized for reception and unloading of gas in liquid form.

Once the calculation of step A has been performed, the estimating and adjusting method 5 can pass directly to a step B, or else pass through an intermediate step A'. Step A' consists in determining a safety margin in order to be certain that the energy balance of the gas in liquid form is lower than the requirements of the place of destination on arrival. Thus, step A' is not essential for the smooth running of the estimating and adjusting method 5, which can do without the safety margin to perform all the calculations and estimations, but nevertheless contributes to optimizing the adjustment of the energy balance of the gas in liquid form. The safety

margin can be determined automatically from the route plan and/or weather conditions, or manually via the control monitor 6. The safety margin is used for a calculation during a step E. Step A' can therefore take place at any time prior to step E.

- 5 Step B of the estimating and adjusting method 5 occurs after step A or step A'. Step B consists in establishing the first operating plan of the condensation function of the supply system 8. The first operating plan of the condensation function of the supply system 8 indicates, over time, at what time of the journey the condensation function remains active or inactive and at what time the latter is activated or deactivated. The
- 10 establishment of the first operating plan depends on the amount of excess gas phase generated from the gas in liquid form during the journey. It is in fact understood that, for example, if it is determined that no excess gas phase generated from the gas in liquid form is generated during the journey, the supply system has no gas phase generated from the gas in liquid form to condense and therefore does not
- 15 need to be active during the journey. Such a surplus may result from a case where the consumer of the floating structure is shut down, the boil-off of the gas in liquid form continuing to occur. The excess gas phase generated from the gas in liquid form is estimated by the computer 7, which therefore transmits the information to the control box so that the estimating and adjusting method 5 can perform step B.
- 20 Step C takes place parallel or successively to step B. Step C is based on the same principle as step B, since it allows the establishment of the second operating plan for the cooling function of the supply system 8. Like for step B, the second operating plan of the cooling function of the supply system 8 indicates, over time, at what time of the journey the cooling function remains active or inactive and at what time the
- 25 latter is activated or deactivated. The establishment of the second operating plan also depends on the quantity of excess gas phase generated from the gas in liquid form during the journey, estimated by the computer 7. The estimate of excess gas phase generated from the gas in liquid form is therefore taken into account for steps B and C.
- 30 The estimating and adjusting method 5 then continues with a step D, which calculates an energy balance of the gas in liquid form at a time t . Fig. 3 showing the course of the estimating and adjusting method 5 during its first launch, the time t

here corresponds to the moment of departure or before the departure of the floating structure. To calculate the energy balance of the gas in liquid form at time t , the estimating and adjusting method 5 needs the characteristics of the gas in liquid form, in particular used during step A to calculate the maximum authorized temperature of the gas in liquid form contained in the tank on arrival, such as the total mass of gas in liquid form of the gas in liquid form, or the specific heat capacity of the gas in liquid form. These characteristics can be provided by the control monitor 6, just like for step A. The calculation of the energy balance of the gas in liquid form at time t also requires the average temperature of the gas in liquid form contained in the tank at time t . The average temperature of the gas can be measured for example using a temperature sensor located in the tank. It is therefore the supply system 8 that supplies the average temperature in the tank and that transmits this to the control box so that the estimating and adjusting method 5 can carry out the calculation of step D.

Once step D has been completed, the estimating and adjusting method 5 continues with a step E that consists in calculating a maximum energy balance. The maximum energy balance corresponds to the limit of the requirements of the place of destination that the energy balance of the gas in liquid form contained in the tank must not cross, under penalty of the cargo being refused once the floating structure has arrived at the place of destination. The energy balance of the gas in liquid form can, however, cross this maximum energy balance limit during the journey without consequences, but must return below this maximum energy balance before the floating structure reaches the place of destination. It is understood that the maximum energy balance is a target for adjusting the energy balance of the gas in liquid form contained in the tank during the journey.

For this calculation of the maximum energy balance during step E, the estimating and adjusting method 5 needs the characteristics of the gas in liquid form and the maximum authorized temperature of the gas in liquid form contained in the tank on arrival calculated during step A. The data provided and the calculations done during step A can therefore be transmitted for the calculation of step E. If the estimating and adjusting method 5 has carried out step A', in other words if the safety margin has been determined and selected, said safety margin is also transmitted to be taken into

account for the calculation of the maximum energy balance. Thus, the maximum energy balance calculated during step E corresponds to the real maximum energy balance in the absence of a safety margin, or to a virtual maximum energy balance, lower than the real maximum energy balance due to the safety margin being taken into account in the calculation.

The next step of the estimating and adjusting method 5 is a step F ensuring the estimation of the energy balance of the gas in liquid form contained in the tank on arrival from the journey. Step F makes it possible to determine what the energy balance of the gas in liquid form contained in the tank will be on arrival from the journey, while keeping the operating plans for the condensation and cooling functions that were established during steps B and C. To perform such an estimate, the calculation is based on the energy balance of the gas in liquid form at time t calculated during step D, as well as on the operating plans for the condensation and cooling functions established during steps B and C. The latter having been established for the entire journey during steps B and C, the estimating and adjusting method 5 can then estimate the change in the energy balance of the gas in liquid form during this step F, the condensation and cooling functions being capable of varying said energy balance of the gas in liquid form depending on whether they are active or inactive and when they activate and deactivate. The energy balance of the gas in liquid form contained in the tank on arrival can therefore be determined from these data.

The estimating and adjusting method 5 then continues with a step G that ensures the adjustment of the operating plans for the condensation and cooling functions of the supply system 8. These adjustments are made based on a comparison between the maximum energy balance calculated during step E and the estimated energy balance of the gas in liquid form contained in the tank on arrival, calculated in step F. As a reminder, the estimated energy balance of the gas in liquid form contained in the tank on arrival calculated during step F is based on the operating plans for the condensation and cooling functions drawn up during steps B and C. Step G therefore makes it possible to modify this estimated energy balance of the gas in liquid form contained in the tank on arrival by adjusting the operating plans for the condensation and cooling functions.

When the estimated energy balance of the gas in liquid form contained in the tank on arrival is greater than the maximum energy balance, this means that the cargo of gas in liquid form will, on arrival, be at a saturation pressure of the gas in liquid form that is excessive in relation to the maximum requirements of the place of destination. The operating plans for the condensation and cooling functions must therefore be adjusted in order to reduce the temperature of the gas in liquid form contained in the tank and, by analogy, the energy balance of the gas in liquid form.

When the estimated energy balance of the gas in liquid form contained in the tank on arrival is lower than the maximum energy balance, this means that the cargo of gas in liquid form will, on arrival, be in compliance with the requirements of the place of destination, but that it is nevertheless possible to make adjustments allowing a rise in the temperature of the gas in liquid form contained in the tank if such adjustments prove useful in terms of energy saving. The operating plans for the condensation and cooling functions must therefore be adjusted in order to allow an increase in the temperature of the gas in liquid form contained in the tank and, by analogy, of the energy balance of the gas in liquid form.

Step G therefore determines the optimal adjustments of the operating plans for the condensation and cooling functions of the supply system 8 so as to best respond to the situation. Examples of adjustments to the operating plans will be presented later.

The estimating and adjusting method 5 finally ends with a step H, implementing the operating plans adjusted during step G. Step H marks the end of the estimating and adjusting method 5 and sends the adjusted operating plans of the condensation and cooling functions to the supply system 8 so that the latter implements them. The details of the operation of the supply system 8 will be presented hereinafter.

Fig. 4 is a schematic representation of the method for estimating and adjusting the energy balance of the gas in liquid form during repetition by iteration thereof, that is to say, when the estimating and adjusting method 5 is launched during the journey after having been launched a first time according to Fig. 3. Most of the steps of the estimating and adjusting method 5 are similar to what has been described previously, and reference will therefore be made to the description of Fig. 3 for the explanations relating thereto. Like for Fig. 3, the solid arrows represent the progress of each of the steps of the estimating and adjusting method 5, and the dotted arrows

correspond to a transmission of data between two steps of the estimating and adjusting method 5 or between an element of the system for managing the energy balance of the gas in liquid form and a step of the estimating and adjusting method 5.

When the estimating and adjusting method 5 is repeated by iteration, it is no longer useful to initiate step A. Indeed, the result of the calculation of step A, i.e. that of the maximum authorized temperature of the gas in liquid form contained in the tank on arrival, is invariable over time. The result of step A being used, however, for the calculation of step E, said result must be kept during the journey, for example by means of a memory of the control box.

Step A' consisting in selecting the safety margin is also not repeated. The safety margin may, however, be made to vary, independently of the progress of the estimating and adjusting method 5, either because it has been configured to vary over time when the estimating and adjusting method 5 was started the first time, or because it was changed manually through the control monitor 6. The variation of the safety margin is the reason why step E is maintained within the estimating and adjusting method 5, since it is a factor that is likely to vary over time for the calculation of step E.

When the estimating and adjusting method 5 is repeated by iteration, it therefore begins with step B. Steps B and C take place such that during the first launch of the estimating and adjusting method 5, the quantity of excess gas phase generated from the gas in liquid form still being calculated and supplied by the computer 7.

Step D also takes place identically to what was described above. In contrast, a step D' takes place, parallel to step D, which also calculates the energy balance of the gas in liquid form at time t , but according to a calculation different from that of step D. The calculation of the energy balance of the gas in liquid form at time t of step D' is done from an energy balance of the gas in liquid form at a previous time t , calculated during a previous iteration of the estimating and adjusting method 5, as well as from the executions of the condensation and cooling functions since the departure of the floating structure. The energy balance of the gas in liquid form at a previous time t can be recovered for example from the buffer memory of the control box. The executions of the condensation and cooling functions are at the origin of the heat

transfer carried out by the condensation function and of the cold transfer carried out by the cooling function toward the gas cargo in liquid form. The executions of the condensation and cooling functions can therefore be measured by sensors located at the elements of the supply system 8 ensuring the condensation and cooling of the gas in liquid form, which transmits this data to the control box for application during step D'.

After calculating the energy balances of the gas in liquid form at time t of steps D and D', only the energy balance of the gas in liquid form at time t having the highest value is retained. The latter is considered to have the most pessimistic value, the priority being to remain below the maximum energy balance calculated subsequently.

The remainder of the estimating and adjusting method 5 then takes place in accordance with what has been described in Fig. 3. Once the estimating and adjusting method 5 is completed, the adjustments of the operating plans for the condensation and cooling functions are transmitted to the supply system 8, and the estimating and adjusting method 5 can repeat again directly from step B depending on the setting of the control box. Advantageously, the control box is configured to repeat the estimating and adjusting method 5 at regular intervals throughout the journey, according to the flow of Fig. 4, for example once a day or every six hours.

Fig. 5 is a general representation of the supply system 8 ensuring the functions of condensation and cooling of the gas in liquid form. In general, the supply system 8 interacts with the tank 9 as well as with a set of consumers.

The supply system 8 is able to ensure temperature management of the gas in liquid form of the tank 9. To do this, the supply system 8 comprises a liquid inlet 81 and a gas inlet 82. The liquid inlet 81 connects the supply system 8 to the tank 9, and is capable of drawing in the gas in liquid form 13, for example by means of a gas pump in liquid form 26. The gas inlet 82 extends from a tank head that may comprise a certain quantity of gas phase 14 generated from the gas in liquid form to the supply system 8. The gas phase 14 generated from the gas in liquid form can be suctioned for example by a compressor 27 in order to be conducted to the supply system 8.

The supply system 8 also comprises a gas outlet 83 that extends from the supply system 8 to the set of consumers. By way of example, the consumers can be a propulsion engine 16, an electric generator 17, a combustion chamber 18 or a

degassing mat 28. The propulsion engine 16 makes it possible to advance the floating structure during the journey and is able to be supplied by the gas phase 14 generated from the gas in liquid form. The electric generator 17 supplies the floating structure with electricity, for example the lighting or the on-board network of the floating structure, and more generally any entity requiring a power supply. The gas phase 14 generated from the gas in liquid form therefore serves as fuel for one and/or the other of these consumers. Thus, for example in the event of an excess of gas phase 14 generated from the gas in liquid form, the supply system 8 can suction the gas phase 14 generated from the gas in liquid form within the gas inlet 82. The gas phase 14 generated from the gas in liquid form can then be treated by the supply system 8 and then leave the latter through the gas outlet 83, for example in order to supply the propulsion engine 16 or the electric generator 17.

The gas phase 14 generated from the gas in liquid form and not used to supply the propulsion engine 16 or the electric generator 17 represents the excess gas phase 14 generated from the gas in liquid form. This excess gas phase 14 generated from the gas in liquid form can be burned by the combustion chamber 18 or be released into the atmosphere by the degassing mat 28.

The excess gas phase 14 generated from the gas in liquid form can also return to the supply system 8 via a bypass 84 in order to be condensed by the latter. Once this is done, the gas in condensed liquid form returns to the tank 9 through a liquid outlet 85 of the supply system 8.

If the gas in liquid form 13 needs to be cooled, the latter is drawn in by the gas in liquid form pump 26 and circulates within the liquid inlet 81 as far as the supply system 8, where it is cooled. The cooled gas in liquid form 13 then returns to the tank 9 through the liquid outlet 85.

Fig. 6 is a schematic representation of a first embodiment of the supply system 8 ensuring the condensation and cooling functions of the gas in liquid form.

Like for Fig. 5, the supply system 8 manages the temperature of the tank 9. The tank 9 is at least partially filled with a certain quantity of gas in liquid form 13. The tank head may also comprise a certain quantity of gas phase 14 generated from the gas in liquid form. The tank 9 also comprises at least the gas in liquid form pump 26. The tank 9 also comprises a first temperature sensor 10. It is from this first

temperature sensor 10 that the average temperature of the gas in liquid form 13 is measured and transmitted to the control box for the calculation of step D of the estimating and adjusting method. For the example of Fig. 6, the first temperature sensor 10 of the tank 9 records the temperature of the gas in liquid form that surrounds it. If the floating structure comprises a plurality of tanks 9 each comprising a first temperature sensor 10, an average of the temperatures is taken and then sent to the control box.

As previously indicated, the condensation function of the supply system 8 allows condensation of the excess gas phase 14 generated from the gas in liquid form. To do this, the gas phase 14 generated from the gas in liquid form of the tank 9 is suctioned by the compressor 27 located outside the tank and constituting a gas phase circuit 15. The gas phase circuit 15 transports the generated gas phase 14 from the gas in liquid form that extends until it emerges at the propulsion engine 16 and/or the electric generator 17 with the aim of being used as fuel by these latter.

The gas phase 14 generated from the gas in liquid form and not used to supply the propulsion engine 16 or the electric generator 17 represents the excess gas phase 14 generated from the gas in liquid form and circulates within an excess circuit 19. The excess circuit 19 allows the circulation of the excess gas phase 14 generated from the gas in liquid form to a first heat exchanger 11. It is the first heat exchanger 11 that performs the function of condensing the excess gas phase 14 generated from the gas in liquid form, owing to a heat exchange between a first pass 111 and a second pass 112. The first pass 111 is traversed by the excess gas phase 14 generated from the gas in liquid form, which is then cooled by the second pass 112, so that the excess gas phase 14 generated from the gas in liquid form condenses and goes into a liquid state. It is thus understood that when the condensation function of the supply system 8 is active, the excess gas phase 14 generated from the gas in liquid form is directed to the first heat exchanger 11 via the excess circuit 19. If the condensation function of the supply system 8 is inactive, then the excess gas phase generated from the gas in liquid form is directed to the combustion chamber 18 to be burned or to the degassing mat 28 to be released into the atmosphere. In order to condense the excess gas phase 14 generated from the gas in liquid form, a fluid having a temperature lower than the change of state

temperature of the excess gas phase 14 generated from the gas in liquid form circulates within the second pass 112.

Once the excess gas phase 14 has been generated from the gas in liquid form condensed by the first heat exchanger 11, the condensed gas circulates in a condensed gas circuit 20 as far as a return circuit 21 that directs the condensed gas to the tank 9.

Regarding the cooling function of the supply system 8, the gas in liquid form 13 contained in the tank 9 is first suctioned by the gas in liquid form pump 26. The gas in liquid form 13 suctioned the gas in liquid form pump 26 circulates to a second heat exchanger 12. It is the second heat exchanger 12 that performs the function of cooling the gas in liquid form 13, owing to a heat exchange between a third pass 121 and a fourth pass 122. The gas in liquid form 13 suctioned by the gas in liquid form pump 26 circulates in the second heat exchanger 12 through the fourth pass 122 and is cooled. In order to cool the gas in liquid form 13, which is already at a very low temperature, a fluid with a temperature lower than the gas in liquid form 13 circulates within the third pass 121. The third pass 121 can be part of a cooling circuit external to the supply system 8, and not shown in Fig. 6. The external cooling circuit can for example be part of a vacuum evaporator-type system.

Subsequently, after being cooled by the second heat exchanger 12, the cooled gas in liquid form 13 returns to the tank 9 through the return circuit 21. Thus, the cooled gas in liquid form 13 makes it possible to globally cool the tank 9, the temperature of the cooled gas in liquid form 13 being lower than the temperature of the gas in liquid form 13 remaining in the tank 9.

The heat exchanges of the first heat exchanger 11 and of the second heat exchanger 12 are measured by a plurality of temperature sensors. Thus, the supply system 8 comprises two second temperature sensors 24, each located at the inlet and at the outlet of the first heat exchanger 11, and two third temperature sensors 25, each located at the inlet and at the outlet of the second heat exchanger 12. By calculating a temperature difference between the outlets and the inlets of each of the heat exchangers, it is possible to measure the heat input into the tank 9 owing to the second temperature sensors 24 and the cold input into the tank 9 owing to the third temperature sensors 25. The heat input and the cold input are data

used for to calculate the execution of the condensation and cooling functions of the supply system 8, said executions serving to calculate the energy balance of the gas in the form liquid at time t of step D' of the estimating and adjusting method. This data is therefore sent to the control box by the supply system 8.

5 At the end of the estimating and adjusting method, the supply system 8 receives the adjusted operating plans for the condensation and cooling functions. The supply system 8 then modifies its operation according to the adjusted operating plans by being able to program the activation or deactivation of one and/or the other of the condensation and cooling functions.

10 Fig. 7 schematically represents a second embodiment of the supply system 8. Compared to the first embodiment presented in Fig. 6, only the implementation of the cooling function of the supply system 8 is different. Reference will therefore be made to the description of Fig. 6 for any part of the supply system 8 common to the two embodiments.

15 In this second embodiment of the supply system 8, the latter implements its cooling function in combination with a function of supplying the consumers of the floating structure. Indeed, when the gas phase 14 generated from the gas in liquid form is suctioned into the gas phase circuit 15, it passes through the second exchanger 12, circulating within the third pass 121. The gas in liquid form 13 contained in the tank 9
 20 is first suctioned by the gas in liquid form pump 26 and then circulates through the fourth pass 122 located within the second heat exchanger 12. The heat exchange taking place between the third pass 121 and the fourth pass 122 makes it possible both to increase the temperature of the gas phase 14 generated from the gas in liquid form so that it is adequate to supply the propulsion engine 16 and/or the
 25 electric generator 17, but also to sub-cool the gas in liquid form 13 suctioned by the gas in liquid form pump 26. Subsequently, after having been cooled by the second heat exchanger 12, the cooled gas in liquid form 13 circulates in a cooled gas circuit 23 as far as the return circuit 21, which directs the cooled gas in liquid form 13 into the tank 9.

30 Thus, the cooled gas in liquid form 13 returns to the tank 9 and makes it possible to globally cool the latter, the temperature of the cooled gas in liquid form 13 being lower than the temperature of the gas in liquid form 13 remaining in the tank 9.

The gas in liquid form 13 circulates in this way if the cooling function is active. The supply system 8 therefore allows the condensation and cooling functions to be active or inactive simultaneously, insofar as gas phase 14 generated from the gas in liquid form is present for the cooling function and excess gas phase 14 generated from the gas in liquid form is present for the condensation function.

Fig. 8 to 11 show a curve of the change in the energy balance of the gas in liquid form contained in the tank as a function of time, that is to say, during the journey of the floating structure, and as a function of the operating plans for the condensation and cooling functions shown in the upper part of each of Fig. 8 to 11. Fig. 8 and 9 correspond respectively to an estimate and an adjustment following a situation where the estimated energy balance of the gas in liquid form on arrival is lower than the maximum energy balance. Fig. 10 and 11 correspond respectively to an estimate and an adjustment following a situation where the estimated energy balance of the gas in liquid form is higher than the maximum energy balance.

For each of Fig. 8 to 11, the initial situation presented is the launch of the estimating and adjusting method at a time t during the journey of the floating structure between departure 50 and arrival 51.

Each of the curves of the energy balance as a function of time of Fig. 8 to 11 comprises a real maximum energy balance 32 and the virtual maximum energy balance 33, that is to say, which takes the safety margin into account. The virtual maximum energy balance 33 is lower than the real maximum energy balance 32, the difference depending on the value of the safety margin. The real maximum energy balance 32 is present only as an indication, since for each of the figures, the adjustment of the energy balance of the gas in liquid form contained in the tank is done according to the virtual maximum energy balance 33. The real maximum energy balance 32 is constant over time. Advantageously, the virtual maximum energy balance 33 gradually approaches the real maximum energy balance over time, but for reasons of clarity, the virtual maximum energy balance 33 is also shown as being constant over time in Fig. 8 to 11.

Fig. 8 to 11 also each show the curves of the first operating plan 36 of the condensation function and of the second operating plan 37 of the cooling function over time. The ordinates of the curves of the operating plans have only two positions:

position 0 and position 1. When the operating plans are in position 0, this means that the associated functions are inactive. When the operating plans are in position 1, this means that the associated functions are active, which consequently authorizes the condensation and/or the cooling of the gas in liquid form via the supply system. For each of the situations, it is assumed that the two operating plans are fundamentally in position 1 throughout the journey, that is to say, the condensation and cooling functions are authorized throughout the journey.

Fig. 8 therefore shows a first situation during the journey of the floating structure. Thus, at time t , the estimating and adjusting method starts, and the energy balance of the gas in liquid form at time t 38 is obtained during step D or D' of the estimating and adjusting method, either from the temperature of the gas in liquid form contained in the tank, or from the execution of the condensation and cooling functions from departure 50. It is possible to observe the change of the energy balance of the gas in liquid form contained in the tank from departure 50 and until time t , the change corresponding to a measured energy balance 34. The measured energy balance 34 is shown in solid lines because it has already been measured in real time from the departure 50, the first measurement corresponding to a starting energy balance 30, determined when the estimating and adjusting method was launched for the first time. The change in the energy balance of the gas in liquid form after time t is in dotted lines and represents a forecast energy balance 35 that is therefore evaluated by the estimating and adjusting method, more precisely during step F and from the energy balance of the gas in liquid form at time t 38. The estimate of the energy balance 31 of the gas in liquid form contained in the tank on arrival 51 therefore corresponds to an estimate of the value of the energy balance when the floating structure reaches the arrival 51 if the operating plans as shown in Fig. 8 are maintained until this arrival 51.

It is noted in Fig. 8 that without adjustment of the operating plans for the estimating and adjusting method according to the invention, the estimated energy balance 31 of the gas in liquid form contained in the tank on arrival 51 is less than the virtual maximum energy balance 33, calculated during step E of the estimating and adjusting method. The gas in liquid form contained in the tank therefore meets the

requirements of the place of destination. However, it is possible to adjust the operating plans in order to limit the energy consumption of the supply system.

Fig. 9 shows a curve implementing step G of the estimating and adjusting method according to the invention, with operating plans adjusted with respect to those shown in Fig. 8. The estimating and adjusting method always takes place at time t and after the observation that the estimated energy balance 31 of the gas in liquid form contained in the tank on arrival 51 was lower than the virtual maximum energy balance 33. The estimating and adjusting method therefore adjusts the operating plans in order to guarantee energy savings. Thus, although this is already the case in the example shown, the first operating plan 36 of the condensation function is adjusted to be kept active, i.e. in position 1, until the arrival 51 from the journey. The excess gas phase generated from the gas in liquid form is therefore fully condensed, which does not lead to cargo losses.

Furthermore, since the estimated energy balance 31 of the gas in liquid form contained in the tank on arrival 51 is lower than the virtual maximum energy balance 33, it is also possible to deactivate the cooling function at an estimated time dt during the journey. To determine the estimated time dt , the estimating and adjusting method implements one or more iterations where the adjustment of the second operating plan 37 of the cooling function and the recalculation of the estimated energy balance 31 of the gas in liquid form contained in the tank on arrival 51 successively alternate. Here, the adjustment of the second operating plan 37 of the cooling function consists in selecting a time when the cooling function is deactivated by taking the arrival 51 as the target. The iterations continue as long as the estimated energy balance 31 of the gas in liquid form contained in the tank on arrival 51 is less than the virtual maximum energy balance 33, the selected time when the cooling function is deactivated being increasingly earlier than the previous one with each new occurrence, and the calculation of the estimated energy balance 31 of the gas in liquid form contained in the tank on arrival 51 being carried out each time with the new adjustment of the second operating plan 37 of the previously determined cooling function. These iterations thus make it possible to determine the optimal estimated time dt so that the estimated energy balance 31 of the gas in liquid form contained in the tank on arrival 51 does not exceed the virtual

maximum energy balance 33, but while deactivating the cooling function as soon as possible in order to save maximum energy.

Once the estimated time dt has been obtained, the estimating and adjusting method adjusts the second operating plan 37 for the cooling function and transmits it to the supply system. The second adjusted operating plan 37 of the cooling function is visible in Fig. 9, where it can be seen that the cooling function switches to position 0 following the adjustment, resulting in its deactivation at the estimated time dt . Thus, between the estimated time dt and the arrival 51, the cooling function is kept deactivated. Knowing this, and given that the condensation function is always active, the temperature of the gas in liquid form contained in the tank, and by analogy the energy balance of the gas in liquid form contained in the tank, presents a more significant increase between the estimated time dt and the arrival 51 than on the curve in Fig. 8. The estimated time dt , owing to the iterations of the estimating and adjusting method mentioned above, is, however, calculated so as to cause an increase in the estimated energy balance 31 of the gas in liquid form contained in the tank on arrival 51, but without the latter exceeding the virtual maximum energy balance 33 upon arrival 51 at the place of destination.

The gas in liquid form contained in the tank therefore always meets the requirements of the place of destination, but energy savings are achieved between the estimated time dt and the arrival 51 given that the cooling function is deactivated during this time and therefore does not need to be supplied with energy. The estimating and adjusting method has therefore made it possible to limit the energy waste while keeping the gas in liquid form in accordance with the requirements of the place of destination.

Fig. 10 still shows the change curve of the energy balance of the gas in liquid form contained in the tank over time, but this time in the opposite situation relative to Fig. 8 and 9. Indeed, according to the estimating and adjusting method, during time t of the journey, the energy balance of the gas in liquid form at time t 38 is calculated, then the estimating and adjusting method calculates the estimated energy balance 31 of the gas in liquid form contained in the tank on arrival 51 from the energy balance of the gas in liquid form at time t 38. As can be seen in Fig. 10, the estimated energy balance 31 of the gas in liquid form contained in the tank on

arrival 51 is greater than the virtual maximum energy balance 33, and even the real maximum energy balance 32, despite the constant activation of the cooling function throughout the entire journey as evidenced by the second operating plan 37 for the cooling function visible in Fig. 10.

In this situation, upon arrival 51, and if the operating plans for the condensation and cooling functions are not adjusted, the gas in liquid form contained in the tank will not meet the requirements of the place of destination, resulting in refusal of the cargo by the latter. To avoid this, it is essential to lower the saturation pressure of the gas in liquid form contained in the tank, leading to a drop in the energy balance of the gas in liquid form also contained in the tank, in order to meet the requirements of the place of destination upon arrival 51. A given time $d't$ is indicated in Fig. 10 and corresponds to the time when the forecast energy balance 35 exceeds the virtual maximum energy balance 33, i.e. the time from which the energy balance of the gas in liquid form contained in the tank no longer complies with the requirements of the place of destination.

The adjustments necessary to overcome the situation mentioned in Fig. 10 are shown in Fig. 11. Thus, if this is not already the case, the estimating and adjusting method adjusts the second operating plan 37 of the cooling function so that the latter is active until the arrival 51 of the journey.

As mentioned previously, the main factor leading to a rise in the temperature of the gas in liquid form contained in the tank as well as in the energy balance of the latter is due to the condensation of the excess gas phase generated from the gas in liquid form. Indeed, although the latter is condensed in order to enter the liquid form, the temperature of the condensed gas is higher than the temperature of the gas in liquid form contained in the tank. In the long run, the return of the condensed gas to the tank therefore leads to a rise in the temperature of the gas in liquid form contained in the tank. The best way to stop such a rise in temperature is therefore to implement the first adjusted operating plan 36 for the condensation function so that the latter is deactivated.

Thus, the estimating and adjusting method adjusts the first operating plan 36 for the condensation function. The condensation function is therefore programmed to be deactivated at the given time $d't$, that is to say, at the moment when the estimated

energy balance 34 reaches the virtual maximum energy balance 33. The estimating and adjusting method thus makes it possible to keep the condensation function active for as long as possible. When the given time $d't$ arrives, the condensation function is deactivated. The increase in the energy balance of the gas in liquid form contained in the tank is then stopped owing to the deactivation of the condensation function, but also because the cooling function is kept active. The estimated energy balance 31 of the gas in liquid form contained in the tank on arrival 51 is therefore kept at the level of the virtual maximum energy balance 33, which corresponds to the requirements of the place of destination. In this configuration, between the given time $d't$ and the arrival 51, the excess gas phase generated from the gas in liquid form is no longer condensed by the supply system.

Fig. 12 shows a first example of a curve of the change in the safety margin 60 as a function of time, from departure 50 to arrival 51. This first example shows a safety margin 60 decreasing over time. In other words, the closer the floating structure becomes to the place of destination, the more the safety margin 60 decreases and consequently the closer the virtual maximum energy balance comes to the real maximum energy balance, given that the virtual maximum energy balance is recalculated in each step E by iterations of the estimating and adjusting method with the safety margin 60, which decreases as the floating structure approaches its destination.

The value of the safety margin may also depend on the amount of information held by the personnel of the floating structure concerning the journey, for example the weather conditions during the journey or the sea conditions. Thus, a higher safety margin 60 may be indicated if there is no information about the conditions of the journey.

Fig. 13 shows a second example of the change in the safety margin 60 over time. At the start of this journey, the safety margin 60 decreases over time, like in the previous figure. However, it is possible that an unforeseen event 61 may occur. The event 61 can be a natural phenomenon, for example a meteorological phenomenon such as a storm or fog, capable of slowing down the speed of the floating structure. The event 61 can also be a mechanical incident, for example a breakdown of the floating structure, liable to immobilize the latter for a non-negligible period of time.

Such an event 61 therefore lengthens the travel time to the place of destination. In this situation, the safety margin 60 as it was programmed on departure 50 is no longer adequate for the journey. It is therefore possible to reprogram the safety margin 60 in order to adapt it to the consequences of the event 61, that is to say, the slowing down or the immobilization of the floating structure in the examples given above. In Fig. 13, the safety margin 60 is raised when the event 61 has occurred, then decreases again over time. This modification guarantees certainty concerning the virtual maximum energy balance and makes it possible to avoid errors that could potentially lead to the refusal of the cargo of gas in liquid form upon arrival at the place of destination.

Of course, the invention is not limited to the examples that have just been described, and numerous modifications can be made to these examples without departing from the scope of the invention.

The invention, as it has just been described, achieves the goal that it had set itself, and makes it possible to propose a method for estimating and adjusting an energy balance of a gas in liquid form contained in a tank of a floating structure so that said energy balance of the gas in liquid form complies with the requirements of a place of destination where the delivery of the gas in liquid form is intended, while optimally adjusting the energy consumption of the supply system. Variants not described here could be implemented without departing from the context of the invention, since, in accordance with the invention, they comprise an estimating and adjusting method according to the invention.

CLAIMS

1. Method for estimating and adjusting (5) an energy balance of a gas in liquid form (13) contained in at least one tank (9) of a floating structure (1) intended to deliver said gas in liquid form (13) to a given place of destination (2), the floating structure (1) comprising a system (8) for supplying fuel to a consumer of the floating structure (1) capable of carrying out a function of condensation of a gas phase (14) generated from the gas in liquid form and/or a function of cooling the gas in liquid form (13), characterized in that the estimating and adjusting method (5) comprises the following steps:

- a step A of calculating the maximum authorized temperature of the gas in liquid form contained in the tank on arrival at the place of destination, based on the maximum saturation pressure requirements of gas in liquid form of the place of destination (2) and the characteristics of the gas in liquid form contained in the tank,
- a step B of establishing a first operating plan (36) for the condensation function of the gas phase (14) generated from the gas in liquid form carried out by the supply system (8) until the arrival (51) at the place of destination (2), said first operating plan (36) being established from an estimate of an excess gas phase (14) generated from the gas in liquid form in the tank (9) during a journey (3),
- a step C of establishing a second operating plan (37) for the cooling function of the gas in liquid form (13) carried out by the supply system (8) until arrival (51) at the place of destination (2), said second operating plan (37) being established from the estimate of the excess gas phase generated from the gas in liquid form during the journey (3),
- a step D of calculating an energy balance of the gas in liquid form at a time t (38) from the temperature of the gas in liquid form (13) contained in the tank (9) and the properties of the gas in liquid form (13) contained in the tank (9),
- a step E of calculating a maximum energy balance (32, 33) from the maximum authorized temperature of the gas in liquid form (13), calculated in step A, and the characteristics of the gas in liquid form (13) contained in the tank (9),
- a step F of estimating the energy balance (31) of the gas in liquid form contained in the tank on arrival (51) from the journey (3) from the operating plans (36, 37) of the condensation and cooling functions determined in steps B and

C and from the energy balance of the gas in liquid form at time t (38), determined in step D,

- a step G of adjusting the first operating plan (36) and/or the second operating plan (37),

- a step H of implementing the supply system (8) according to the operating plans (36, 37) of the condensation and cooling functions of the gas in liquid form (13) adjusted in step G.

2. Method for estimating and adjusting (5) the energy balance according to the preceding claim, wherein step G consists in activating the condensation function as long as the estimated energy balance (31) of the gas in liquid form contained in the tank (51) on arrival (3) from the journey, calculated in step F, is less than the maximum energy balance (32, 33) calculated in step E.

3. Method for estimating and adjusting (5) the energy balance according to one of the preceding claims, wherein step G consists in stopping the cooling function at an estimated time dt that guarantees that the estimated energy balance (31) of the gas in liquid form contained in the tank on arrival (51) from the journey (3), calculated in step F, is less than the maximum energy balance (32, 33) calculated in step E.

4. Method for estimating and adjusting (5) the energy balance according to claim 1, wherein step G consists in stopping the condensation function as long as the estimated energy balance (31) of the gas in liquid form contained in the tank on arrival (51) from the journey (3), calculated in step F, is greater than the maximum energy balance (32, 33) calculated in step E.

5. Method for estimating and adjusting (5) the energy balance according to claim 1 or 4, wherein step G consists in activating the cooling function as long as the estimated energy balance (31) of the gas in liquid form contained in the tank on arrival (51) from the journey (3), calculated in step F, is greater than the maximum energy balance (32, 33) calculated in step E.

6. Estimating and adjusting method (5) according to one of the preceding claims, repeated by iteration starting from step B and during the journey (3) of the floating structure (1).

7. Estimating and adjusting method (5) according to claim 6, comprising an additional step D', carried out simultaneously with step D, of calculating the energy balance of the gas in liquid form at time t (38) from the execution of the condensation and cooling functions from the departure (50) of the floating structure (1) and until

time t and from an energy balance of the gas in liquid form at time t (38) calculated during an earlier iteration.

8. Estimating and adjusting method (5) according to claim 7, wherein the energy balance of the gas in liquid form at time t (38) conserved for step F is the highest among the energy balance of the gas in liquid form at time t (38) calculated in step D and the energy balance of the gas in liquid form at time t (38) calculated in step D'.

9. Estimating and adjusting method (5) according to one of claims 1 to 5, comprising an additional step A' of selecting a safety margin (60) for the maximum energy balance (32, 33) of the gas in liquid form (13) as a function of the characteristics of the journey (3) of the floating structure (1), step E being performed taking said safety margin (60) into account.

10. Estimating and adjusting method (5) according to claim 9, wherein step A' is repeated by iteration during the journey (3) of the floating structure (1).

11. Estimating and adjusting method (5) according to claim 9 or 10, wherein the safety margin (60) decreases as the floating structure (1) approaches the place of destination (2).

12. Estimating and adjusting method (5) according to one of the preceding claims, wherein the floating structure (1) is equipped with at least one engine (16) powered at least partially by the gas phase (14) generated from the gas in liquid form, the estimation of the excess gas phase generated from the gas in liquid form liquid during the journey (3) being established from an image value of the heat inputs into the tank (9) and an estimate of the consumption of the engine (16).

13. System (4) for managing an energy balance of a gas in liquid form (13) contained in at least one tank (9) of a floating structure (1), implementing the estimating and adjusting method (5) according to one of the preceding claims, said management system (4) comprising at least one fuel supply system (8) for a consumer of the floating structure (1) and at least one computer (7) having the function of estimating a quantity of excess gas phase (14) generated from the gas in liquid form during a journey (3) of the floating structure (1).

14. Floating structure (1) for transporting gas in liquid form (13) comprising a system (4) for managing the energy balance of said gas according to the preceding claim.