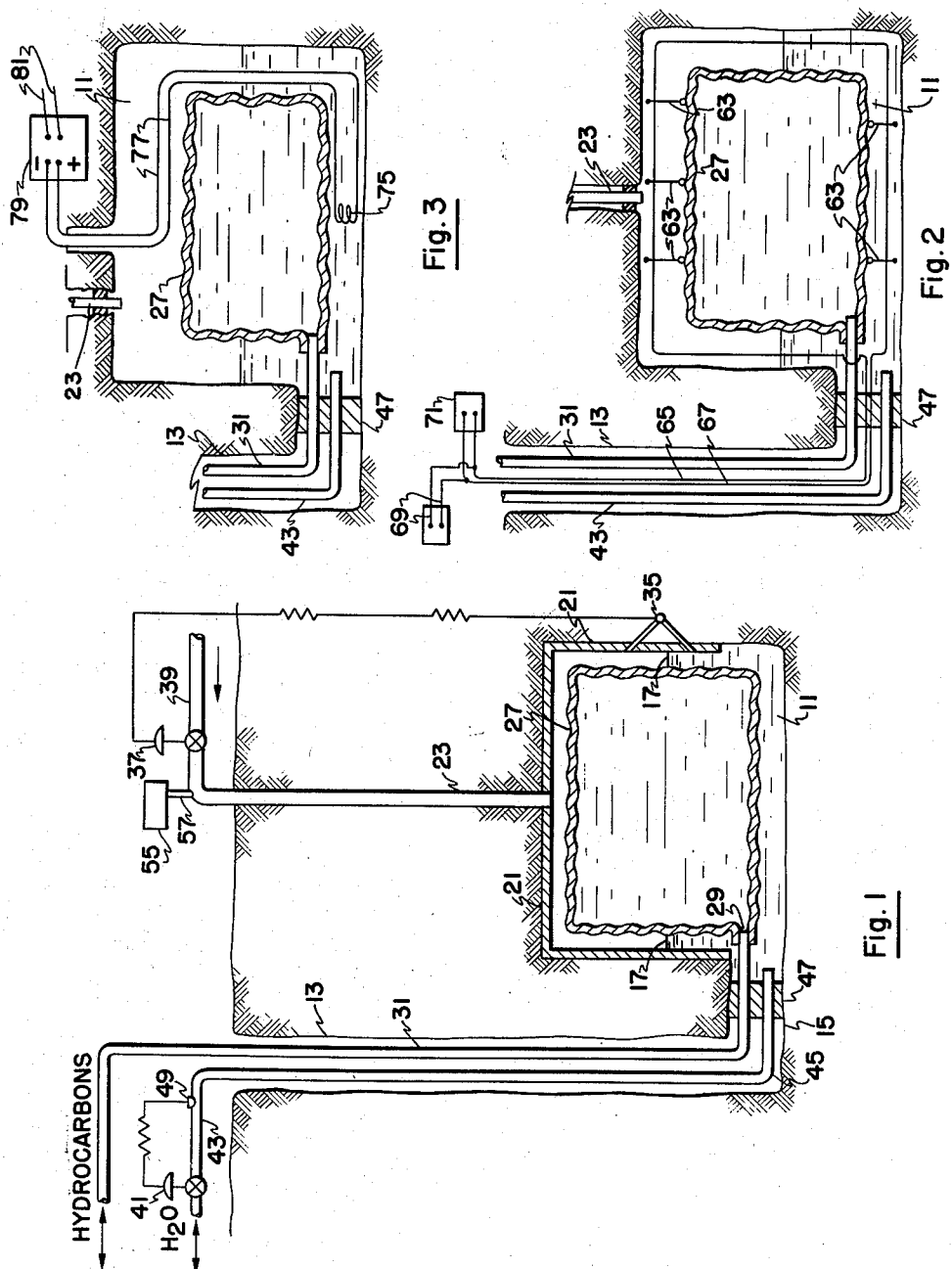


Aug. 2, 1960

K. O. JOHNSON
UNDERGROUND STORAGE RESERVOIR FOR LIGHT
HYDROCARBONS IN SEMIPERMEABLE ROCK
Filed Dec. 20, 1955

2,947,147



Kenneth O. Johnson Inventor

By *Small, Sinkem & Thomas* Attorneys

1

2,947,147

UNDERGROUND STORAGE RESERVOIR FOR LIGHT HYDROCARBONS IN SEMIPERMEABLE ROCK

Kenneth O. Johnson, Chatham, N.J., assignor to Esso Research and Engineering Company, a corporation of Delaware

Filed Dec. 20, 1955, Ser. No. 554,267

7 Claims. (Cl. 61—.5)

The present invention relates to an improved method and system for storing volatile hydrocarbons under pressure. It relates more particularly to a system for storing materials such as propane, butane, mixtures thereof, and other normally gaseous materials, especially organic materials, which can be liquefied at ordinary atmospheric or ground temperatures by mere application of pressure. The system is particularly suited to the storage of liquefied petroleum gas ("LPG") but it may be applied also to storage of gasoline, alcohol, ammonia and other products, some of which are not necessarily gaseous at ordinary pressures.

It has been proposed in the prior art to store underground various liquids of the general type mentioned, especially those such as volatile and non-volatile hydrocarbons. It has also been proposed to use hydrostatic pressure to maintain the liquid state of liquefied petroleum gases and the like. It has also been proposed to use hydraulic pressure to remove stored hydrocarbons as well as other liquids from underground storage.

According to the present invention, use is made of these principles in a novel manner. It is one object of the invention to store volatile liquid products underground in a system where waste and loss of such products is substantially prevented. For this purpose an impervious membrane or liner material is employed. Another object is to employ a combination of gas pressure and hydraulic pressure for collapsing a fluid tight membrane or liner in an underground cavern, to prevent damage thereto by undue contact with rough wall surfaces. Still another object is to simplify and make more economical the construction of underground cavern storage facilities for volatile hydrocarbons, and other liquids. A further object is to detect readily and effectively any leakage of the stored material in such caverns or facilities.

These and other objects will become more readily apparent as this description proceeds. Hence, reference will next be made to the accompanying drawing in which

Fig. 1 shows in diagrammatic form a vertical section through an underground storage system according to the invention;

Fig. 2 shows alternative means for controlling water level, etc., in such a system;

Fig. 3 shows a modification where water pressure, rather than elevation, is used as a control.

An underground cavern, indicated at 11, is formed at a suitable depth in the earth to withstand the vapor pressure of the material to be stored therein. In the case of propane or propylene storage, for example, a storage depth might be around 200 feet or more, although obviously if the earth structure is solid rock, a much lesser depth would suffice. For storage of butane, pentane, etc. required pressures are much less. For ammonia, the required liquefying pressure is roughly the same as for propane or propylene.

The cavern 11 may be formed in any suitable manner, e.g. by sinking a more or less vertical shaft 13 from the

2

surface of the ground to a suitable depth, then tunneling laterally as indicated at 15. The excavated material can then be removed and hoisted to the surface according to well known mining procedures. The cavern walls are made as smooth as reasonably possible. The upper part of the cavern, at least above a water line 17, should at least be caulked to fill large cracks, fissures and voids. It may be coated with a continuous impervious coating 21 if desired, although this is not necessary where the depth below the water table provides hydrostatic pressure greater than the vapor pressure of the stored material, as is preferred. This film, where used, may be a plastic material such as polyvinyl chloride or other hydrocarbon proof coating.

The upper part of the chamber connects to a pipe or shaft 23 leading to the surface of the ground. Upon completion of the excavation and its interior purging or coating 21, a suitable flexible liner 27 or membranous receptacle is provided of a size and shape to fill the entire storage cavern when completely filled. It may be wholly or only partly collapsible, but a substantially completely collapsible liner is preferred.

The liner or membrane 27 is made of any suitable fluid tight and hydrocarbon resistant sheet material such as flexible plastic sheeting, hydrocarbon resistant rubber, imperviously coated textile fabric, and the like. When entirely filled, the membrane is distended until it substantially completely fills the cavern 11. However, it is desirable to keep at least a thin cushion of gas, preferably an inert gas, on all sides of the membrane or liner to avoid large areas of direct contact and consequent abrasion thereof against the cavern walls. The means for substantially preventing such contact will next be described.

The amount of water retained in the cavern is preferably controlled so as to keep it continuously up to a level 17. The reason for maintaining such level is to keep the liner or membranous receptacle 27 afloat at all times, whether full, empty or partly full. Since the hydrocarbon fluids suitable for this type of storage are always of lower specific gravity than water, the filled or partly filled liner is always afloat. If liquids heavier than water are used, float means may be attached to the liner as will be obvious. This liner 27 is attached by a connecting nipple 29 to a pipe or conduit 31 which extends to the surface of the ground. Through conduit 31 the liner 27 may be filled or emptied. The length and width of the liner and the manner of its attachment to pipe 31 are such that it tends, even when full, to float free of all surrounding walls and provide a space for water on all sides as well as at the bottom.

With the arrangement just described, the liner 27, especially when quite full, would tend to float against the ceiling of the cavern. Such floating would permit direct contact between the liner top surface fibres and the earth strata from which cavern 11 is excavated or the cavern coating 21 is applied. The shifting movement of the liner due to filling and emptying, flow of water, etc., would eventually cause abrasion and early leaking of the membrane. In order to avoid this, a gas, preferably inert gas such as CO₂, nitrogen, or a non-oxidizing gas such as hydrogen or methane, is supplied through line 23 at suitable pressure to balance the pressure within the liner or membrane 27. For storage of non-combustible liquids, of course, air may be used.

In order to maintain the proper gas pressure, a level controller 35 is provided in the wall of the cavern, Fig. 1, to detect a minimum and maximum desired water level. When water tends to rise, the controller 35 opens a control valve 37 in the inert gas line 39 connecting with pipe or conduit 23, previously mentioned. At the same time, a pressure controlled valve 41 in a water supply line

3

or conduit 43 is operative to maintain a balanced water pressure in the system. Conduit 43 connects with a conduit 45 which passes through a liquid tight bulk head 47 in tunnel 15. Alternatively, this conduit may be installed in shaft 13 if desired.

A pressure control device 49, installed in conduit 43, operates valve 41 to open or close it as required. Hydrocarbons to be stored are fed into the storage line or conduit 31, which is also sealed through bulk head 47, into the membranous liner or container 27. The latter expands, causing an increase in pressure within the storage zone. This increase in pressure opens valve 41 to allow water to flow out. It also compresses the gas in the upper part of the storage zone, permitting water to rise above level 17. As it rises, however, the level control 35 operates to open the valve 37 and admit gas under pressure through line 23 until the water is pushed down to its proper level. Conversely, the inert gas control will function to release gas pressure at valve 37 when the system is being filled, or when the water falls below the desired level. A pump, not shown, but obvious to those skilled in the art, may be connected with valve 37 for this purpose.

The level control device 35 may be a simple float element with appropriate connections to a conventional valve operating device.

When the walls of the storage compartment are water permeable as is preferably the case for economy of construction, it is preferable to form the compartment at such a distance below the normal water table in the ground that the water pressure equals, or somewhat exceeds the vapor pressure of the stored material. In the latter case, water may seep more or less continuously into the storage zone and will be withdrawn automatically by operation of valve 41. When needed, an appropriate pump may be provided with or in lieu of valve 41 to drive water in the required direction, or in both directions, if that is needed. To empty the stored liquid, water is introduced through conduit 43, 45 to compress and collapse the liner 27. At the same time, inert gas from line 23 is adjusted to keep the liner balanced and out of abrasive contact with the cavern ceiling and side walls.

On the other hand, the system is also quite operable under conditions where water seeps out of the storage compartment rather than in. In this case, the outgoing seepage is replaced by operation of valve 41 and/or the pump just mentioned.

A sampling device 55 is connected by means of a capillary tube 57 to the line 23. Alternatively, it may be connected directly with compartment 11 if desired. Its purpose is to take frequently, and continuously if desired, samples of the gas outside of the membranous liner 27 to detect gas leakage through the membrane. This arrangement makes it possible to follow the condition of the membrane. Corrective action may be taken in case of a leak by entrance through shaft 13, tunnel 15 and bulk head 47. The latter, in ordinary construction, will contain a suitable manhead or other entrance, not shown.

The arrangement shown and described above has several advantages over caulked reservoirs, operated without a collapsible or flexible liner. It provides a more positive protection against leakage and loss of stored products.

It makes it possible to detect leakage immediately, since the leaking fluids quickly vaporize and appear at the sampler, due to their low partial pressure. Moreover, the storage and removal of products from storage are simple operations.

Referring now to Fig. 2, the system shown is generally the same as Fig. 1, except for the controls for water and inert gas. In cavern 11, liner 27 is mounted, just as in Fig. 1. A vertical shaft 13 and a gas conduit 23 are also provided. Instead of using direct water level controls 35, however, a series of contact elements 63 is provided. These elements constitute feelers for the position of

4

the membrane or liner 27. They are connected electrically through conductors 65, 67, to the water control pump and valve assembly indicated diagrammatically at 69 and the gas control pump and valve assembly indicated at 71. When water supply raises the liner 27 too firmly against the feelers 63 at the top of the cavern, water is withdrawn and gas pressure is increased. Conversely, when the liner sinks too low, burning undue pressure on feelers 63 at the bottom, the water pump or valve is operated to bring in more water and keep the liner properly "centered" within the cavern. Gas pressure is adjusted simultaneously.

In Fig. 3, the cavern and shafts are the same as in Figs. 1 and 2, as are the conduit connections. Here, however, a syphon type pressure detector 75 is used to sense water pressure and to control the water supply and inert gas supply through suitable connections 77 to an instrument box 79. The latter, through leads 81, controls the water pump and valve facilities. By keeping the water pressure at the syphon 75 between a predetermined minimum and maximum, the membranous container 27 may be kept afloat at the desired levels, regardless of the extent to which it is filled. As it is emptied, pressure decreases and water flows in. As the water level rises, the pressure on syphon 75 increases more rapidly than the pressure at the top of the cavern, hence maximum water pressure causes the water supply to be cut off before the liner rises too high. A gas pressure control at the top of the cavern may also be used, if desired, but by proper choice of the maximum and minimum water pressures at the syphon, this usually is not necessary. With this arrangement, a constant supply of gas in the cavern is all that is required. Where the gas can leak out, a separate gas supply control is needed, as in Fig. 1 or Fig. 2.

It will be understood that modifications and variations may be made without departing from the spirit of the invention and it is intended that the following claims cover such, so far as their scope and the state of the prior art permits.

What is claimed is:

1. A process of storing fluids, including liquefied normally gaseous materials, in a subterranean storage chamber inherently capable of resisting pressures at least equal to the vapor pressure of said fluids at the natural temperature of said chamber, comprising at least partially flooding said chamber with water to produce a pressure in said chamber at least equal to the vapor pressure of said fluids at said chamber temperature, introducing said fluids in liquid form into a hallow, flexible and collapsible membrane contained in said chamber thereby expanding said membrane within said chamber and displacing water from said chamber against said flooding water pressure and thereby buoying said membrane in said flooding water, introducing into said chamber externally of said membrane a gaseous material initially at a pressure sufficient to displace water from said chamber against said flooding pressure thereby establishing a depressed water surface level therein and exposing a portion of said membrane to the pressure of said gaseous material and at this pressure limiting expansion of said fluids whereby to maintain said membrane out of contact with the boundary surfaces of said chamber, and maintaining said water surface level in said chamber within predetermined upper and lower limits by discharging water from said chamber at least in part by increasing the pressure of said gaseous material therein externally of said membrane and admitting water into said chamber at least in part by decreasing the pressure of said gaseous material therein externally of said membrane, said gaseous material pressure in said chamber externally of said membrane being increased and decreased in automatic response to variation of said water surface level from said predetermined upper and lower limits.

2. A process according to claim 1, wherein said fluids

to be stored are liquefied petroleum gases and said gaseous material introduced into said chamber externally of said membrane is a non-oxidizing gaseous material.

3. A system for the storage of fluids in liquid form, including liquefied normally gaseous materials, comprising a subterranean chamber having a natural overburden capable of resisting pressures at least equal to the vapor pressure of the fluid stored at the natural temperature of the chamber, a source of water external to said chamber and means, including a first conduit communicating with said chamber, for introducing water into said chamber from said source of water under pressures at least equal to said vapor pressure and withdrawing water from said chamber, a source of gaseous material external to said chamber and means, including a second conduit communicating with said chamber, for introducing gaseous material into said chamber from said source of gaseous material under pressure at least equal to said vapor pressure and withdrawing gaseous material from said chamber, a collapsible-expandable closed container of a flexible, membranous material substantially impervious to said fluids and to water substantially freely disposed within said chamber and adapted for water flotation therein, means including a third conduit communicating with said container for introducing and withdrawing said fluids in liquid form into and from said container, and means for maintaining a substantially constant and depressed water surface level in said chamber between predetermined upper and lower limits comprising a valve in each of said first and second conduits for controlling introduction into and withdrawal from said chamber of water and gaseous material respectively, said last-named means further comprising means responsive to pressure in said first conduit to operate said first conduit valve to introduce water into and withdraw water from said chamber as the pressure in said first conduit and said chamber decreases and increases respectively.

4. A system for the storage of fluids in liquid form, including liquefied normally gaseous materials, comprising a subterranean chamber having a natural overburden capable of resisting pressures at least equal to the vapor pressure of the fluid stored at the natural temperature of the chamber, a source of water external to said chamber and means, including a first conduit communicating with said chamber, for introducing water into said chamber from said source of water under pressures at least equal to said vapor pressure and withdrawing water from said chamber, a source of gaseous material external to said chamber and means, including a second conduit communicating with said chamber, for introducing gaseous material into said chamber from said source of gaseous material under pressures at least equal to said vapor pressure and withdrawing gaseous material from said chamber, a collapsible-expandable closed container of a flexible membranous material substantially impervious to said fluids and to water substantially freely disposed within said chamber and adapted for water flotation therein, means including a third conduit communicating with said container for introducing and withdrawing said fluids in liquid form into and from said container, and means for maintaining a substantially constant and depressed water surface level in said chamber between predetermined upper and lower limits comprising a valve in each of said first and second conduits for controlling introduction into and withdrawal from said chamber of water and gaseous material respectively, said last-named means further comprising a water surface level sensing means in said chamber activated by changes in water surface level in said chamber to operate said second conduit valve whereby to increase the pressure of said gaseous material introduced into said chamber through said second conduit as said water surface level in said chamber rises and to decrease the pressure of said gaseous material in said chamber as said water surface level subsides, thereby re-

spectively discharging water from and admitting water into said chamber.

5. A system for the storage of fluids in liquid form, including liquefied normally gaseous materials, comprising a subterranean chamber having a natural overburden capable of resisting pressures at least equal to the vapor pressure of the fluid stored at the natural temperature of the chamber, a source of water external to said chamber and means, including a first conduit communicating with said chamber, for introducing water into said chamber from said source of water under pressures at least equal to said vapor pressure and withdrawing water from said chamber, a source of gaseous material external to said chamber and means, including a second conduit communicating with said chamber, for introducing gaseous material into said chamber from said source of gaseous material under pressures at least equal to said vapor pressure and withdrawing gaseous material from said chamber, a collapsible-expandable closed container of a flexible membranous material substantially impervious to said fluids and to water substantially freely disposed within said chamber and adapted for water flotation therein, means including a third conduit communicating with said container for introducing and withdrawing said fluids in liquid form into and from said container, and means for maintaining a substantially constant and depressed water surface level in said chamber between predetermined upper and lower limits comprising a valve in each of said first and second conduits for controlling introduction into and withdrawal from said chamber of water and gaseous material respectively, said last-named means further comprising operating means for said first conduit valve, operating means for said second conduit valve, and an electric circuit associated with at least said operating means for said second conduit valve whereby said operating means for said second conduit valve is actuated, said electric circuit including means sensitive to changes in water surface level in said chamber and adapted to energize said circuit to actuate said operating means for said second conduit valve to increase pressure of gaseous material in said chamber as the water surface level therein rises and decrease pressure of gaseous material in said chamber as the water surface level therein subsides with reference to said upper and lower water surface level limits, thereby respectively discharging water from and admitting water into said chamber.

6. A system according to claim 5, wherein said means sensitive to changes in water surface level in said chamber comprise pressure sensitive, feeler elements extended into contact with said collapsible-expandable closed container, whereby to sense the rise and fall of said container produced during water flotation thereof by rise and fall of said water surface level.

7. A system according to claim 5, wherein said means sensitive to changes in water surface level in said chamber comprise a pressure sensitive device submerged in the water maintained in said chamber, and responsive to changes in hydrostatic pressure occasioned by changes in water surface level in said chamber.

References Cited in the file of this patent

UNITED STATES PATENTS

703,824	Quinn	July 1, 1902
2,042,383	Bird et al.	May 26, 1936
2,211,958	Mahaffey	Aug. 20, 1940
2,387,598	Mercier	Oct. 23, 1945
2,659,209	Phelps	Nov. 17, 1953
2,747,774	Breitenbach	May 29, 1956
2,798,639	Urban	July 9, 1957

FOREIGN PATENTS

760,036	France	Dec. 6, 1933
---------	--------	--------------