

Oct. 29, 1968

A. R. KHAN ET AL
UNDERGROUND CAVERN STORAGE FOR LIQUEFIED GASES NEAR
ATMOSPHERIC PRESSURE

3,407,606

Filed Feb. 14, 1966

3 Sheets-Sheet 1

Fig. 1

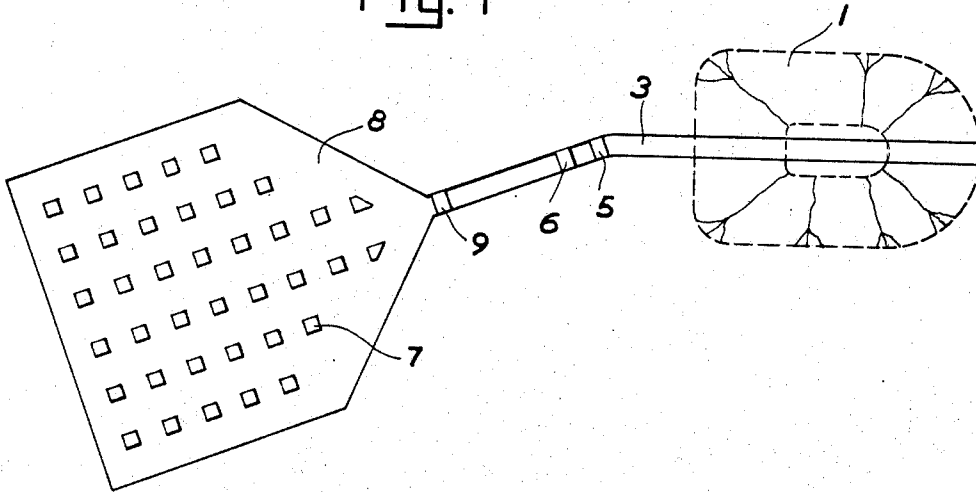
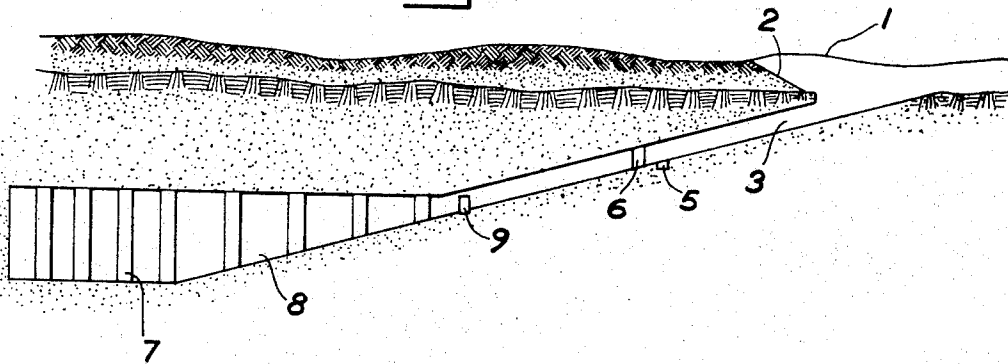


Fig. 2



INVENTOR.
AMANULLAH KHAN
BERTRAM E. EAKIN &
PHILLIP J. ANDERSON
BY
Bar, Freeman & Molinare
ATTORNEYS

Oct. 29, 1968

968 A. R. KHAN ET AL 3,4
UNDERGROUND CAVERN STORAGE FOR LIQUEFIED GASES NEAR
ATMOSPHERIC PRESSURE

3,407,606

Filed Feb. 14, 1966

3 Sheets-Sheet 2

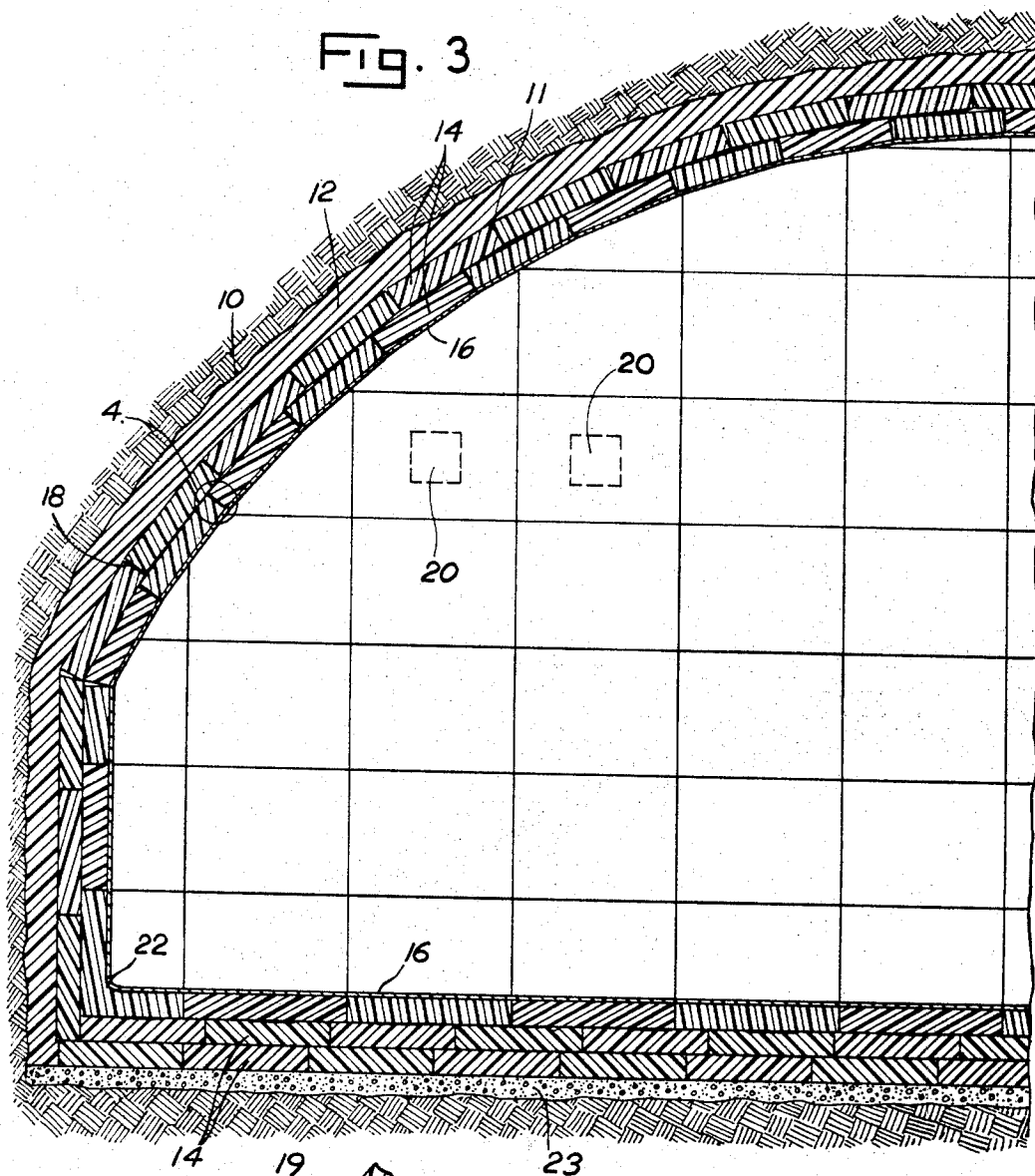
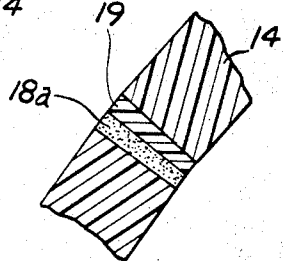


Fig. 4

INVENTOR.
AMANULLAH KHAN
BERTRAME E. EAKIN
BY PHILLIP J. ANDERSON
Bair, Freeman & Molinare
ATTORNEYS

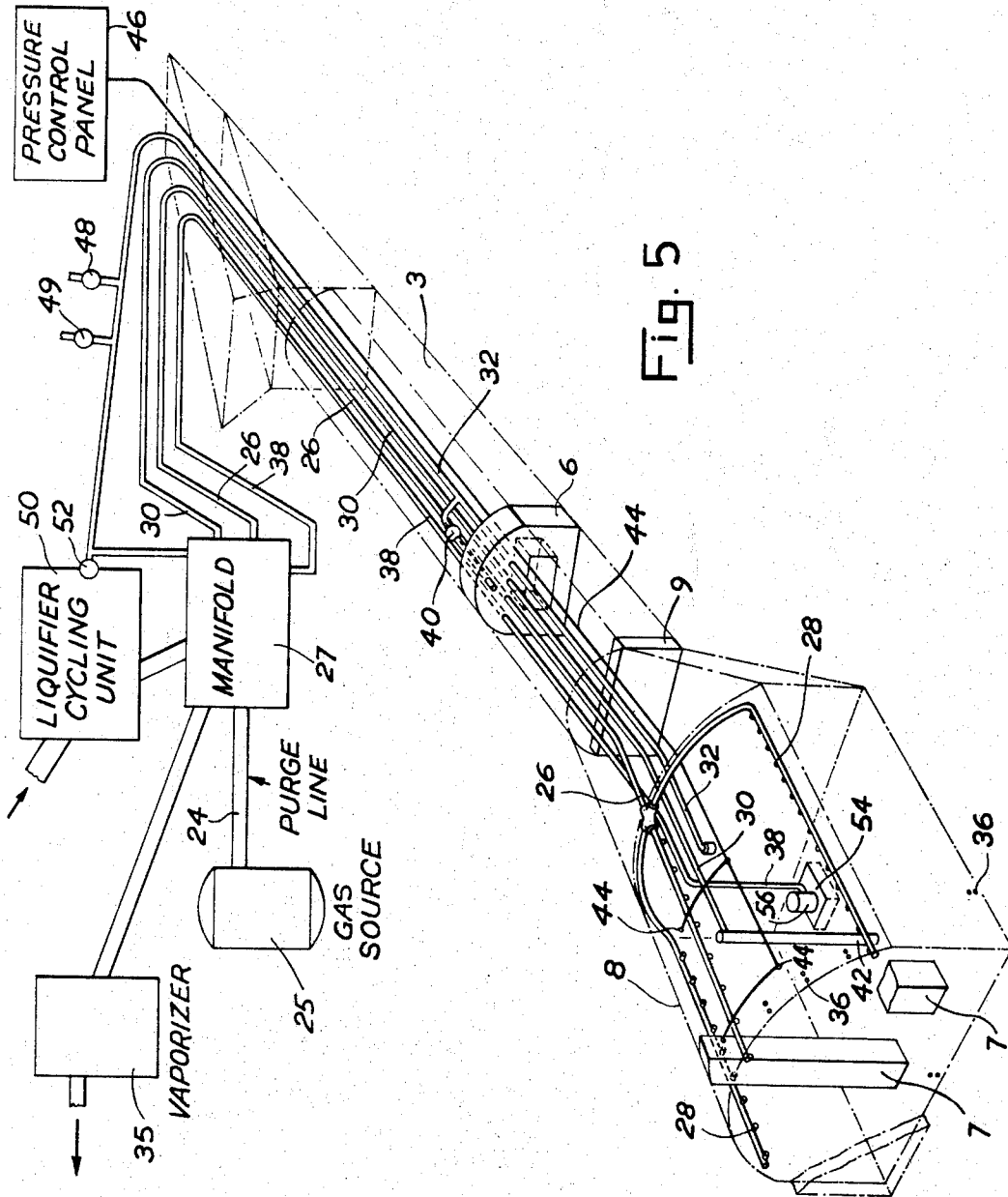
Oct. 29, 1968

A. R. KHAN ET AL
UNDERGROUND CAVERN STORAGE FOR LIQUEFIED GASES NEAR
ATMOSPHERIC PRESSURE

3,407,606

Filed Feb. 14, 1966

3 Sheets-Sheet 3



INVENTOR
AMANULLAH KHAN
BERTRAM E. EAKIN &
PHILLIP J. ANDERSON
BY *Bair, Freeman & Molinare*
ATTORNEYS

1

3,407,606

UNDERGROUND CAVERN STORAGE FOR LIQUEFIED GASES NEAR ATMOSPHERIC PRESSURE

Amanullah R. Khan, Chicago, Bertram E. Eakin, Naperville, and Phillip J. Anderson, Deerfield, Ill., assignors to Institute of Gas Technology, a not-for profit corporation of Illinois

Filed Feb. 14, 1966, Ser. No. 527,158
10 Claims. (Cl. 61—5)

ABSTRACT OF THE DISCLOSURE

An underground chamber for storing liquid gases at substantially atmospheric pressure and cryogenic temperatures. An inclined adit has its upper end at ground level and its lower end suspends into a rock-enclosed cavern. Means are provided at the adit for sealing the cavern from the passage of liquid or vapor into or out of the cavern. Sealing means are provided on the surface of the rock cavern for minimizing leakage of surrounding vapor or liquid water into the cavern. Thermal insulation covers and is contiguous with the interior surface of the cavern. Liquid and vapor impervious barrier means are secured to the innermost surface of the thermal insulation to prevent passage of liquid or vapor from the cavern through the insulation. Means are provided for transporting liquid gas into and out of the cavern for storing the liquid gas therein at substantially atmospheric pressure and at a temperature substantially at the normal boiling temperature of the stored liquid gases at atmospheric pressure.

This invention relates to a new and improved method for storing large volumes of liquefied gases underground at substantially atmospheric pressure in a safe and economical manner. More particularly, the invention relates to the storage of liquefied gases in rock caverns, or rock structures such as quarried excavations near the ground surface, the caverns or structures being insulated and lined to provide low evaporation rates and safe containment of the low temperature liquid gases at substantially atmospheric pressure. Whereas the particular designs of the caverns embodying this invention were made for the storage of liquefied natural gas, the storage cavern may be successfully utilized for storage of other gases which have been cooled to a liquid state at atmospheric pressures such as ethane, propane, and butane as well as ammonia, carbon dioxide, argon, nitrogen and hydrogen.

Storage of liquefied gases in the past has been at either atmospheric pressure or superatmospheric pressure. When stored at atmospheric pressure, the gas must be liquefied and maintained in storage in liquid form which in the case of natural gas means maintenance at about -258° F. Insulation is required to reduce heat influx to the boiling liquid in order to reduce the cost of reliquefaction plant facility. Present practice is to store liquefied gases in aboveground metal or concrete containers and in belowground or partially belowground concrete containers. These containers are insulated to conform to the permissible rate of evaporation.

Storage in such containers presents certain difficulties. In the case of aboveground insulated containers which store large quantities of highly volatile combustible liquid a large area of uninhabited ground and suitable diking must surround it for reasons of safety. Also, another limitation of aboveground storage containers is the size limitation restricting capacity to 300,000 barrels. Multiple installations are therefore required for large volume storage (3,000,000 barrels).

Where belowground or partially belowground concrete containers are employed, maximum capacity is restricted

2

by design considerations which would result in multiple unit installation for storage of large volumes of liquefied gas. In either case, the gases in liquid and vapor state are not completely confined belowground at any substantial depth. Systems of the above descriptions are shown in U.S. Patents 3,151,416 and 3,196,622.

Liquefied gases have heretofore been stored completely belowground in rock caverns at superatmospheric pressures and relatively higher temperatures as described in U.S. Patents 3,058,316 and 3,205,665. The high pressure necessitates the location of the cavern at a depth sufficient for the overburden pressure to balance or overcome the liquid storage pressure. In addition, maintenance of the pressure presents problems and requires a small diameter vertical shaft. Storage volume is lost when storing gases at relatively high temperatures and pressures due to the decreased density of the liquid. The high pressure techniques utilize an ice or ice matrix to create impermeability of the rock mass to the liquid or vaporized gas. Under certain conditions of pressure and temperature, undesirable formation of hydrocarbon hydrates can occur resulting in loss of stored product. Thermal cycling or warmup of the cavern are difficult since melting of the ice matrix may result in loss of compactness and impermeability of the system. These types of high pressure storage systems also are uninsulated because no economical method of insulating is available and consequently these systems experience high rates of gas vaporization due to high heat influx rates from the bare rock to the low temperature liquefied gas.

In order for such caverns to be insulated, the density of any insulation used must be high enough to withstand the internal pressure. This results in markedly reducing the insulating character of the material used and requires a greater thickness of insulation. Thus the increased depth, pressure and insulation (if any of these are employed) are costly. Such storage systems are uneconomical for large volume storage of liquefied gases.

Now, therefore, it is an object of this invention to provide a method of storage for liquefied gases whereby these difficulties can be overcome and which method is more economical, safer and simpler to construct than the systems heretofore in practice.

Another important object of this invention is to provide a safe, large volume storage method wherein a single storage unit, rather than multiple installations, may be employed.

It is also an object of this invention to provide an economical method for storage of liquefied gases including such gases as methane, natural gas, ethane, propane, butane, hydrogen, ammonia, carbon dioxide, argon, nitrogen and other gases at atmospheric pressure and cryogenic temperatures.

A particular object of this invention is to ensure maximum safety in the storage of large quantities of energy wherein both liquid and gas phases are confined completely belowground.

Yet another object of this invention is to minimize the surface land area required for storage of liquefied gases to permit maximum utilization of surface land area for other purposes, especially in populous areas.

Still another object of this invention is to utilize modern mining techniques which permit a large area inclined adit for performing necessary excavation rapidly and economically.

It is also an object of this invention to utilize the irregularly shaped containers resulting from such excavation for the containment of liquefied gases.

An additional particular object of this invention is to provide an insulation material to prevent heat influx from the bare rock to the cold liquid.

Still another object of this invention is to ensure that the surrounding rock is not exposed to extremely low temperatures.

Yet another object of this invention is to provide means for filling, emptying, relieving and instrumenting an underground storage cavern for liquefied gases through a single entry in a bulkhead system thereby attenuating leaks from the cavern.

Other objects and advantages of the invention will become evident as the invention is more fully described hereinafter and from the following description of a preferred embodiment.

The foregoing objects are accomplished by providing an underground chamber for storing liquid gases at substantially atmospheric pressure and cryogenic temperatures wherein the chamber comprises an inclined adit having an upper end at ground level and a lower end in a rock-enclosed cavern, means for sealing the cavern from the passage of liquid or vapor into or out of the cavern, sealing means on the surface of the rock cavern for minimizing leakage of surrounding vapor or liquid water into the cavern, thermal insulation covering and contiguous with the interior surface of the cavern, liquid and vapor impervious barrier means secured to the innermost surface of the thermal insulation to prevent passage of liquid or vapor from the cavern through the insulation, means for transporting liquid gas into and out of the cavern for storing liquid gas therein at substantially atmospheric pressure and at a temperature substantially at the normal boiling temperature of the stored liquid gases at atmospheric pressure.

In the drawings wherein like reference numerals indicate like parts:

FIG. 1 is a diagrammatic plan view of an underground storage cavern illustrating the method of entry to the cavern and excavation;

FIG. 2 is a diagrammatic side elevation illustrating the method of entry to the cavern and excavation;

FIG. 3 is a partial side view in section showing a typical means for insulating and lining the irregular rock faces of the cavern;

FIG. 4 is an enlarged view of a portion of FIG. 1 showing a sealed joint; and

FIG. 5 is a perspective view showing a portion of a cavern with the necessary valves, flow lines and control elements for operation in storing liquefied gases.

Broadly speaking, the invention comprises excavating a mined room and pillar cavern by means of a large inclined entry which permits rapid ingress and egress of heavy equipment for the purpose of efficient and economical excavation; coating the walls, floor, roof and pillars with a moisture or water sealant; insulating all rock surfaces with one or more layers of a foamed insulating material providing internal to the insulation a liner material which is impervious to liquid and gas; providing the entry with a double bulkhead system to contain liquid and gas; providing means for filling, emptying, relieving and instrumenting through the double bulkhead thereby ensuring safe storage completely belowground of liquefied gases at atmospheric pressure.

Before excavation, it is essential to determine by means of test borings the geological formations, the nature and type of rock and the presence of underground water. Determination of the structural qualities of the rock at cryogenic and ambient temperatures and the prevalent fracture patterns are conducive to the safe design of the caverns. Notwithstanding that the rock will at no time encounter cryogenic temperatures, this preliminary information is useful for evaluating the spalling qualities of the rock in the event there is liquid migration through unforeseen cracks or ruptures in the liner-insulation system. It should be understood that the surrounding rock is the external structural member of the storage cavern and; since the rock is subjected only to the hydrostatic weight of liquid, the size of openings or spans between

pillars is largely governed by the structural character of the rock.

Where necessary, particularly in the roof, bolting may be required to ensure the structural integrity. Such bolting is well known in the mining art and will not be described in detail herein. Bolts should be made of materials which do not exhibit brittle failure and that are capable of withstanding cryogenic temperatures. Thermally induced stresses in the roof are reduced considerably by efficient insulation the extent of which depends on the low vaporization rates desired. The impermeable liner material ensures that no migration of liquid or vapor will occur through or into the insulation.

Referring to the drawings, FIG. 1 illustrates diagrammatically the method of entry and excavation employed in construction of a cavern according to the invention. Conventional mining equipment is used throughout. The initial step in the excavation consists of exposing the entry portal by stripping the topsoil 1 to bedrock. The volume of soil to be removed is dependent upon the depth of the soil and its angle of repose 2 (FIG. 2). Once the soil has been removed and banked at the portal, inclined entry 3 is driven in the bedrock to the selected depth. The slope of inclined entry 3 is controlled by the grade which the excavating vehicles may traverse. Either a straight or curvilinear entry may be used depending upon the surface land area available. The use of a curvilinear entry reduces the plan view space required by the entry. During the driving of the entry, it may be necessary to support a portion of or the entire length of the entry with roofbolts or props due to surfacial weathering of the rock. Water influx through fissures may be controlled by suitable means such as grouting. A sump 5 is excavated along the inclined entry 3 to handle water influx due to precipitation and runoff from the portal. Pump and piping means (not shown) are provided to discharge accumulated water from sump 5 to ground level.

After completing inclined entry 3, storage cavern 8 is excavated. In layered rock such as sedimentary rocks, foliated or banded metamorphic rocks, and igneous rocks which exhibit sheeting, jointing and/or fracturing, it is preferable to form a room and pillar cavern. The span of each room and the dimensions of pillars 7 depends upon the structural behavior of the rock as determined from the physical tests of cores taken during the site selection and the presence and character of discontinuities exposed in the rock during the mining operation. Good mining practices are to be used throughout the operation. The percentage of the cavern represented by the pillars will vary from 50 percent to less than 10 percent depending upon the above parameters. In massive, competent, monolithic rock, pillar supports may be eliminated by using an arched roof and roofbolts. Suitability of such structure will have been determined prior to excavation from analysis of the above mentioned borings and tests of cores.

As above mentioned, bolting of the cavern roof as is well known in the mining art may be required to ensure structural integrity. Where bolts are utilized, a wire mesh is preferably installed beneath the seating plate of the bolt to prevent raveling of the rock around the bolt. Raveling reduces the tension in the bolt and hence its effectiveness. Between the bolts and suitable fasteners (utilized where bolts are unnecessary) this mesh retains any loose rock or roof fragments.

After excavating the cavern and emplacing bolts, fasteners and wire mesh as necessary, loose debris is removed and the walls, roof, and floor are washed if coated with dust. A water sealant is then applied to the bare rock, preferably by spraying, to prevent water or moisture leakage into the cavity. Any commercially available water sealant material can be used such as silicone or thorium base sealant materials. The cavity is then ready for installation of the insulation-liner system hereinafter described.

For economical and expeditious excavation of the cavity, any well-known mining technique for shallow mining may be used. One particularly useful method involves removing rock in horizontal slices. In this technique, the top slice is driven across the cavity from the entry to the dimensions dictated by the shape of the cavity. Driving of this slice is accomplished by alternate rounds of drilling and blasting and mucking the broken rock which is removed through the entry by suitable vehicles or by a movable conveyor system. After removing the top slice, the entry is extended along its slope and a second slice is driven horizontally across the cavity to the desired dimensions. If the cavity has an arched roof, the second slice will be larger in plan than the top slice. If a flat roof is used, the dimensions of the second slice will coincide with the top slice. Handling of broken rock in cutting the second slice is similar to that previously used. Slices are repeated until the cavity is mined to the desired depth. Water bearing fissures or fractures encountered in driving a slice are sealed with cement or chemical grouts as required.

As best seen in FIGS. 2 and 4 inclined entry 3 is provided with a vapor barrier 6 and a liquid bulkhead 9 which constitute the double bulkhead system of the invention. Liquid bulkhead 9 functions as a weir and is located in the inclined entry below the vapor barrier. The height of bulkhead 9 is determined by the liquid level at maximum-fill conditions and its function is to restrain the liquid within the cavern. Although we prefer to use such bulkhead, it may be eliminated, if desirable, and the liquid gas restrained in the cavern solely by the vapor barrier. Bulkhead 9, if used, extends across the width of the entry and may be constructed of any material preferably steel, capable of withstanding the liquid load. The design load of bulkhead 9 is similar to that of a retaining wall. In construction, the bulkhead preferably is keyed into the walls and floor and may utilize rock bolts or back fill if required or desired to support the liquid load. The insulation and vapor impermeable liner are secured to the surface of the liquid bulkhead to cover entirely all exposed surfaces. The location of the liquid bulkhead in the inclined entry is selected to maintain sufficient space between the top of the bulkhead and the roof of the entry to accommodate all piping and lines. This obviates passing the piping and lines through the bulkhead which would present difficulties in sealing.

The level of the base of vapor barrier 6 in the inclined entry should be above the maximum level of liquid in the cavity. Thus, at no time will the vapor barrier be in contact with the liquid being stored but rather only with the cooled vapors.

Vapor barrier 6 is constructed as described in copending application Ser. No. 527,288 filed Feb. 14, 1966, and essentially consists of a cast concrete frame which is keyed into the walls, floor, and roof of the entry. A suitable number of anchors are embedded in the rock and extend into the concrete frame to restrict relative movements between the concrete and the rock mass. The anchors are made of materials which will not exhibit brittle failures at cryogenic temperatures. Within the concrete frame, a double walled metal access-door frame is mounted. This frame is fabricated with an expansion joint to allow differential movement between the concrete frame member and the metal frame member. The surface of the metal frame toward the storage cavity is fabricated of a material which will not exhibit brittle failure at cryogenic temperatures and the metal surface toward the portal may be constructed of carbon steel and does not require an expansion joint. The space between the double walls of the access-door is filled with a suitable insulant such as polyurethane foam. All piping and lines pass through the double walled access-door frame where a gas tight seal and suitable expansion-contraction provisions are made on the surface of the metal frame toward the storage cavity.

A preferred insulation and liner system is shown in FIG. 3 and is described in detail in copending application Ser. No. 526,983, filed Feb. 14, 1966.

Broadly, the insulation system used in this invention which has been found suitable for use on the irregularly shaped walls and ceiling of a rock cavern consists of a water and moisture sealant layer 10 applied directly on the rock, a layer of foamed-in-place insulation 12, such as polyurethane, and two or more layers of sheet insulation 14, with an essentially impermeable plastic or metallic liner 16 on the exposed surface of the interior layer of insulation. The internal layers of sheet insulation are secured at their edges with a non-setting mastic. The final layer of insulating panels are joined together with cryogenic-type tape.

Many organic insulations are seriously attacked by moisture, generally causing softening of the material and increase in heat leak through the affected material. For this reason, every effort is made to ensure a "dry" cavern before start of insulation. Any major water influx encountered during construction should be sealed off by use of standard techniques such as pneumatic grouting with non-shrinking or expanding type mortars or chemical grouts. However, since almost all rocks contain moisture, and the cavern will generally be constructed below the ground-water table in the area, water will tend to seep into the cavern through microfractures in most of the exposed rock surface. This seepage can be stopped by spray application of one or more coatings of any conventional material available commercially for this purpose, e.g., silicone or thorium base sealant materials.

General mining techniques tend to leave an irregularly shaped surface exposed. However, it is possible to construct a series of smooth connected surfaces at some preselected average distance from the irregular rock surfaces by use of standard scaffolding techniques similar to those used in placing forms for the pouring of concrete walls. However, since the outward pressure generated by foamed-in-place insulation is much lower than that generated by the hydrostatic action of poured concrete, the load on these forms is lower, and they may be of much lighter construction. Also, only one surface need be formed, since the rock surface is itself the exterior form. If suitable insulation material is available which can be poured in place for the entire thickness of the insulation at a single application, this would be a preferred manner of construction. When presently available foam-type organic insulations are used, it is more economical to prepare standard panels of a uniform size and thickness at a factory by special machines and then utilize a multiple layer type construction. This type of construction is also required due to the high coefficient of thermal contraction of the present organic-type foam insulations.

When the multiple layer insulation system described in copending application Ser. No. 526,983 filed Feb. 14, 1966 is utilized, with the use of precast panels, it is possible and preferable to use the layer of panels next to the foamed-in-place insulation as the forms. In this manner the first two layers of insulation are installed in a single operation, and if a material, such as urethane, is used as the poured-in-place material, a strong bond is formed between the poured-in-place insulation and the rock, and between the poured-in-place insulation and the panels. The edges of the panels used as the forms are "battered" with a non-setting mastic compound 18 (FIG. 3) which helps to seal and prevent gas or liquid movement through the insulation. The same mastic is used on the edges and back of each new layer of panels as they are installed, except for the innermost layer of insulation.

The interior layer of insulation panels contains the liquid and gas barrier as an integral part of the panel. A suitable material for this barrier or liner is Mylar film or aluminum or other metal foil coated with Mylar, preferably a Mylar-aluminum-Mylar laminate with a backing of light weight fiber cloth for increased tear resistance.

Such a material is impermeable to gas or liquid, even at cryogenic temperatures, and suitable adhesives and application methods are available to make tape-type joints which are also essentially impermeable. Care must be exercised in handling the laminate to prevent creasing the material, as this tends to form pin holes which will cause leakage. Also, it is essential in order to form a good seal, that the liner be on a smooth, firm backing. This condition is adequately met when the liner is installed during the manufacturing process as an integral part of the panel.

The insulation panels for the interior layer are provided with a relatively thin layer of open cell foam 19 commonly referred to as "flexible" foam, adhered to the four edges of each panel. These panels are then installed by using a suitable cryogenic adhesive, such as urethane adhesive, on approximately one quarter of the back surface in the center of each panel as shown at 20 in FIG. 3, and continuously along all four edges on the "flexible" foam as shown at 18a in FIG. 4. In this manner each panel is restrained in place only at its center, and the edges are free to move due to thermal contraction as the cavern is cooled. The "flexible" foam provides the same function for this exterior layer as the non-setting mastic provides for the central layers, keeping the edges between panels filled as the panels contract or expand with changes in cavern temperature. However, the open cell structure, and the fact that only a fraction of the space between the exterior and central layer are filled with adhesive, provides a path for any gas leaking through pin holes in the liner or the tape seals to migrate to the ceiling of the cavern. Here the gas can either be removed through the gas exhaust line described hereinafter or could flow through an opening in the liner directly into the gas space above the liquid in the cavern. Both methods prevent any buildup of pressure between the liner and insulation, due to either liquid or gas leakage, which might tend to cause a major failure of the liner.

After installation of the interior layer of insulation, the joints between panels are sealed with a wide tape of a material similar to the liner and a suitable cryogenic adhesive. This adhesive may be a normal type such as urethane, or a pressure-temperature sensitive type. These tapes are installed with slack provided in both the vertical and horizontal directions, to allow for contraction of the insulation without placing the liner material in tension, as described in copending application Ser. No. 526,983 filed Feb. 14, 1966.

The floor insulation differs from that used on the walls and ceiling in several significant details. The floor is finished with a slight grade from edges to center of each room with all rooms designed to drain to a liquid sump. To provide a smooth surface for insulation, the floor is covered with a minimum layer of concrete 23, and then sealed with the same water sealant as used on the rock walls. All floor insulation is in panel form, with all layers, except the exterior layer, joined with the non-setting mastic on the back and edges of each panel. The final exterior layer also contains the vapor and liquid impenetrable liner as an integral part of the panels, and is installed as on the walls. Joints are sealed with the cryogenic-type tape.

At the edges between the walls and floor, a special precast insulation panel is used, which has the liner as an integral part of it, and provides a smooth transition from the horizontal to the vertical plane as shown at 22 in FIG. 3. Some of the forms of the various special edge pieces are described in copending patent Ser. No. 526,983 filed Feb. 14, 1966. The floor liner and the wall liner are sealed to these edge pieces with the same tape seal as used on wall and floor.

The use of machine-made standard size insulation panels is a distinct economy. Suitable panels can be commercially prepared such that a kraft paper Mylar laminate on each surface is an integral part of the manufacturing process. These panels for use in the exterior layer of insula-

tion are provided with one surface covered with the liner laminate. These covered panels are less susceptible to damage in shipping and installation, and are protected from moisture from manufacture to installation, thus insuring their good insulation quantities. These coatings will in turn provide additional protection from damage due to possible water seepage through the rock wall sealants over the lifetime of the cavern.

FIG. 4 is a diagrammatic perspective view of an arched cavern showing the inclined entry, piping the control apparatus of the invention. Broadly, the cavern and its associated equipment includes:

- (a) Purge lines 24 for inerting the atmosphere in the cavern prior to introduction of the storage gas.
- (b) Spray lines 26 and nozzles 28 for initial cooldown of the liner and insulation.
- (c) Liquid fill lines 30.
- (d) Boil-off vapor return lines 32.
- (e) Liquid pump 56, controls and power lines.
- (f) Temperature sensing devices 36 and their necessary connections (not shown).
- (g) Liquid withdrawal line 38.
- (h) Overpressure relief line 40 and control devices.
- (i) Various liquid level indicators 42 and their connections.
- (j) Pressure monitoring devices 44 and connections and regulating controls 46.

How the above devices are utilized in the storage system illustrated in FIG. 4 is best shown by describing the cavern operation.

The first phase in initiating operation of the storage facility is purging of the storage cavity 6 with an inert gas if a flammable gas in the liquid state is to be stored. This prevents the flammable gas from forming an explosive or flammable mixture during the initial filling period which exhibits a high vaporization rate. An inert gas is introduced into the cavity through the purge lines 24 from the gas source 25 to a manifold 27 which provides distribution of the purge gas to the initial cooldown spray lines 26 and the liquid fill line 30. The return purge gas is withdrawn from the cavity through the liquid withdrawal line 38 and the vapor return line 32.

The composition of the gas in these lines is monitored until the cavern is properly purged at which time the liquefied gas to be stored is injected into the cavity. Initial liquid injection to the cavity is through the cooldown spray lines 26. The nozzles 28 are so arranged that the interior surfaces of the insulation are cooled uniformly at a desired rate to minimize thermal stresses. The rate of cooldown is a very important factor in the successful initiation of the cavern operation. Temperature sensing devices 36 are placed at strategic locations within the insulation to provide a measure of the uniformity of cooldown and the temperature distribution within the insulation. The temperature distribution will also be utilized to control the rate of cooling so as to minimize thermal stress in the insulation. The gas vaporized during this period of operation will be withdrawn from the cavity through the vapor return lines 32. Flare valve 48 is opened and the initial portion of this mixture of storage and inert gas is flared. This is done as a safety measure and to avoid mixing the purge gas with the stream going through the cycling unit 50. Relief valve 49 is maintained closed except to relieve excess pressure as a safety measure. As soon as analysis of the composition of this gas indicates that nearly pure vapor of the liquid gas being injected is being flared, flare valve 48 is closed and valve 52 is opened. The gas stream can then be utilized as fuel gas, gas sales, by withdrawal through valve 49, or recompression for reliquefaction. When the desired insulation temperature has been obtained, injection of liquid into the cavity through the liquid fill line 30 is started. Liquid gas injection through the spray lines is maintained, as desired, during the initial filling of the cavern. Liquid level indicators 42 of the magnetic float type or any other suitable type are installed

at desired locations to monitor the liquid level. As filling of the cavity progresses, the pressure in the overlying gaseous phase is monitored at selected points by suitable monitoring devices 44 which are connected to a control panel 46. The pressure of the overlying gaseous phase may be varied or held at a desired value by overpressure relief lines 40 and control devices but in no case is allowed to exceed substantially atmospheric or near atmospheric pressure.

During periods when it is considered undesirable to liquefy gas from an external source of supply, the boil off gas may be recompressed for reliquefaction, utilized for gas sales, or utilized as fuel gas.

The liquid stored in the cavity may be withdrawn as desired. Withdrawal is through the liquid withdrawal line 38 from a sump 54 which is located at any desired point within the cavity to which the floor has been sloped to provide complete drainage. The mechanism which provides the energy for withdrawal is a pump 56 located within the sump 54. This pump may be operated without or in conjunction with pumps located at the surface. The pressure of the overlying gaseous phase may be maintained or varied during this period by means of the overpressure relief lines 40 and their associated control devices. The liquid withdrawn from the cavity can then be processed for sales through the vaporizer 35.

Refilling of the cavity with liquid gas may be accomplished by the steps outlined above. The steps may be modified depending on the temperature of the insulation and composition of the overlying gas phase to eliminate the purge and spray cooling.

Those skilled in the art will recognize that various modifications can be made in our invention which are within the scope and spirit of the invention which we intend to be limited solely by the appended claims.

We claim:

1. Method for storing liquid gases underground at substantially atmospheric pressure comprising the steps of: (1) excavating an underground rock enclosed cavern having an inclined adit of relatively large cross-sectional area, (2) sealing the entire interior surrounding rock surface of said cavern with water impervious sealant to minimize leakage of surrounding liquid water or vapor into said cavern, (3) insulating the interior rock surface of said cavern with a plurality of contiguous layers of foam insulation, (4) securing a liquid and vapor impervious barrier material to the innermost surface of one layer of said insulation to prevent loss of stored liquefied gas through said insulation layers, (5) securing a liquid and vapor sealing means across the said cross-sectional area of said inclined adit, and (6) maintaining said cavern at substantially atmospheric pressure and at a temperature substantially at the normal boiling point of the liquefied gas stored at said pressure.

2. Method of claim 1 wherein said foam insulation contiguous with the rock surface of said cavern is foamed-in-place rigid cellular insulation supported on its outer surface by a plurality of panels of rigid cellular insulation.

3. Method of claim 2 wherein the layer of said foam insulation contiguous with the rock surface of said cavern is foamed-in-place polyurethane foam supported on its outer surface by a plurality of panels of rigid foamed polyurethane.

4. Method of claim 1 wherein sealing of said interior rock surface is effected by spraying sealant material on said surface.

5. Method of claim 1 wherein said cavern is purged and cooled to substantially the temperature of the liquefied gas to be stored therein, prior to storing of said liquefied gas therein.

6. An underground chamber for storing liquefied gases at substantially atmospheric pressure comprising an inclined adit of relatively large cross-sectional area having its upper end at ground level, a rock-enclosed cavern at the lower end of said adit, means in said adit for sealing off said cavern from passage of liquid or vapor into or out of said cavern, sealing means on the surface of said rock cavern impervious to vapor or liquid water for minimizing leakage of surrounding vapor or liquid water into said cavern, thermal insulating means covering and contiguous with the interior surface of said cavern, liquid and vapor impervious barrier means secured to the innermost surface of said insulating means for preventing passage of liquid or vapor from said cavern through said insulating means, and means for transporting liquefied gas into and out of said cavern for storing said gas therein at substantially atmospheric pressure and at a temperature substantially at the normal boiling temperature of the stored liquefied gases at said pressure.

7. Chamber of claim 6 wherein said insulation comprises a plurality of layers of cellular foam material.

8. Chamber of claim 7 wherein said foam material is rigid foamed polyurethane and wherein the layer of foam contiguous with the rock surface is foamed-in-place rigid polyurethane.

9. Chamber of claim 6 further comprising means for purging and cooling said cavern prior to storage of liquefied gas therein.

10. Chamber of claim 9 further comprising means for monitoring temperature and pressure within said cavern.

References Cited

UNITED STATES PATENTS

2,932,170	4/1960	Patterson et al.	61—.5
2,947,146	8/1960	Looffbourow	61—.5
2,961,840	11/1960	Goldtrap	61—.5 X
3,064,436	11/1962	Looffbourow et al.	61—.5
3,151,416	10/1964	Eakin et al.	52—169 X
3,159,006	12/1964	Sliepevich	61—.5 X
3,205,665	9/1965	Van Horn	61—.5
3,285,014	11/1966	Nachshen	61—.5

FOREIGN PATENTS

176,115	8/1961	Sweden.
---------	--------	---------

EARL J. WITMER, *Primary Examiner*.