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METHOD AND APPARATUS FOR REMOVAL OF LIQUEFIED
GAS FROM UNDERGROUND CAVERNS
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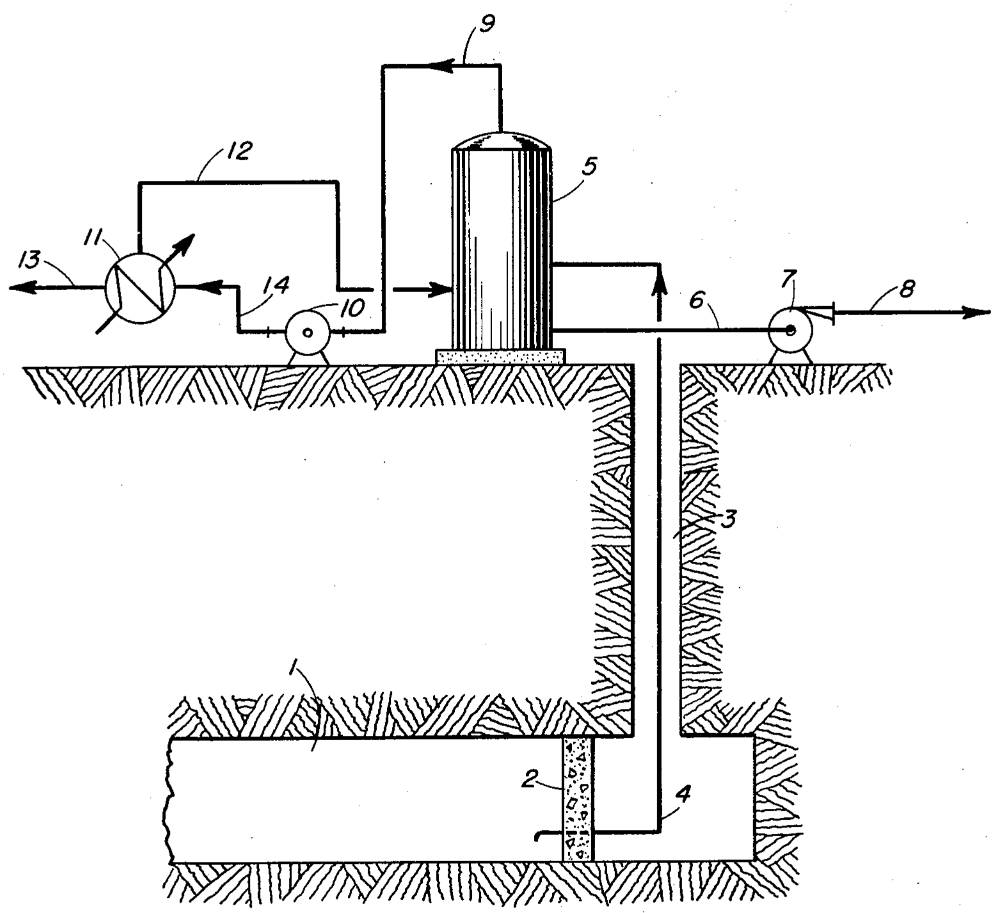

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METHOD AND APPARATUS FOR REMOVAL OF LIQUEFIED GAS FROM UNDERGROUND CAVERNS

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The present invention relates to a method and apparatus assembly adapted for withdrawal of liquefied gas from underground caverns.

As those skilled in the art are aware, underground natural caverns are employed for storage of gases in liquefied form, illustrations of such gases being hydrocarbons such as propane, butane, and others, as well as mixtures of such gases. For such usage, the caverns are excavated, at an elevation substantially below ground surface level, out of strata that possesses suitable structural characteristics and sufficiently impermeable to the liquefied gas under storage. Although such caverns may vary considerably as to overall size and volume, they are usually of such magnitude with respect to volume and internal surface area that they dwarf other means, such as tanks, used for storage of liquefied gases at either below or above ground level.

For transference of liquefied gas from liquefied gas storage facilities that do not present a relatively large internal surface area exposed to compressed vapors, transference of liquefied gas may and has been effected in practical manner by pressurizing of the storage facility with a gas such as that stored in liquid form in the storage facility. For such facilities, which include transference between surface storage and tank cars as well as between underground storage vessels and surface storage facilities, the pressure differential required to transfer the liquefied gas is small as is the surface area exposed to compressed vapor in the vessel from which the liquefied gas is transferred. Hence, for such facilities, it is relatively simple to develop, by gas pressurizing means, sufficient pressure head in the vessel from which the liquefied gas is being transferred to accomplish the desired transfer by pressurizing the vapor space in the vessel. However, and as is discussed more fully hereinafter, such conventional methods for liquid gas storage facilities that do not present a relatively large surface area, such as is characteristic of underground natural caverns, exposed to compressed vapor in the storage facility are highly impractical for use with such underground natural caverns.

Due to the relatively large size of the underground caverns, they have a large internal surface area available for condensation of compressed vapors. Hence, for controlled withdrawal of liquefied gas from the cavern to ground surface level, or above, it is highly impractical to effect transfer of the liquefied gas by means such as pressurizing of the cavern with a gas, such as the gas stored therein in liquid form, to displace the liquefied gas from the cavern. For example, in the use of compressed gas for pressurizing the cavern to displace liquefied gas therefrom, and transference of the liquefied gas to a substantially higher elevation, the large internal surface area of the cavern available for condensation of compressed vapor results in condensation of pressurizing gas with considerable loss of its pressurizing effect. Thus, to effect displacement of liquefied gas from the cavern to a substantially higher

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elevation by such pressurization of the cavern, the amount and rate of introduction of pressurizing gas into the cavern would be of such magnitude as to render such means highly impractical, particularly due to excessive requirements for compressing and attendant equipment that would be necessary to supply pressurizing gases in an amount and at a rate sufficient to provide sufficient pressure over and above the loss of pressurizing effect due to condensation of pressurizing gas in the cavern. Use of a pressurizing gas other than that stored as a liquid in the cavern produces additional objectionable features in that it results in introduction into the cavern of material foreign to the liquefied gas under storage as well as introduction of contaminating materials that may be present in the pressurizing gas. Such objectionable features of pressurizing methods for withdrawal of liquefied gas from a cavern are not only encountered with caverns of the single chamber type but, even more so, with underground caverns of the labyrinth type which present a larger internal surface area available for condensation of compressed pressurizing gas. The primary object of this invention is the provision of a method and apparatus assembly for use with an underground cavern for transference of liquefied gas to a substantially higher elevation in a highly practical, effective manner and without encountering objectionable features of pressurizing systems as aforedescribed.

In accordance with this invention, the transfer of liquefied gas from an underground cavern to a substantially higher elevation is effected by provision of a receiving means at an elevation substantially above the cavern, means for flow of liquid from the underground cavern to the receiving means, and correlation of conditions in the receiving means with those existing in the cavern whereby the liquefied gas is transferred from the cavern to the receiving means without need for resort to pressurization of the cavern as aforedescribed. More specifically, the invention relates to controlled reduction of pressure and other conditions in the receiving means with respect to the pressure and temperature existing in the cavern whereby liquefied gas from the cavern is transferred to the receiving means due to expansion of the liquefied gas and self-elevation by release of its potential internal energy.

In order to further describe the invention, reference is made to the accompanying drawing setting forth, in diagrammatic manner, an illustrative embodiment of an apparatus assemblage suitable for carrying out the invention for transference of liquefied gas, illustratively liquid propane, from an underground cavern to a substantially higher elevation. In the embodiment shown, cavern 1 represents an excavated cavern suitable for storage of a liquefied gas (e. g., propane) having a shaft portion 3 adapted to accommodate means, such as conduits, for filling of the cavern and withdrawal means for liquefied gas. In order to prevent escape of material from the cavern into the shaft, suitable means such as concrete bulkhead 2 are disposed in the cavern and, as shown, a conduit means such as conduit 4 extends through the bulkhead into the cavern. At an elevation substantially above the cavern, and preferably above ground level, a receiving vessel 5 is provided and which, by means such as conduit 4, is in direct communication with the liquefied gas under storage in the cavern. Receiving vessel 5 is provided with a conduit 6 for withdrawal of liquid that accumulates in vessel 5 and, at a top portion of vessel 5, with a conduit 9 for withdrawal of vapor from vessel 5. As shown, vapor line 9 is connected to compressor 10 from which vapor passing through line 9 is compressed by compressor 10, and passed through line **14** to condenser **11**, with return of condensed vapor through line **12** to vessel **5**. Uncondensed vapors from condenser **11** that exits through line **13** may be disposed of or treated as described more fully hereinafter. In the apparatus assembly shown, a suitable means, such as pump **7** is provided for pumping of the liquid that accumulates in tower **5** and passes through line **8**, to liquefied gas storage.

With use of such an apparatus assembly for removal of liquefied gas from the cavern, and prior to the start of operations for withdrawal of liquefied gas, the receiving vessel **5** and liquid withdrawal conduit **4** are full of propane vapor at the condensation pressure of propane at the temperature of the cavern. For start of the operation for transference of liquefied propane, compressor **10** is started whereby vapor is withdrawn from conduit **4**, the pressure in receiving tank **5** is reduced, and liquid propane begins to rise in conduit **4**. Propane is vaporized from the surface of the liquefied propane in conduit **4** until the liquid is chilled to a reduced saturation temperature at which time the pressure in the receiving vessel **5** is further reduced and the liquid rises further in conduit **4**. As rise of liquid occurs in conduit **4**, the vaporization that occurs below the surface of the liquid in the conduit forms a liquid-vapor mixture of reduced density as compared to the liquid itself which results in elevation of the liquid in the conduit. Such a process of vaporization from the surface of the liquid propane in the conduit, chilling of the liquid propane to a reduced saturation temperature, and resultant reduction in pressure in the receiving vessel continues until the vapor-liquid mixture in conduit **4** rises to receiving vessel **5**. In vessel **5**, the liquid-vapor mixture entering therein from conduit **4** disengages into its vapor and liquid components due to reduction in velocity in vessel **5** which is of larger cross-sectional area than conduit **4**. The vapor passes out through line **9** and compressor **10** to condenser **11** wherein condensation of propane vapor is effected and condensed propane is returned via line **12** to the receiving vessel. Uncondensed vapor that may pass through condenser **11** and exiting via line **13** may be vented to the atmosphere or, if desired, may be returned to the cavern. The liquid propane disengaged in vessel **5** accumulates in that vessel and is withdrawn via line **6** through pump **7** to an above ground liquid propane storage facility. In an operation as aforedescribed, in which expansion of liquid propane occurs in conduit **4**, a result of such expansion is the release of potential energy which is utilized by the liquid in its self-elevation with resultant increase of velocity in conduit **4** and overcoming friction in the conduit.

In order to illustrate practice of an embodiment of the invention, but without intent of limitation thereto, the following data are presented. Such data are illnstrative of results obtained by use of a system as aforedescribed for withdrawal of liquefied propane from an underground cavern of the labyrinth type of the following characteristics:

Cavern volume (cu. ft.)	860,000.
Cavern surface (sq. ft.)	140,000.
Liquid surface (sq. ft.)	50,300.
Depth (ft.) of cavern below ground level	360.
Material stored in cavern	Liquid propane.
Pressure in cavern	105 p. s. i. g.
Temperature in cavern	65° F.

For liquid propane withdrawal from such a cavern, the receiving vessel **5** consisted of a steel tank 5 feet in diameter (internal) and 10 feet in height and conduit **4**, communicating with the receiving vessel and the liquid propane in the cavern, consisted of a metal pipe having an internal diameter of 4 inches. With the conditions existing in the cavern as aforedescribed and by controlling the conditions in vessel **5** to a pressure of 68 lbs. p. s. i. g. and a temperature of 35° F., liquid propane was withdrawn from the system via line **8** at an average rate of 120 gals./min. over an 8 hour period. An important feature is that for such an embodiment, the amount of vapor withdrawn via line **9** amounted to only about 8% by weight of the liquefied propane withdrawn from the system.

Although the particular conditions employed in the described embodiment provided particularly effective withdrawal of propane in liquid form from the cavern, it should be understood that the conditions for liquefied gas withdrawal may be varied depending on the particular conditions, such as temperature and pressure, that exist in the cavern, and the elevation above the cavern to which it is desired to transfer the liquefied gas. Thus, for a particular application, the temperature and pressure of the receiving vessel is correlated with the corresponding conditions existing in the cavern to provide a pressure differential between that in the cavern and the receiving vessel such that active boiling of the liquid in conduit **4** occurs to provide a self-actuating lift for the liquid from the cavern to the receiver as aforedescribed. Moreover, the pressure differential between the receiving vessel and cavern should be so controlled that a large flash vaporization is not obtained and which would result if too large a pressure differential is employed. Thus, in practical embodiment, the conditions existing in the cavern are so correlated with those in the receiving means whereby the mixture entering the receiving means is substantially composed of liquefied gas and, for example, consisting of about 80 to 90% or more of liquid in transference of a liquefied gas such as propane, and a somewhat lower proportional amount of liquid to vapor in the case of a heavier gas such as butane.

It should be apparent from the foregoing description of the invention and the data presented herein that practice of the invention provides a highly practical and effective method for transference of liquefied gases, without substantial vaporization thereof, from an underground cavern of exceptionally large internal surface area to an elevation substantially above the cavern. Provision of a method and apparatus assembly that provides for such elevation of liquefied gases to above ground level from underground caverns at considerable depth without substantial vaporization and without need for resort to pressurizing of the cavern clearly provides a marked advance in the art for withdrawal of liquefied gases from underground caverns.

It should be further apparent to those skilled in the art that modifications may be made without departure from the spirit of the invention. For example, and in the apparatus assembly as aforedescribed, means may be included, if desired, for further control of the system by use of a liquid level indicating device in receiving vessel **5** for controlling the level of the liquid accumulating therein. Such control on the liquid level may be effected by having the liquid level device actuate pump **7** to adjust the discharge of pump **7** so as to maintain a desired liquid level in vessel **5**.

While there are above disclosed but a limited number of embodiments of the invention herein presented, it is possible to produce still other embodiments without departing from the inventive concept herein disclosed, and it is desired therefore that only such limitations be imposed on the appended claims as are stated therein.

What is claimed is:

1. A method for withdrawing a liquefied gas, stored in an underground excavated cavern, through a confined conduit means providing open communication between the liquefied gas in the cavern and a receiving zone disposed at an elevation substantially higher than said cavern, said liquefied gas being stored in said excavated cavern which is disposed at a sufficient depth such that the liquid head in the conduit, when said conduit is full of liquefied gas, is greater than the static pressure in said cavern and

said cavern is further characterized by being of such large internal surface area that flow of liquefied gas through the conduit into the receiving means is not obtainable by substantial pressurizing of the cavern with a gas such as is stored in liquefied form in the cavern, which comprises maintaining in said receiving zone a pressure lower than the pressure existing in said cavern to provide a pressure differential less than sufficient to vaporize a substantial amount of liquefied gas in said conduit but to vaporize a controlled relatively small amount by weight of liquefied gas in the conduit to reduce the density of the liquefied gas and static pressure in the conduit sufficiently to provide a self-actuating lift of said liquefied gas, in admixture with a relatively small amount of vaporized liquefied gas, through said conduit and into the receiving zone, and disengaging liquefied gas from the mixture that enters the receiving zone.

2. A method, as defined in claim 1, wherein the liquefied gas is propane.

3. A method, as defined in claim 1, wherein the liquefied gas is propane and the pressure differential between the cavern and receiving zone is controlled to vaporize not more than about 10% by weight of the liquefied propane in the conduit.

4. In combination with an underground excavated cavern in which a liquefied gas is stored, a receiving means disposed at an elevation substantially higher than said cavern, a confined conduit means providing open communication between said cavern and said receiving means, said cavern being disposed at a depth such that the liquid head in the conduit, when said conduit is full of said liquefied gas, is greater than the static pressure in said cavern and said cavern being further characterized by having an internal surface area sufficiently large that liquid flow through the conduit into the receiving zone is not obtainable by substantial pressurizing of the cavern with a gas of substantially the same composition as the stored liquefied gas, and pressure-controlling means for controlling the pressure in said receiving means to a pressure lower than the pressure in said cavern to provide a pressure differential between said cavern and receiving zone that is not sufficiently large to vaporize a substantial amount of the liquefied gas in said conduit but to vaporize a controlled, relatively small amount by weight of said liquefied gas in said conduit, to sufficiently reduce the density of the liquefied gas and static pressure in said conduit to provide a self-actuating lift of said liquefied gas, in admixture with a relatively small amount of vaporized liquefied gas, through said conduit and into the receiving zone, and means for withdrawal of liquefied gas from said receiving zone.

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