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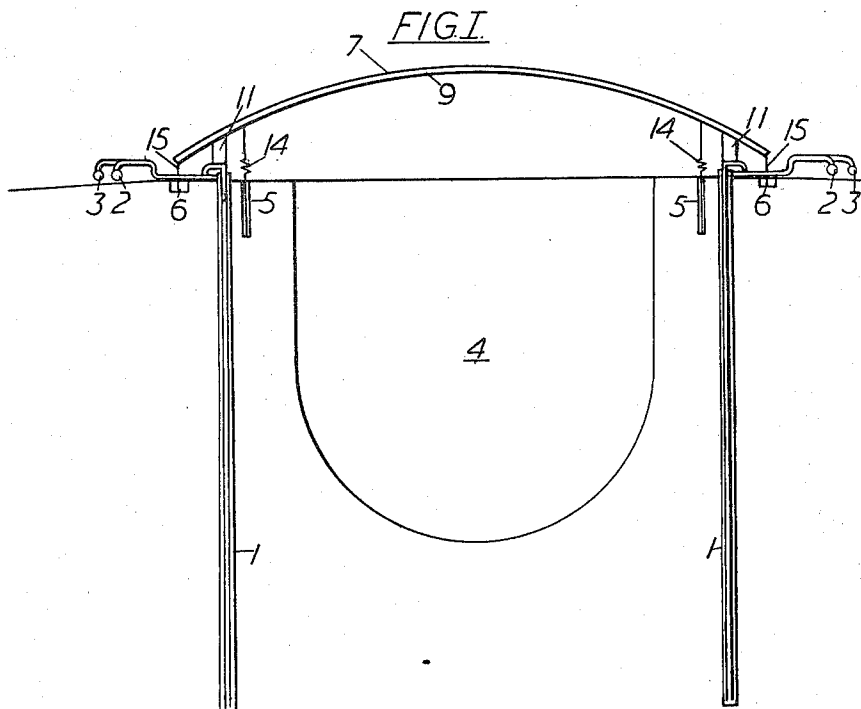
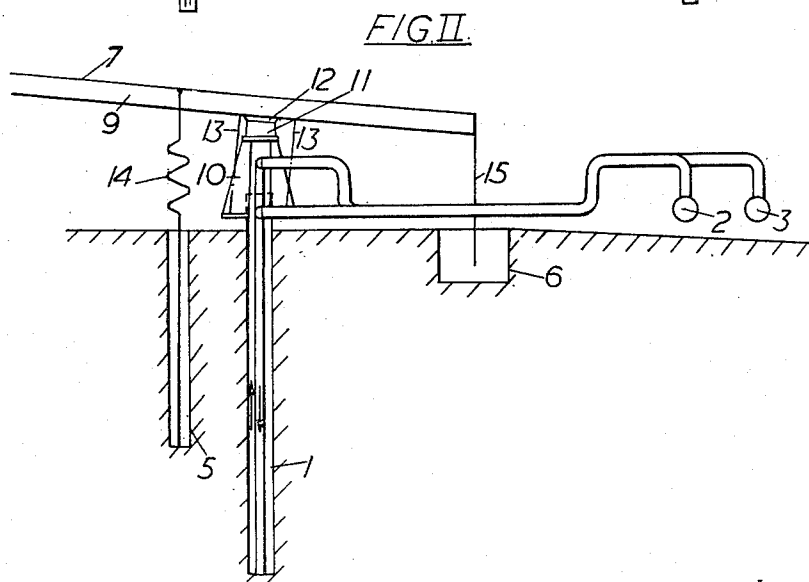
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ROOFS FOR RESERVOIRS

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3,175,370

ROOFS FOR RESERVOIRS

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Continuation of application Ser. No. 154,520, Nov. 24, 1961. This application Mar. 24, 1964, Ser. No. 354,475 Claims priority, application Great Britain, Feb. 7, 1961, 4,513/61

9 Claims. (Cl. 62—45)

This application is a continuation of application Serial No. 154,520, now abandoned, of Etienne M. Schlumberger and Arnold Jozef Willem Ploum, filed November 24, 1961, for Roofs for Reservoirs.

This invention relates to roofs for reservoirs for the storage of liquefied gases, particularly liquefied natural gas or methane and liquefied petroleum gases such as ethane, propane and butane.

In this specification, the expression "liquefied gas" means a liquid which boils at atmospheric pressure at a temperature below the ambient temperature.

In this specification, the expression "a hole in the surface of the earth" means a hollow place in the surface of the earth which has a substantial area on the plane of the surface in relation to its capacity, i.e., it is not intended to include narrow shafts or wells.

U.S. patent application Serial No. 23,439, filed April 20, 1960, now abandoned, describes a reservoir for the storage of liquefied gases which comprises a hole in the surface of the earth, the earth formation surrounding said hole containing a liquid which solidifies at the boiling point of the liquefied gas to be stored, a thermally insulated roof completely covering said hole, a gas vent and conduit and pumping means for filling and discharging liquid from said reservoir. Such a reservoir is hereinafter called "a ground reservoir."

When a ground reservoir is filled with liquefied gas, the liquid in the surrounding earth formation is solidified and the formation is sealed by the frozen liquid.

According to said application, the roof over the hole may be made of any suitable material such as steel, particularly carbon steel, aluminum or wood. In the case of wood, it should be suitably sealed at the joints. The roof must be thermally insulated to prevent as far as possible transfer of heat from the atmosphere into the reservoir. This insulation may be on top of the roof or beneath it or both. In the case of insulation beneath the roof, it may be fixed in contact with the underside of the roof or it may be suspended a short distance from the underside.

The said application also illustrated a method of sealing the joint between the roof and the surrounding earth formation. The roof with its suspended thermal insulation is built a small way into the surface of the surrounding earth. A layer of cement is laid on the earth surface adjacent to the perimeter of the roof and a layer of a thermally insulating material, such as perlite or fibre glass, is laid on the cement. The portion of the formation in the corner between the roof and the side of the basin is kept frozen if necessary by artificial means.

The above method of sealing the joint between the roof and the surrounding earth formation suffered from the demerit that it made no allowance for movements of the earth on freezing, and the present invention provides an improved method of sealing which avoids the strains that may be set up in the roof when the earth freezes.

Accordingly, the present invention provides a thermally insulated roof for a ground reservoir which is sealed into the earth by means of a continuous vapor-impervious membrane extending down from the roof into a slot in the earth, which slot is filled with a material which is a

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liquid at ambient temperature but which is solid when the reservoir is in use.

Preferably, two continuous vapor-impervious membranes extending from the roof to the earth are used in spaced-apart relationship to define a closed space between the outer part of the roof and the ground, which space can be kept full of an inert gas, such as nitrogen or carbon dioxide. The outer membrane need not penetrate into the earth's surface provided a fairly gas-tight seal is made with the earth.

The roof may be made of any of the materials described for that purpose in application Ser. No. 23,439 and may be insulated by means of the materials described for that purpose in that specification. The inner membrane may be made of stainless steel, aluminum or other material capable of resisting the cold to which it is to be subjected. Preferably, this membrane is corrugated for flexibility, horizontal corrugations in that part above the ground and vertical corrugations in that part in the slot in the ground being particularly suitable. Also, the whole or part of the membrane may be formed out of dimpled metal sheet, again for flexibility. The membrane is eventually sealed into the slot by means of a freezing liquid. However, it is preferable that the liquid used in the slot does not freeze at too early a stage during the filling of the reservoir. For example, when water is used as sealing liquid in the slot, it might, under some conditions, freeze at a very early stage before the membrane and earth movements due to the extremely low temperatures pertaining when the reservoir is being filled have taken place. Hence it is a preferred feature of this invention that the sealing liquid in the slot is one which solidifies at a temperature about, but not below, that of the ground surrounding the slot when the reservoir is in use. Typical examples of such liquids will be described hereinafter.

The outer membrane, if used, may be of metal, wood, rubber or canvas. It may also penetrate into a slot in the earth but, since it is more remote from the cold of the reservoir, it will not generally require a special sealing liquid. Depending on its distance from the reservoir, materials such as water or bitumen may be used.

The roof is not supported by the membranes and therefore requires suitable supporting members. It is possible when the ground has to be pre-frozen to use the freezing pipes for this purpose. To allow radial movement of the roof due to contraction, the roof may be allowed to slide on top of metal-lined wooden blocks on top of the supports.

When the reservoir is in operation, the pressure of the gas in the reservoir will tend to lift the roof from its supports and the roof should therefore be held down, for example by tie rods connected to the supports.

A preferred embodiment of the invention will now be described with reference to FIGURES I to IV of the drawings.

FIGURE I is a cross-sectional view of a ground reservoir complete with roof in accordance with this invention.

FIGURE II is an enlarged drawing of that part of FIGURE I within the rectangle enclosed by dashed lines,

FIGURE III is an enlarged drawing of what part of FIGURE II within the rectangle enclosed by dashed lines, and

FIGURE IV is a cross-section of FIGURE III as viewed from the centre of the reservoir.

The reservoir is to be built in an area where the soil already contains a proportion of water sufficient to form a solid ice sheath after freezing. The ground is first frozen by means of freezing pipes 1 installed in the ground round the projected cavity. Each pipe consists of an outer pipe closed at the bottom and an inner pipe

open at the bottom, both made of aluminum. The inner and outer pipes are connected to ring mains 3 and 2 respectively and the refrigerant, e.g., cold liquid propane, flows from ring main 3 (which in turn connects to a refrigeration system not shown in the drawing) down the inner pipes and up the annular space between the inner and outer pipe 1 into ring main 2 and back to the refrigeration system. The number of pipes depends on the diameter of the projected cavity and can vary from 18 to 30 pipes for a cavity having a diameter of 6 meters (20 feet) and from 80 to 120 for a cavity having a diameter of 30 meters (100 feet). The pipes should be long enough to go well below the bottom of the cavity, e.g. 2 meters (6 feet) lower and should preferably extend into an impervious layer below the cavity, if there is such an impervious layer at a reasonable distance below the bottom of the cavity.

When the earth is sufficiently frozen, the hole 4 is excavated. In the case shown in the drawings, the hole is circular in cross-section. It may be lined, e.g. with a coarse cotton cover, to avoid contamination of contents. Also, to reduce boil-off losses at initial stages of storage, it may be lined with cheap insulation, e.g. wood shavings embedded in wax or frozen mineral oil, glass fibre mats. Such lining need not be liquid-tight.

A circular slot 5 is also excavated around the hole between it and the freezing pipes and a smaller circular slot 6 is excavated outside the freezing pipes around the perimeter of the hole at or near where the edge of the roof will be.

The circular roof 7 is of aluminum or carbon steel and is constructed with radial I-beam stiffeners 8. It is thermally insulated on its under surface, e.g. by means of polyurethane or polystyrene foams as shown at 9.

Supporting plates 10 built on the top of the freezing pipes 1 carry wooden blocks 11, each covered on top by a metal liner 12 on which the I-beam stiffeners of the roof rest and can slide. In order to hold the roof down against the pressure of the gas when the reservoir is in use, tie rods 13 subtend from the I-beams 8 to the supporting plates 10.

To seal the cavity from the atmosphere, a continuous circular membrane 14 of aluminum or stainless steel is welded to the roof and extends into the slot 5. The membrane may be a simple metal sheet but as shown has a horizontal corrugation above the ground and a vertical corrugation below the ground. The slot 5 is filled with a liquid which will become solid at the temperature of the ground surrounding the slot when the reservoir is in use. Clearly this temperature is a function of the temperature of the stored liquid, the distance between the slot and the reservoir and time. If a reservoir of the type now being described is used for liquefied natural gas, suitable liquids for use in the slot are those having a melting point of about, but not below, minus 90° centigrade, e.g. n-heptane, n-octane, n-propane, n-butyl alcohol, the monoethyl ether of ethylene glycol, ethyl acetate, isopropyl alcohol and appropriate mineral oil fractions. If n-propane is being stored, liquids for use in the slot are those having a melting point of about, but not below, 10° centigrade e.g. suitable mixtures of water with ethylene glycol or isopropyl alcohol. Water itself may be used in some circumstances and also waxy mineral oils.

At the outer edge of the roof, a second membrane 15, e.g. a rubber or canvas sheet, extends all round the roof down into the hole 6 in which it is sealed, e.g. by a bitumen composition. The annular space between the membranes 14 and 15, the roof and the earth is continually purged by means of an inert gas such as nitrogen or carbon dioxide.

The reservoir is of course fitted with a gas vent and conduit and pumping means for filling and discharging the liquid to be stored. These are now shown in FIGURES I to IV but they may be as described in application Serial No. 23,439.

A further embodiment of the invention will now be described with reference to FIGURE V of the accompanying drawings. This embodiment illustrates the use of a single membrane and also shows how that membrane is modified where it is necessary to take pipes through it.

FIGURE V shows a cross-section of the perimeter of a ground reservoir complete with roof in accordance with the invention. The relation of FIGURE V to the whole reservoir and roof is the same as the relation of FIGURE II to FIGURE I.

In FIGURE V, references 1, 4, 5, 7, 9, 10, 11, 12 and 14 have the same significance as in FIGURES I to IV. However, the supporting plates 10 built on the top of the freezing pipes 1 have been turned through 90° as compared with FIGURES I and IV so that they now face the centre of the reservoir. These supporting plates 10 carry wooden blocks 11 each covered by a metal liner 12 on which rests a circular girder 16 extending completely round the reservoir. This girder is fixed to the blocks 11 through liner 12 in such a way as to allow some horizontal movement of the girder. The roof 7, which in this case has no radial stiffeners, is welded to the girder 16 as at 17. Additional thermal insulation 18 can extend down from the insulation 9 below the roof to the ground.

In the ground reservoir of FIG. V, the conduit means for filling and emptying pass through the extension of the roof down to the ground instead of through the upper part of the roof as described in application Serial No. 23,439. For the sake of simplicity, only two of these conduits are shown, i.e. the main filling line 19 and a spray line 20 for spraying the cold liquid on the walls of the reservoir during the early stages of filling to ensure uniform cool down. While the membrane 14 will generally be as shown in FIGURES I and II, where the conduits pass through it as in FIGURE V, bellows 21 and 22 are provided to allow for movement of the conduits in relation to the membrane on expansion and contraction. If desired, the inner or outer surfaces of the thermal insulation 18 and 9 which is situated outside the membrane 14 can be sealed and the annular space between the membrane 14 and the thermal insulation 18 can be kept full of an inert gas, such as nitrogen. The slot 5 is filled with a suitable liquid as in FIGURES I and II.

We claim:

1. A thermally insulated roof for a ground reservoir having a slot extending around the outer edge of the reservoir, said slot containing a material which is liquid at ambient temperature and solid when the reservoir is in use,

(a) a continuous vapor impervious membrane extending down from the roof into said slot,

(b) a second continuous vapor impervious membrane extending down from the roof to the earth outside of, and in spaced relation with the first continuous vapor impervious membrane to define a closed space between the outer part of the roof and the ground and the two membranes for containing an inert gas,

(c) supporting members extending upwardly from the ground near the perimeter of the roof,

(d) metal lined wooden blocks between said supporting members and said roof, and engaging said roof in sliding contact to allow for radial movement of the roof due to contraction.

2. A thermally insulated roof for a ground reservoir having a slot extending around the outer edge of the reservoir, and slot containing a material which is liquid at ambient temperatures and solid when the reservoir is in use,

(a) a continuous vapor impervious membrane extending down from the roof into said slot,

(b) supporting means between the roof and ground,

(c) metal-lined wooden blocks between said supporting means and roof, engaging said roof in sliding contact to allow for radial movement of the roof due to contraction.

3. The invention as claimed in claim 2, wherein said supporting members are freeze pipes having means for circulating a freezing fluid therein.

4. A thermally insulated roof for a ground reservoir having a slot extending around the outer edge of the reservoir, said slot containing a material which is liquid at ambient temperature and solid when the reservoir is in use,

(a) a continuous vapor impervious membrane extending down from the roof into said slot,

(b) a series of freeze pipes extending into the earth near the perimeter of said ground reservoir, and

(c) load-bearing means supporting said roof on said freeze pipes.

5. A thermally insulated roof for a ground reservoir having a slot extending around the outer edge of the reservoir, said slot containing a material which is liquid at ambient temperature and solid when the reservoir is in use,

(a) a continuous vapor impervious membrane extending down from the roof into said slot,

(b) a second continuous vapor impervious membrane extending down from the roof into the earth outside of, and in spaced relation with, the first continuous vapor impervious membrane to define a closed space between the outer part of the roof and the ground and the two membranes,

(c) said reservoir being constituted by frozen ground at the perimeter of the excavation, and including freezing pipes extending into the ground around the perimeter of said ground reservoir,

(b) bearing means between said freezing pipes and said roof supporting the roof on said pipes.

6. A thermally insulated roof for a ground storage system for low-temperature liquids comprising an earthen reservoir,

(a) a continuous vapor-impervious membrane extending down from said roof into the earth adjacent the perimeter of said reservoir,

(b) sealing means for sealing said membrane to the earth,

(c) said sealing means being of a material which is liquid at ambient temperature but which is solid when the reservoir is used to store a low-temperature liquid,

(d) freezing pipes extending into the ground at the perimeter of said reservoir,

(e) bearing means supporting said roof on said freezing pipes.

7. A thermally insulated roof for a ground reservoir formed as a hole in the earth, for storing liquefied gas at below 32° F.,

(a) rigid roof supporting means firmly embedded in the ground near the periphery of said hole,

(b) bearing means supporting said roof near its periphery on said supporting means;

(c) a thin, continuous vapor impervious flexible member, incapable of supporting the weight of said roof, extending down continuously from the roof into a slot formed in the surface of the earth near the periphery of said hole,

(d) sealing means sealing said slot to a level above the bottom of said member,

(e) said sealing means being liquid at ambient temperature but solid at the temperature of the ground surrounding said slot when the reservoir is in use,

(f) said bearing means being constructed to permit thermal expansion and contraction between said roof and said supporting means.

8. A thermally insulated roof as claimed in claim 7, said flexible member having corrugations for flexibility.

9. A thermally insulated roof as claimed in claim 8, said corrugations in the flexible member being horizontal in that portion above the ground and vertical in that portion which is in the slot below the ground.

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