

DESCRIPTION

TITLE: STORAGE SYSTEM AND METHOD FOR STORING FLUIDS COMPRISING MEANS FOR REDUCING RISKS

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Technical field

10 The present invention relates to underground storage and notably to the storage of fluids, for example hydrogen or oxygen. More particularly, the invention relates to the field of risk reduction in a fluid storage system and, in particular, in a high-pressure fluid storage system, which may be at between 100 bar and 1200 bar, and more particularly between 200 bar and 500 bar.

15 The invention also relates to an underground fluid storage method.

Technological background

20 The risks in such a system are mainly related to explosions and/or fires caused by a leak of the fluid contained in the reservoirs. Indeed, an explosive fluid such as hydrogen is highly inflammable and instantly causes a powerful detonation. This type of incident leads to structural damage and/or potentially fatal personal injury.

Existing solutions notably involve reducing risk in the event of fluid leaks, and for example provide a pressure relief valve that opens if a quantity of fluid is released into the cavity, to direct the fluid into a pipe and discharge it.

25 However, this type of installation is not reliable because the pipes of the discharge system are liable to blocking. Similarly, the valve is liable to cease functioning efficiently over time. This requires maintenance and, if necessary, replacement components. In addition, since the fluid is not directly diluted in the air, an increase in pressure can cause an explosion and consequential damage to the
30 discharge system.

Disclosure of the invention

5 The invention is therefore intended to overcome the aforementioned drawbacks by proposing an effective solution that is not subjected to mechanical stresses that give rise to additional maintenance operations.

10 The invention relates to an underground storage system for storing fluids comprising a hole in a plot of land, said hole having a bottom, a support element comprising at least one opening, a joining element inserted into the opening in the support element, the joining element including ventilation vents to allow the fluid
15 contained in the reservoir to be discharged in the event of a leak, at least one reservoir, said reservoir having a longitudinal axis, a lower end closed by a first closure means, and an upper end closed by a second closure means. The upper end is joined to the support element via the joining element such that the reservoir is suspended inside the hole and such that an axial clearance able to absorb any axial thermal expansion of said
20 reservoir remains between the first closure means of the reservoir and the bottom of the hole.

25 Advantageously, the support element separates an upper cavity from a lower cavity, said upper cavity being open and comprising a first diameter greater than a second diameter of the lower cavity. Thus, the reservoir is completely buried below ground level, including the second closure means which closes the upper end of the reservoir. Such a configuration of the storage system enables any deflagration that may break out to be guided into the hole thus reducing the deflagration angle in the event of an explosion.

30 Advantageously, the lower cavity is filled with a deflagration-proof fluid and/or solid. This means that the lower cavity cannot be filled with oxygen because it is already full. The amount of oxygen in the lower cavity is therefore zero or negligible. Therefore, in the event of a leak in a reservoir, the risk of explosion is considerably reduced, or even zero.

According to one embodiment, the deflagration-proof fluid and/or solid comprises antibacterial agents and/or anti-corrosion agents.

Advantageously, the upper end of the reservoir comprises a lifting plug system for use when handling the reservoir, and a connection system for connecting the valves and pipes for use when storing and distributing the fluid contained in the reservoir.

Advantageously, the reservoir comprises at least one metal tube, said metal tube having at least one end provided with at least one threaded portion.

The reservoir comprises at least two metal tubes screwed together, so as to form a column of tubes.

5 Advantageously, the axial clearance capable of absorbing any axial thermal expansion of the reservoir satisfies the following inequality:

[Math 1]

$$G \geq (L^2 * \beta * \alpha) + [20 * \alpha * 80 * (1 - e^{-0.11*L})]$$

10 Where: G is the length of the axial clearance expressed in meters, L represents the length of a reservoir expressed in meters, β represents the geothermal gradient expressed in degrees Celsius per meter, and α represents the coefficient of thermal expansion of the metal expressed in meters per degree Celsius.

15 According to one embodiment, the storage system comprises a plurality of reservoirs, each reservoir having a longitudinal axis, a lower end and an upper end, said upper end of each reservoir being joined to the support element via a joining element such that each reservoir is suspended inside the hole.

Optionally, the first closure means and/or the second closure means is able to close the reservoir by screw-fastening.

20 Advantageously, the hole comprises at least one lining, said lining being made of concrete, cement or steel.

The invention also relates to an underground storage method for storing fluids using a storage system as described above. The method includes at least the following steps:

- making a hole in a plot of land, said hole having a bottom,
- 25 - providing a support element comprising at least one opening able to receive a joining element, the joining element comprising ventilation vents to allow the fluid contained in the reservoir to be discharged in the event of a leak,
- providing at least one reservoir, said reservoir having a longitudinal axis, a lower end and an upper end,
- 30 - providing a first closure means able to close said reservoir at its lower end, and a second closure means able to close the reservoir at its upper end,
- joining said upper end to the support element via the joining element such that the reservoir is suspended inside the hole and such that an axial clearance able

to absorb any axial thermal expansion of said reservoir remains between the first closure means of the reservoir and the bottom of the hole.

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Definitions

The “lower end” of the reservoir is understood to be that end of the reservoir that is in the vicinity of the bottom of the hole. This “lower end” is defined in contrast to the end referred to as “upper end” of the reservoir, which is in the vicinity of the support element and therefore the surface of the ground.

“Axial clearance” is understood to be a length which extends along the longitudinal axis of the reservoir and is measured between the first closure means of the reservoir and the bottom of the hole. It should be noted that the position of a reservoir does not have to be perfectly vertical. In this case, the longitudinal axis of the reservoir is at an angle in relation to the vertical in the frame of reference (x; y). This angle has a maximum value of 15°. In this case, the axial clearance is measured by orthogonal projection onto the vertical axis passing through a point on the first closure means that is closest to the bottom of the hole. In other words, the axial clearance always corresponds to the shortest distance, measured between the bottom of the hole and the first closure means.

A “threaded metal tube” is understood to be a tube comprising at least one end having at least one threaded portion, able to be joined to a threaded metal tube comprising at least one end having at least one complementary threaded portion. The thread may be male or female.

The “bottom of the hole” is understood to be the surface of the bottom of the hole. Thus, when the hole is lined and said lining is cemented, the expression “bottom of the hole” then denotes the surface of the layer of cement at the bottom of the hole. If the lining is not cemented, the term “bottom of the hole” very simply denotes the surface of the ground at the bottom of the hole.

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Brief description of the drawings

Other aims, features and advantages of the invention will become apparent on reading the following description, given solely by way of non-limiting example and made with reference to the appended drawings in which:

- [Fig. 1] is a schematic view of the general structure of an underground storage system;

- [Fig. 2] is a schematic view representing the joining element of an underground storage system;

- [Fig. 3] is a schematic view of the ventilation vents on the joining element of an underground storage system;

- [Fig. 4] is a schematic view of a support element separating a lower cavity from an upper cavity in an underground storage system;

- [Fig. 5A] is a schematic view of a reservoir in an underground storage system including a lifting plug system; and

- [Fig. 5B] is a schematic view of a reservoir in an underground storage system including a connection system.

Detailed description

Figure 1 illustrates a sectional view of a storage system 1 according to one embodiment of the invention. As illustrated, the system is positioned in a frame of reference (x; y) in which the axis x of the frame of reference (x; y) is a horizontal axis and the axis y of the frame of reference (x; y) is a vertical axis.

The storage system 1 comprises a hole 2 made in a plot of land 3, a support element 4 placed on a surface of the ground S of the plot of land 3, six reservoirs 5 suspended from the support element 4 in the hole 2 (only four reservoirs 5 are visible in figure 1) and a joining element 6 which comprises ventilation vents to allow the fluid contained in the reservoir 5 to be discharged in the event of a leak. In various embodiments, the storage system 1 generally comprises at least one reservoir 5.

The hole 2 has a bottom 7 and comprises a lining 8. The hole 2 may be obtained by boring or by excavating. The hole 2 is of substantially circular cylindrical

shape and has a mean diameter of 4 meters. The lining 8 is made of cement and extends vertically from the ground surface S to the bottom 7 of the hole 2.

5 The support element 4 is a circular cylindrical plate which separates the storage system 1 into an upper cavity C1 and a lower cavity C2. The support element 4 has a central body and a flange, said flange having a lower surface resting on the ground S. The central body has a first thickness and the flange has a second thickness. The support element 4 further comprises an upper surface, said upper surface being opposite the lower surface of the flange.

10 The support element 4 also comprises one or more openings 9. The openings 9 are through-holes made in the first thickness of the body of the support element 4. In the illustrated embodiment, the support element has six openings.

Each reservoir 5 is suspended from the support element 4 via a joining element 6. Thus, for each reservoir 5 of the storage system 1, an axial clearance G remains between the first closure means 10, which closes the reservoir 5 at its lower end 11, and the bottom 7 of the hole 2. The purpose of this axial clearance G is to absorb any axial thermal expansion of the reservoir 5, which occurs notably during filling and emptying operations. Thus, for each reservoir 5, the dimensioning of the axial clearance G, and notably its length, depends directly on the conditions of the surrounding area of the storage system 1, notably conditions regarding temperature, pressure and the ability of the reservoir 5 to expand when it is subjected to temperature and pressure variations, notably during filling and emptying operations. Thus, the axial clearance G of any reservoir 5 of the storage system 1 satisfies the following inequality:

[Math 1]

$$G \geq (L^2 * \beta * \alpha) + [20 * \alpha * 80 * (1 - e^{-0.11*L})]$$

25 Where: G is the length of the axial clearance expressed in meters. L represents the length of a reservoir 5 expressed in meters. β represents the geothermal gradient expressed in degrees Celsius per meter. The geothermal gradient β varies depending on the geological formation in which the storage system 1 is placed. Thus, β is such that $0.02^\circ/\text{m} \leq \beta \leq 2^\circ/\text{m}$. α represents the coefficient of thermal expansion of the metal expressed in degrees Celsius-1. The coefficient of thermal expansion α varies depending on the type of metal from which the tubes used to form a reservoir 5 are made. Thus, α is such that $8*10^{-6} \text{ }^\circ\text{C}^{-1} \leq \alpha \leq 18*10^{-6} \text{ }^\circ\text{C}^{-1}$.

30 The reservoirs 5 are tubular, with a circular cross section, and each have a longitudinal axis, a lower end 11 and an upper end 12.

Each reservoir 5 is closed at its lower end 11 by a first closure means 10, and each reservoir 5 is closed at its upper end 12 by a second closure means 13. In the embodiment illustrated in figure 1, the lower end 11 and the upper end 12 of each reservoir 5 are threaded ends, and the first closure means 10 and the second closure means 13 also have a thread, said thread complementing the thread of the lower end 11 and of the upper end 12. As a result, the lower end 11 is sealingly closed by screw-fastening with the first closure means 10, and the upper end 12 is sealingly closed by screw-fastening with the second closure means 13.

The second closure means 13 is fitted with sensors 14, such as pressure gauges, thermometers and leak detectors. Of course, the first closure means 10 may also contain pressure gauges, thermometers and leak detectors. Other types of sensors can be used depending on the nature of the parameters to be monitored.

Each reservoir 5 may comprise a plurality of tubes A. In the embodiment illustrated in figure 1, the reservoirs 5 include multiple threaded tubes A. Thus, the tubes A are screwed to one another so as to form a column C of tubes A. In this way, each reservoir 5 is formed by an assembly that includes a column C, closed at its ends 11, 12 by closure means 10, 13. A reservoir 5 may also be composed of a single tube A, closed at its ends 11, 12 by closure means 10, 13.

Each reservoir 5 is joined to a joining element 6 visible in figure 2. Each joining element 6 is inserted into an opening 9 and held by a flange 15 which abuts against the upper surface of the support element 4. Each joining element 6 is thus suspended from the support element 4. In this way, each reservoir 5 is suspended from the support element 4 via the joining element 6 to which it is joined.

For example, a joining element 6 is a tubular metal part of circular section, which comprises a tubular body 16, a flange 15 and ventilation vents 17.

The body 16 of the joining element 6 is fastened to the upper end 12 of a reservoir 5, preferably by screwing. The body 16 of the joining element 6 includes a male or female thread (not shown) complementary to the thread of the upper end 12 of the reservoir 5 to which said joining element 6 is joined. The flange 15 comprises an upper surface 18 and a lower surface 19, the ventilation vents 17 passing through these two surfaces 18, 19. In a variant, the body 16 of the joining element 6 may be fastened by welding. In another variant, the body 16 of the joining element 6 comprises a male thread complementary to a female thread of the opening 9 in the support element 4, and the joining element 6 is thus screwed into the opening 9.

In the embodiment illustrated in figure 1, the tubular body 16 of each joining element 6 is inserted into an opening 9 in the support element 4. Each joining element 6 rests on the support element 4 via its lower surface 19 bearing against the upper surface of the support element 4. In addition, each joining element 6 is joined to a reservoir 5 by screwing at the upper end 12 of said reservoir 5.

The flange 15 therefore enables the joining element 6 to rest on the upper surface of the support element 4. As a result, the joining element 6 does not need to be fastened to the support element 4, for example by welding or by screwing, thereby simplifying assembly of the storage system 1, notably in order to suspend the reservoirs 5.

Figure 3 illustrates a reservoir 5 suspended from the support element 4 via the joining element 6. Indeed, the assembly comprising the joining element 6 fastened to the upper end 12 of the reservoir 5 is inserted into the opening 9 and bears against the upper face of the support element 4. In this configuration, the opening 9 has a larger diameter than the outside diameter of the joining element 6. There is therefore a radial space between the support element 4 and the joining element 6.

If there is no means of ventilation in such a storage system 1 and a leak occurs, the released fluid accumulates in the hole and builds up pressure before causing an explosion, and/or detonation, and/or fire. To minimize these risks, ventilation vents 17 create an air circulation passage between the upper cavity C1 and the lower cavity C2. The storage system 1 is thus not hermetically sealed, which allows the fluid released from the reservoirs 5 to be discharged easily to the outside of the storage system and the hole, in the event of a leak. The ventilation vents 17 are holes passing through the flange of the joining element 6. The ventilation vents can be, for example, holes in a ventilation grille, circular holes and/or rectangular holes. Of course, ventilation vents may have other forms not described in this document.

The total ventilation area is expressed in the following equations:

[Math 2]

$$A = N_{vent} * A_{vent}$$

$$A \leq A_{gap} * 0.9$$

Where A is the total ventilation area, N_{vent} is the number of ventilation vents 17 greater than or equal to 1, A_{vent} is the area of one ventilation vent 17, A_{gap} is the total area of the radial space between the support element 4 and the joining element 6, which is calculated using the following equation:

[Math 3]

$$A_{gap} = \frac{\pi}{4}(d_9^2 - d_6^2)$$

Where gap is the width of the radial space, which is calculated using the following equation:

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[Math 4]

$$Gap = (d_9 - d_6)/2$$

Where d9 is the diameter of the opening 9, and d6 is the external diameter of the joining element 6.

10 The support element 4 separates the upper cavity C1 from the lower cavity C2. According to an embodiment shown in figure 4, the upper cavity C1 is open and comprises a first diameter D1 greater than a second diameter D2 of the lower cavity C2.

In the event of deflagration, this configuration guides the explosion and reduces the pressure induced by the deflagration.

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Indeed, if there is a leak of the fluid in the storage system 1 and there is a pressure build-up therein before it can be discharged correctly through the ventilation vents 17, an explosion may occur. Such an explosion causes structural damage and/or potentially fatal personal injury. In order to reduce the range of the deflagration, once the fluid is outside the hole 2, an upper cavity C1 is created, this cavity having a larger diameter than a lower cavity C2 into which the fluid is released.

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In the example illustrated in figure 4, the upper cavity C1 guides the overpressurized gas flow towards the outside of the storage system 1 in a conical shape with a solid angle α , the apex of which coincides with the bottom of the upper cavity C1, which corresponds to the support element 4. This ensures that surrounding structures are avoided. The angle α is determined as a function of the depth d of the upper cavity C1. If there is no upper cavity C1, the angle α is equal to 90°, and the explosion risks damaging the surrounding structures. Preferably, the depth of the upper cavity C1 is at least one meter.

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Another means of reducing the risk of explosion and/or fire in the storage system 1 is to at least partially fill the hole 2, in particular to at least partially fill the lower cavity C2, with a material comprising at least one deflagration-proof fluid and/or at least one deflagration-proof solid.

In the event of a leak from the reservoir 5, filling the lower cavity C2 makes it possible to direct the fluid released around the support element 4, in order to avoid

an increase in the pressure in the lower cavity C2. The released fluid is thus rapidly diluted in the upper cavity C1 via the ventilation vents 17 and the risks of explosion and fire are avoided. Filling the lower cavity C2 also reduces or eliminates its oxygen content to prevent detonations in the event of a leak of inflammable fluid.

5 The deflagration-proof material is a liquid and/or a solid, for example demineralized water, fresh water, salt water, sand, brine or oil. It may also include antibacterial agents such as chlorine, an antibacterial filter, or hydrogen peroxide, and anti-corrosion agents.

10 This material must not induce pressure on the lower cavity C2 and on the reservoirs 5.

The volume of the material is characterized by the following equation:

[Math 5]

$$Vm = Vc2 - VR$$

15 Where Vm is the volume of the material, Vc2 is the volume of the lower cavity C2, and VR is the volume of the reservoirs contained in the lower cavity C2.

The volume of the lower cavity C2 is calculated using the following equation:

[Math 6]

$$Vc2 = \frac{\pi}{4} * rc2^2 * hc2$$

20 Where rc2 designates the radius of the lower cavity C2, and hc2 is the height of the lower cavity C2.

The volume of the reservoirs 5 is calculated using the following equation:

[Math 7]

$$VR = \left(\frac{\pi}{4} * rR^2 * hR \right) * NR$$

25 Where rR is the radius of a reservoir 5, hR is the height of a reservoir 5, and NR is the number of reservoirs 5 contained in the storage system 1.

The pressure of the material is characterized by this equation:

[Math 8]

$$Pm = hc2 * VMm * g$$

30 Where Pm is the pressure of the material, VMm is the density of the material, and g is the intensity of earth gravity.

Figures 5a and 5b illustrate the closure means 13 of the upper end 12 of a reservoir 5. The upper portion of the closure means 13 comprises a male or female

connector machined to enable the valves and pipes for distributing the fluid contained in the reservoir 5 to be connected.

According to an embodiment illustrated in figure 5a, a thread is machined on the external diameter of the upper portion of the closure means 13 to enable a lifting plug 20 to be fitted. This embodiment is substantially used when handling the reservoir 5 typically during the maintenance phases, for example if components have to be replaced. The lifting plug 20 comprises a body 22 and a lifting means 24. The body 22 has a first female threaded seat 23 joined by screwing to the male connector of the upper portion of the closure means 13. The body 22 further comprises a second seat 25 axially opposite the first seat 23. The second seat 25 is configured to receive and fasten the lifting means 24. The lifting means 24 is inserted and fastened in the second seat 25 by screwing. According to the embodiment illustrated in figure 5a, the lifting means 24 is a lifting ring. According to another embodiment illustrated in figure 5b, a thread is machined on the internal diameter of the upper portion of the closure means 13 to enable a connection system 21 to be fitted. This connection system is used to connect the valves and pipes of the reservoir 5 to external machines, enabling the distribution of the fluid contained in the reservoir 5 to be managed.

This system is advantageous in that it allows the use of several nozzles required for the operations to be performed on the storage system 1. The installation of a lifting plug 20 notably obviates the risk of injury or damage to the structures when handling the reservoir 5. Moreover, the internal thread and the external thread made on the upper portion of a given closure means 13 prevent the lifting plug 20 and the connection system 21 from being fastened at the same time to the same reservoir 5. Such a configuration forces the operator to empty the reservoir 5 before removing the connection system 21 and fastening the lifting plug 20 in order to handle the reservoir 5, for example for maintenance. This prevents the operator from handling a full reservoir. A storage system with such characteristics therefore presents less risk.

The storage system 1 can be used to store any type of fluid, in particular explosive gases. The fluid can be hydrogen, oxygen, methane, nitrogen, ammonia, the fluid preferably being hydrogen.

The invention also relates to an underground storage method for storing fluids using a storage system 1 as described above.

According to this method, during a first step, a hole 2 is made in a plot of land 3, said hole 2 having a bottom 7.

During the next step of the method, a support element 4 is provided comprising at least one opening 9 capable of receiving a joining element 6, the joining element 6 comprising ventilation vents 17 to allow the fluid contained in the reservoir 5 to be discharged in the event of a leak.

5 In the next step, at least one reservoir 5 is provided, said reservoir 5 having a longitudinal axis, a lower end 11 and an upper end 12, followed by a first closure means 10 capable of closing said reservoir 5 at its lower end 11, and a second closure means 13 capable of closing the reservoir 5 at its upper end 12.

10 Said upper end 12 is then joined to the support element 4 via the joining element 6 such that the reservoir 5 is suspended inside the hole 2 and such that an axial clearance G able to absorb any axial thermal expansion of said reservoir 5 remains between the first closure means 10 of the reservoir 5 and the bottom 7 of the hole 2.

CLAIMS

1. An underground storage system (1) for storing fluids, characterized in that
 5 said system (1) comprises:

 - a hole (2) made in a plot of land (3), said hole (2) having a bottom (7),
 - a support element (4) comprising at least one opening (9),
 - a joining element (6) inserted into the opening (9) in the support element (4), the
 10 joining element (6) having ventilation vents (17) to allow the fluid contained in
 the reservoir (5) to be discharged in the event of a leak,
 - at least one reservoir (5), said reservoir (5) having a longitudinal axis, a lower end
 (11) closed by a first closure means (10), and an upper end (12) closed by a second
 closure means (13),
 said upper end (12) being joined to the support element (4) via the joining element
 15 (6) such that the reservoir (5) is suspended inside the hole (2) and such that an
 axial clearance (G) able to absorb any axial thermal expansion of said reservoir
 (5) remains between the first closure means (10) of the reservoir (5) and the bottom
 (7) of the hole (2).
2. The storage system (1) as claimed in claim 1, wherein the support element
 20 (4) separates an upper cavity (C1) from a lower cavity (C2), said upper cavity (C1)
 being open and comprising a first diameter (D1) greater than a second diameter (D2)
 of the lower cavity (C2).
3. The storage system (1) as claimed in claim 2, wherein the lower cavity (C2)
 is filled with a deflagration-proof fluid and/or solid.
- 25 4. The storage system (1) as claimed in claim 3, wherein the deflagration-
 proof fluid and/or solid comprises antibacterial agents and/or anti-corrosion agents.
5. The storage system (1) as claimed in any one of claims 1 to 4, wherein the
 upper end (12) of the reservoir (5) comprises a lifting plug system (20) for use when
 handling the reservoir (5), and a connection system (21) for connecting the valves and
 30 pipes for use when storing and distributing the fluid contained in the reservoir (5).
6. The storage system (1) as claimed in any one of claims 1 to 5, wherein the
 reservoir (5) comprises at least one metal tube (A), said metal tube (A) having at least
 one end provided with at least one threaded portion.

7. The storage system (1) as claimed in any one of claims 1 to 6, wherein the reservoir (5) comprises at least two metal tubes (A) screwed together, so as to form a column (C) of tubes.

5 8. The storage system (1) as claimed in any one of claims 1 to 7, wherein the first closure means (10) and/or the second closure means (13) is able to close the reservoir (5) by screw-fastening.

9. The storage system (1) as claimed in any one of claims 1 to 8, comprising a plurality of reservoirs (5), each reservoir (5) having a longitudinal axis, a lower end (11) and an upper end (12), said upper end (12) of each reservoir (5) being joined to
10 the support element (4) via a joining element (6) such that each reservoir (5) is suspended inside the hole (2).

10. An underground storage method for storing fluids using a storage system (1) as claimed in any one of claims 1 to 9, characterized in that it comprises at least the following steps:

- 15 - making a hole (2) in a plot of land (3), said hole (2) having a bottom (7),
- providing a support element (4) comprising at least one opening (9) able to receive a joining element (6), the joining element (6) comprising ventilation vents (17) to allow the fluid contained in the reservoir (5) to be discharged in the event of a leak,
- 20 - providing at least one reservoir (5), said reservoir (5) having a longitudinal axis, a lower end (11) and an upper end (12),
- providing a first closure means (10) able to close said reservoir (5) at its lower end (11), and a second closure means (13) able to close the reservoir (5) at its upper end (12),
- 25 - joining said upper end (12) to the support element (4) via the joining element (6) such that the reservoir (5) is suspended inside the hole (2) and such that an axial clearance (G) able to absorb any axial thermal expansion of said reservoir (5) remains between the first closure means (10) of the reservoir (5) and the bottom (7) of the hole (2).