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Kuhne

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[54] **UNDERGROUND STORAGE OF GAS**

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[51] **Int. Cl.** **B65g 5/00**

[58] **Field of Search** 61/.5; 48/190

[56] **References Cited**

UNITED STATES PATENTS

1,934,029	11/1933	Asbury	48/190
2,930,197	3/1960	Carpenter	61/.5
3,056,265	10/1962	Swinney	61/.5
3,355,893	12/1967	Kuhne	61/.5
3,491,540	1/1970	Lennemann	61/.5

FOREIGN PATENTS OR APPLICATIONS

668,782	8/1963	Canada	61/.5

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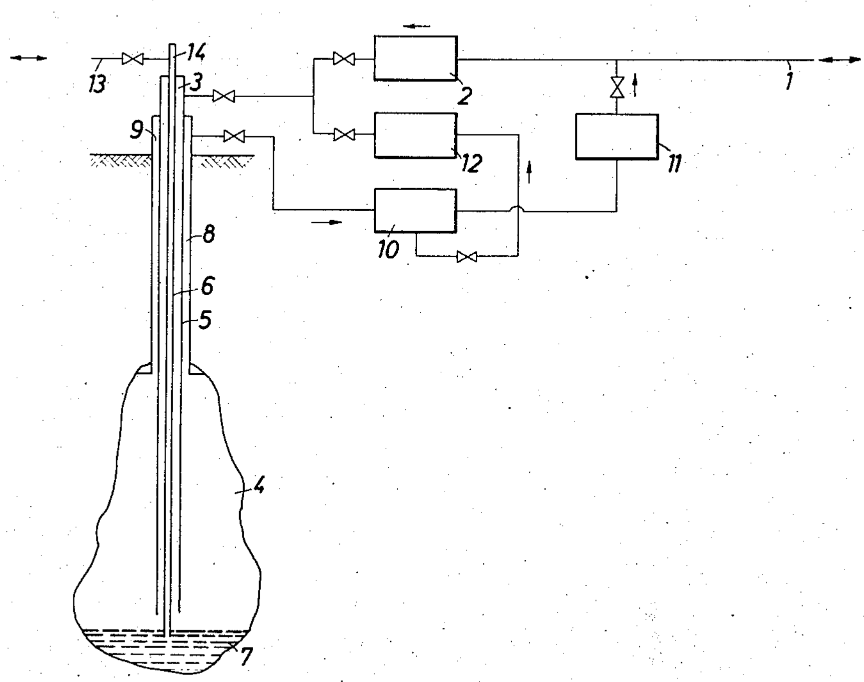
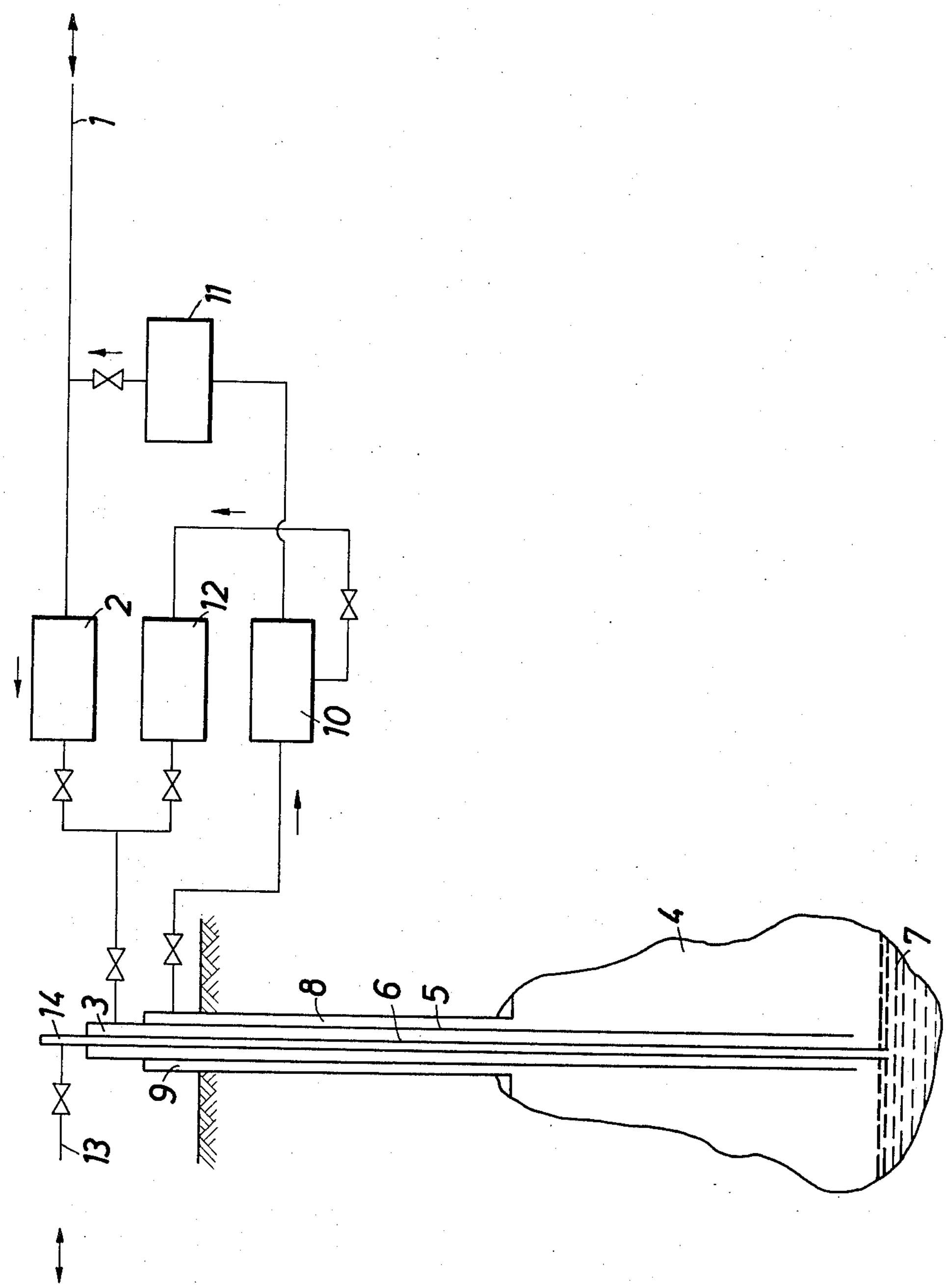
[57] **ABSTRACT**

A method is disclosed for storage of a gas which is soluble in a liquid hydrocarbon in an underground storage cavity wherein the cavity is continuously filled with liquid even when recovering the gas.

7 Claims, 1 Drawing Figure

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UNDERGROUND STORAGE OF GAS

BACKGROUND OF THE INVENTION

The invention relates to a method and to apparatus for the storage recovery of gases soluble in liquid hydrocarbons in and from underground cavities, caverns or voids.

It is known to use underground caverns for storing gases and liquids for the purpose of covering peak requirements and for storing hydrocarbons, particularly crude oils, middle distillates and lighter hydrocarbons, for the building up of stocks. Gases, particularly natural gas, are stored in and extracted or withdrawn from the stores by compression and expansion of the contents of the "dry" caverns. For this purpose, the pressures must not be below a determined minimum pressure for the sake of the required stability, and must not exceed a determined maximum pressure by reason of the limited resistance of the rock to fracture, both being dependent upon the existing depth.

Thus, for example, in German Auslegeschrift No. 1,246,641 there is described a method for the subterranean storage of liquids in a cavern in a salt deposit. In this method, the pressure of a compressed medium is used for withdrawing the liquid through a rising tube. The method is characterized in that for the storage only part of the cavern is filled with the liquid to be stored, there being introduced over the liquid, and preferably up to the roof of the cavern, cushion of liquefied gas in equilibrium with the overlying vapor phase, the depth of the cavern, the level of the liquid stored in the cavern and the height of the cushion of liquefied gas being so selected that upon withdrawal substantially all of the liquid is removed or extracted from the cavern when all of the liquefied gas has evaporated.

This method has the disadvantage that the salt cavern is not always completely filled with the stored liquid. Moreover, this method is used exclusively for the storage of liquids, the dissolved gas serving solely as the drive medium for the extraction or withdrawal of the liquid.

It is also known that gases which are soluble in hydrocarbons may be dissolved in liquid hydrocarbons stored underground.

In contrast to the former method, the latter method involves exclusively the storage of gaseous hydrocarbons.

The invention disclosed in U.S. Pat. No. 2,930,197 relates to a method and to apparatus for the storage of gaseous petroleum components or derivatives under high pressure in caverns, and particularly to the storage of such components as ethylene. The gas is stored by introducing it into the cavern through a pipe line which terminates below the surface of a quantity of oil pumped into the cavern. As the gas rises through the oil, a portion of the rising gaseous petroleum constituents dissolves in the oil. The undissolved gas is returned to the first pipe line through a second pipe line provided in the above-ground portion of the borehole tubing and is then pumped back into the body or pool of oil in the cavern. This process is repeated until the oil is saturated with the gas. The internal pressure in the cavern may amount to about 32 to 70 atmospheres according to the amount of ethylene dissolved in the oil, for example n-heptane. The gas is recovered by opening a valve in the above-ground portion of the borehole tubing. The dissolved gas is liberated by the absorption oil as a result of the increased temperature internally of the cavern when the pressure in the cavern falls upon opening of the valve. This method has the disadvantage that, according to the U.S. Pat. No. 2,930,197, only part of the cavern is filled with the absorbing liquid and the borehole is never filled therewith to a level which is above-ground, that is, to above ground level, and is thus subject to excess pressure increases with increasing gas filling. This excess pressure, particularly at the generally occur depths of salt deposits is unable to prevent the cavern from being reduced in size and even being completely closed by the flowing together of rock salt already plasticized by the rock pressure.

Owing to the plastic properties of salt formations or deposits, the greater the tendency of the voids or cavities, particularly salt caverns, to shrink the lower the counter-pressure exerted by their contents (i.e., liquid and gas) upon the rock faces or walls. The time for which caverns of this kind can be used is determined by the ratio of the internal pressure to the rock or roof pressure. The range of fluctuations of the rock or roof pressure has disadvantageous consequences, since shrinkage stresses rise due to partial relief or evacuation. This is a slow process because when the internal pressure rises again, these impulses for movement are not reduced immediately and decay only over an extended period of time.

Caverns constantly filled with a liquid are much less susceptible to these convergence-accelerating tendencies. The shrinkage may even be virtually completely suppressed if the pressure of the liquid completely filling the cavern is increased to the order of magnitude of the rock or roof pressure. This occurs automatically where the discharge of liquid from a cavern with liquid is stopped by means of a shut-off device or valve provided at the top of the borehole. The internal pressure produced in the cavern by residual shrinkage approaches asymptotically the rock or roof pressure with simultaneous utilization of the compressibility of the fluid.

It has also been proposed to store natural gas or methane in chilled liquid propane. In order to attain practical significance, this method involves a high capital expenditure for the necessary heat insulation and considerable operating costs for maintaining a constant low temperature in the storage tank or container. This method seeks to convert the natural gas and propane and/or butane, if necessary with an admixture of air into a mixture having appropriate combustion qualities and to offer such mixture to the consumer.

It is an object of this invention to provide a method for the storage and recovery of gases, which are soluble in liquid hydrocarbons in and from subterranean caverns in which the changing loads or stresses applied to the caverns are avoided or substantially reduced whereby a substantially constant storage volume may be maintained.

SUMMARY OF THE INVENTION

A method for the storage in, and recovery from, an underground cavern a gas solublized in a liquid hydrocarbon solvent therefrom which comprises introducing the gas to be stored into a cavern which is completely filled with liquid all or a part of which comprises the solvent to form a rich solvent solution of the gas and recovering the dissolved gas by withdrawing rich solvent from the cavern and thereafter reducing the pressure on the rich solvent in order to liberate the dissolved gas, while replacing the rich solvent with a pressure-equalizing amount of a liquid comprising lean solvent or a displacement liquid or both.

DESCRIPTION OF THE INVENTION

In the method according to the invention, the gas or gases to be stored are introduced through a feed pipe which extends to the lower part of a subterranean cavern which is filled completely with liquid hydrocarbons in which the gases dissolve, the cavern being in communication through a borehole with aboveground, the gases being recovered by withdrawal of the liquid hydrocarbons containing the dissolved gases by expansion.

The gas to be stored may be any normally gaseous material, for example, hydrogen, methane, ethane, propane, ethylene and propylene.

The method according to the invention affords the advantage that the cavern is filled completely with a liquid medium and a deformation or reduction in the size of the cavern is thus substantially avoided.

A distinctive feature of the method according to the invention comprises replacing rich solvent withdrawn from the cavern with a volume of liquid corresponding to the volume of withdrawn liquid is introduced to the cavern so that the liquid volume may remain equal and the pressure ratios or conditions may be maintained substantially constant. The liquid so introduced may comprise lean solvent or may comprise a higher specific gravity liquid which is preferably introduced through a further pipe which extends into the lower part of the cavern and terminates below the orifice of the gas feed pipe.

This development affords the advantage that the internal pressure in the cavern remains substantially constant even upon extraction or withdrawal of the rich solvent containing dissolved gas.

The preferred liquid of higher specific gravity is water, particularly salt water which is introduced into the cavern. Alternatively, the salt water in the sump or bottom of a salt cavern may be used for equalizing the liquid volume and for maintaining substantially constant the pressure ratios or conditions.

The invention also comprises apparatus for carrying out the method, the apparatus being characterized in that the borehole extending into the underground cavity or cavern is associated with a feed pipe one end of which extends into the lower zone or part of the cavern whilst its other end above ground is connected by a pipe line to a device for conveying the gaseous hydrocarbons to be stored, the upper end of the borehole being also connected by a further line to a separator in which the stored rich solvent may be separated into lean solvent and a gas.

This apparatus enables the gases which are to be stored to be introduced into the lower part of the subterranean cavern filled with liquid which consists wholly or for the major part of one or more liquid hydrocarbons, so that the gases as they rise are dissolved in the liquid hydrocarbon solvent as a result of the prevailing pressure conditions. The cavern is filled with liquid as far as the borehole annular space disposed aboveground, to produce the internal pressure.

The distinguishing feature of another embodiment or modification of the invention consists in the provision of a further pipe by which salt water, for example, in the sump of the cavern is placed in communication with an equalizing or expansion tank disposed above ground, the further pipe being mounted coaxially with the feed pipe to project beyond, and preferably from, the top and bottom ends of the pipe.

The equalization or balancing of the volume by the salt water in the lower zone of the cavern may thus be carried out simultaneously with the withdrawal of the dissolved gases without the stored liquid material returning or flowing to the equalizing or expansion tank.

It follows from the above that the application of the invention affords particular advantages where regulatory provisions have to be met and/or where liquid hydrocarbons have to be stored for building up a stock. The otherwise unused capacity of a cavern is thus additionally utilized for the storage of gases.

The invention is diagrammatically illustrated by way of example in the accompanying drawing which also shows further inventive features.

The subterranean cavity or cavern **4** contains, preferably, crude oil which is free from gas under normal conditions, or a gas-free fraction or refined product thereof, for example a gas oil which is a petroleum fraction having a boiling range between kerosine and light lubricating oils. Methane, for example, is more readily absorbed at low temperatures than at temperatures corresponding to the temperatures which exist in the deposits, stratum or strata in which the cavern is disposed, but the fluids in the cavern are subject to the high pressure applied by the weight of the salt water column which extends to above ground level. Where a depth of 1,000 meters is involved, the pressure may for example, amount to 120 atmospheres. Solubility increases in direct proportion to the pressure. At temperature of 35°C. and a pressure of 120 atmospheres, the solubility of methane in gas oil is about 40 normal cubic meters of gas per cubic meter of gas oil. This implies that 200,000 cubic meters of gas oil absorb 8 million normal cubic meters of gas with only a slight increase in the total volume. Up to 14 million normal cubic meters of gas may be stored by increasing the pressure in the cavern, which pressure may be increased to about 200 atmospheres where a depth of 1,000 meters is involved.

A virtually total recovery of the gas without any residual gas cushion in the store cavern may be obtained in optional cycles by pressure release. For total recovery, the pressure on a volume of the fluid mixture withdrawn from the store cavern is reduced in a separating installation to substantially atmospheric or a still lower pressure. The gas can be passed without further treatment by means of a low-pressure compressor installation to a consumer whilst the liquid product of pressure release, namely the liquid hydrocarbon or hydrocarbons, for example the gas oil, is simultaneously pumped back into the cavern.

The gas to be stored is passed through line **1** to a high-pressure compressor **2** which forces the gas into an annular space **3** in a feed pipe **5** which extends into the lower section of a subterranean cavern **4**, the annular space **3** being formed by the feed pipe **5** and an inner coaxial pipe **6**. The cavern **4** is filled mainly with oil, only the lowermost section into which the pipe **6** extends, being filled with salt water **7** which is immiscible with and has a higher specific gravity than the oil.

The gas introduced under pressure is, as it rises in the oil filling of the cavern, absorbed by the oil; this process may be continued to saturation point.

In accordance with the changing pressure conditions prevailing in the cavern **4** and its associated borehole **8,** which pressure conditions vary according to the depth, a gas cap develops at the upper end **9,** that is at the position of the lowest pressure. When necessary, that is to say, when gas is to be withdrawn from the store, the gas cap may be discharged through a separator **10.** The dry gas leaving the separator **10** is then returned by a low-pressure compressor **11** to the gas network through the conduit **1.** The oil which separates from the gas in the separator **10** is returned by means of a pump **12** to the annular space **3** and thus to the lower section of the cavern.

Upon absorption of the gas, the oil in the cavern increases slightly in volume. This increase in volume is equalized through the pipe **6** which dips into the body of salt water **7** present in the lowermost part of the cavern **4,** a volume of salt water equal to such increase in volume being fed from the upper end of pipe **6** through a line **13** to a salt water tank (not shown). Salt water returns from the tank to the cavern **4** along the same path when the volume of the oil in the cavern is reduced as a result of gas being withdrawn from the cavern. The pressure conditions required for storing the gas by dissolution in the oil are produced by the weight of the salt water column in the pipe **6** which extends from the top **14** of the borehole into the body of salt water **7** present in the lowermost part of the cavern **4.** An equalization of the volume is not necessary when the increase in volume which would otherwise occur can be taken up by the compressibility of the liquids in the cavern in the form of a pressure rise without the walls of the cavern being fractured; this is dependent upon the depth at which the cavern is disposed, that is to say, upon the geological conditions.

I claim:

1. In a method for the storage of a gas which is soluble in a liquid hydrocarbon the improvement which comprises first

introducing the gas into an underground cavern which contains a storage liquid comprising a hydrocarbon in which the gas is soluble in order to at least partially solubilize said gas for storage and, when at least a portion of said gas is to be removed,

removing storage liquid containing said portion of said dissolved gas substantially and,

replacing said storage liquid with a pressure equalizing amount of a replacement liquid of higher specific gravity and immiscible with the storage liquid.

2. A method according to claim **1** in which the replacement liquid is water.

3. A method according to claim **1** in which the replacement liquid is brine.

4. In a method for the storage and recovery from an underground cavern in a salt deposit of a gas comprising hydrogen or a normally gaseous hydrocarbon the improvement which comprises

introducing said gas to be stored into a cavern containing a lean liquid comprising a normally liquid hydrocarbon in which the gas is soluble in an amount sufficient to at least partially solubilize the gas and provide a rich storage liquid,

recovering the dissolved gas by withdrawing rich storage liquid from the cavern by volumetrically displacing the rich storage liquid with water in an amount sufficient to substantially maintain constant pressure conditions and

reducing the pressure thereon to liberate the dissolved gas.

5. A method according to claim **4** in which the water is brine.

6. A method according to claim **4** in which the storage liquid is a petroleum fraction.

7. A method according to claim **4** in which the petroleum fraction is a hydrocarbon petroleum gas oil fraction.

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