

Field of the invention

The present invention relates to the leak testing of a multi-membrane tank. In particular, the present
5 invention relates to a method that can be used for leak testing the secondary membrane of a multi-membrane tank without the need to remove the primary membrane.

Prior art

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Multi-membrane tanks are used industrially in various fields, to contain gaseous, liquid or solid material of various kinds. This type of tank comprises a bearing structure which provides mechanical rigidity, a primary
15 membrane intended to be in contact with the product contained in the tank, and a secondary membrane arranged between the primary membrane and the bearing structure. The secondary membrane is intended to contain the product in the event of a leak in the
20 primary membrane.

There are various methods in existence for diagnosing the tightness of the secondary membrane. If, during testing, the secondary membrane proves to be non-
25 compliant, then this membrane has to be repaired. Now, locating any non-compliance without removing the primary membrane is not an easy task and is somewhat imprecise.

30 For example, in documents FR 2 517 802 and WO 2007/144458, a non-compliance is detected by analysing the composition of a gas. In order to locate a non-compliance, it is necessary to provide a multitude of pipes tapping off gas for analysis at various points.
35 This therefore entails a structure that is complex and expensive and the precision of which is limited.

FR 2 531 516 describes a method for detecting leaks in the secondary membrane of a liquefied-gas tank, in

which ice cubes of carbon dioxide which have solidified on the external face of the primary membrane at -160°C are detected as cold spots as the primary membrane heats back up, because of their thermal inertia.

5 However, it is difficult to get an optical camera or a thermograph to work at the very low temperatures used in this method.

Summary of the invention

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One problem that the present invention intends to address is that of providing a test method which does not have at least some of the aforementioned disadvantages of the prior art. In particular, one
15 object of the invention is to allow a non-compliance of the secondary membrane to be located without the need to remove the primary membrane or the bearing structure. Another object of the invention is to allow a non-compliance of the secondary membrane to be
20 located using a structure that is simple, and notably without the need for numerous pipes.

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The solution proposed by one embodiment of the invention is a method of leak testing a tank, the said
25 tank comprising a bearing structure, a primary membrane intended to be in contact with a product contained in the tank, and a secondary membrane arranged between the primary membrane and the bearing structure, in which the space between the primary membrane and the
30 secondary membrane is known as the primary space and the space between the secondary membrane and the bearing structure is known as the secondary space, the primary space containing a first gas that is
35 lower than the mean temperature of the primary membrane. This method comprises the steps consisting in:

- injecting into the secondary space a second gas that has a condensing temperature higher than the mean temperature of the primary membrane,
- generating in the secondary space a pressure that is
- 5 raised with respect to that in the primary space, and
- detecting any hot spot(s) that might be on the primary membrane that correspond to a deposit of the second gas that has condensed upon contact with the primary membrane.

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By virtue of these features, in the event of non-compliance of the secondary membrane, the second gas escapes into the primary space and comes into contact with the primary membrane, in the vicinity of the leak.

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Because it has a condensing temperature higher than the mean temperature of the primary membrane, the second gas condenses and, in so doing, transfers energy in the form of heat, corresponding to its latent heat of change of state, to the primary membrane. A hot spot is

20 therefore generated on the primary membrane. Detecting this hot spot inside the tank allows the non-compliance of the secondary membrane to be located.

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Advantageously, detection is carried out during a detection period which is substantially simultaneous with the generation of raised pressure in the secondary space, or immediately after this generation, but before the temperatures between the various zones of the membrane have completely evened out.

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The second gas can be chosen so that it condenses into a solid or liquid form. The formation of a liquid phase does, however, have the advantage of allowing the deposited condensed gas to run gradually as this

35 deposit is formed opposite the leak. Thus, the condensation reaction can be sustained more easily by maintaining the pressure in the secondary space for a significant length of time, for example one or more

minutes. The possibility of thus maintaining over time the hot spot that results from the condensation reaction makes detecting this hot spot far easier, particularly when it exhibits limited contrast.

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According to one embodiment, the raised pressure in the secondary space is sustained for a duration longer than 10 minutes.

10 For preference, the method involves cooling the primary membrane to a mean temperature lower than ambient temperature. This allows good control over the condensation conditions.

15 In one advantageous embodiment, the method is performed at a membrane mean temperature higher than -5°C , preferably higher than 0°C . Thus, the method can be carried out under practical conditions with little in the way of restrictions and with a limited expenditure
20 of energy.

Advantageously, the second gas is a mixture, the method involving generating the mixture with a composition that depends on the mean temperature of the primary
25 membrane. That means that the condensing temperature can be adapted to suit, for example, the ambient temperature or the mean temperature of the primary membrane. For preference, the condensing temperature of the second gas obtained in this way lies between the
30 mean temperature and ambient temperature.

According to one embodiment, the second gas is a mixture of pentane and/or perfluoropentane and nitrogen. These gases are particularly suitable for a
35 test in which, to start off with, the secondary space is at ambient temperature and in which the objective is to obtain a liquid phase upon contact with the primary membrane.

For preference, any hot spot(s) that might be on the primary membrane are detected using at least one temperature sensor and/or at least one infrared
5 detector, this (these) being arranged inside the tank.

According to one embodiment, the surface of the primary membrane inside the tank is temporarily covered with a coating capable of substantially eliminating the
10 mirrorlike reflectivity of the surface, and the hot spots are detected using a thermal camera. For example, the coating may contain water droplets.

Advantageously, the method comprises the steps
15 consisting in removing the first gas from the primary space and the second gas from the secondary space, and heating the primary membrane up to ambient temperature. This allows the tank to be repaired or, if no non-compliance has been detected, brought into service,
20 after the test.

The invention also proposes a tank comprising a bearing structure, a primary membrane intended to be in contact with a product contained in the tank, and a secondary
25 membrane arranged between the primary membrane and the bearing structure, in which the space between the primary membrane and the secondary membrane is known as the primary space and the space between the secondary membrane and the bearing structure is known as the
30 secondary space, characterized in that it comprises:

- a first injector able to inject into the primary space a first gas that is incondensable or that has a condensing temperature lower than the mean temperature of the primary membrane,
- 35 - a second injector able to inject into the secondary space a second gas that has a condensing temperature higher than the mean temperature of the primary membrane,

- a pressurizing device able to generate in the secondary space a pressure that is raised with respect to that in the primary space, and
 - a detector able to detect any hot spot(s) that might
- 5 be on the primary membrane.

This tank is suitable for implementing the test method according to one embodiment of the invention.

10 According to one embodiment, the said second gas is a mixture, the said second injector being able to create the said mixture with a composition that is determined as a function of the mean temperature of the primary membrane.

15 According to one embodiment, the said primary space and the said secondary space contain a thermally insulating material, with the said tank being able to contain liquefied natural gas. The tank may, for example, be a

20 land-based tank or a storage tank incorporated into a ship.

Brief description of the drawings

25 The invention will be better understood, and other objects, details, features and advantages thereof will become more clearly apparent, during the course of the following description of one particular embodiment of the invention, which is given solely by way of

30 nonlimiting illustration and with reference to the attached drawings. In these drawings:

- Figure 1 is a diagram illustrating the principle of forced condensation,
 - Figure 2 is a graph illustrating the condensing
- 35 temperature of a gas as a function of its concentration in a gaseous mixture,
- Figure 3 is a view in cross section of one wall of a tank, the tightness of which is being tested,

- Figure 4 is a diagram of a tank suitable for implementing the test method according to one embodiment of the invention, and
- Figure 5 schematically depicts one of the components of Figure 4.

Detailed description of one embodiment of the invention

Figure 1 depicts a wall 1, the mean temperature of which is T_m . A gas at the pressure P is brought into contact with the wall 1, as depicted by the arrow 2. If the condensing temperature T_c of the gas is higher than the temperature T_m , the gas will condense in the form of a liquid or solid deposit 3. In so doing, the gas transfers energy in the form of heat, corresponding to its latent heat of condensation, to the wall 1. This heat transfer is represented by the arrows 4. Thus, locally, the wall 1 has a temperature T higher than T_m . Condensation is said to be forced condensation when the temperature T_m , the pressure P and the nature of the gas are controlled.

The gas may be:

- A pure gas, the intrinsic physical properties of which correspond to the desired condensing temperature.
- A mixture of an incondensable gas and of a condensable gas, the concentrations of which are controlled in order to adapt the condensing temperature. Specifically, as the graph of Figure 2 shows, a pure gas which has a condensing temperature T_p will, once diluted to the concentration $X\%$ in an incondensable gas, have a condensing temperature T_c lower than T_p .
- A mixture of several condensable gases which, once combined, have a desired condensing temperature T_c .

The way in which the principle of forced condensation allows a leak to be detected in the secondary membrane of a multi-membrane tank is now explained with reference to Figures 3 to 5.

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The tank 5 comprises a bearing structure 6 which gives it its mechanical rigidity, a primary membrane 8 intended to be in contact with the product contained in the tank 5, and a secondary membrane 7 arranged between the primary membrane 8 and the bearing structure 6. The space that lies between the primary membrane 8 and the secondary membrane 7 is known as the primary space 10. The space that lies between the secondary membrane 7 and the bearing structure 6 is known as the secondary space 9.

The creation of the tank 5 will not be described in detail because there are several options known to those skilled in the art. The tank may, for example, be an LNG tank produced using a known technique. If it is, thermally insulating material is present in the primary space 10 and in the secondary space 9.

The tank 5 also comprises an injector 11 connected to the primary space 10 by a pipe 12, an injector 13 connected to the secondary space 14 by a pipe 14, a cooling device 15 connected to the inside of the tank 5 by a pipe 16, and pipes 17 respectively connecting the inside of the tank, the primary space 10 and the secondary space 9 to an exhaust and pressure management device. The aforementioned components allow a leak 18 in the secondary membrane 7 to be detected and located as described hereinbelow.

35 The leak testing method according to one embodiment of the invention entails successively conditioning the tank for testing, actual testing, then deconditioning the tank.

Conditioning the tank for testing involves:

- Regulating the temperature of the primary membrane in order to achieve a desired temperature. 5 This may be performed using climate control devices or by injecting a liquid coolant into the tank 5. For example, the cooling device 15 injects liquid nitrogen into the tank 5. Ideally, after this step, the temperature of the primary membrane is uniform. 10 However, because of various thermal stresses, the primary membrane may have a slightly non-uniform temperature. Thus, hereinbelow, mention is made of the mean temperature T_m of the primary membrane.

- Injecting a neutral gas into the primary space 15 10. What is meant by a neutral gas is a gas that does not condense at the temperature T_m either because it is an incondensable gas or because its condensing temperature is lower than T_m . This can be done using the injector 11 or, in the case of ambient air, by 20 placing the primary space in communication with the atmosphere.

- Injecting a reactive gas into the secondary space 9. What is meant by a reactive gas is a gas that condenses at a temperature higher than T_m . As explained 25 hereinabove, this may be a pure gas or a mixture. This can be done using the injector 13.

The three steps mentioned hereinabove can be performed simultaneously or consecutively, in any order.

30 The test itself involves increasing the pressure of the reactive gas in the secondary space 9 and detecting any hot spots that might be on the primary membrane 8, advantageously from inside the tank.

35 Specifically, as shown in greater detail in Figure 3, if the secondary membrane 7 has a leak 18, reactive gas escapes into the primary space 10 because of the

pressure difference between the secondary space 9 and the primary space 10. This is symbolized by the cloud 19 and the arrow 20.

5 Thus, at the leak 18, reactive gas comes into contact with the primary membrane 8 and forms condensation 21. In so doing, as explained hereinabove, the reactive gas transfers heat to the primary membrane 8 which is therefore locally hotter than the temperature T_m . By
10 detecting this hot spot 22, it is possible to locate the leak 18. The hot spot 22 may be detected for example using a temperature sensor or by a sensor that detects the emitted infrared radiation, arranged inside the tank.

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Deconditioning the tank for testing involves:

- Removing the gases from the primary space 10. This can be done notably by using one of the pipes 17, either by evacuating this space, then
20 filling it if necessary, or by sweeping it with the gas it is intended to contain when in service.
- Removing the reactive gas from the secondary space 9. This can also be done notably by using
25 one of the pipes 17, either by evacuating this space, then filling it if necessary, or by sweeping it with the gas it is intended to contain when in service.
- Raising the temperature of the primary
30 membrane. This can be done either using climate control devices or by convection of air at ambient temperature.

The aforementioned three steps can be performed
35 simultaneously or consecutively, in any order.

In one exemplary embodiment, the neutral gas is nitrogen and the reactive gas is a mixture of 50% by

volume of nitrogen and 50% by volume of pentane. The pentane is liquid at atmospheric pressure and ambient temperature. Its vaporization temperature is 36°C. In the aforementioned mixture, its condensing temperature at which it condenses to a liquid phase drops to about 18°C.

The tank 5 for testing is, for example, a storage tank of a methane carrier, the primary membrane 8 of which is at the ambient temperature of 25°C. The inside of the storage tank is cooled so that the primary membrane has a mean temperature T_m of 10°C. Because of thermal insulation, the temperature in the secondary space 9 is higher than 20°C. The nitrogen/pentane mixture can therefore be injected into the secondary space 9 without the risk of it condensing. Next, a raised pressure of a few millibar is generated. The nitrogen/pentane mixture enters the primary space 10 at the leak 18 and condenses upon contact with the primary membrane 8, generating a hot spot.

Furthermore, the degree to which the pentane is diluted in the nitrogen can be modified in order to adapt the condensing temperature of the pentane. Thus, if the ambient temperature is, for example, 35°C or 10°C, it is possible to carry out the test by adapting the temperature T_m and the degree to which the pentane is diluted.

To do that, advantageously, the injector 13 is able to create a mixture with the desired proportions. For example, as shown by Figure 5, the injector 13 comprises a reservoir 23 intended to contain the carrier gas (nitrogen in the aforementioned example) and a reservoir 24 intended to contain, in liquid form, the condensable gas (pentane in the aforementioned example). These two reservoirs are connected, respectively by a pipe 25 and by a pipe 26, to an

evaporator 30 in which the mixture is created. The evaporator 30 is connected to the secondary space 9 by the piping 14. A control device 29 provides control over the degree to which the pentane is diluted by acting on the evaporator 30 and on two flow meters 27 and 28 arranged on the pipes 25 and 26 respectively.

Many other gases may be chosen, according to the desired condensing temperatures. For example, perfluoropentane may be used at least in part in place of the pentane in the aforementioned example and proves safer because of its low flammability.

In one embodiment in which the primary membrane is at a positive temperature and in which an infrared camera is used to detect the hot spots, it is advantageous in the tank conditioning phase for the inside of the membrane to be coated with water droplets, for example by sweeping its surface with a stream of vapour, in order to form a diffusing layer which considerably reduces the mirrorlike reflectivity of the surface. Such a diffusing or opacifying coating can improve the measurement of local emissivity of the surface of the membrane using an infrared camera.

Although the invention has been described in conjunction with one particular embodiment, it is quite clear that it is not in any way restricted thereto and that it encompasses all technical equivalents of the means described and combinations thereof where these fall within the scope of the invention.

CLAIMS

1. Method of leak testing a tank (5), the said tank comprising a bearing structure (6), a primary membrane (8) intended to be in contact with a product contained in the tank, and a secondary membrane (7) arranged between the primary membrane and the bearing structure, in which the space between the primary membrane and the secondary membrane is known as the primary space (10) and the space between the secondary membrane and the bearing structure is known as the secondary space (9), the primary space containing a first gas that is incondensable or that has a condensing temperature lower than the mean temperature of the primary membrane, the said method comprising the steps consisting in:

- injecting into the secondary space a second gas that has a condensing temperature higher than the mean temperature of the primary membrane,
- generating in the secondary space a pressure that is raised with respect to that in the primary space, and
- detecting any hot spot(s) (22) that might be on the primary membrane that correspond to a deposit of the second gas that has condensed upon contact with the primary membrane.

2. Method of leak testing according to Claim 1, characterized in that the second gas condenses into a liquid form upon contact with the primary membrane.

3. Method of leak testing according to Claim 1 or 2, characterized in that detection is carried out during a detection period which is substantially simultaneous with the generation of raised pressure in the secondary space.

4. Method of leak testing according to Claim 3, in which the raised pressure in the secondary space is sustained for a duration longer than 10 minutes.
- 5 5. Method of testing according to Claim 1, involving cooling the primary membrane to a mean temperature lower than ambient temperature.
- 10 6. Method of leak testing according to Claim 5, in which the mean temperature of the primary membrane is higher than -5°C , preferably higher than 0°C .
- 15 7. Method of testing according to one of Claims 5 and 6, in which the second gas is a mixture, the method involving generating the mixture with a composition that depends on the mean temperature of the primary membrane, so that the condensing temperature of the second gas lies between the mean temperature and ambient temperature.
- 20 8. Method of testing according to one of the preceding claims, in which the second gas is a mixture of pentane and/or perfluoropentane and nitrogen.
- 25 9. Method of testing according to one of the preceding claims, in which any hot spot(s) that might be on the primary membrane are detected using at least one temperature sensor and/or at least one infrared detector, this (these) being arranged inside the tank.
- 30 10. Method of leak testing according to one of Claims 1 to 9, in which the surface of the primary membrane inside the tank is temporarily covered with a coating capable of substantially eliminating the mirrorlike reflectivity of the surface, and the hot spots are
- 35 detected using a thermal camera.

11. Method of leak testing according to Claim 10, in which the coating contains water droplets.

12. Method of testing according to one of the preceding claims, comprising the steps consisting in:
5 - removing the first gas from the primary space and the second gas from the secondary space,
- heating the primary membrane up to ambient temperature.

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13. Tank (5) comprising a bearing structure (6), a primary membrane (8) intended to be in contact with a product contained in the tank, and a secondary membrane (7) arranged between the primary membrane and the bearing structure, in which the space between the primary membrane and the secondary membrane is known as the primary space (10) and the space between the secondary membrane and the bearing structure is known as the secondary space (9), characterized in that it
15 comprises:

- a first injector (11) able to inject into the primary space a first gas that is incondensable or that has a condensing temperature lower than the mean temperature of the primary membrane,
25 - a second injector (13) able to inject into the secondary space a second gas that has a condensing temperature higher than the mean temperature of the primary membrane,
- a pressurizing device able to generate in the secondary space a pressure that is raised with respect to that in the primary space, and
30 - a detector able to detect any hot spot(s) (22) that might be on the primary membrane that correspond to a deposit of the second gas that has condensed upon
35 contact with the primary membrane.

14. Tank according to the preceding claim, in which the said second gas is a mixture, the said second

injector being able to create the said mixture with a composition that is determined as a function of the mean temperature of the primary membrane, so that the condensing temperature of the second gas lies between
5 the mean temperature and ambient temperature.

15. Tank according to one of Claims 13 and 14, in which the said primary space and the said secondary space contain a thermally insulating material, with the
10 said tank being able to contain liquefied natural gas.