United States Patent

[11] 3,581,513

[72] Inventors **John L. Jr. Cranmer**
Chicago;
Bertram E. Eakin, Naperville, Ill.; Eugene P. McCann, Tewksbury, Mass.

[21] Appl. No. **818,771**
[22] Filed **Apr. 23, 1969**
[45] Patented **June 1, 1971**
[73] Assignee **Institute of Gas Technology**
Continuation-in-part of application Ser. No. 702,293, Feb. 1, 1968, now abandoned.

[54] **METHOD AND SYSTEM FOR FREEZING ROCK AND SOIL**
15 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **62/50,** 61/.5, 61/36, 62/52, 62/54, 62/260
[51] **Int. Cl.** **B65g 5/00,** F17c 7/02
[50] **Field of Search** 62/45, 55, 50, 260, 54, 52; 61/.5, 36

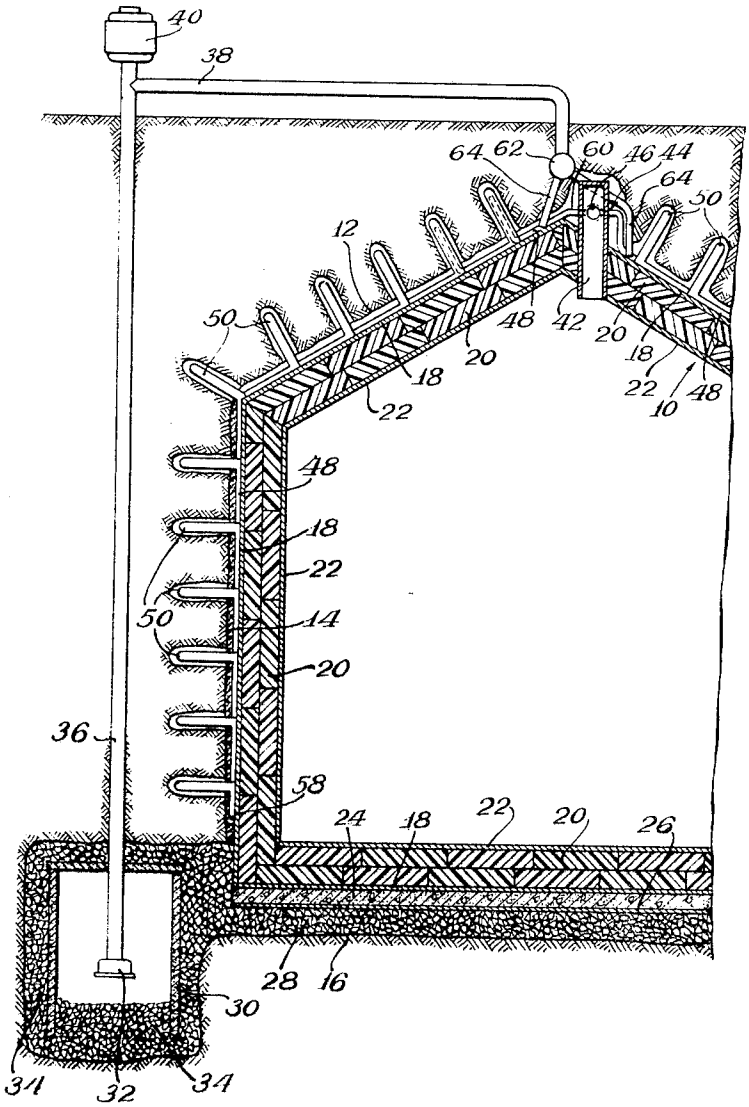
[56] **References Cited**

UNITED STATES PATENTS

2,148,109	2/1939	Dana et al.	62/54
3,110,156	11/1963	Niemann	62/45
3,183,675	5/1965	Schroeder	62/260X
3,267,680	8/1966	Schlumberger	61/.5X
2,961,840	11/1960	Goldtrap	62/260X
3,041,850	7/1962	Nunn	62/260X
3,246,479	4/1966	Kelley	62/45
3,304,728	2/1967	DeHaan	62/50
3,344,607	10/1967	Vignovich	62/45X
3,354,654	11/1967	Vignovich	62/45

Primary Examiner—Robert A. O'Leary
Assistant Examiner—Albert W. Davis
Attorney—Allegretti, Newitt & Witcoff

ABSTRACT: A system and method for freezing water in the rock and/or soil formation surrounding a chamber, at least partially below ground level, used for storing liquid gas at cryogenic temperatures. Gas boiled from the liquid gas in the chamber is vented and is distributed to a plurality of series connected heat exchangers positioned in the surrounding formation. The cold gas freezes the water in the formation surrounding the heat exchangers to thereby improve the insulating properties of the insulation surrounding the chamber and to ultimately stop any seepage of water around the chamber.

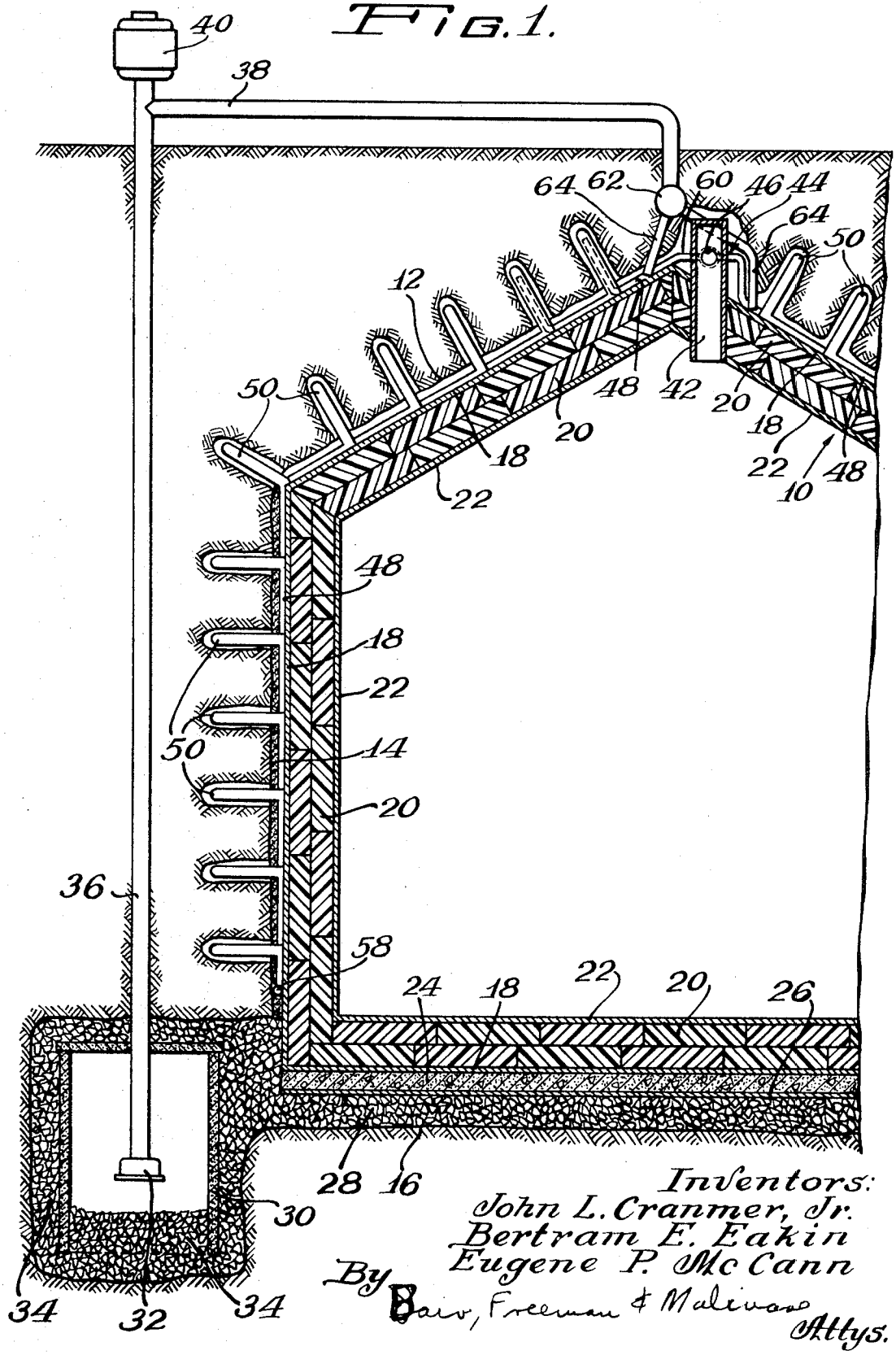


PATENTED JUN 1 1971

3,581,513

SHEET 1 OF 3

FIG. 1.



Inventors:
John L. Cranmer, Jr.
Bertram E. Eakin
Eugene P. McCann

By Baird, Freeman & Malevanec
Attys.

FIG. 2.

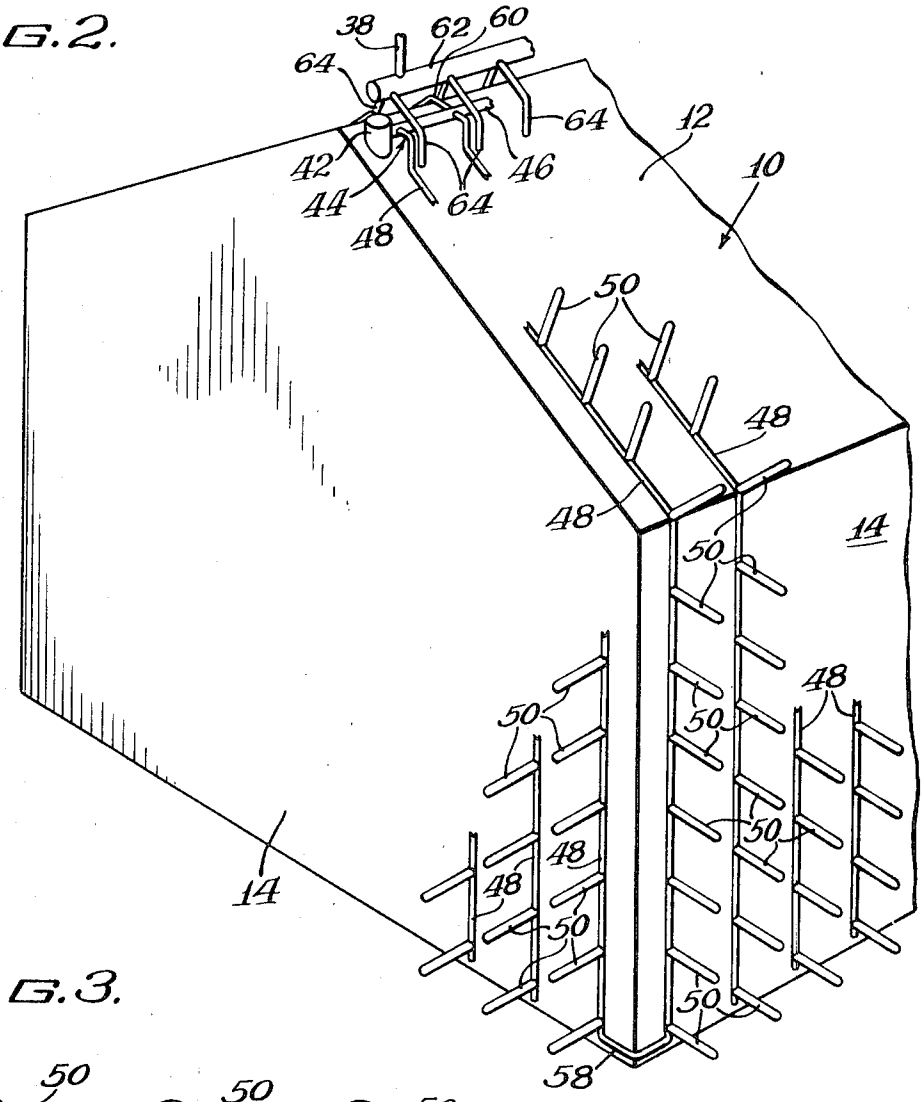
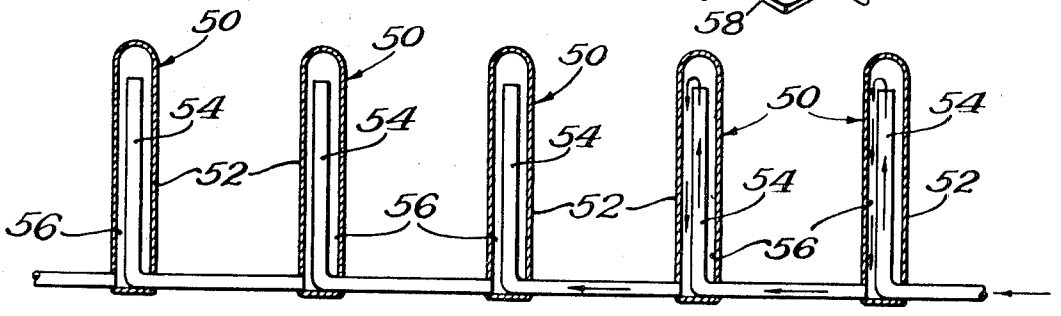


FIG. 3.



Inventors:
John L. Cranmer, Jr.
Bertram E. Eakin
Eugene P. McCann
By Bair, Freeman & Molinare
Attys.

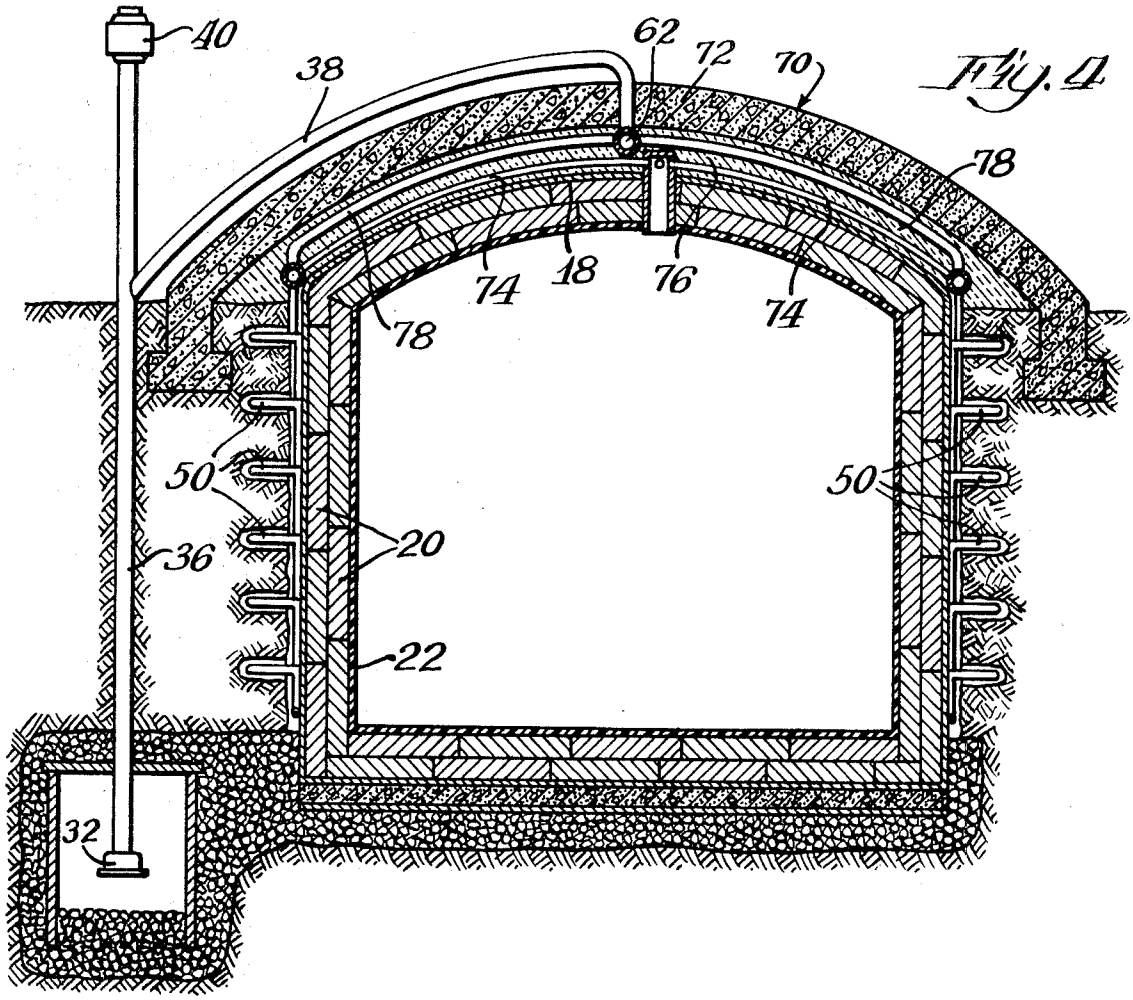


Fig. 4

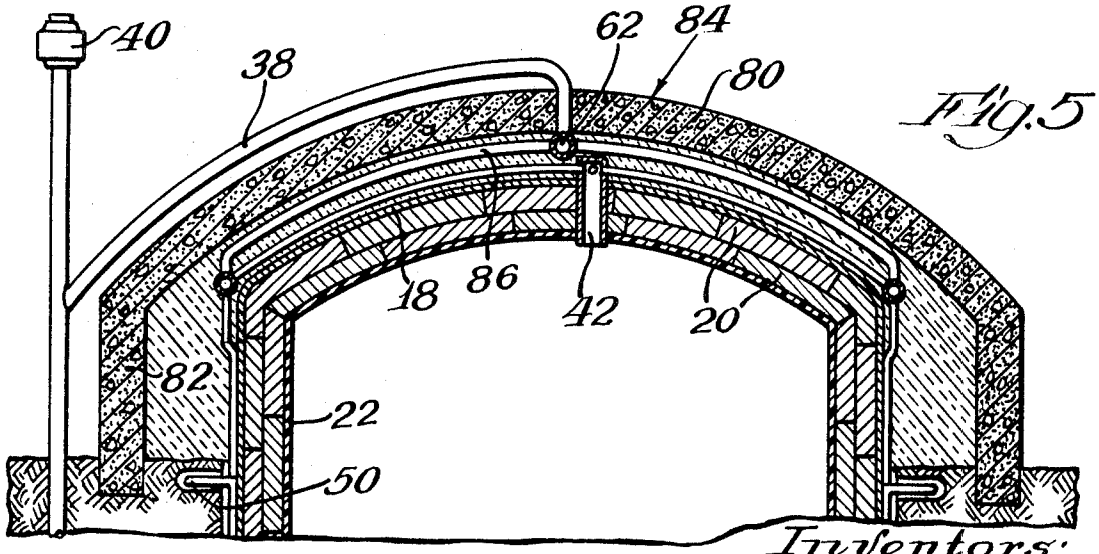


Fig. 5

Inventors:
John L. Cranmer, Jr., Bertram E. Eakin
and Eugene P. McCann
By Bair, Freeman & Malinzak Attys.

METHOD AND SYSTEM FOR FREEZING ROCK AND SOIL

REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of our copending application Ser. No. 702,293, filed Feb. 1, 1968, now abandoned.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION AND DESCRIPTION OF THE PRIOR ART

This invention relates to a method and system for freezing water in an earth formation surrounding a chamber which is at least partially below the ground and is used for storing liquid gas at cryogenic temperatures and it particularly relates to such a method and system which ultimately substantially prevents the inflow of water to the storage chamber and which also increases the efficiency of the thermal insulation surrounding the chamber for maintaining the stored liquid gas at cryogenic temperatures.

In U.S. Pat. application Ser. No. 526,983, filed Feb. 14, 1966, now U.S. Pat. No. 3,418,812, there is disclosed an insulation system for an underground chamber used for the storage of liquified gases at cryogenic temperatures. Although the insulation system described in the prior application is satisfactory in chambers which are surrounded by substantially dry areas, it has been found that where the chambers are surrounded by relatively wet rock or ground or where the water table is relatively high, the waterproofing of the chamber from external water is inadequate. In the prior application, it is disclosed that a water and moisture sealant is sprayed onto the internal surface of the earth formation, such as rock or soil, after excavating, cleaning, and drying the chamber.

In practice, in underground chambers constructed in relatively wet areas, it has been found that moisture or water seeps through and not only comes into contact with the low temperature insulation to adversely affect the insulating properties of the insulation, generally foamed plastic, but the water also works its way up through the insulation to an internal liquid barrier; the low temperature in the cavern freezes the water outside the barrier. The ice, thus formed, will ultimately break the internal liquid barrier. Such a condition cannot be tolerated because such breakage of the internal barrier permits leakage of the stored liquid gas.

In copending application, Ser. No. 702,471, of Bertram E. Eakin and John L. Cranmer, Jr., filed on even date herewith and now abandoned in favor of continuation-in-part application, Ser. No. 794,339, there is disclosed an insulation and waterproofing system for underground chambers which substantially avoids the problems encountered when such underground chambers are constructed in relatively wet areas. In the system disclosed in this second application, a water barrier, such as sheet metal, is secured to the top, sides, and bottom of the cavern. Insulating material is mounted inside the water barrier, and a second liquid barrier is secured to the opposite side of the insulation. The second liquid barrier is in contact with the liquid in the cavern. Water-permeable material fills the void spaces between the sides and floor of the cavern so that external water may be transmitted to a sump pump which pumps the water away from the chamber.

Although the insulating and waterproofing system in the second application is quite acceptable, it would be even more desirable if the required pumping could be dispensed with after a period of time. One way in which the required pumping of the second application can be substantially dispensed with after a period of time is by use of a simple and economical system for freezing at least the sides of the rock or soil surrounding the chamber or where the chamber roof is entirely below ground, for freezing the top and sides.

Frozen rock or soil surrounding the chamber increases the efficiency of the insulation and provides improved control over the amount of boiling of the liquid gas contained within the chamber. Freezing of the rock also substantially avoids water control problems in the area around the chamber. Furthermore, the frozen rock or soil will provide a "fail-safe" system because, as the rock becomes frozen, it becomes gastight and if there is a failure of the liquid barrier containing the liquid gas, the gas will be contained by the rock structure, and not leak out to the surrounding area, becoming a hazard to persons and property.

SUMMARY OF THE INVENTION

It is therefore an important object of this invention to provide an improved method and system for freezing water in an earth formation surrounding at least a portion of an underground chamber used for storing liquid gas at cryogenic temperatures.

It is also an object of this invention to provide a method and system for freezing water surrounding an underground chamber formed at least partially in rock and/or soil, wherein boiled off gas from the liquid gas is used for freezing the water in the formation surrounding the chamber.

It is another object of this invention to provide an improved method and system for freezing water in the soil and rock surrounding an underground chamber used for storing liquid gas at cryogenic temperatures wherein the frozen soil and rock acts to substantially avoid water seepage into the chamber.

It is yet another object of this invention to provide a method and system for freezing water in rock and soil surrounding an underground chamber for storing liquid gas at cryogenic temperatures wherein the method and system are highly effective, efficient, and economical.

It is still a further object of this invention to provide a system for freezing water in the rock and soil surrounding an underground chamber for storing liquid gas at cryogenic temperatures wherein the insulating properties of the insulation surrounding the chamber are enhanced.

It is also another object of this invention to provide a system for freezing the water in the rock and soil surrounding an underground chamber for storing liquid gas at cryogenic temperatures wherein the freezing of the soil and rock is accomplished in a relatively short period of time.

Further purposes and objects of this invention will appear as the specification proceeds.

Generally, our improved system for freezing water in the rock and soil surrounding a chamber, at least partially below ground, used for storing liquid gas at cryogenic temperatures includes a vent in the upper portion of the chamber for venting the gas boiled off from the liquid gas stored in the chamber, a plurality of series connected heat exchangers are positioned in the rock and soil surrounding the chamber, the heat exchangers being connected to the vent, and conduits directing the boiled off gas through the heat exchangers so that the cold gas freezes the water in the rock and soil surrounding the heat exchangers.

BRIEF DESCRIPTION OF THE DRAWINGS

Particular embodiments of the present invention are illustrated in the accompanying drawings wherein:

FIG. 1 is a schematic cross-sectional view illustrating our improved method and system for effecting the freezing of the rock and soil surrounding an underground chamber used for storing liquid gas at cryogenic temperatures;

FIG. 2 is a diagrammatic perspective view showing the heat exchangers and distribution means to the heat exchangers for the cold gas for freezing of the water surrounding the chamber, and also showing the distribution means for passing water to the top of the chamber;

FIG. 3 is a detailed cross-sectional view through the heat exchangers used for freezing the water in the rock and soil surrounding the cavern;

FIG. 4 is an alternate embodiment of our invention wherein the storage chamber has its top extending above ground level; and

FIG. 5 is another alternate embodiment of our invention wherein the storage chamber has its top and a substantial portion of the sides extending above the ground.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the schematic drawing of FIG. 1, an underground chamber, generally 10, is excavated in a suitable manner, preferably by the method disclosed in U.S. Pat. application Ser. No. 527,158, now U.S. Pat. No. 3,407,606. The chamber 10 is preferably surrounded by rock although, particularly in the upper portions of the chamber 10, soil may also surround portions of the chamber. The chamber 10 includes a domed top 12, sides 14, and a floor 16 in the surrounding rock or soil.

A water barrier 18 is secured to the top, sides 14 and the floor 16 of the chamber 10. The mounting of the water barrier sheet 18 may be accomplished by the use of studs (not shown) preferably mounted in the rock surrounding the chamber 10, which studs are secured to the outer surface of the water barrier 18. Preferably, the water barrier 18 is a continuously formed steel sheet. As described in copending application Ser. No. 702,471, of Bertram E. Eakin and John L. Cranmer, Jr., filed on even date herewith, a water-permeable filler material (not shown) is desirably poured in the space defined between the irregular sides 14 of the chamber 10 and the sides of the water barrier 18. The material, preferably a water permeable concrete, such as "popcorn" or "no fines" concrete, is permeable to water passing between the formation defining the chamber 10 and the water barrier 18 so that water passes downwardly to the lower portion of the chamber 10. Thus the filler material, by filling the voids between the planar surface of the water barrier 18 and the irregular surface of the chamber sides 14, also transfers load-bearing support for the hydrostatic pressure of the liquid gas within the chamber 10 to the rock load bearing sides 14 of the chamber 10.

Thermal insulation, generally 20, is placed in contact with the inner surface of the water barrier 18 to provide thermal insulation to maintain the liquid gas within the cavern 10 at the desired cryogenic temperatures. Any number of layers of insulation 20 are used to maintain the gas at the desired temperature. Preferably, the insulation 20 comprises a plurality of foamed plastic blocks, such as polyurethane blocks, about 2 feet square by 2—4 inches thick. The material preferably is sufficient to provide a temperature difference of 100° between the inner and outer surfaces of the insulating blocks. The insulation 20 completely surrounds all sides of the chamber 10 so that the thermal insulation maintains the liquid gas at the necessary cryogenic temperature.

At least the inner surface of the inner layer of insulation 20 in contact with the liquid gas is covered by a liquid barrier, generally 22, which prevents the egress of liquid gas from the chamber 10. The liquid barrier 22 is preferably metallic or a plastic-metal laminate, such as a Mylar-aluminum-Mylar-Dacron laminate, which is commercially available. The liquid barrier 22 must be nonreactive with the liquid gas contained within the chamber 10 and it must also be unaffected by the cryogenic temperatures.

A concrete slab 24 is located immediately below the bottom of the floor of the water barrier 18. A vapor barrier 26, such as polyethylene sheeting, is placed between the concrete slab 24 and water permeable crushed stone 28 is laid in the space between the concrete slab 24 and the rock floor 16 of the chamber 10. The crushed stone 28 permits the water to flow under the stored liquid gas. Preferably, the rock floor 16 is slanted in a direction towards a sump, generally 30. A sump pump 32 is contained within the tile sump 30 which is surrounded by water permeable crushed stone 34 which communicates both with the layer of crushed stone 28 above the floor 16 and with the water permeable filler material between the rock sides 14 and the water barrier sides 18. Water that passes around and under the chamber 10 is thereby pumped by the sump pump 32 upwardly through a pipe 36 to an outlet 38. The sump pump 32 is the type which can be replaced for repairs by working from the surface.

The important features of this invention involve a system for freezing at least the rock top and sides 14 defining the chamber 10. By freezing the ground or rock around the chamber 10, water seepage is thereby substantially eliminated since the water is transformed into ice. Secondly, by lowering the temperature of the rock, the thermal insulating properties of the insulation 20 are enhanced not only in assisting in preventing the egress of water to the insulation 20 but also by lowering the temperature surrounding the chamber 10. The lower the temperature of the surrounding earth formation, the less heat loss through the walls of the chamber 10 and the less load required for the refrigerating system used for maintaining the liquid gas in the chamber 10 at the desired cryogenic temperatures. The frozen rock or ground defining the chamber 10 also provides a "fail-safe" system to avoid a dangerous situation in the event that anything does happen to either of the liquid barriers 18 or 22 surrounding the liquid gas stored within the chamber. After freezing the earth surrounding the chamber 10, it is no longer necessary to continuously operate the sump pump 32 to remove water from the lower portion of the chamber 10 and except for any minor amount of water that may seep into the sump 30, after the freezing of the earth formation is completed, the pump 32 is seldom, if ever, operated.

The freezing in our system and method is accomplished economically in a relatively short period of time. The freezing water in rock and soil surrounding a large underground chamber 10 normally presents an enormous problem in time and equipment requirements. The system and method of the present invention provides a system which effectively freezes the rock formation surrounding the chamber 10 in a highly efficient and economical manner, and in a relatively short period of time, such as about 1—3 years.

A vent tube 42 is positioned in the upper central portion of the chamber 10 and vents the boiled-off gas from the liquid gas contained within the chamber 10. The boiling of the liquid gas normally occurs in the case of liquid natural gas when the temperature goes above about −258° F., the cold liquid vaporizes or boils off. Thus, the domed upper portion of the chamber 10 normally contains gas. This gas, however, is at extremely cold temperatures, such as just above −258° F., and we provide a method and system for utilizing this cold gas for freezing the earth formation surrounding the chamber in a relatively short period of time. The vent tube 42, as shown in FIGS. 1 and 2, is connected to a distribution piping system, generally 44. The vent 42, which passes through the liquid barrier 22, the insulation 20, and the water barrier 18, is connected to an elongated distribution pipe 46 passing longitudinally along the domed upper central portion of the chamber 10. A plurality of pipes or conduits 48 pass down along the top and sides of the chamber 10 and extend laterally from the distribution pipe 46.

As shown best in FIG. 3, each of the pipes or conduits 48 is connected to a plurality of heat exchange units 50. The heat exchangers 50 generally comprise a series of interconnected cylindrical units. Each of the units 50 comprises an outer closed cylinder 52 and a concentric inner pipe 54 which extends upwardly from the piping 48 and has an open upper end. An annular space 56 is thereby defined between the outer cylinder 52 and the inner pipe 54.

The cylindrical heat exchangers 50, as shown best in FIG. 1, are embedded at spaced intervals in the earth formation in the sides 14 and top 12 of the chamber 10. Cold gas passing downwardly through 57 annular space 56 absorbs heat from the rock and soil formation and freezes water in the formation. As the gas passes progressively in series through each of the heat exchangers 50, the temperature of the gas gradually rises so that the rock top portion 12 of the chamber 10 freezes before the side 14 of the chamber. At the point where the gas leaves the last heat exchanger in a lateral string or piping system 48 when the system is first in operation, little if any freezing of the water contained within the earth formation is accomplished in the lower portions of the pipes 48. At the end of the string of pipes 48, a collection manifold or pipe 58 is

connected to each of the lower ends of the piping 48 and the collection pipe 58, connected to a discharge pipe which takes the warmed gas to a point where the gas may be distributed to customers or to a plant (not shown) for reliquefying the gas and pumping it back inside the chamber 10.

In order to prevent an ice buildup on the outside surface of the water barrier 18, the water which is pumped from the sump 30 through the outlet pipe 38 is recirculated to the area at the top central portion 60 of the chamber 10 to maintain an above water freezing temperature (+32° F.) on the outside surface of the water barrier 18, until the rock and/or soil is frozen and natural water leakage into the chamber 10 has ceased. If this water were not recirculated through the elongated distributor pipe 62 and distributed through distributor pipes 64 to flow evenly over the outer surface of the water barrier 18, the natural water, dripping from the top of the earth formation, would freeze on the outside surface of the water barrier 18. This would cause ice loads for which the chamber roof structure (not shown) is not designed and which could cause failure of the roof structure, resulting in abnormally high boiloff of natural gas, and unsafe condition. During the latter stages of operation of the cooldown system, the recirculating water may be heated to provide adequate temperature control on the outside surface of the water barrier 18.

Although the most effective use of our invention is in gas storage chambers which are completely below ground level, the concepts of our invention are also effectively used when the storage tanks are not completely below ground level, as shown in the embodiments of FIGS. 4 and 5.

In the embodiment of FIG. 4, a gas storage chamber or tank 70 has its sides 14 below ground level, just as the tank 10 of the embodiment of FIG. 1. However, the roof 72 of the tank 70 is above ground level. The chamber is formed simply as a hole in the ground rather than by employing an adit which would advantageously be used in constructing the completely underground chamber of FIG. 1.

The water barrier 18 is secured to the roof 72 by suitable means, such as studs (not shown). The overhead pipe 46 is connected to the vent tube 42 and has laterally extending pipes 74 passing between the water barrier 18 and the roof 72 of the chamber 70. For greatest efficiency of our system the lateral pipes 74 are covered by insulation 76. Heat exchangers 50 are located only in the earth sides 14 of the chamber 70 and communicate with the lateral distribution pipes 74. The water outlet pipe 38 extends downwardly through the roof 72 and communicates with the overhead distribution pipe 62. The distribution pipe 62 distributes the water to the individual pipes 78 which direct water only to the sides 14 to be frozen by action of the cold gas passing through the annular heat exchanger 50.

The embodiment of FIG. 5 is similar to that of FIG. 4 except the roof 80 and at least a portion of the sides 82 of the storage chamber or tank 84 project above the ground. In this embodiment, the lateral distribution pipes pass between the water barrier 18 and the concrete roof 80 and between the water barrier 18 and the concrete sides of the roof 80. The lateral pipes communicate with the heat exchangers 50 embedded in the earth formation which defines the sides 82. Water distribution pipes 86 also direct water to the earth formation surrounding the chamber sides.

The structure of the embodiments of FIGS. 4 and 5 is substantially the same as that of FIG. 1, except for the upper portion of the storage chamber. All the described embodiments, however, use the described system for freezing the earth formation surrounding at least a portion of a storage tank for storing liquid gas.

By the use of our described system and method, the formation surrounding a chamber formed at least partially below the ground may be readily frozen in a highly effective, simple, and economical manner and in a relatively short period of time. The cold source required for freezing the water in the rock or soil formation around the chamber is supplied from the boiled off gas from the liquid stored in the chamber. Similarly, most of the water to be frozen in the formation surrounding the chamber is supplied from the water which is collected in the sump. It is to be understood that more or less water may be added to the recirculating water depending upon the desired quantity of water which is to be added through the distributors for soaking the rock and soil surrounding the chamber. It is thus seen, after the system has been constructed, that there is little if any expense involved in accomplishing the desired results. After the side or sides and top surrounding the chamber are frozen solid, the pumping system may be shut off since there is essentially no more water to create a problem in the area surrounding the chamber.

While in the foregoing, there has been provided a detailed description of particular embodiments of the present invention, it is to be understood that all equivalents obvious to those having skill in the art are to be included within the scope of the invention as claimed.

What we claim and desire to secure by Letters Patent is:

1. A system for freezing water, said system comprising a chamber storing liquid gas at cryogenic temperatures, a formation surrounding and exteriorly spaced of said chamber and containing water, water-barrier means intermediate at least the upper and side portions of said chamber and said formation, at least a portion of said liquid gas being boiled off to the gaseous state, means in the upper portion of said chamber for venting said boiled-off gas, heat exchanger means positioned in at least the sidewalls of said formation, and means directly interconnecting said heat exchanger means and said venting means for passing said boiled-off gas to said heat exchanger means for progressively freezing the water in the formation surrounding said heat exchanger means.

2. The system of claim 1 wherein said chamber includes a top and sides, said heat exchanger means comprises a plurality of heat exchangers in said formation adjacent said top and sides, and said interconnecting means comprises conduit means connecting said heat exchanger means in series.

3. The system of claim 1 wherein said vent means is interconnected to said interconnecting means at the central portion of said upper portion.

4. The system of claim 1 wherein said chamber includes a bottom portion, water-permeable means surrounding said chamber, and pump means are in communication with said water-permeable means for pumping water, which is not frozen at the heat exchanger means, upwardly from the bottom portion of said chamber.

5. The system of claim 4 wherein means are provided for distributing said pumped water at the central portion of the upper portion of said chamber for passage thereof over said water-barrier means for avoiding ice formation thereon.

6. The system of claim 1 wherein said heat exchanger means comprises series connected cylindrical members in said formation having an inner pipe passing cold boiled-off gas upwardly and an outer annual portion for passing the gas downwardly to an outlet portion.

7. The system of claim 1 wherein said formation is earth and said chamber is at least partially below ground level.

8. The system of claim 7 wherein said chamber has at least its sides below the ground, said heat exchanger means comprises a plurality of heat exchangers in the earth formation surrounding the sides below the ground and said interconnecting means comprises conduit means connecting said heat exchanger means in series.

9. The system of claim 7 wherein said chamber includes a bottom portion, water-permeable means surround said chamber, and pump means are in communication with said water-permeable means for pumping water, which is not frozen at the heat exchanger means, upwardly from the said bottom portion of said chamber.

10. A method for freezing water, said method comprising the steps of providing a chamber having a formation containing water spaced there around and being used for storing liquid gas at cryogenic temperatures, providing water-barrier means intermediate at least the upper and side portions of said

chamber and said formation, at least a portion of said gas being boiled off to the gaseous state, venting said boiled gas from the liquid gas in said chamber, distributing said boiled-off gas in a closed system to a plurality of heat exchanger means positioned in at least the sidewalls of said formation, and freezing the water surrounding said heat exchanger means in said formation with said boiled-off gas.

11. The method of claim 10 including the steps of first freezing the upper portion of said formation and then freezing the water at the sidewall heat exchanger means of said formation.

12. The method of claim 10 including the steps of collecting water from around said chamber, and pumping said collected water and distributing at least a portion of said water over said water-barrier means to avoid ice formation thereon.

13. The method of claim 10 wherein said formation is provided as an earth formation and said chamber is provided at least partially below ground level.

14. The method of claim 13 including the steps of providing water-barrier means around said chamber, collecting water from around said chamber, pumping said collected water and distributing at least a portion of said water over said water-barrier means to avoid ice formation thereon.

15. The method of claim 13 wherein the heat exchanger means at the upper portion of said formation are frozen before the water at the heat exchanger means surrounding the lower portion of said formation are frozen.