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2,932,170

REFRIGERATED UNDERGROUND STORAGE SYSTEM

Filed March 24, 1954

3 Sheets-Sheet 1

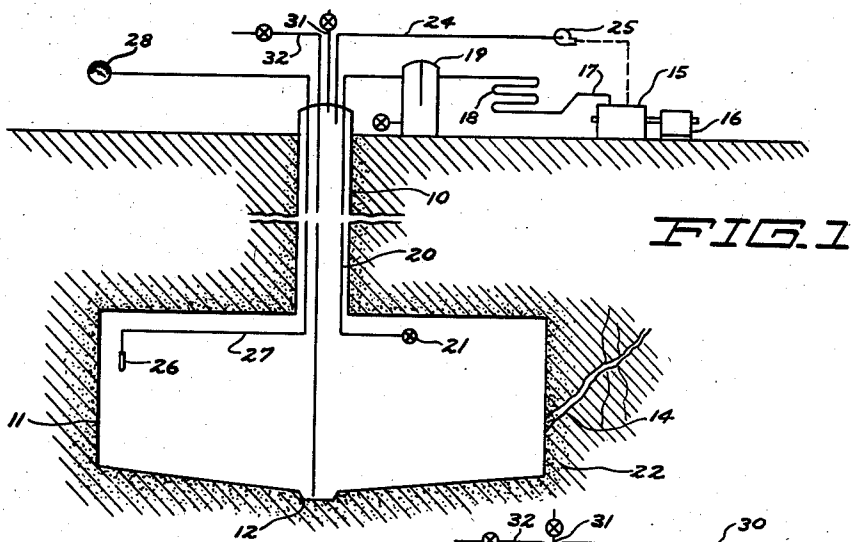


FIG. 1

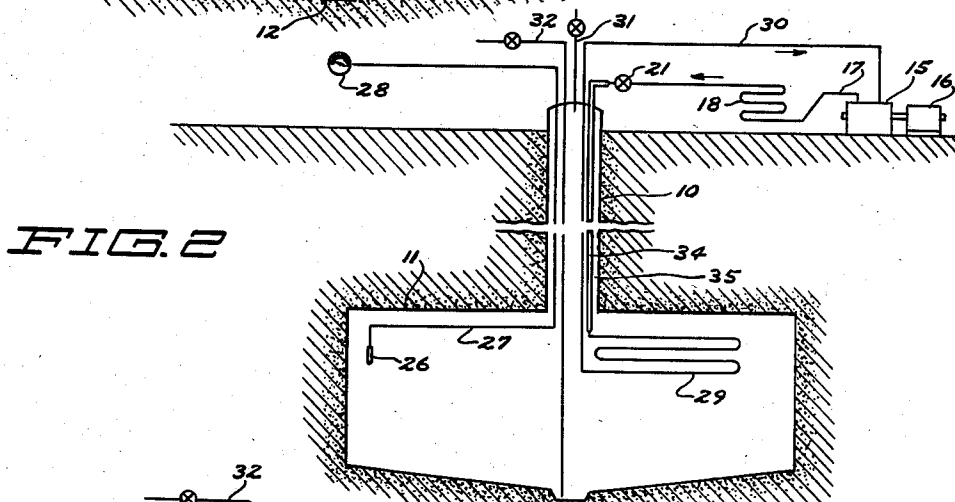


FIG. 2

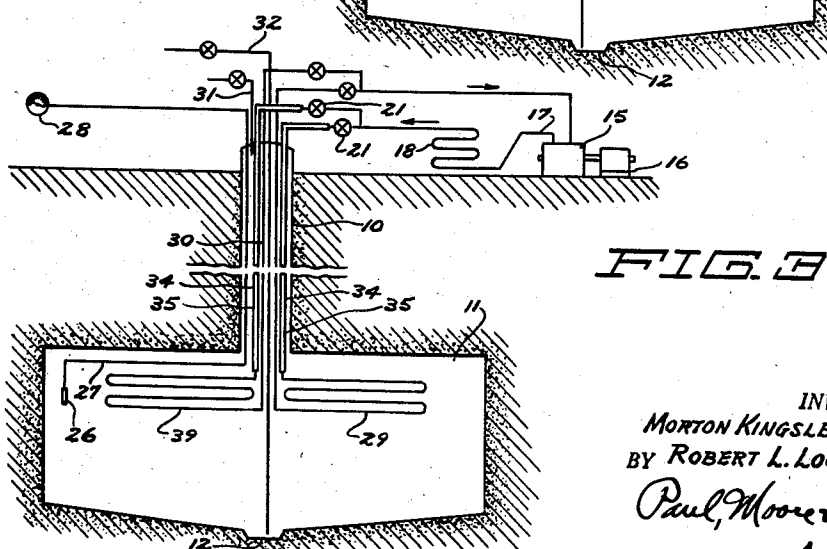


FIG. 3

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3 Sheets-Sheet 2

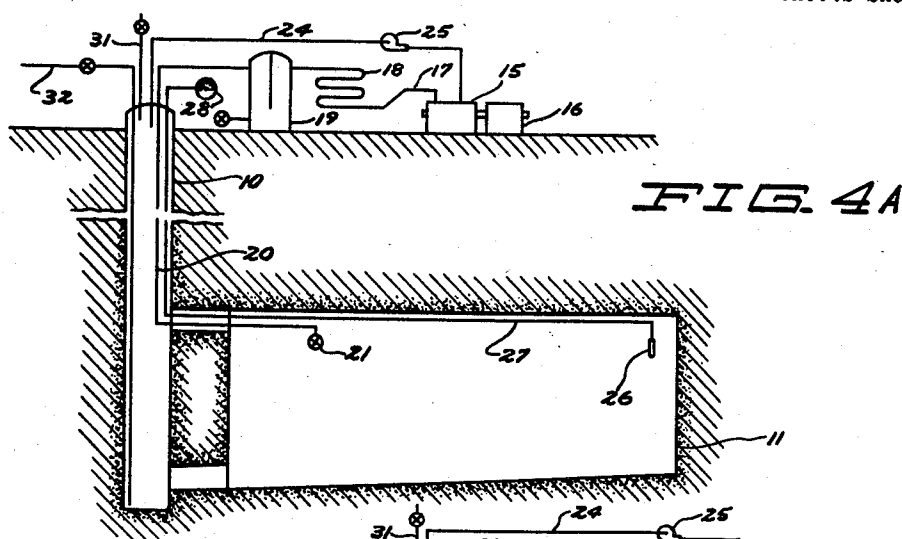


FIG. 4A

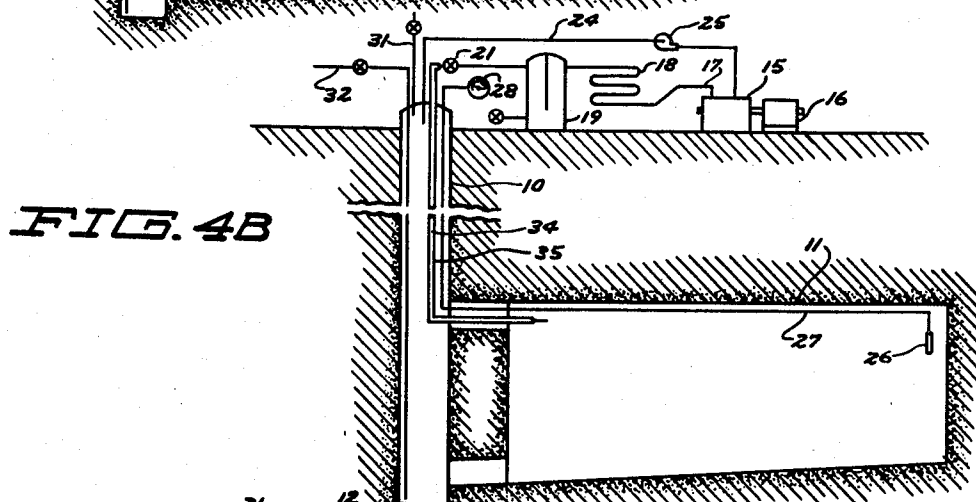


FIG. 4B

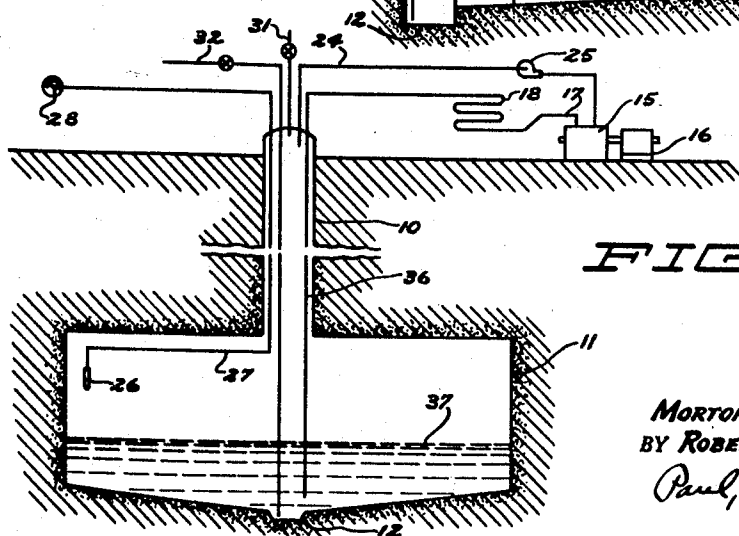


FIG. 5

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3 Sheets-Sheet 3

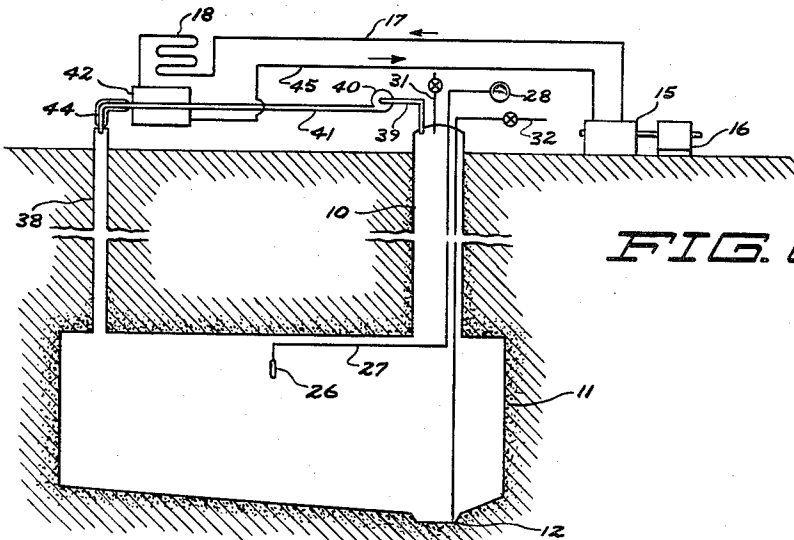


FIG. 6

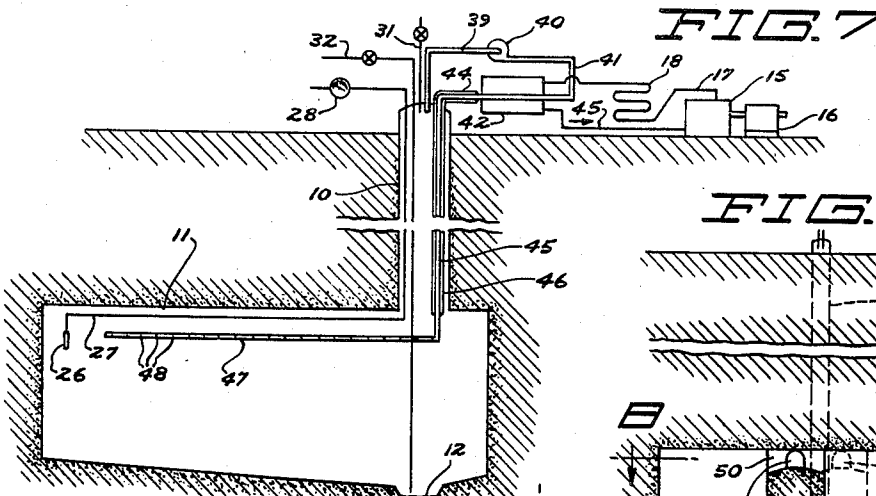


FIG. 7

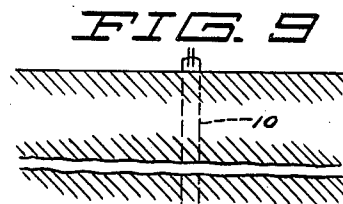


FIG. 9

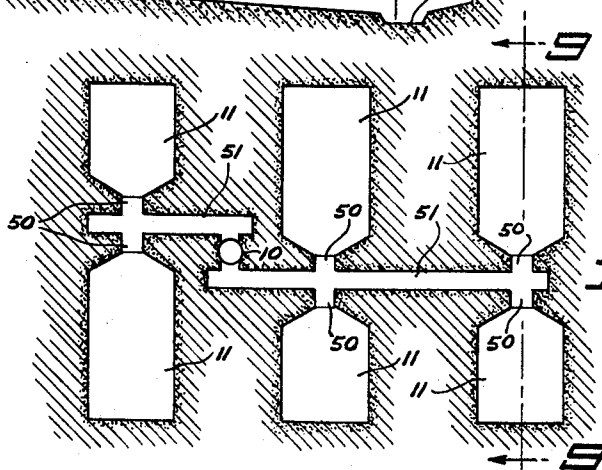


FIG. 8

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REFRIGERATED UNDERGROUND STORAGE SYSTEM

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Application March 24, 1954, Serial No. 418,388

8 Claims. (Cl. 61—5)

This invention relates to underground storage systems suitable for the storage of fluids, either gaseous or liquid, such as petroleum hydrocarbons, natural gas, ammonia, and the like. More particularly, this invention relates to refrigerating the walls of underground storage systems to maintain them sealed against leakage, either of the stored fluid out into the surrounding earth formations or of natural ground fluids into the storage vaults.

Constantly expanding demand and production of liquid or liquifiable petroleum products such as liquid propane, gasoline, fuel oils and the like, has created a definite problem in providing extensive and suitable storage facilities for such materials. Due to the high vapor pressure of liquified petroleum gas, particularly propane, butane, high volatile gasoline, and the like, the cost of storage in surface equipment, such as steel tanks, becomes excessive due to the pressure resistant construction required to withstand the pressure of the stored material in a safe manner. The problem becomes acute where it is necessary to store large quantities of such materials during the off season. In addition to the expense involved in the construction of massive surface tankage, there is an additional disadvantage arising out of necessity of maintenance to prevent rusting or corrosion and fire hazards. Likewise, evaporation losses may be high when petroleum products having fractions volatile at ordinary temperatures are stored in open or vented tanks.

In order to overcome these difficulties, it has been proposed to store liquid petroleum products in porous water bearing formations, in water leached caverns and salt formations, or in abandoned mines in impermeable shale or limestone formations.

It is desirable that underground storage of liquified petroleum or natural gas be located at or reasonably adjacent the place of consumption rather than the place of origin so as to relieve the peak loads on transportation and production equipment. However, due to the differing earth formations in different parts of the country, desirable locations for construction of underground storage chambers are not always present at terminals adjacent points of consumption of the products. The available sites for construction of underground vaults or chambers for the storage of gas liquid and liquifiable petroleum products may therefore be less than ideal in many locations.

Because the earth formations available for construction of underground storage systems may present less than ideal conditions a frequent problem encountered is one of leakage. The stored fluid may permeate the surrounding earth formation contaminating wells and streams and resulting in waste of the valuable fluid. Where the storage vault is in water bearing strata the seepage of water into the vault may gradually fill up the vault reducing its capacity and in many cases absorbing or reacting with the stored fluid. For example, the underground storage of anhydrous ammonia is impossible unless water may be excluded from the storage cell.

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It is the principal object of this invention to provide underground storage systems, the walls of which are sealed by being refrigerated.

Another object of this invention is to provide methods for refrigerating the walls of underground storage systems.

Other objects of the invention will become apparent as the description proceeds.

To the accomplishment of the foregoing and related ends, this invention then comprises the features hereinafter fully described and particularly pointed out in the claims, the following description setting forth in detail certain illustrative embodiments of the invention, these being indicative, however, of but a few of the various ways in which the principles of the invention may be employed.

The invention is illustrated by the illustrations wherein corresponding numerals refer to the same parts and in which:

Figure 1 is a simplified and diagrammatic sectional view of an open storage system for freezing the side walls of a storage cell using air as a refrigerant;

Figure 2 is a similar diagrammatic view of an open storage system for original freezing of the side walls and/or maintaining low temperatures in the storage cell in which the refrigerant may be different from the stored fluid;

Figure 3 is a diagrammatic view of a closed storage system, similar to Figure 2, for original freezing and/or maintaining low temperature in the storage cell in which the refrigerant may be different from the stored fluid;

Figures 4a and 4b are diagrammatic views of two forms of a closed storage system using air or a stored gaseous fluid as refrigerant for original freezing and/or maintenance of low temperature within the storage cell;

Figure 5 is a diagrammatic view of a closed storage system using a liquifiable storage product as refrigerant;

Figure 6 is a diagrammatic view of an open or closed storage system in which a surface refrigerating plant is used to cool circulating air or the stored product;

Figure 7 is an alternative form of open or closed storage system in which a surface refrigerating plant is used to cool circulating air or the stored product;

Figure 8 is a top plan view, in section, of a modified form of storage system for multiple storage chambers; and

Figure 9 is a vertical section taken along the line 9—9 and in the direction of the arrows of Figure 8.

Broadly stated, this invention comprises the utilization of the cooling effect that results when gases expand and liquids vaporize to freeze the walls of underground storage chambers for fluids and to maintain the walls at low temperatures for the purpose of sealing the storage chambers against leakage. The subterranean excavations are sealed by initially reducing the temperature with the chambers so that water in pores, fractures or other underground channels freezes, thus plugging those channels, and then maintaining the chamber walls permanently frozen. At the same time, in the case of gas storage, the volume of each unit of gas is reduced so that more units can be stored in each volume unit of excavation, with or without compression. In the case of excavation in saturated sand and weak rock refrigeration may be used as an aid in constructing storage systems by consolidating the weak earth formation.

The invention is particularly directed to excavated underground storage for methane, ethane, propane, butane, hexane, natural gas and anhydrous ammonia, but it is useful in sealing any subterranean excavation in which low temperatures can be tolerated and in which there are no agents or substances, capable at low tempera-

tures of preventing freezing or dissolving ice, in direct contact with the walls of the excavation.

Due to the high vapor pressure of liquified petroleum gas, particularly propane, butane, high volatile gasoline, and the like, storage in surface vessels has been excessively expensive and losses due to evaporation have been high. When propane or a similar product is stored in a refrigerated underground vault its vapor pressure is substantially reduced, materially reducing the storage problem. Liquification of natural gas, with its greatly increased storage-ability, is possible in a refrigeration storage system maintained at a sufficiently low temperature.

By the means of this invention all of the surfaces of a storage chamber or series of storage chambers may be sealed substantially uniformly without special and expensive preparation of the chamber surfaces and without the necessity of building stagings to gain access to all parts of these surfaces. This fact is particularly important since in order to excavate rock most efficiently it is desirable to make the chambers as large as possible and to work in such a manner that it is not necessary to re-enter the chambers after the excavation is complete. Thus, the serious hazards involved in getting back into large chambers may be avoided through this invention.

In addition a seal may be created which will not be broken by movement or other disturbance of the chamber surfaces after the chambers are charged with the stored product. Particularly in very large chambers occasional falls of loose rock may occur. In such an event, in chambers sealed by the method of this invention the walls are self-sealing. In the event of earth movement such as might be generated by an earthquake the possibility of underground storage systems opening up and discharging their stored products is minimized.

This invention contemplates the storage of products which are subject to deterioration due to the action of heat and/or light, such as, for example, fuel used in jet propelled aircraft. In addition to the storage of liquids the invention is useful for the storage of solid materials, such as grains, soybeans, seeds and the like.

Referring now to the drawings, and particularly to Figure 1, there is here shown a sectional view, in simplified and diagrammatic form; of an open system for originally freezing the walls of the storage chambers and maintaining low temperatures in the chambers if pressure is not required. The system comprises a shaft 10 from the surface of the earth leading to a subterranean vault or chamber 11. The chamber is preferably provided with a sump 12 at its bottom to collect the water which flows into the chamber through the walls. There is shown at 14 a representation of a fracture of the type through which a stored product might escape. The cooling system at the surface comprises a compressor 15 driven by a suitable motor 16. The compressed air from the compressor pump is conducted through a suitable conduit 17 to a condenser or cooling tower 18 and thence through a moisture trap 19, and, by means of conduit 20, down through the shaft 10 to the storage chamber 11. The end of conduit 20 is provided with a suitable expansion valve 21. The cooling effect of the expanding air as it leaves conduit 20 through valve 21 lowers the temperature of the air within the storage chambers and the temperature of the surrounding walls. The cooling system is operated continuously to lower the temperature of the walls of the storage chambers until the moisture present in the wall freezes and thereafter to maintain the walls frozen. The chambers are preferably maintained at a temperature below 20° F. However, in some cases in which a gaseous product is to be maintained liquified the temperature may be much lower. For example, methane may be maintained in liquid state at -116.5° F. under a pressure of 45.8 atmospheres. The ice present at the wall surfaces and extending for some distance into the surrounding formation (as shown at

22) effectively seals the system against loss of the stored product by leakage through the walls. For most efficient operation the cold air exhausting from the access shaft is recirculated, as through duct 24 and blower 25, to the compressor 15. A plurality of thermocouples 26 or other temperature detecting means are disposed with the storage chamber and connected by means of cables 27 to a gauge or meter 28 at the surface.

In referring to this system, and throughout the specification, the term "open" is used to designate a system which is maintained at atmospheric pressure and which is therefore readily accessible for inspection, pumping, valve adjustment and the like. A system which is intended ultimately to be "closed," that is, maintained under pressure and accessible only in rare emergency situations, may initially be cooled by means of an open system and later changed to one of the closed systems to be described. The use of air as the refrigerant is advantageous during the construction and original freezing of the storage chambers since it permits of ready access by workmen without danger of exposure to noxious fumes.

The storage chambers may consist of single cells as illustrated but in most instances will be made up of a multiplicity of chambers communicating through appropriate drifts and tunnels (as will be described in connection with Figures 8 and 9) with a common shaft. Instead of being located beneath the surface of the ground, as illustrated, the storage chambers may be excavated in a hill or mountain, in which event the access shaft 10 will be replaced by a tunnel. If the chamber elevation is above ground water level, water may be introduced into the chamber walls by flooding the chambers just before freezing and then pumping out the water after a thin shell of ice has formed, by spraying water onto the walls as they are freezing, by introducing water into the ground formations adjacent the walls through small holes drilled from the surface or from separate under ground openings or other like methods which will result in the formation of a sealing barrier of ice surrounding the storage chamber.

The access shaft or tunnel may be sealed with a liner of thickness appropriate to the pressure of the chamber. This liner will usually be a steel conduit set in concrete, or concrete and grout, with a manhole for access at the surface and a capping with piping for input and output of product and refrigerant, provision for pumps, gauges, vents, drains, thermocouple cables, thermometers and the like. Alternatively, the shaft or tunnel may be back-filled for a substantial depth with concrete in which the required pipes and cables are set or it may be bulkheaded at some depth with concrete and then left open or back-filled with sand. These methods of closing off a shaft or a tunnel are well known in the art and, except for whatever additional passages that may be required for the added accouterments of the refrigerating systems, form no part of this invention.

Referring now to Figure 2, there is here shown an open refrigerated storage system in which the refrigerant may be different from the stored product. In this system the refrigeration plant itself is a closed system such as encountered in a conventional cooling or cold storage plant and the refrigerant is at all times out of direct contact with the stored product. Thus, ammonia may be used as a coolant for stored methane, or "Freon" refrigerants may be used for propane storage, or the like. In this system there is a compressor 15 driven by a suitable motor 16. The compressed coolant passes through a conduit 17 to a cooling tower 18 and thence through conduit 20 down the shaft to the expansion valve 21 located in the storage cell. The compressed gas from expansion valve 21 expands into an evaporator coil 29 disposed about the walls of the storage cell 11. The refrigerant is returned from coil 29 through a conduit 30 to the compressor 15 and recirculated. A product input pipe 31 and product outlet 32 are provided addi-

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tionally. These pipes may be used interchangeably depending upon the densities of the stored products.

In Figure 3 there is shown a closed system corresponding generally to the open system shown in Figure 2. The cooling system of Figure 3 comprises the motor driven compressor 15, conduit 17 and condenser 18. Expansion valve 21, however, is located at the surface for easy access for adjustment and repair if necessary. The evaporator coil 29 is joined to the discharge of the expansion valve by means of conduit 34. Because conduit 34 is a cold pipe it is preferably insulated at 35 for the length of its descent through shaft 10 in order to minimize cold loss in the shaft. A plurality of thermocouples 26 are spaced about the chamber 11 to measure freezing progress. As a precautionary measure in this closed system an auxiliary evaporating coil 39 valved at the surface and accessory piping may be provided to insure maintenance of low temperatures in the storage cell in the event of breakdown of the first.

In this, as in other closed systems water inflow may be reduced and initial freezing assisted by maintaining the chamber pressure equal to the ground water pressure.

The closed storage system of Figure 3 may initially be operated as an open system during construction and original freezing of the chamber walls. In this event and in the case of the system of Figure 2 safe access is afforded workmen during construction and initial freezing without danger from the stored product.

The systems shown in Figures 2 and 3 are adaptable to the storage of solid materials, such as grains. When so used the evaporator coils 29 are preferably disposed not only around the wall surfaces of the chamber but through the center of the chamber as well. The floor surface in this instance is preferably tapered downwardly so that the solid material will fall by gravity to a central depression from which it can be elevated to the surface. The solid material is preferably cooled somewhat before introduction into the storage system.

Alternatively, the stored solid products may be cooled by circulating cooling gases in direct contact with the solids. In this instance gas permeable retaining bulkheads are erected, spaced apart from the floor and walls of the storage vaults and from each other to provide a system of ducts through which the cooling gas may be circulated and returned to the surface for recooling and recirculation.

In Figures 4a and 4b there are shown two forms of a closed system in which air, methane or other stored gas may be used as the refrigerant both for the original freezing of the storage chamber walls and to maintain the low temperatures. In most instances this system will be utilized during product storage after the system of Figure 1 has been used in the construction and original freezing of the walls. Although showing an alternative shaft location, essentially this system differs from that shown in Figure 1 only in that the storage cell is maintained under pressure. Increased power efficiency (while at the same time decreasing bulk of stored gas) may be obtained by pressuring the storage chamber. In this system the expansion valve 21 may discharge into the storage chamber 11 at the end of conduit 20, as in Figure 4a, or it may alternatively be located at the surface discharging into conduit 34 which is insulated at 35 to prevent cold loss, as shown in Figure 4b.

Figure 5 illustrates a closed storage system in which the product to be stored is liquifiable, such as butane, propane, ethane, ammonia or the like, and is used as the refrigerant for the original freezing and/or maintaining the low temperature. In this system the product is compressed in the compressor 15, circulated through the cooling tower 18 through conduit 36 to pool 37 of the liquified stored product at the bottom of storage cell 11 which is maintained at low temperature. This low temperature is maintained by the cooling effect of the evaporating product passing from the liquid to the vapor state. The vapors

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are returned from the dome of the shaft through duct 24 to the compressor 15 and reliquified and recirculated.

The system shown in Figures 6 and 7 includes a refrigerating plant using any convenient refrigerant located entirely upon the surface to cool air or the stored product which is then circulated to cool the subterranean storage chambers. In this system there are preferably used two shafts or a shaft and a well of diameter sufficient to pass the required fluid volume. Although somewhat less efficient, a single shaft containing an insulated cooled gas input conduit of sufficient size to pass the required fluid volume, as shown in Figure 7, can be used. In the illustrated form, using one shaft 10 and a cased well 38, the well serves as an input conduit for the cooled gaseous product and shaft 10 as a return. The dome of shaft 10 is tapped by a duct 39 to a circulating pump 40. Pump 40 discharges into a conduit 41 to a heat exchanger 42 and thence to a conduit 44 returning to the storage cell through well 38. The refrigerant in the cooling plant at the surface is compressed by the compressor 15, passed through condenser 18 and thence to heat exchanger 42 and back through pipe 45 to the compressor. The circulating gas from the storage cell 11 is cooled in passing in heat exchanging relation with the cold refrigerant and in turn cools the storage chamber walls and maintains them cold.

The modified form of this system shown in Figure 7 utilizes a single shaft and a return conduit in the shaft. The dome of shaft 10 is tapped by duct 39 to circulating pump 40. The pump 40 discharges to pipe 41 to the heat exchanger 42 and thence through a pipe 44 to return conduit 45 which returns the cooled gas to the storage cell 11. Conduit 45 is insulated at 46 to concentrate cooling in the storage chambers. If desired, return conduit 45 may be provided with an extension pipe 47 having perforations 48 to distribute the cold fluid through the storage cells.

In Figures 8 and 9 there is shown a typical installation of the system of this invention in a multiple chamber storage unit. In this system the storage unit comprises a plurality of storage cells 11, each communicating through upper entries 50 with an upper tunnel 51 and through lower entries 52 with a lower tunnel 54. Tunnels 51 and 54 are in direct communication with shaft 10. The floors of the storage cells 11 and lower entries 52 preferably slope toward the lower tunnel 54 which in turn preferably slopes toward the sump 12 at the bottom of the shaft 10. In adapting such a multiple cell unit to the cooling system of Figure 7, the insulated return conduits 45 are passed down through shaft 10 and upper tunnels 51 and extensions 47 are provided extending through upper entries 50 into the individual storage vaults. Each storage cell may be cooled through its own individual return conduit or a single cooling return conduit may have branch extensions serving two or more chambers. Thermocouples or other measuring devices are strategically located in each chamber and suitable valve means are provided for distributing the cold fluid as appropriate for the conditions indicated. The stored product is drawn through the lower entries 52 and lower tunnel 54 and up shaft 10 for recirculation through the heat exchanger and return to the storage vaults.

The construction and arrangement of the storage cells and associated shafts, entries, tunnels and the like do not per se form any part of this invention. One form of such construction and arrangement is disclosed and claimed in a co-pending joint application of one of the instant inventors in Serial No. 401,835, filed January 4, 1954, for Underground Storage System by Robert L. Loofbourov and Harold A. Kramer, now abandoned.

Although air is relatively inefficient as a refrigerating fluid, it is often advantageous to use it during construction and for initial cooling of the storage system according to the open system of Figure 1 since the chamber remains readily accessible to workmen. Air introduced

into this system at the rate of 380 pounds per minute compressed to seven atmospheres pressure, conducted to the storage area and expanded to atmospheric pressure is capable of removing about one million B.t.u.'s per hour from the storage system. The total cooling necessary to reduce the entire storage area to a low temperature in the desired range between about plus 20° F. and minus 10° F. will depend, of course, upon a wide variety of circumstances; such as, initial ground temperature, magnitude of the storage system, and the like. It is to be understood, however, that any temperature below that at which the ground water freezes may be used and is contemplated within this invention.

In the systems of Figures 2, 3 and 5 about one million B.t.u.'s per hour can be removed from the system using propane as the refrigerant by maintaining the cooling system under about 2.9 atmospheres pressure, introducing propane to the compressor at the rate of about 170 pounds per minute, compressing it to about 10.5 atmospheres and then permitting it to re-expand to the pressure of the system.

In a system such as that of Figures 4a and 4b maintained under high pressure of the order of 54 atmospheres cooling may be effected at the rate of about one million B.t.u.'s per hour by compressing air at the rate of 2200 pounds per minute to about 82 atmospheres and then expanding to the pressure of the system. About the same cooling effect is obtained by similarly compressing and expanding natural gas or methane at the rate of about 850 pounds per minute. The efficiency of power is increased and the bulk of the circulating fluid decreased by pressuring the entire storage system as in Figures 4a and 4b.

As many apparently widely differing embodiments of this invention may be made without departing from the spirit and scope thereof, it is to be understood that we do not limit ourselves to the specific embodiments disclosed herein.

What we claim is:

1. A method of sealing the walls of an underground storage system for fluid products against leakage of the stored fluid which comprises continuously circulating a cooling fluid adjacent to the walls of the storage system to freeze the ground water therein and seal the storage system against leakage of the stored fluid and thereafter continuously recirculating the cooling fluid to maintain the walls frozen, said cooling fluid being circulated through a conduit system so that no contact between the cooling fluid and stored product may be had.

2. The method according to claim 1 further characterized in that the cooling fluid circulated adjacent to the walls of the storage system is a compressible fluid and the walls are cooled by compressing the compressible fluid at the earth's surface and circulating that fluid for expansion into the storage system in a coil system adjacent to the walls of the storage system but out of communication therewith so that no contact between the cooling fluid and stored product may be had, whereby the cooling effect of the expanding fluid lowers the temperature of the earth formation adjacent the walls of the storage system freezing the ground water therein and sealing the storage system against leakage.

3. The method according to claim 2 further characterized in that the compressible fluid is selected from the group consisting of air and fluid storage products.

4. An underground storage system for fluid products comprising a subterranean storage chamber, an access channel communicating from said storage chamber to the earth's surface, means in said access channel for introducing and withdrawing the stored product, means sealing the access channel from escape of stored product therethrough, gas compression means on the surface adjacent to the mouth of said access channel, an evaporator coil disposed adjacent to the walls of said storage chamber, said coil being in communication with said compression means, and gas expansion means disposed between said compression means and coil, the subterranean storage chamber being substantially completely surrounded by frozen earth formation whereby the ground water in said formation is present as ice effectively sealing the walls of the chamber against leakage of the stored product.

5. An underground storage system according to claim 4 further characterized in that said storage chamber comprises a plurality of interconnected storage cells, each of which is provided with an evaporator coil disposed adjacent to the walls of the storage cells.

6. A method of sealing the walls of an underground cavity which comprises cooling the walls of said cavity by compressing air at the earth's surface and circulating that compressed air for expansion into the underground cavity whereby the cooling effect of the expanding compressed air lowers the temperature of the earth formation adjacent the walls of the cavity, freezing the ground water therein, and sealing the cavity against leakage, and thereafter continuously repeating the process to maintain the walls frozen.

7. A method of sealing the walls of an underground cavity which comprises cooling the walls of said cavity to freeze the ground water therein and seal the cavity against leakage by circulating a cooled fluid in contact with the wall of said cavity, said cooled fluid being the fluid normally contained within said cavity cooled by withdrawing said fluid from the underground cavity to the earth's surface and passing said withdrawn fluid in heat-exchanging flow with the cooling coil of an independent external refrigeration plant and then reinjected into said cavity.

8. A method according to claim 7 further characterized in that said cooled fluid is air.

References Cited in the file of this patent

UNITED STATES PATENTS

711,012	SooySmith	Oct. 14, 1902
1,342,781	Vedder	June 8, 1920
1,938,205	Yeomans	Dec. 5, 1933
2,550,886	Thompson	May 1, 1951
2,645,093	Daxelhofer	July 14, 1953
2,659,209	Phelps	Nov. 17, 1953
2,713,775	Cottle	July 26, 1955
2,796,739	Meade	June 25, 1957

FOREIGN PATENTS

322,136	Germany	June 17, 1920
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