

MONITORING OF A SEALED AND THERMALLY INSULATED TANK

Technical Field

The invention relates to the field of the monitoring sealed and thermally insulated tanks intended to contain a low-temperature liquefied fuel gas, particularly in the case of a membrane tank, in which tank a wall of the tank comprises a multilayer structure mounted on a bearing wall, the multilayer structure comprising a sealing membrane in contact with the liquefied fuel gas contained in the tank and a thermally insulating barrier arranged between the sealing membrane and the bearing wall, and in which tank the thermally insulating barrier comprises insulating solid substances and a gaseous phase kept under a negative relative pressure, using a suction device connected to the thermally insulating barrier.

Background

Sealed and thermally insulated tanks may be used for storing and/or transporting low-temperature liquefied fuel gases, for example a gas with a high methane content commonly referred to as liquefied natural gas (LNG), the boiling point of which is at around -162°C at atmospheric pressure.

In membrane tank technology, one wall of the tank comprises a multilayer structure mounted on a bearing wall and comprising at least one sealing membrane and at least one thermally insulating barrier arranged between the sealing membrane and the bearing wall. The or each thermally insulating barrier comprises insulating solid substances that form a supporting surface to support the or each sealing membrane.

In order to increase the insulation capability of the or each thermally insulating barrier, publication FR-A-2535831 proposes keeping the gaseous phase of the secondary thermally insulating barrier under an absolute pressure lower than the ambient atmospheric pressure, namely at a negative relative pressure.

Moreover, the use of such a liquefied fuel gas tank assumes that strict safety conditions can be adhered to and notably that any losses of sealing of a membrane can be detected as effectively as possible. Thus, there are certain regulations that demand that the content of the insulation spaces be analyzed at least every 30 minutes.

Document FR2317649 discloses a method for checking the variations in porosity of the primary and secondary sealing membranes arranged on each side of an intermediate space. The secondary thermal insulation barrier is filled with a mixture of nitrogen and argon. The intermediate space between the two sealing
5 membranes is swept with a stream of nitrogen, and the methane and argon contents of the stream of nitrogen are analyzed in order to detect leaks of the primary sealing membrane or of the secondary sealing membrane. The intermediate space is kept at a depression in order to encourage gas to migrate through the sealing membranes.

10 **Summary**

One idea underlying the invention is that of providing monitoring methods and devices suited to effective detection of the presence of the fuel gas in the thermally insulating barrier, even when the gaseous phase is kept under a negative relative pressure.

15 According to one embodiment, the invention provides a method for monitoring a sealed and thermally insulated tank intended to contain a low-temperature liquefied fuel gas,
in which method a wall of the tank comprises a multilayer structure mounted on a bearing wall, the multilayer structure comprising a sealing membrane in contact with
20 the liquefied fuel gas contained in the tank and a thermally insulating barrier arranged between the sealing membrane and the bearing wall, the thermally insulating barrier comprising insulating solid substances and a gaseous phase kept under a negative relative pressure, the method comprising:
obtaining a sample of dilute gas by withdrawing a sample of the gaseous phase
25 under negative relative pressure in the thermally insulating barrier through a sampling duct opening to the outside of the tank wall and by adding a controlled quantity of inert gas to the gaseous phase that is to be withdrawn or that has been withdrawn,
compressing, namely raising the pressure of the dilute gas sample up to an
30 operating pressure of a gas analyzer, and
measuring a concentration of the fuel gas in the dilute gas sample using the gas analyzer.

According to some embodiments, such a monitoring method may involve one or more of the following features.

According to one embodiment, the method further comprises:
determining a concentration of the fuel gas in the gaseous phase of the thermally
5 insulating barrier as a function of the measured concentration and of the quantity of
inert gas added to the gaseous phase.

According to one particular embodiment, the method comprises:
- determining a dilution ratio brought about by the addition of a controlled quantity of
inert gas to the gaseous phase that is to be withdrawn or that has been withdrawn
10 according to measurements of the pressure and of the temperature of the gaseous
phase that is to be withdrawn or that has been withdrawn before and after the
addition of the controlled quantity of inert gas to the gaseous phase; and
- determining a concentration of the fuel gas in the gaseous phase of the thermally
insulating barrier as a function of the measured concentration and of the dilution
15 ratio brought about by the addition of a controlled quantity of inert gas.

The fuel gas may consist of liquefied natural gas, liquefied petroleum gas (LPG), ethylene or the like.

The use of an inert gas makes it possible to increase the quantity of
substance in the sample that is to be analyzed, without the risk of creating an
20 explosive mixture. For example, the inert gas may be selected from the group
consisting of dinitrogen, helium, argon and mixtures thereof

According to various embodiments, the negative relative pressure corresponds to an absolute pressure of below 10 kPa, preferably of below 1 kPa.

According to some embodiments, the operating pressure of the gas
25 analyzer is comprised between 80 kPa and 120 kPa, preferably between 86 kPa
and 108 kPa. With these operating pressures it is possible to use gas analyzers that
are relatively inexpensive and readily available.

The fuel gas concentration may be measured using various known
detection techniques. For example, the gas analyzer may comprise a fuel gas
30 detector selected from the group consisting of infrared detectors, notably those that
work by measuring absorbance and/or transmittance, and electrochemical-cell
detectors.

There are two methods that can be used for diluting the low-pressure gaseous phase present in the insulating barrier. The first method involves mixing the inert gas with the gaseous phase before the withdrawing of the sample, namely in the insulating barrier. A second method involves mixing the inert gas with the gaseous phase after the taking of the sample, namely in the monitoring device. These two methods may be combined.

According to an embodiment corresponding to the first aforementioned method, the step of obtaining the sample of dilute gas comprises: adding a controlled quantity of inert gas to the gaseous phase in the thermally insulating barrier in order to increase the relative pressure of the gaseous phase in the thermally insulating barrier from a negative first value to a negative second value, and withdrawing a sample of the gaseous phase under the relative pressure equal to the second negative value in the thermally insulating barrier through the sampling duct opening to the outside of the tank wall so as to obtain the dilute gas sample, and reducing the relative pressure of the gaseous phase in the thermally insulating barrier from the second negative value to the first negative value after having withdrawn the sample of the gaseous phase.

According to some embodiments, the first negative value is less than 1 kPa, preferably less than or equal to 0.1 kPa, and the second negative value is greater than or equal to 1 kPa.

According to an embodiment corresponding to the second aforementioned method, the step of obtaining the dilute gas sample comprises: withdrawing a sample of the gaseous phase under the negative relative pressure in the thermally insulating barrier through the sampling duct opening to the outside of the tank wall, and adding a controlled quantity of inert gas to the withdrawn gaseous phase sample.

In that case, the steps of withdrawing, diluting and compressing the sample may be performed jointly by means of a Venturi-effect suction device, the Venturi-effect suction device comprising: a main pipe having an inlet connected to a source of the inert gas under pressure and an outlet connected to a measurement enclosed space or to an intermediate enclosed space, and

a suction pipe having an upstream end connected to the sampling duct and a downstream end opening laterally into a convergent-divergent of the main pipe in such a way that a stream of inert gas along the main pipe causes a depression in the suction pipe.

- 5 According to one embodiment, the step of taking the sample comprises: pumping the gaseous phase sample through the sampling duct towards an intermediate enclosed space, and isolating the intermediate enclosed space from the thermally insulating barrier.

10 According to another embodiment corresponding to the second aforementioned method, the controlled quantity of inert gas is added to the intermediate enclosed space, the step of compressing the dilute gas sample comprising: pumping the dilute gas sample from the intermediate enclosed space towards a measurement enclosed space coupled to the gas analyzer.

- 15 In embodiments, the step of compressing the dilute gas sample, namely of raising the pressure of the dilute gas sample, may comprise: storing the withdrawn sample of gaseous phase in an intermediate enclosed space connected to the sampling duct, and moving a mobile wall in the intermediate enclosed space in order to confine the dilute gas sample to a measurement enclosed space of smaller capacity than the intermediate enclosed space.
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For example, the measurement enclosed space consists of an end portion of the intermediate enclosed space or of a smaller-sized enclosed space connected to the intermediate enclosed space.

- 25 According to one embodiment, the steps of diluting and compressing the sample are performed by means of a Venturi-effect suction device, the Venturi-effect suction device comprising: a main pipe having an inlet connected to a source of the inert gas under pressure and an outlet connected to a measurement enclosed space, and
- 30 a suction pipe having an upstream end connected to the intermediate enclosed space and a downstream end opening laterally into a convergent-divergent of the main pipe in such a way that a stream of inert gas along the main pipe causes a depression in the suction pipe.

- According to one embodiment, the invention also provides a monitoring device suitable for a sealed and thermally insulated tank intended to contain a low-temperature liquefied fuel gas, in which tank a wall of the tank comprises a multilayer structure mounted on a bearing wall, the multilayer structure comprising a
- 5 sealing membrane in contact with the liquefied fuel gas contained in the tank and a thermally insulating barrier arranged between the sealing membrane and the bearing wall, the thermally insulating barrier comprising insulating solid substances and a gaseous phase kept under a negative relative pressure, the monitoring device comprising:
- 10 a sampling duct connecting the thermally insulating barrier to the outside of the tank wall, said sampling duct being equipped with an isolation valve;
 an intermediate enclosed space connected to the thermally insulating barrier by the sampling duct;
 a measurement enclosed space connected to the intermediate enclosed space,
- 15 a gas analyzer coupled to the measurement enclosed space for measuring a concentration of the fuel gas in the measurement enclosed space,
 a pumping device connected to the sampling duct and able to withdraw a sample of the gaseous phase under the negative relative pressure in the thermally insulating barrier and to transfer the sample of the gaseous phase to the measurement
- 20 enclosed space,
 an inert gas reservoir connected to the intermediate enclosed space and designed to add a quantity of inert gas to the gaseous phase that has been withdrawn, in the intermediate enclosed space, and
 a measurement device for measuring the quantity of inert gas added to the gaseous
- 25 phase.

According to some embodiments, such a monitoring device may comprise one or more of the following features.

According to one embodiment, the measurement enclosed space is connected directly or indirectly to the sampling duct via an isolation valve.

- 30 According to one embodiment, the device further comprises a data processing system able to determine a concentration of the fuel gas in the gaseous phase of the thermally insulating barrier as a function of the concentration measured by the gas analyzer and of the quantity of inert gas added to the gaseous phase.

According to one embodiment, the data processing system is able to determine a dilution ratio brought about by the addition of a controlled quantity of inert gas to the gaseous phase that is to be withdrawn or that has been withdrawn as a function of measurements of the pressure and temperature of the gaseous phase that is to be withdrawn or that has been withdrawn before and after the addition of the controlled quantity of inert gas to the gaseous phase and to determine a concentration of the fuel gas in the gaseous phase of the thermally insulating barrier as a function of the concentration measured by the gas analyzer and of the dilution ratio brought about by the addition of a controlled quantity of inert gas.

The pumping device may be produced in various ways. According to one embodiment, the pumping device comprises a vacuum pump, for example of the Roots type or some other type.

The pumping device may be dedicated to the monitoring device or, for the sake of economy, the pumping device can be shared between the monitoring device and a device for regulating the pressure of the insulating barrier that is used to permanently maintain the negative relative pressure in the insulating barrier.

According to one embodiment, the pumping device comprises a Venturi-effect suction device, the Venturi-effect suction device comprising:
 a main pipe having an inlet connected to the reservoir of inert gas and an outlet connected to the measurement enclosed space, and
 a suction pipe having an upstream end connected to the sampling duct by way of the intermediate enclosed space and a downstream end opening laterally into a convergent-divergent of the main pipe in such a way that a stream of inert gas along the main pipe causes a depression in the suction pipe.

According to one embodiment, the invention also provides a sealed and thermally insulated tank intended to contain a low-temperature liquefied fuel gas and equipped with an aforementioned monitoring device,
 in which tank a wall of the tank comprises a multilayer structure mounted on a bearing wall, the multilayer structure comprising a primary sealing membrane in contact with the liquefied fuel gas contained in the tank, a secondary sealing membrane arranged between the primary sealing membrane and bearing wall, a primary thermally insulating barrier arranged between the primary sealing

membrane and the secondary sealing membrane, and a secondary thermally insulating barrier positioned between the secondary sealing membrane and the bearing wall, and in which tank a or each thermally insulating barrier comprises insulating solid substances and a gaseous phase kept under a negative relative
5 pressure, the monitoring device comprising a first sampling pipe opening into the primary thermally insulating barrier and a second sampling pipe opening into the secondary thermally insulating barrier.

Such a tank may form part of an on-shore storage facility, for example for storing LNG, or may be installed in a floating, in-shore or off-shore structure, notably
10 a methane tanker ship, a floating storage and regassification unit (FSRU), a floating production storage and off loading (FPSO) unit or the like.

According to one embodiment, a ship for carrying a cold liquid product comprises a double hull and an aforementioned tank arranged in the double hull.

According to one embodiment, the invention also provides a method for
15 loading or unloading such a ship, in which method a cold liquid product is carried through insulated piping from or to a floating or on-shore storage facility to or from the tank of the ship

According to one embodiment, the invention also provides a transfer system for transferring a cold liquid product, the system comprising the
20 aforementioned ship, insulated piping arranged in such a way as to connect the tank installed in the hull of the ship to a floating or on-shore storage facility and a pump for causing the cold liquid product to flow in a stream through the insulated piping from or to the floating or on-shore storage facility to or from the tank of the ship.

Certain aspects of the invention are based on the idea of making it easier to
25 analyze a gaseous phase available at low pressure, and therefore in small quantities, while at the same time limiting the costs of the sample withdrawing and/or analysis means.

Brief Description of the Figures

The invention will be better understood, and further objects, details,
30 features and advantages thereof will become more clearly apparent, during the course of the following description of a number of entirely nonlimiting and illustrative

particular embodiments of the invention, given with reference to the attached drawings.

- Figure 1 is a schematic depiction of a membrane tank and of a device for monitoring this tank.
- 5 • Figure 2 is a schematic depiction of a measurement enclosed space that can be used in the monitoring device of figure 1.
- Figure 3 is a depiction similar to figure 1, showing a tank monitoring device according to another embodiment.
- Figure 4 is an enlarged view in cross section of the region IV of figure 3.
- 10 • Figure 5 is a depiction similar to figure 1 showing a tank monitoring device according to another embodiment.
- Figure 6 is a time diagram showing a variation in pressure that can be achieved in the insulating barrier of the tank of figure 5.
- 15 • Figure 7 is a schematic artist's view depicting, with cutaway, a tank of a methane tanker ship that can be equipped with a monitoring device and a terminal for the loading/unloading of this tank.

Detailed Description of Embodiments

Figure 1 depicts a membrane tank 1 very schematically in cross section. This tank comprises a bearing structure 2 defining a cavity in which the tank is constructed, an insulating barrier 3 comprising insulating elements fixed to the interior surfaces of the bearing structure 2, and a liquidtight and gastight membrane 4, for example made of sheet metal, covering the entire interior surface of the tank.

According to an embodiment depicted in figure 5, a secondary sealed membrane may be interposed between the bearing structure 2 and the sealed membrane 4, so as to separate two insulating barriers one on each side of the secondary sealed membrane. This arrangement has not been depicted in figure 1.

The bearing structure 2 is also produced so that it is substantially gastight. Thus, the insulating barrier 3 is arranged in an insulation space which is insulated from the ambient pressure by the sealed membrane 4 and by the bearing structure 2. Pressure regulating devices, not depicted, may be used to maintain a low gas

pressure in the insulation space, for example a pressure of the order of 0.1 to 1 kPa, so as to lower the thermal conductivity of the insulating barrier 3 still further.

A monitoring device may be used in order to monitor the composition of the gaseous phase in the insulation space, so as to detect any potential leak in the sealed membrane 4. The monitoring of the only insulation space 3, which will be described hereinafter, may be performed in the same way for each of the insulation spaces in the case of a tank that includes a number of successive membranes.

To do that, the monitoring device 10 of figure 1 comprises a sampling duct 11, which passes through the bearing structure 2 and opens into the insulating barrier 3 so that a sample of the gaseous phase can be drawn up at this point. Multiple sampling ducts, not depicted, may be arranged in the same way at various locations in the tank in order to be able to sample the gaseous phase in several corresponding zones of the insulating barrier 3.

The sampling duct 11 connects the insulating barrier 3 to an intermediate enclosed space 12 via a vacuum pump 13 and an isolation valve 14. A connecting pipe 18 also connects a pressurized dinitrogen reservoir 15 to the intermediate enclosed space 12 via an isolation valve 16. A system of sensors 17 is provided so that a quantity of dinitrogen introduced from the pressurized dinitrogen reservoir 15 into the intermediate enclosed space 12 can be measured. Sensors that can be used for that purpose are, for example, a flow meter coupled to the connecting pipe 18 and/or temperature and pressure sensors coupled to the intermediate enclosed space 12.

The intermediate enclosed space 12 may be used as follows:

- A sample of the gaseous phase present in the insulating barrier 3 is transferred by the vacuum pump 13 to the intermediate enclosed space 12. The sample may be a very small quantity of the gaseous phase, depending on the power of the vacuum pump 13 and/or on the time available in which to take a sample.
- The valve 14 is closed to isolate the intermediate enclosed space 12.
- A determined quantity of dinitrogen is added from the reservoir 15 to the intermediate enclosed space 12 using the valve 16. For example, the quantity of dinitrogen may be measured via measurements of the pressure and temperature in the intermediate enclosed space 12 before

and after the addition of dinitrogen. The addition of dinitrogen to the enclosed space 12 allows the sample to be diluted in order both to obtain a larger quantity of substance for analysis and to raise a little the pressure of the gaseous phase that is to be analyzed.

5 The pressure in the intermediate enclosed space 12 is then higher than that prevailing in the insulating barrier 3. It is, for example, of the order of 1 to 10 kPa. This will not necessarily be sufficient for a chemical analysis to be able to be performed easily given that the most commonplace gas analyzers operate at pressures close to atmospheric pressure. It is therefore possible either to analyze
10 the dilute gas directly in the intermediate enclosed space 12 or to perform an additional compression of the dilute gas beforehand so that use can be made of faster and/or less expensive gas analyzer equipment.

In order to perform this additional compression, figure 1 depicts a connecting pipe 24 connecting the intermediate enclosed space 12 to a
15 measurement enclosed space 21 of smaller size by means of a second pump 20 and two isolation valves 22 and 23. The connecting pipe 24 may be used as follows:

- After dinitrogen has been added in the intermediate enclosed space 12, the valves 14 and 16 remain closed and the valves 22 and 23 are opened and the pump 20 is activated so that it compresses and
20 transfers the dilute gas from the intermediate enclosed space 12 to the measurement enclosed space 21.
- When the pressure in the measurement enclosed space 21 reaches a value high enough for the gas analyzer 25 to operate, the valve 23 is closed and the concentration of methane in the dilute gas is measured
25 using the gas analyzer 25.

Gas analyzers 25 capable of measuring a methane concentration are, for example, available from the Swedish company Consilium AB.

A data processing system 30 may then be used to calculate the methane concentration in the insulating barrier 3 prior to dilution, from measurement signals
30 supplied by the gas analyzer 25, which are indicated schematically by the arrow 31, and measurement signals supplied by the system of sensors 17, which are indicated schematically by the arrow 32.

The methane concentration in the insulating barrier may notably be calculated on the basis of the following equation:

$$[C(CH_4)]_{\text{insulating barrier}} = \frac{[C(CH_4)]_{\text{measured}}}{\vartheta}$$

where:

- 5 - $[C(CH_4)]_{\text{insulating barrier}}$ is the methane concentration in the insulating barrier prior to dilution;
- ϑ is the dilution ratio brought about by the addition of a controlled quantity of inert gas to the gaseous phase that has been withdrawn; and
- $[C(CH_4)]_{\text{measured}}$ is the methane concentration measured by the gas analyzer 25.

10 The dilution ratio ϑ is calculated by means of the measurement signals supplied by the system of sensors 17 and delivering measurements of the pressure and of the temperature in the intermediate enclosed space 12 before and after the addition of dinitrogen.

According to one embodiment, the dilution ratio ϑ may be calculated using
15 the following formula:

$$\vartheta = \frac{P_{\text{Before dilution}}}{P_{\text{After dilution}}} \text{ where:}$$

$P_{\text{Before dilution}}$ is the pressure (in Pa) inside the intermediate enclosed space before dilution; and

$P_{\text{After dilution}}$ is the pressure (in Pa) inside the intermediate enclosed space after
20 dilution by addition of a controlled quantity of inert gas.

According to another embodiment, the dilution ratio ϑ can be calculated by taking into account the temperature of the gaseous phase that has been sampled before and after the addition of inert gas to the gaseous phase, using the following formula:

$$25 \quad \vartheta = \frac{P_{\text{Before dilution}} \times T_{\text{After dilution}}}{P_{\text{After dilution}} \times T_{\text{Before dilution}}} \quad \text{where:}$$

$P_{\text{Before dilution}}$ is the pressure (in Pa) inside the intermediate enclosed space before dilution; and

$P_{\text{After dilution}}$ is the pressure (in Pa) inside the intermediate enclosed space after dilution by addition of a controlled quantity of inert gas;

$T_{\text{Before dilution}}$ is the temperature (in K) prevailing inside the intermediate enclosed space before dilution; and

- 5 $T_{\text{After dilution}}$ is the temperature (in K) prevailing inside the intermediate enclosed space after dilution.

The data processing system 30, for example a programmed computer, may also perform an alarm function by emitting an alarm signal when the methane concentration in the insulating barrier 3 exceeds a predetermined threshold.

- 10 In the same way, the concentrations of other gases, notably oxygen, of water vapor, or of other hydrocarbons in the gaseous phase withdrawn can be researched. Corresponding gas analyzers are available in the marketplace for performing these measurements. The hydrocarbon products are generally detectable using an infrared analyzer.

- 15 Figure 1 depicts two pumps 13 and 20 situated one of them upstream and the other of them downstream of the intermediate enclosed space 12. In an alternative form, just one of the two pumps 13 and 20 is provided and is used to perform all the steps, namely to withdraw the initial sample, then to compress the dilute sample. One of the pumps 13 and 20 can cumulatively perform the function of
- 20 maintaining the low operating pressure in the insulation space 3. For that, a pipe discharging to the atmosphere and a corresponding control valve need to be provided.

In an alternative form, an additional pump, not depicted, is provided on the piping 18 for transferring the dinitrogen.

- 25 Figure 2 depicts another embodiment of the monitoring device, in which the additional compression of the dilute gas can be performed directly in the intermediate enclosed space. Elements similar or identical to those of figure 1 bear a reference numeral increased by 100 in relation to figure 1.

- 30 In the embodiment of figure 2, the measurement enclosed space 121 is contiguous with one end of the intermediate enclosed space 112 and a piston 120 is mounted with the ability to move in a sealed manner in the intermediate enclosed space 112 in order to be able to drive the dilute gas contained in the intermediate

enclosed space 112 into the measurement enclosed space 121. The view on the left depicts the piston 120 at the start of the compression step and the view on the right depicts the piston 120 at the end of the compression step. For the reminder, operation is similar to the monitoring device of figure 1.

5 There are various ways of causing the sample that is to be analyzed to be sucked up through the sampling duct. In the embodiment of figure 3, use is made of a Venturi-effect suction device depicted in an enlarged view in figure 4, which simultaneously allows a quantity of the gaseous phase to be sucked up in the insulating barrier and this sample to be diluted in a quantity of inert gas. Elements
10 that are similar or identical to those of figure 1 bear a reference numeral increased by 200 in relation to figure 1.

The Venturi-effect suction device 220 comprises a main pipe 35 with a convergent-divergent geometry and having an inlet end connected by the connecting pipe 218 to the pressurized dinitrogen reservoir 215 and an outlet end
15 connected by the connecting pipe 224 to the measurement enclosed space 221. An isolation valve 216 is provided on the connecting pipe 218 in order to control the distribution of dinitrogen from the reservoir 215. A system of sensors 217 is provided for measuring the quantity of dinitrogen introduced from the pressurized dinitrogen reservoir 215 into the main pipe 35. An isolation valve 223 is provided on the
20 connecting pipe 224 so as to be able to close the measurement enclosed space 221 for the duration of the measurement by the gas analyzer 225.

Operation is as follows:

- When the valves 216 and 223 are open, a stream of pressurized dinitrogen enters the inlet end of the convergent-divergent, as indicated
25 by the arrows 37, and through a Venturi effect causes a depression in the lateral duct 36 of the Venturi-effect suction device 220 which is connected to the sampling duct 211. What then follows is the sucking of a quantity of the gaseous phase contained in the insulating barrier 203 as indicated by the arrow 38. The stream of gaseous phase drawn up and the stream of dinitrogen combine in the outlet end of the
30 convergent-divergent, as indicated by the arrows 39 and flow towards the measurement enclosed space 221 through the connecting pipe 224.

- The dilute gas sample obtained is then analyzed in the measurement enclosed space 221, in the same way as described above.

For preference, a valve, not depicted, is also provided on the sampling duct 211 and is opened only after a stable stream of nitrogen has been established at an appropriate speed in the main pipe 35. That makes it possible to avoid reflux of dinitrogen towards the insulating barrier 203 during the phase of starting the stream of dinitrogen. Similarly, this valve can be closed at the end of the sampling before the stream of dinitrogen is interrupted.

The Venturi-effect suction device 220 of figure 4 may also be used in conjunction with an intermediate enclosed space situated upstream of the lateral duct 36.

In a corresponding embodiment which has not been depicted, the monitoring device 210 of figure 3 is connected to the intermediate enclosed space 12 of figure 1 in such a way that the lateral duct 36 of the Venturi-effect suction device 220 takes the place of the connecting duct 24 of figure 1. The function of the pump 20 can then be performed by the Venturi-effect suction device 220 which replaces the pump 20 and which also performs the dilution of the sample in the dinitrogen. As a result, a prior addition of dinitrogen to the intermediate enclosed space 12 is not absolutely essential in this case and the reservoir 15 of figure 1 may potentially be omitted.

The embodiments described hereinabove add dinitrogen to the gaseous phase sample taken in the insulating barrier. As an alternative, an addition of dinitrogen may be made in the insulating barrier before the sample that is to be analyzed is withdrawn.

A corresponding embodiment will now be described with reference to figures 5 and 6. Elements analogous or identical to those of figure 1 bear a reference numeral increased by 300 in relation to figure 1.

Figure 5 shows a double sealing membrane tank 301 in which a secondary sealing membrane 40 separates the insulating barrier into a primary insulating barrier arranged in a primary insulation space 41 situated between the primary membrane 304 and the secondary membrane 40 and a secondary insulating barrier arranged in a secondary insulation space 42 situated between the secondary membrane 40 and the bearing walls 302.

A monitoring device 310 intended to monitor the composition of the gaseous phase in the primary space 41 will be described first of all.

The sampling duct 311 opens at one end into the primary space 41 and at the other end into a gas manifold 46 and bears an isolation valve 45. The gas
 5 manifold 46 is connected to the suction side of a vacuum pump 320 which is thus able to draw up a sample of the gaseous phase present in the primary space 41 when the valve 45 is open. The delivery side of the vacuum pump 320 is connected by the connecting pipe 324 equipped with a valve 323 to the measurement enclosed space 321 equipped with the gas analyzer 325. The valve 323 allows the
 10 measurement enclosed space 321 to be closed after the sample that is to be analyzed has been taken and for the duration of the measurement.

A bypass pipe 47 fitted with a valve 48 branches off the connecting pipe 324 upstream of the valve 323 and allows the stream delivered by the pump 320 to be directed towards installations other than the measurement enclosed space 321,
 15 notably towards a degassing pipe opening to the ambient atmosphere or any other discharge system, potentially through a gas reprocessing system in order to avoid pollution. This arrangement notably allows the entire gas withdrawing circuit to be purged and evacuated prior to each taking of a sample, so as to render the operation of sample taking and analysis both more precise and quicker. This
 20 arrangement may be provided in the same way in the other embodiments described hereinabove.

A discharge pipe 49 fitted with a valve 50 may also be provided for connecting the measurement enclosed space 321 to the degassing pipe or other discharge system. This arrangement makes it possible to release the sample of gas
 25 after it has been analyzed without having to mobilize the bypass pipe 47. It also allows gas to sweep through the measurement enclosed space 321, this gas for example being an inert gas so as to prevent the build-up of traces of gas liable to corrupt the successive analyses.

The monitoring device 310 may be used as follows:

- 30
- Assuming that the gas sampling circuit has initially been purged and that the valves 48 and 50 have been closed, the first step is to activate the pump 320, unless it is one that operates continuously, and to open the valve 45 and the valve 323 in order to cause a quantity of the

gaseous phase to be drawn up from the primary space 41 into the measurement enclosed space 321.

- When the pressure in the measurement enclosed space 321 reaches a value compatible with operation of the gas analyzer 325, the valve 323 is closed and analysis of the withdrawn gas is performed as described hereinabove.
- After analysis, the measurement enclosed space 321 is purged by creating a vacuum.

The analysis equipment 51 comprising the vacuum pump 320, the gas analyzer 325, the measurement enclosed space 321 and its ancillary circuits can be produced in the form of a portable mobile apparatus. The gas manifold 46 allows the analysis equipment 51 to be shared by several sampling ducts opening into different zones of the primary space 41 and possibly of the secondary space 42. Figure 5 thus shows two sampling ducts opening into different zones of the primary space 41. The sample taking may thus be performed successively in the various zones by opening the various valves 45 in sequence.

The increase in pressure in the measurement enclosed space 321 may be very slow according to the power of the vacuum pump 320 and the pressure of the gas prevailing in the insulating barrier 3. In order to limit the duration of the sample-taking and analysis process, it is possible to manage the pressure in the primary space 41 in such a way as to temporarily increase the pressure each time a sample that is to be analyzed has to be taken.

To do that, figure 5 shows an injection device comprising a reservoir of pressurized dinitrogen 315, a primary injection pipe 55 equipped with a valve 56 and connecting the dinitrogen reservoir 315 to the primary space 41, and a secondary injection pipe 57 equipped with a valve 58 and connecting the dinitrogen reservoir 315 to the secondary space 42.

The valve 56 may be controlled in such a way as to regulate the pressure in the primary space in the way illustrated in figure 6.

Figure 6 shows the gas pressure 65 in the primary space as a function of time during the course of a cycle of the taking of a sample for analysis. Outside of the sample-taking period, the pressure is maintained at a low pressure P1, for example of the order of 0.1 to 1 kPa, so as to maximize the thermal insulation.

The means used to maintain this low pressure may be a system, not depicted, completely independent of the monitoring device described here. For example, it may be vacuum pumps regulated by an automatic controller with a pressure setpoint and capable of starting the pumps when this setpoint is crossed in the upwards direction and of switching the pumps off when this setpoint is crossed in the downwards direction, preferably with some degree of hysteresis in order to improve the overall stability.

In one embodiment, this keeping the pressure down may, on the other hand, be a second function of the vacuum pump 320, in order to save on hardware.

A few instants before the actual withdrawing of the sample, the sampling cycle is begun at the instant t_0 by deactivating the means used for keeping the pressure down, this causing a first rise in pressure, which is relatively slow, because of the natural leakages from the primary space 41, for the duration 60.

At the instant t_1 , the valve 56 is opened in order to cause an injection of gaseous dinitrogen into the primary space 41. This injection is performed until such time as a high pressure P_2 is obtained at the instant t_2 . The valve 56 is then closed. Then, there is a waiting time 61 until the instant t_3 in order for the gaseous phase to become sufficiently uniform through natural diffusion.

The pressure P_2 is a negative relative pressure not as low as P_1 , for example of the order of 0.5 to 10 kPa. The higher the pressure P_2 , the greater the expenditure of energy needed to return the primary space 41 to the pressure P_1 .

At the instant t_3 , the vacuum pump 30 is activated and the valve 45 and the valve 323 are opened in order to cause a quantity of the gaseous phase to be sucked from the primary space 41 into the measurement enclosed space 321 during a sample taking phase 62. The pressure in the primary space 41 therefore begins to drop.

At the instant t_4 , the valve 323 is closed and the means of maintaining pressure are reactivated in order to cause the pressure in the primary space 41 to drop to the pressure value P_1 and remain there until the next sampling cycle. This sampling cycle may be reduced to a total duration of a few minutes.

By accurately measuring the pressure and the temperature in the primary space 41 using the system of sensors 317, it is possible accurately to measure the

dilution ratio brought about by the addition of nitrogen to the primary space 41 and therefore to calculate afterwards the concentration of gas prior to dilution. The data processing system 300 is used for that purpose. In-tank temperature measurements can be performed by a fiber optic system or the like.

5 The secondary space 42 may be monitored in the same way using means similar to those described with reference to the primary space 41. For that, a secondary space monitoring device may be produced independently of the primary space monitoring device, as indicated schematically by the numeral 410. As an alternative, certain means may be shared for the monitoring of the two spaces 41
10 and 42. For example, in one embodiment, not depicted, the analysis equipment 51 can be shared by connecting the sampling duct 69 equipped with the valve 68 to the manifold 46.

 In one embodiment which has not been depicted, the measurement enclosed space 321 of the monitoring device 310 can be produced in a similar way
15 to the intermediate enclosed space 112 of figure 2, so as to achieve an increase in pressure of the gas in the measurement enclosed space 321 before it is analyzed. An additional addition of dinitrogen in the measurement enclosed space 321 is possible but not compulsory, which means that the piping 118 in figure 2 can be omitted in this embodiment. This measurement enclosed space incorporating the
20 compression means can be used in combination with the vacuum pump 320 or, for preference, with no vacuum pump at all, thereby making it possible to reduce the cost of the monitoring device.

 In one embodiment, all or part of the monitoring device, notably the vacuum pump 320, is placed inside a double-walled transverse structure referred to as a
25 cofferdam that separates two tanks of a methane tanker ship. Such an arrangement makes it easier for the pump to be shared by several sample-taking points situated at different locations in one or both tanks. In one embodiment, eight sample-taking points are provided per tank, these preferably all being connected to the same sampling manifold.

30 Although the description given hereinabove refers only to dinitrogen and to methane, other pairs of fuel gas and inert gas can be used in a similar way. The gas used to dilute the sampled gaseous phase needs to be selected in such a way as to

avoid any dangerous, notably explosive, chemical reaction and to avoid disrupting the measurement of the concentration of the chemical species being researched.

The techniques described hereinabove for creating a device for monitoring insulation spaces can be used in different types of reservoirs, for example to monitor
 5 the primary space and/or the secondary space of an LNG reservoir in a on-shore facility or in a floating structure such as a methane tanker ship or the like.

With reference to figure 7, a cutaway view of a methane tanker ship 70 shows a sealed and insulated tank 71 of prismatic overall shape mounted inside the double hull 72 of the ship. The wall of the tank 71 comprises a primary sealing
 10 barrier intended to be in contact with the LNG contained in the tank, a secondary sealing barrier arranged between the primary sealing barrier and the double hull 72 of the ship, and two insulating barriers arranged respectively between the primary sealing barrier and the secondary sealing barrier and between the secondary sealing barrier and the double hull 72.

15 In a way known per se, loading/unloading piping 73 arranged on the top deck of the ship may be coupled, by means of suitable connectors, to a maritime or harbor terminal so as to transfer a cargo of LNG from or to the tank 71.

Figure 7 depicts one example of a maritime terminal comprising a loading and unloading station 75, an underwater pipe 76 and an on-shore facility 77. The
 20 loading and unloading station 75 is a fixed off-shore facility comprising a mobile arm 74 and a tower 78 supporting the mobile arm 74. The mobile arm 74 bears a bundle of insulated flexible hoses 79 which can be connected to the loading/unloading piping 73. The orientable mobile arm 74 adapts to suit all sizes of methane tanker. A connecting pipe, not depicted, extends inside the tower 78. The loading and
 25 unloading station 75 allows the methane tanker 70 to be loaded and unloaded from or to the on-shore facility 77. This installation comprises liquefied gas storage tanks 80 and connecting pipes 81 connected by the underwater pipe 76 to the loading or unloading station 75. The underwater pipe 76 allows the liquefied gas to be transferred between the loading or unloading station 75 and the on-shore facility 77
 30 over a long distance, for example 5 km, this making it possible to keep the methane tanker 70 a large distance away from the shore line during the loading and unloading operations.

In order to generate the pressure necessary for transferring the liquefied gas, use is made of pumps carried onboard the ship 70 and/or of pumps with which the on-shore facility 77 is equipped and/or of pumps with which the loading and unloading station 75 is equipped.

- 5 Although the invention has been described in conjunction with a number of particular embodiments, it is quite clear that it is not in any way restricted thereto and that it comprises all technical equivalents of the means described and combinations thereof where these fall within the scope of the invention.

- 10 The use of the verb "comprise", "have" or "include" and conjugated forms thereof does not exclude the presence of other elements or steps other than those listed in a claim. The use of the indefinite article "a" or "an" when describing an element or a step does not, unless mentioned otherwise, exclude there being a plurality of such elements and steps.

- 15 In the claims, any reference symbol between parentheses should not be interpreted as constituting a limitation of the claim.

CLAIMS

1. A method for monitoring a sealed and thermally insulated tank (1, 201, 301) intended to contain a low-temperature liquefied fuel gas, in which method a wall of the tank comprises a multilayer structure mounted on a bearing wall, the multilayer structure comprising a sealing membrane in contact with the liquefied fuel gas contained in the tank and a thermally insulating barrier (3, 203, 41, 42) arranged between the sealing membrane and the bearing wall, the thermally insulating barrier comprising insulating solid substances and a gaseous phase kept under a negative relative pressure, the method comprising:
 - 10 obtaining a sample of dilute gas by withdrawing a sample of the gaseous phase under negative relative pressure in the thermally insulating barrier through a sampling duct (11, 111, 211, 311, 69) opening to the outside of the tank wall and by adding a controlled quantity of inert gas to the gaseous phase that is to be withdrawn or that has been withdrawn,
 - 15 raising the pressure of the dilute gas sample up to an operating pressure of a gas analyzer (25, 125, 225, 325), and measuring a concentration of the fuel gas in the dilute gas sample using the gas analyzer.
2. The method as claimed in claim 1, further comprising:
 - 20 - determining a dilution ratio brought about by the addition of a controlled quantity of inert gas to the gaseous phase that is to be withdrawn or that has been withdrawn according to measurements of the pressure and of the temperature of the gaseous phase that is to be withdrawn or that has been withdrawn before and after the addition of the controlled quantity of inert gas to the gaseous phase; and
 - 25 - determining a concentration of the fuel gas in the gaseous phase of the thermally insulating barrier as a function of the measured concentration and of the dilution ratio brought about by the addition of a controlled quantity of inert gas.
3. The method as claimed in one of claims 1 and 2, in which the fuel gas consists of methane.
- 30 4. The method as claimed in one of claims 1 to 3, in which the inert gas is selected from the group consisting of dinitrogen, helium, argon and mixtures thereof.

5. The method as claimed in one of claims 1 to 4, in which the negative relative pressure corresponds to an absolute pressure of below 10 kPa, preferably of below 1 kPa.

6. The method as claimed in one of claims 1 to 5, in which the operating
5 pressure of the gas analyzer (25, 125, 225, 325) is comprised between 80 kPa and 120 kPa, preferably between 86 kPa and 108 kPa.

7. The method as claimed in one of claims 1 to 6, in which the gas analyzer comprises a fuel gas detector selected from the group consisting of infrared detectors and electrochemical-cell detectors.

8. The method as claimed in one of claims 1 to 7, in which the step of
10 obtaining the sample of dilute gas comprises:
adding a controlled quantity of inert gas to the gaseous phase in the thermally insulating barrier in order to increase the relative pressure (65) of the gaseous phase in the thermally insulating barrier from a negative first value (P1) to a negative
15 second value (P2), and
withdrawing a sample of the gaseous phase under the relative pressure equal to the second negative value in the thermally insulating barrier through the sampling duct (11, 111, 211, 311, 69) opening to the outside of the tank wall so as to obtain the dilute gas sample, and
20 reducing the relative pressure (65) of the gaseous phase in the thermally insulating barrier from the second negative value to the first negative value after having withdrawn the sample of the gaseous phase.

9. The method as claimed in claim 8, in which the first negative value is less than 1 kPa, preferably less than or equal to 0.1 kPa, and the second negative
25 value is greater than or equal to 1 kPa.

10. The method as claimed in claim 8 or 9, in which the step of raising the pressure of the dilute gas sample comprises:
storing the withdrawn sample of gaseous phase in an intermediate enclosed space (112, 321) connected to the sampling duct, and
30 moving a mobile wall in the intermediate enclosed space in order to confine the dilute gas sample to a measurement enclosed space (121) of smaller capacity than the intermediate enclosed space.

11. The method as claimed in one of claims 1 to 10, in which the step of obtaining the dilute gas sample comprises:
 withdrawing a sample of the gaseous phase under the negative relative pressure in the thermally insulating barrier through the sampling duct opening to the outside of
 5 the tank wall, and
 adding a controlled quantity of inert gas to the withdrawn gaseous phase sample.

12. The method as claimed in claim 11, in which the steps of withdrawing, diluting and compressing the sample are performed by means of a Venturi-effect suction device (220), the Venturi-effect suction device comprising:
 10 a main pipe (35) having an inlet connected to a source of the inert gas under pressure and an outlet connected to a measurement enclosed space or to an intermediate enclosed space, and
 a suction pipe (36) having an upstream end connected to the sampling duct and a downstream end opening laterally into a convergent-divergent of the main pipe in
 15 such a way that a stream of inert gas along the main pipe causes a depression in the suction pipe.

13. The method as claimed in claim 11 or 12, in which the step of taking the sample comprises:
 pumping the gaseous phase sample through the sampling duct (11, 111, 211, 311)
 20 towards an intermediate enclosed space (12, 112, 221, 321), and
 isolating the intermediate enclosed space from the thermally insulating barrier.

14. The method as claimed in claim 13, in which the controlled quantity of inert gas is added to the intermediate enclosed space (12, 112), the step of compressing the dilute gas sample comprising:
 25 pumping the dilute gas sample from the intermediate enclosed space towards a measurement enclosed space (21, 121) coupled to the gas analyzer.

15. The method as claimed in claim 13, in which the steps of diluting and compressing the sample are performed by means of a Venturi-effect suction device (220), the Venturi-effect suction device comprising:
 30 a main pipe (35) having an inlet connected to a source of the inert gas under pressure and an outlet connected to a measurement enclosed space, and
 a suction pipe (36) having an upstream end connected to the intermediate enclosed space and a downstream end opening laterally into a convergent-divergent of the

main pipe in such a way that a stream of inert gas along the main pipe causes a depression in the suction pipe.

16. A monitoring device (10, 210) suitable for a sealed and thermally insulated tank (1, 201) intended to contain a low-temperature liquefied fuel gas, in which tank a wall of the tank comprises a multilayer structure mounted on a bearing wall, the multilayer structure comprising a sealing membrane in contact with the liquefied fuel gas contained in the tank and a thermally insulating barrier (3, 203) arranged between the sealing membrane and the bearing wall, the thermally insulating barrier comprising insulating solid substances and a gaseous phase kept under a negative relative pressure,
- the monitoring device comprising:
- a sampling duct (11, 111, 211) connecting the thermally insulating barrier to the outside of the tank wall, said sampling duct (11, 111, 211) being equipped with an isolation valve (14):
- an intermediate enclosed space (12, 112) connected to the thermally insulating barrier by the sampling duct;
- a measurement enclosed space (21, 121, 221) connected to the intermediate enclosed space,
- a gas analyzer (25, 125, 225) coupled to the measurement enclosed space for measuring a concentration of the fuel gas in the measurement enclosed space,
- a pumping device (20, 112, 220, 320) connected to the sampling duct and able to withdraw a sample of the gaseous phase under the negative relative pressure in the thermally insulating barrier and to transfer the sample of the gaseous phase to the measurement enclosed space (21, 121, 221),
- an inert gas reservoir (15, 215) connected to the intermediate enclosed space (12, 112) and designed to add a quantity of inert gas to the gaseous phase that has been withdrawn, in the intermediate enclosed space (12, 112), and
- a measurement device (17, 217, 317) for measuring the quantity of inert gas added to the gaseous phase.

17. The device as claimed in claim 16, further comprising a data processing system (30, 330) able to determine a dilution ratio brought about by the addition of a controlled quantity of inert gas to the gaseous phase that has been withdrawn as a function of measurements of the pressure and temperature of the gaseous phase that has been withdrawn before and after the addition of the

controlled quantity of inert gas to the gaseous phase and to determine a concentration of the fuel gas in the gaseous phase of the thermally insulating barrier as a function of the concentration measured by the gas analyzer and of the dilution ratio brought about by the addition of a controlled quantity of inert gas.

5 18. The device as claimed in either one of claims 16 and 17, in which the pumping device comprises a vacuum pump (20).

19. The device as claimed in one of claims 16 to 18, in which the pumping device comprises a Venturi-effect suction device (220), the Venturi-effect suction device comprising:

10 a main pipe (35) having an inlet connected to the reservoir of inert gas and an outlet connected to the measurement enclosed space, and
a suction pipe (36) having an upstream end connected to the sampling duct by way of the intermediate enclosed space and a downstream end opening laterally into a convergent-divergent of the main pipe in such a way that a stream of inert gas along
15 the main pipe causes a depression in the suction pipe.

20. A sealed and thermally insulated tank (71) intended to contain a low-temperature liquefied fuel gas and equipped with a monitoring device (10, 210, 310, 410) as claimed in one of claims 16 to 19,

in which tank a wall of the tank comprises a multilayer structure mounted on a
20 bearing wall (302), the multilayer structure comprising a primary sealing membrane (304) in contact with the liquefied fuel gas contained in the tank, a secondary sealing membrane (40) arranged between the primary sealing membrane and the bearing wall, a primary thermally insulating barrier (41) arranged between the primary sealing membrane and the secondary sealing membrane, and a secondary
25 thermally insulating barrier (42) positioned between the secondary sealing membrane and the bearing wall, and in which tank a or each thermally insulating barrier comprises insulating solid substances and a gaseous phase kept under a negative relative pressure, the monitoring device comprising a first sampling pipe (311) opening into the primary thermally insulating barrier and a second sampling
30 pipe (69) opening into the secondary thermally insulating barrier.

21. A ship (70) for carrying a cold liquid product, the ship comprising a double hull (72) and a tank (71) as claimed in claim 20 arranged in the double hull.

22. A method for loading or unloading a ship (70) as claimed in claim 21, in which a cold liquid product is carried through insulated piping (73, 79, 76, 81) from or to a floating or on-shore storage facility (77) to or from the tank of the ship (71).

23. A transfer system for transferring a cold liquid product, the system
5 comprising a ship (70) as claimed in claim 21, insulated piping (73, 79, 76, 81) arranged in such a way as to connect the tank (71) installed in the hull of the ship to a floating or on-shore storage facility (77) and a pump for causing the cold liquid product to flow in a stream through the insulated piping from or to the floating or on-shore storage facility to or from the tank of the ship.