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STORAGE OF VOLATILE LIQUIDS

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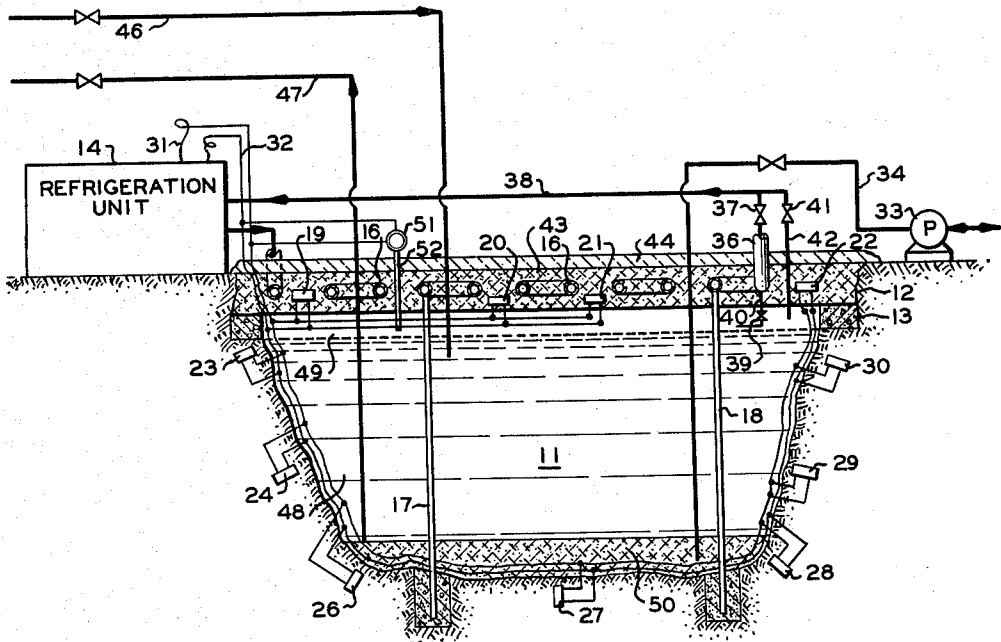


FIG. 1

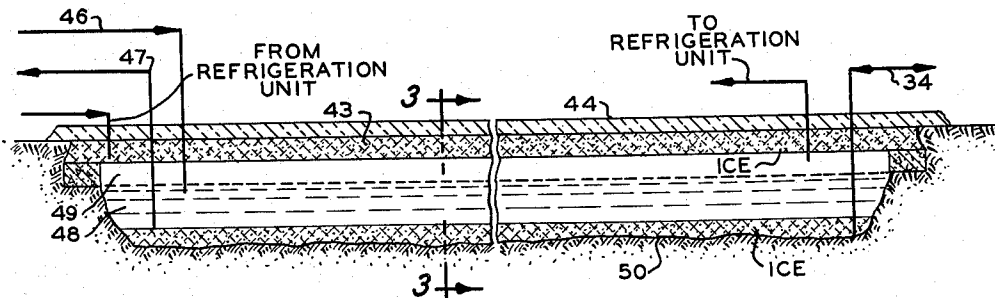


FIG. 2

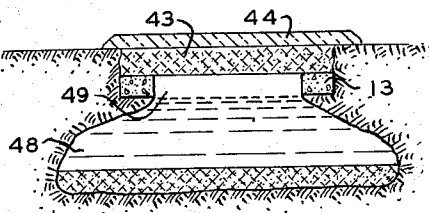


FIG. 3

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STORAGE OF VOLATILE LIQUIDS

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This invention relates to a method of storing volatile liquids. In another aspect it relates to a method of preparing a reservoir for the storage of volatile liquids. In still another aspect this invention relates to a surface earthen storage reservoir made suitable for the storage of volatile liquids therein.

Volatile liquids which are produced in large quantities present a major storage problem. Products such as propane, butane and liquid ammonia require enormous storage facilities during seasons of slack use. In an effort to avoid the expense of metal pressure containers, products of this type have been stored in underground formations provided by mining or dissolving a cavity in a soluble strata. While underground storage of this type has proved quite satisfactory in many instances, a suitable formation is not always readily available at the most convenient storage site. In the storage of other types of products which are less volatile, for example fuel oil, massive storage facilities are provided in open pits or reservoirs, such as abandoned quarries, and equipped with a float roof. This type of storage, however, has not been practicable for volatile products which develop high vapor pressures at ambient temperatures.

According to my invention a method of storing volatile products in surface reservoirs is provided. Volatile liquids are retained in open topped reservoirs by sealing the top opening of said reservoir with an ice cap, and after introducing the volatile liquid into the reservoir, maintaining the temperature of the liquid sufficiently low that its vapor pressure does not exceed that pressure which the ice cap can withstand. Such a storage facility can be provided at a great savings in expense over metal pressure vessels and can be maintained for long periods of time at nominal expense. A method by which I prefer to provide such a storage facility is to use an open pit in the surface of the earth acquired either by excavating or by using an already existing pit, such as an abandoned quarry, and to span the top opening of this pit with a heat exchange conduit. After the refrigeration equipment is in place, the pit is filled with water and an ice cap is formed by freezing a layer of ice on the surface of the water, thus sealing the opening of the pit. The ice cap thus formed is supported by the heat exchange conduits and auxiliary structure and the water is then removed from the pit, leaving an enclosed cavity to receive the volatile product intended for storage therein. The reservoir is then filled with volatile product, such as isobutane or butane. The ice cap is refrigerated to keep it from melting and the product is cooled so that its vapor pressure will not rupture the ice cap. As a method of cooling the ice cap I prefer to use the vapor of the product as the refrigerant and to cool the product by autorefrigeration.

It is an object of my invention to provide a surface storage facility for volatile liquids. It is another object to provide a method of storing volatile liquids in surface pits or earthen reservoirs that can readily be constructed.

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Still another object of my invention is to provide such a surface, earthen storage system for the storage of volatile liquids. It is another object of my invention to provide a method of employing vapors of a volatile stored liquid in a refrigeration cycle to seal the storage reservoir. A still further object is to provide a method of forming a reservoir having an ice cap for a roof. Other objects, advantages and features of my invention will be apparent to those skilled in the art from the following description, appendant claims and drawings in which:

Figure 1 is a view in cross section of an earthen pit employing an ice cap for a cover according to my invention;

Figure 2 is a view in cross section of a preferred type of earthen pit; and

Figure 3 is a sectional view of Figure 2 along line 3—3.

While my invention is especially important in storing volatile liquids, such as liquefied ammonia and liquefied petroleum gases, which must normally be stored under pressure, it can also be applied to the storage of any fluid having a freezing point below that of water. Liquids for which the storage system of my invention is particularly well adapted include liquefied butane and isobutane.

An advantage of the system of my invention is that it can be constructed in almost any locality without regard to the underlying formations. Open pits can be used or ponds can be drained. Abandoned quarries are also suitable. If possible, it is desirable to locate the reservoir in an impervious surface formation, such as shale or clay. If, however, such a formation is not available, a relatively cheap lining can be provided, such as polyethylene film, a thin wall of concrete, or rubber sheet, depending upon the type of product to be stored in the reservoir. Because of the inert character of polyethylene and its resistance to various solvents, I prefer to employ polyethylene film as a liner in situations where such protection is required.

Another solution to the problem of providing fluid-tight walls for the reservoir is to form the pit in a permeable water bearing formation below the water table so that water tends to seep into the pit. In such an application, as the product is cooled to lower its vapor pressure the water in the walls of the pit becomes frozen and thereby provides an impervious barrier to contain the product. Such an approach to the problem of providing an impervious wall in an underground storage facility is disclosed and claimed in Patent No. 2,796,739, issued June 25, 1957, to L. P. Meade and G. F. Downs, Jr.

The refrigeration equipment which is employed for my invention is of a type well known in the art, having as basic components compressors, condensers, a power source, and pumps for moving the fluid through the system. Refrigeration conduit is supported across the opening of the reservoir so that refrigerant can be circulated therethrough to freeze the surrounding water. The preferred method of forming the ice cap around the refrigeration conduit is to fill the pit with water so that the coils are covered by about half the thickness of the desired ice cap. A suitable heat exchange medium is circulated through the coils until the water surrounding the conduits spanning the pit becomes frozen. The thickness of the ice cap can vary considerably, for example, from an inch or less to several feet. The exact thickness of the ice cap is not critical; however, it should be sufficiently thick that its continuity can be maintained. For the storage of ammonia, it is desirable to increase the thickness of the ice cap in order to gain additional strength in the roof and thereby permit higher vapor pressures in the reservoir. For butane storage an ice cap of about 6 inches to 2 feet thick is satisfactory.

After the ice cap has been formed the water is removed

from the reservoir and a layer of insulating material is placed over the ice cap to protect it from damage from the weather and to aid in keeping the surface of the ice from melting. Any suitable type of insulating material, such as sawdust, cork, rock wool, or the like can be used. It is also desirable to provide a continuous covering over the surface of the insulation to protect the ice cap from rain. A suitable protective covering is a layer of sawdust several inches thick over the surface of the ice and a film of polyethylene covering the sawdust layer. Aluminum foil can also be used to advantage to reflect sunlight. The water-tight covering thus formed over the ice cap should be shaped to drain properly.

The structural strength of the roof thus provided lies primarily in the heat exchange conduit and its accompanying structural members. Since the heat exchange coils lie within the ice cap they serve to reinforce it and give the roof considerable strength. The ice itself then serves to provide a continuous covering sealing the top of the reservoir, preventing the escape of volatile liquid to the atmosphere and protecting the stored product from contamination. To further describe the advantages of my invention, reference is now made to the accompanying drawings.

In Figure 1, an open pit or reservoir 11 is shown containing a stored volatile product. The upper edge 12 of reservoir 11 is shaped to provide support for the heat exchange conduits. A concrete slab 13 is formed on the upper edge to aid in supporting the ice cap and prevent caving of the earthen ledge. Refrigeration unit 14 contains the necessary compressors, condensers, pumps and motors and provides the cooling capacity required to circulate a refrigerant through conduit 16 shown spanning the top opening of pit 11. Heat exchange conduit 16 is supported from the floor of the reservoir by support members 17 and 18. Temperature sensing elements 19, 20, 21 and 22 are positioned to lie in the ice cap and thereby enable automatic control of the refrigeration unit to maintain the ice cap at freezing temperatures. In addition, temperature sensitive elements 23, 24, 26, 27, 28, 29 and 30 are spaced in the walls of the reservoir and enable operation of the refrigeration unit to maintain the temperature of said walls below 32° F. In this manner an impervious ice barrier is provided within the walls and floor of the storage reservoir. Such temperature sensitive elements and a control system of this type is shown and explained in detail in the above-mentioned Patent No. 2,796,739, issued to Meade and Downs.

Temperature sensitive elements in the walls of the reservoir and in the ice cap communicate to refrigeration unit 14 through leads 31 and 32. It is desirable to keep the temperature of the ice cap and the walls of the surrounding water bearing formation below about 30 to 31° F. Any elevation in temperature starts the refrigeration unit and thus keeps the ice from melting.

To form the ice cap, water is pumped into the reservoir by pump 33 through conduit 34. After the ice cap has been formed the water is removed by reversing pump 33 or by displacement with the hydrocarbon to be stored in the pit. During the formation of the ice cap refrigerant is circulated through cooling conduit 16 and returned through line 36, valve 37 and return line 38 to the refrigeration unit where it is compressed and condensed in a refrigeration cycle and recirculated through conduit 16. After water has been removed from the reservoir and volatile product stored therein, it is desirable to employ the vapors of the volatile product as the refrigerant. In this case valve 37 is closed and valve 39 in line 40 opened so that refrigerant from coil 16 is passed into the vapor space of the reservoir. Valve 41 in line 42 is opened and vapors from the reservoir pass through line 38 to the refrigeration unit. In this way the reservoir with its stored product becomes a part of the refrigeration system and the product is cooled by autorefrigeration. Ice cap 43 is protected with an insulating layer

44 which, as has been explained previously, can be any insulating material or combination of materials, such as sawdust covered with a film of polyethylene. Product is introduced into the reservoir through line 46 and removed through line 47 as needed. The reservoir in use contains a body of volatile fluid 48 with a vapor space 49 between the liquid and the ice cap. Any water leaking into the reservoir becomes frozen and forms a lower layer 50 which provides an impervious bottom in the reservoir.

To protect the ice cap from possible rupture due to high vapor pressure of the stored product, pressure sensitive element 51 communicates with the vapor space 49 through tube 52. An increase in pressure in the reservoir beyond a predetermined limit fixed to protect the ice cap produces an output which is transmitted to refrigeration unit 14 through leads 31 and 32. Thus the refrigeration unit is operated to maintain the pressure of the reservoir at a safe value by cooling the stored product. For example, when storing butane, the pressure can be maintained at atmospheric which in turn will keep the butane slightly below 32° F.

Other means can be provided to refrigerate the system although autorefrigeration is the most economical. Additional cooling coils can be provided in the reservoir itself as well as in the ice cap and a heat exchange medium, such as brine, circulated through the coils to remove heat from the system. In this manner the refrigeration unit can be independent of the material being stored in the reservoir.

For economy of construction both in forming the earthen pit and in placing the heat exchange conduit spanning the upper opening thereof, I prefer to employ an elongated trench as shown in Figures 2 and 3. In these figures reference numerals correspond to those used in Figure 1 showing the volatile product 48, the vapor space 49, the ice cap 43 and the layer of insulation 44 with a layer of ice 50 in the bottom of the trench. Water is both introduced and removed through line 34 when forming the ice cap, and hydrocarbon is introduced through line 46 and removed from the trench through line 47. The refrigeration cycle is the same as that described in connection with Figure 1, vapors being withdrawn from the vapor space of the reservoir and passed through a refrigeration cycle. Liquefied vapors are permitted to pass through the heat exchange conduit in the ice cap and evaporate, thus removing heat from the ice cap and keeping the temperature thereof below 32° F. As shown in Figure 3, a preferred construction of the trench permits a wider average width than the width of the ice cap sealing the upper opening. A long but relatively shallow trench is easily and cheaply constructed. By narrowing the upper opening, the amount of auxiliary support required for the heat exchange conduit and ice cap is reduced.

To give added strength to the ice cap and increase the efficiency of the insulating layer, a layer of sawdust is floated on the water filling the reservoir while the ice cap is being formed. By agitating the surface of the water, it is possible to incorporate some of the sawdust into the ice layer. The frozen mixture of ice and sawdust is quite strong and forms an excellent insulating layer for the upper surface of the ice cap.

Advantages of this invention are illustrated by the following example. The specific dimensions and conditions are presented as being typical, and this example should not be construed to limit the invention unduly.

An earthen trench 400 feet long and 15 feet deep with an average width of 50 feet is excavated to provide a storage capacity of approximately 55,000 barrels. The walls of the trench are excavated in a concave fashion so that the upper opening is only 40 feet in width. Heat exchange conduit is supported across the opening of the trench and the reservoir is filled with water. An ice cap 400 feet long by 40 feet wide by 6 inches thick is formed by refrigerating the surface of the water filling the trench.

The formation of the ice cap is completed in two days with a 150 horsepower refrigeration unit. After the ice cap is formed, a 3 inch layer of sawdust is placed over the surface thereof and the surface of the sawdust is protected with polyethylene film 6 mils in thickness. The water is then pumped from the trench and replaced with butane refrigerated to a temperature of approximately 32° F. The pressure in the reservoir is maintained at 14.5 pounds per square inch absolute and the ice cap and butane at 31° F. As the surrounding earth becomes cooled by contact with the refrigerated butane, heat transferred from the earth progressively decreases. After operating for several days, substantial equilibrium is reached and the entire system is refrigerated with a 20 horsepower unit.

Storage system of my invention is relatively cheap to install and can be maintained at low expense. Since the investment is low and the equipment utilized of the nature which can be readily dismantled and moved to a new location, the storage system described is excellent for temporary large capacity storage of volatile liquids.

As will be evident to those skilled in the art, various modifications of this invention can be made or followed in the light of the foregoing disclosure and discussion without departing from the spirit or scope thereof.

I claim:

1. An earthen storage system for normally gaseous hydrocarbon liquids comprising, in combination, an earthen reservoir having a top opening, refrigeration conduit spanning said opening, an ice cap surrounding said conduit sealing said opening, said conduit both refrigerating and supporting said ice cap, protective insulating material covering the upper surface of said ice cap, a refrigeration plant equipped to receive, compress, and condense vapors from said reservoir and expand same through said conduit in a refrigeration cycle, said conduit terminating in said reservoir, and means for sensing ice cap temperature and reservoir pressure and operating said refrigeration plant to maintain said temperature and pressure below predetermined limits.

2. A system according to claim 1 wherein said reservoir contains an impermeable liner.

3. A system according to claim 1 wherein said protective insulating material comprises sawdust, at least a portion of which is integral with said ice cap.

4. An earthen storage system for normally gaseous hydrocarbon liquids comprising, in combination, a trench in a permeable water-bearing surface formation, said trench having a top opening, refrigeration conduit spanning said opening along the length of said trench, a layer of ice surrounding said conduit and refrigerated and supported by said conduit sealing said opening, a protective covering of insulating material over the upper surface of said layer of ice, a refrigeration plant, means for withdrawing vapor from said trench to thereby cool volatile hydrocarbon stored therein by autorefrigeration, means for passing said vapor through said refrigeration plant and returning same to said trench through said conduit to thereby cool said ice layer, temperature sensitive elements positioned in said ice layer and in said formation adjacent said trench, a pressure sensitive element in said trench just below said ice layer, and an electrical circuit in combination with said sensitive elements and refrigeration plant whereby refrigeration can be commenced to maintain said ice layer and water adjacent said trench in said formation frozen and the pressure in said trench below a predetermined value.

5. An earthen storage system for normally gaseous hydrocarbon liquids comprising, in combination, an earthen reservoir in a permeable water-bearing surface formation having a top opening, refrigeration conduits spanning said opening, a layer of ice surrounding said conduit and refrigerated and supported by said conduit sealing said opening, a protective covering of insulating material over the upper surface of said layer of ice, a refrigeration plant, means for withdrawing vapor from said reservoir to thereby cool volatile hydrocarbon stored therein by autorefrigeration, means for passing said vapor through said refrigeration plant and returning same to said reservoir through said conduit to thereby cool said ice layer, temperature sensitive elements positioned in said ice layer and in said formation adjacent to said reservoir, a pressure sensitive element in said reservoir just below said ice layer, and an electrical circuit in combination with said sensitive elements and refrigeration plant whereby refrigeration is supplied to maintain said ice layer and water adjacent said reservoir and in said formation frozen and the pressure in said reservoir below a predetermined value.

6. An earthen storage system for a normally gaseous liquid comprising an open-topped earthen reservoir; refrigeration conduit means spanning the opening of said reservoir; an ice cap surrounding said refrigeration conduit means to seal said opening, conduit means for introducing a normally gaseous liquid into said reservoir thus sealed; a refrigeration plant equipped to receive, compress and condense vapors; conduit means for withdrawing vapors of liquid from said reservoir and directing same to said refrigeration plant; and means for expanding the returning condensed vapors to said refrigeration conduit means to said reservoir.

7. An earthen storage system for a normally gaseous liquid comprising an open-topped earthen reservoir, refrigeration conduit means spanning the opening of said reservoir, an ice cap surrounding said refrigeration conduit means to seal said opening, protective insulating material covering the upper surface of said ice cap, conduit means for introducing a normally gaseous liquid into said reservoir, means for sensing the pressure of vapors within said reservoir, means for sensing the temperature of said ice cap, conduit means for removing vapors from said reservoir, means for compressing and condensing the vapors withdrawn from said reservoir, and conduit means for returning the condensed vapors to said reservoir through said refrigeration conduit means in response to said temperature sensing means and said pressure sensing means.

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