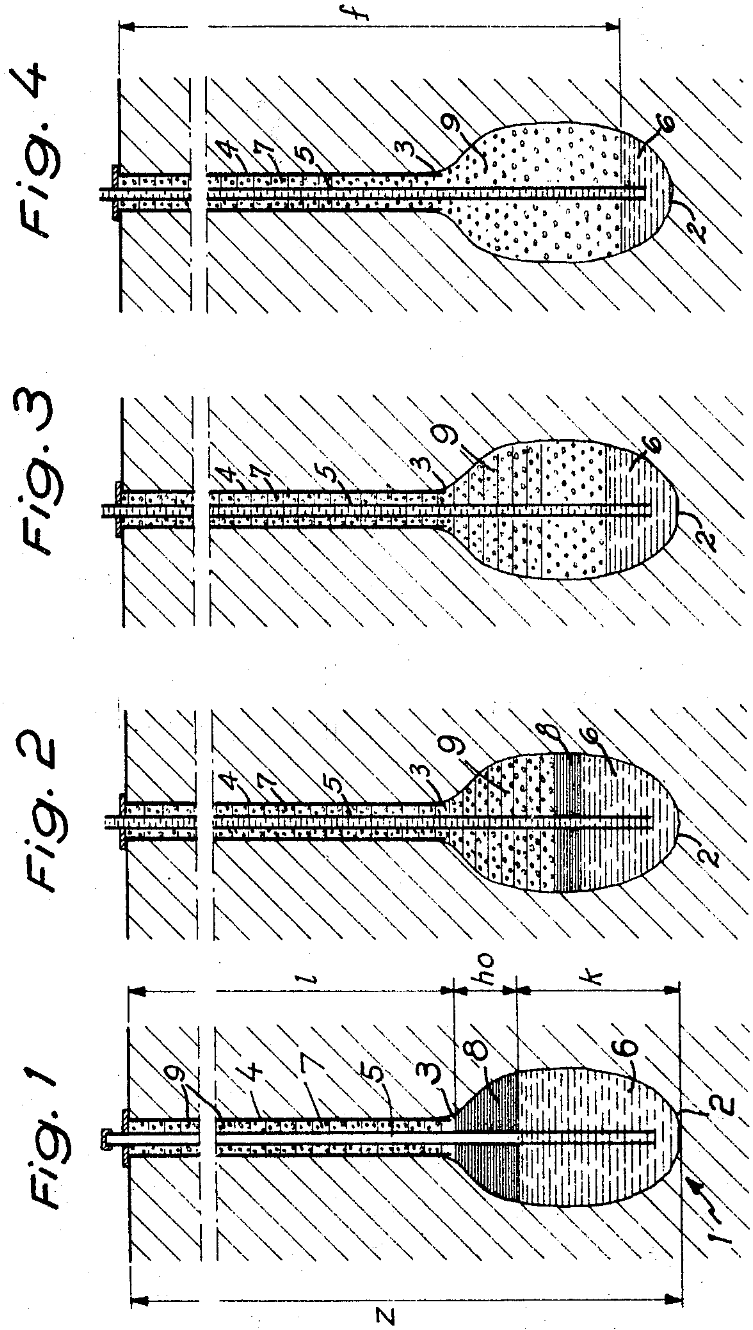
Aug. 5, 1969 | H. CLAMENS | 3,459,002

METHOD FOR THE SUBTERRANEAN STORAGE AND WITHDRAWAL OF A LIQUID

Filed Oct. 11, 1966 | 2 Sheets-Sheet 1




INVENTOR
HENRI CLAMENS
BY
Bacon & Thomas
ATTORNEYS

Aug. 5, 1969 H. CLAMENS 3,459,002

METHOD FOR THE SUBTERRANEAN STORAGE AND WITHDRAWAL OF A LIQUID

Filed Oct. 11, 1966 2 Sheets-Sheet 2

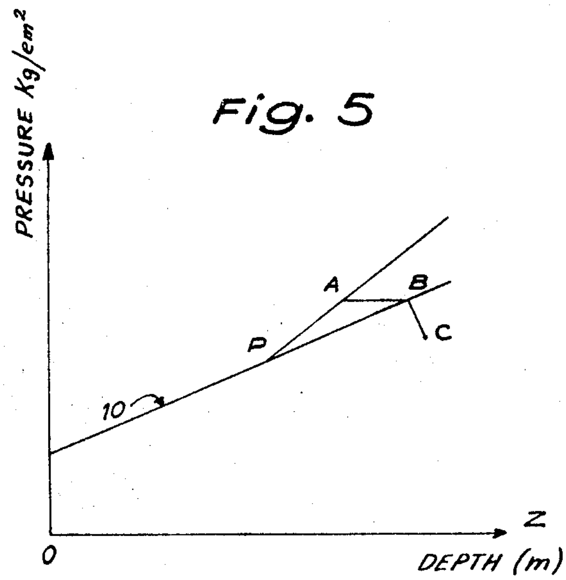



Fig. 5

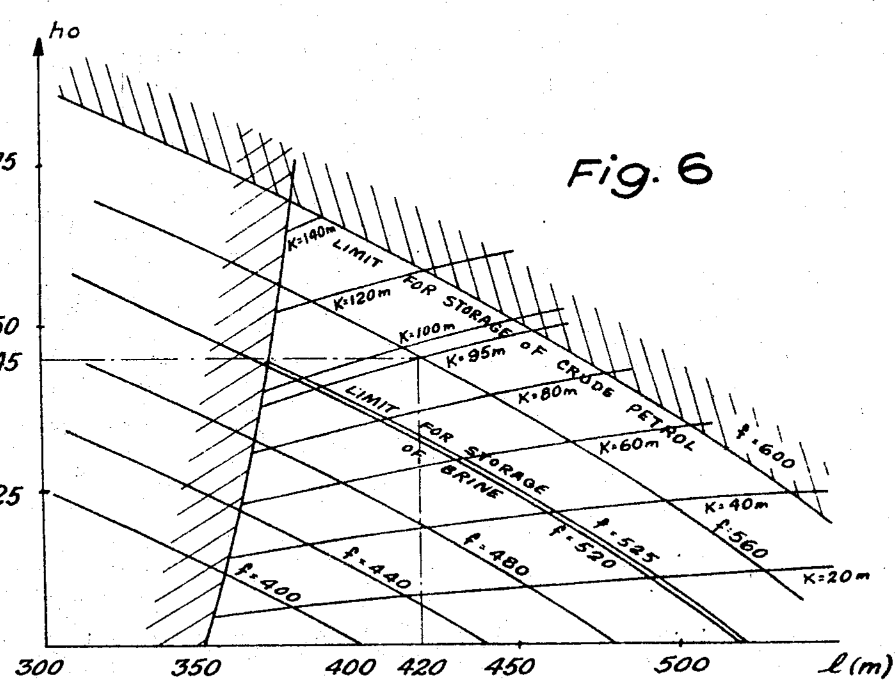



Fig. 6

INVENTOR
HENRI CLAMENS
BY
Bacon & Thomas
ATTORNEYS

United States Patent Office

3,459,002

Patented Aug. 5, 1969

1

3,459,002

# METHOD FOR THE SUBTERRANEAN STORAGE AND WITHDRAWAL OF A LIQUID

Henri Clamens, Pau, France, assignor to Societe Nationale des Petroles d'Aquitaine, Paris, France

Filed Oct. 11, 1966, Ser. No. 585,958
Claims priority, application France, Oct. 13, 1965, 34,759
Int. Cl. B65g *5/00;* E21f *17/16*
U.S. Cl. 61—.5 6 Claims

## ABSTRACT OF THE DISCLOSURE

Tubing connects the summit of the cavity formed in a saline formation to the surface, and a column of withdrawal tubes is disposed coaxially within the tubing and descends to a short distance from the bottom of the cavity. The cavity is partially filled with liquid to be stored by the annular space between the tubing and the column of tubes and there is disposed above the stored liquid, a cushion of liquefied gas in equilibrium with the vapor phase above it, sent through the annular space between the tubing and the column of tubes. The depth of the cavity, the height of the liquid stored in the cavity, and the height of the cushion of liquefied gas, is selected in such a way that at the moment of withdrawal practically all the liquid is evacuated from the cavity when all of the liquefied gas is vaporized.

The present invention relates to a method for the subterranean storage and withdrawal of a liquid, and more particularly of brine or crude petrol, in and from an excavated cavity in a saline geological formation.

Subterranean storage and withdrawal methods for such liquids are already known, which consist after storage, of introducing the liquid to be stored into a subterranean cavity excavated in a layer of salt, by the intermediary of a tube connecting the summit of this cavity to the surface, in the interior of which is disposed coaxially a column of withdrawal tubes descending into the cavity to a short distance from the bottom of the latter, then, at the moment of withdrawal, sending to the surface of the stored liquid, by the annular space between the tubing and the column of tubes, a gas under pressure, which forces the liquid to ascend in the column of tubes and to thus evacuate the storage cavity.

After the expansion of the gas, the pressure exerted by the gas on the liquid decreases rapidly and very substantially, such that if it is desired to extract a considerable quantity of said liquid, it is necessary to resupply the annular space between the tubing and the column of withdrawal tubes with supplementary quantities of gas under pressure which obviously necessitates, during the evacuation of stored liquid, the functioning of the compression installation provided at the surface. It follows that this compression installation is necessarily fixed. Due to the fact that with storage and withdrawal processes using the expansion of a previously compressed gas the available pressure is relatively slight, the output of liquid being extracted is fairly limited.

It is an object of the present invention to overcome the aforementioned drawbacks and particularly to provide a subterranean storage and withdrawal method for a liquid such as brine or crude petrol in and from the cavity excavated in a saline formation, said method permitting the evacuation of a considerable volume of liquid within a relatively short time and at a fairly high and constant pressure during the whole duration of the evacuation of the liquid without it being necessary throughout the entire duration of the evacuation to call upon compression or pumping means disposed at the surface or at the bottom of the cavity.

2

According to the present invention there is provided a subterranean storage and withdrawal of a liquid, such as brine or crude petrol, in a cavity, excavated in a saline formation, the summit of which cavity is connected to the surface by the intermediary of a tubing, in the interior of which is disposed coaxially a column of withdrawal tubes descending into the cavity to a short distance from the bottom of the latter, according to which method the cavity is filled with the liquid to be stored by the annular space between the tubing and the column of tubes to the surface of the liquid, and the pressure of a compressed fluid is used to evacuate the liquid through the column of tubes, wherein, for storage the cavity is only partially filled with the liquid to be stored and there is disposed above the liquid, a cushion of liquefied gas in equilibrium with the vapour phase surmounting it, sent through the annular space between the tubing and the column of tubes, the depth of the cavity, the height of the liquid stored in this cavity and the height of the cushion of liquefied gas, being selected in such a way that at the moment of withdrawal practically all the liquid is evacuated from the cavity when all the liquefied gas is vaporised.

The cushion of liquefied gas preferably extends to the summit of the cavity. In order that the invention may be more clearly understood the following description of an embodiment according to the invention is given purely by way of non-limiting example, with reference to the accompanying drawings in which:

FIGURE 1 shows in schematic section a storage cavity filled with liquid and liquid carbonic gas,

FIGURES 2, 3 and 4 are analogous view of FIGURE 1 showing the various stages of withdrawal,

FIGURE 5 shows the curves of pressure variation of the carbonic gas, as a function of the depth, and

FIGURE 6 shows a graph for the utilisation of the method, drawn for a geothermic gradient of 3° C. per 100 meters.

Referring now to the drawings, in FIGURE 1, the storage and withdrawal installation used comprises a cavity **1**, of which the bottom **2** is at the depth $z$ and the summit **3** at the depth $l$, and which is connected to the surface by a tubing **4**, in the interior of which is disposed, coaxially, a column of tubes **5** descending to a short distance from the bottom **2** of the cavity **1**.

During storage, the cavity **1** is filled with a liquid to be stored **6**, to a predetermined height $k$, reckoned starting from the bottom **2** of the cavity **1**, by the annular space **7** between the tubing **4** and the column of tubes **5**, then is led in by the same annular channel liquefied carbonic gas **8**, forming a cushion of height $ho$ above the stored liquids **6**.

In general, it is sought to store the maximum of liquid in the cavity, and the heights $k$ and $ho$ are calculated in such manner that the cushion of liquid carbonic anhydride **8** comes to the level of the summit **3** of the cavity **1**. Then the tubing **4** is hermetically sealed at the surface to the column of tubes **5**. The liquid carbonic anhydride **8** is then in equilibrium with a diphasic mixture **9** of liquid and with vapour carbonic anhydride contained in the annular space **7**.

In fact, knowing the variation of the pressure of saturated vapour as a function of the temperature, and the average geothermic gradient of the sub-soil in which the cavity **1** is excavated, it is possible to deduce therefrom the curve **10** of the variation of the saturated vapour pressure of the carbonic gas as a function of the depth. For an average geothermic gradient in the vicinity of 3° C. per 100 meters, this curve, appreciably straight, is shown in FIGURE 5.

At the surface of the cushion of liquefied gas **8**, the vapour is saturated, and the pressure of this vapour may be reduced from the straight line **10** of FIGURE 5 and corresponds, whatever may be the height of this surface, with the pressure exerted on a column of the same height as a fluid of density 0.4. The density of the liquid carbonic anhydride being 0.8 and that of the gaseous carbonic anhydride being around 0.2, it results that the fluid **9** occupying the annular space **7** corresponds to a diphasic mixture of liquid and vapour.

In a general fashion, for a geothermic gradient comprising between 3° and 4° per 100 meters of height, the density of the column of corresponding fluid is between 0.3 and 0.6 and the fluid **9** corresponds then always to a diphasic mixture of liquid and vapour, of which the pressure at each height is the saturated vapour pressure provided by reading the curves **10** of FIGURE 5.

Pressure at the interface, carbonic anhydride **8**-stored liquids **6** is equal to the pressure above the cushion of liquedfied gas (point P of curve **10**) increased by the pressure exerted by the height *ho* of the liquefied gas of density 0.8; this pressure is represented by the point A of FIGURE 5, and the curve representing the variation of the pressure in the stored carbonic anhydride as a function of the depth is the curve OPA.

In order to avoid all risk of cracking the saline formation at the summit **3** of the cavity **1**, a pressure limit is imposed on this summit **3** fixed at 0.16*l* in normal exploitation, which represents a sufficient safety margin.

On the other hand, during withdrawal, which is started by opening the closing valve of the column of tube **5** at the surface, the pressure of withdrawal is the difference between the pressure above the stored liquid **6**, at the interface of the cushion of liquefied gas **8** and of this liquid **6**, and the pressure due to the weight of the height of withdrawn liquid in the column of tubes **5**. The fact that the pressure of the column of withdrawn liquid grows more quickly with the depth then the vapour pressure of the carbonic gas, leads to a limit in the maximum depth of storage. Practically, the two preceding conditions involve the following limits for the depth of cavity **1**:

$350m<z<525$ meters for brine and

$350m<z<600$ meters for crude petrol of density 0.8, for an average geothermic gradient of 3° C. per 100 meters.

Under the effect of the pressure of withdrawal, which is practically always greater than 15 kg. cm.², the interface of the liquid carbonic anhydride **8** and of the stored liquid **6** drops, and the height of the cushion of the liquefied gas **8** diminishes (FIGURE 2).

The increase in the saturated vapour pressure with depth and the decrease of the pressure due to the diminution in height of the cushion of liquefied gas **8** substantially compensates, and the pressure above the stored liquid is appreciably constant, whilst the liquefied gas **8** remains.

At the moment where the liquid phase **8** disappears, the pressure of the surface of the liquid is represented by the figurative point B in FIGURE 5 and the vapour phase appears above the brine or the crude petrol to be withdrawn; the interface between the diphasic carbonic anhydride and the vapour carbonic anhydride reascends towards the top (FIGURE 3), until the pressure of the vapour and the surface of the liquid to be withdrawn (point C of FIGURE 5) balances exactly that of the column of this liquid in the column of tubes **5**, which then occurs rapidly. The withdrawal is terminated (FIGURE 4) and the stored liquid is at the final mark *f*.

It is noted then that the height *ho* of the cushion of liquid **6**, must be calculated from the results furnished by the curves of FIGURE 5, as a function of the height $(z-l)$ of the cavity **1** and of the depth $z$ of this cavity, from which calculation there is reduced the useful height $k$ of liquid which can be stored in a cavity given by the relation:

$$k=z-l-ho$$



if it is desired that this cavity should be filled to the maximum.

In practice, for a given goethermic gradient, and taking into account the previously stated limits for the depth of this cavity, there is established a graph of the type of that which is represented in FIGURE 6 and which gives simultaneously for a distance $l$ on the summit **3** of the cavity **1** to the surface, the height of the initial cushion of liquid gas **8** for a height of liquid to be withdrawn $k$, or for a final mark $f$ of the liquid at the end of withdrawal.

For each given geothermic gradient there corresponds a graph analogous to that of FIGURE 6, traced for a geothermic gradient 3° C. for 100 meters.

By way of example, it is estimated that if in a soil of which the geothermic gradient corresponds to the previous graph, there exists a layer of salt of which the roof is at 420 meters and the wall at 560 meters, one could between the two marks effect a cavity in the saline layer which would permit, with an initial cushion of liquid carbonic anhydride of 45 meters height, stocking of crude petrol at a height of 95 meters.

The advantages of the method which has been described are numerous, first of all, residing in the elimination of the compression installation, once the cushion of liquid carbonic anhydride **8** is constituted at the moment of storage.

In certain cases however, it may be necessary to restore provisionally the compression installation to compensate the losses due to solution of carbonic anhydride in the stored liquid.

This advantage is due principally to the existence of practically constant a pressure at the interface of the liquid carbonic anhydride and of the stored liquid.

Due to this method it is possible to dispense entirely with the storage at the surface of brine used normally for evacuating crude petrol filling another cavity.

However, the use of the brine itself may also be suppressed, by storing the cushion of liquid carbonic anhydride directly above crude petrol.

In this case, there is a very high output of crude petrol withdrawal due to the high pressure of withdrawal offered by the above process.

It is also possible to profit from this advantage, by reducing the output of withdrawal, but increasing the loss of charge on withdrawal, by the adoption of a small diameter for the column of tubes **5**, from which arises the possibility of effecting a drilling of reduced diameter, hence more economical.

The carbonic gas used for the application of the method is manufactured from separator gas, by combustion and drying, gas which in the countries of high crude petrol production is currently burnt without being used.

Finally, another advantage of the method according to the invention, resides in the possibility of using the carbonic anhydride under pressure in the annular space **7** as extinction material against a fire which is always possible in petroleum installations.

It is well understood that the object of the previously described invention, is not limited to the embodiment indicated above, but comprises on the contrary all the variations in the application of this method.

I claim:

**1.** A method for the subterranean storage and withdrawal of a liquid, such as brine or crude petrol, in a cavity excavated in a saline formation, wherein tubing connects the summit of the cavity to the surface and a column of valved withdrawal tubes is disposed coaxially within said tubing and descends to within a short distance from the bottom of the cavity, said method comprising; filling the cavity with liquid to be stored by the annular space between the tubing and the column of tubes to a height below the summit of the cavity and substantially above the lower end of the column of tubes; filling the remainder of the cavity and the space between the tubing and the column of withdrawal tubes with a cushion of liquefied gas in the equilibrium with the vapor phase above it; immediately confining the liquefied gas in said cavity and in the said annular space and permitting it to build up pressure therein by sealing, at the upper end thereof, said annular space between the tubing and the column of tubes and closing the valves of the withdrawal tubes, and at a suitable time thereafter, withdrawing the stored liquid from the cavity solely by opening the valves closing the column of withdrawal tubes and permitting the pressure resulting from the vaporization of said liquefied gas to force the stored liquid out of the cavity through the column of withdrawal tubes, the depth of the cavity, the height of the liquid stored in the cavity, and the height of the cushion of liquefied gas, being selected in such a way that, at the moment of withdrawal, practically all of the liquid stored above the lower end of the column of withdrawal tubes is evacuated from the cavity when all of the liquefied gas is vaporized.

**2.** A method according to claim **1**, wherein the cushion of liquefied gas extends to the summit of the cavity.

**3.** A method according to claim **1**, wherein the pressure at the summit of the cavity expressed in kg./cm.$^2$ is less than 0.16 times the depth of the summit expressed in meters.

**4.** A method according to claim **1**, wherein the liquefied gas is carbonic anhydride.

**5.** A method according to claim **4**, wherein for an average geothermic gradient of 3° C. per 100 meters, the depth of the summit of the cavity is greater than 350 meters for storage of brine and for crude petrol.

**6.** A method according to claim **4**, wherein for an average geothermic gradient of 3° C. per 100 meters the depth of the bottom of cavity is less than 525 meters in the case of storage of brine, and than 600 meters in the case of storage of crude petrol of density 0.85.

**References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 2,623,596 | 12/1952 | Whorton et al. | 166—7 |
| 2,729,291 | 1/1956 | Haverfield | 166—7 |
| 2,961,841 | 11/1960 | Giles | 61—.5 X |
| 3,084,743 | 4/1963 | West et al. | 166—9 |
| 3,108,636 | 10/1963 | Peterson | 166—42 |

EARL J. WITMER, Primary Examiner