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2,895,305

L.P.G. REMOVAL FROM UNDERGROUND STORAGE

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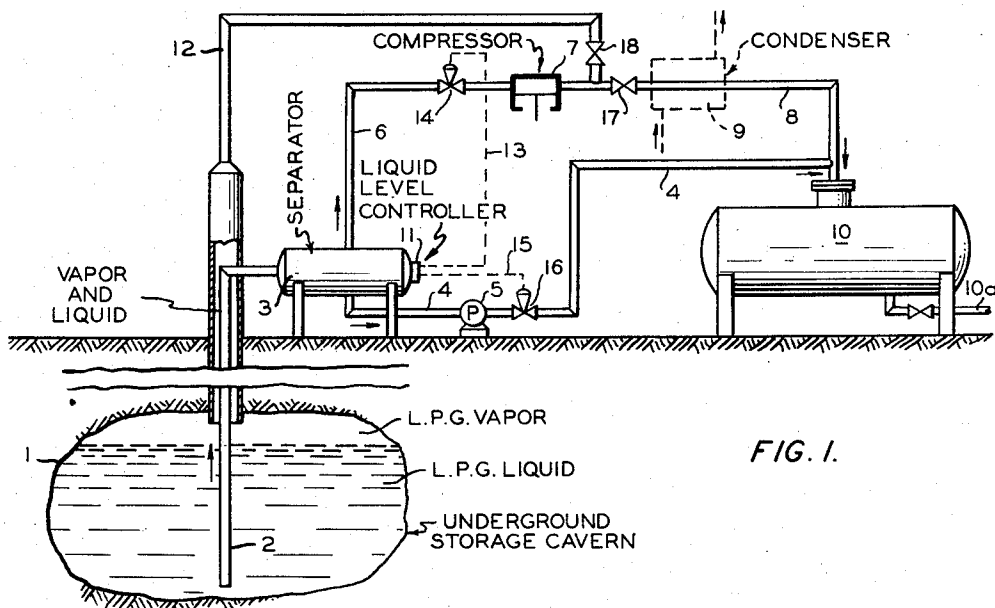


FIG. 1.

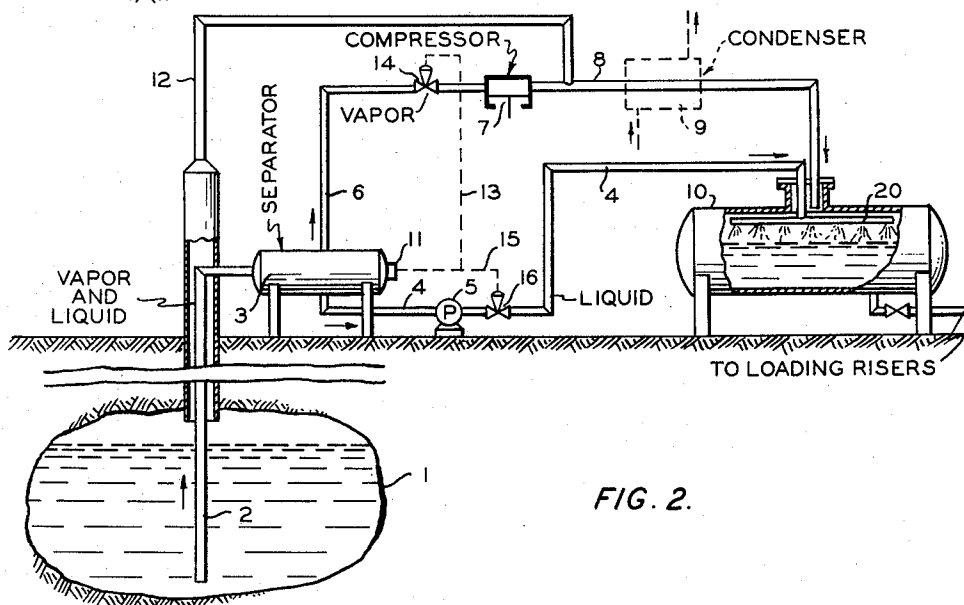


FIG. 2.

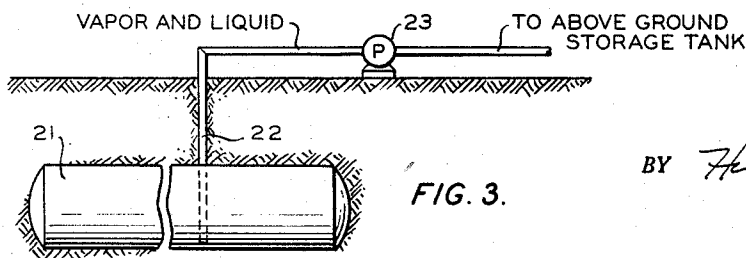


FIG. 3.

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ATTORNEYS

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L.P.G. REMOVAL FROM UNDERGROUND STORAGE

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11 Claims. (Cl. 62—54)

This invention is directed to the withdrawal of L.P.G. (liquid petroleum gas) from underground storage caverns using vapor compressors or pumps to take advantage of the gas lift principle.

Considerable use has been made in recent years of underground storage for L.P.G. The basic reason is economy. Underground storage caverns can be constructed for \$1 to \$10 per barrel of storage capacity whereas an equivalent storage capacity in steel tanks costs about \$20 per barrel. Aside from this, however, underground storage frees a large amount of steel for more strategic uses, an important factor in war time. From a defense consideration underground storage has the advantage of being more nearly bomb proof than above ground storage. As a safety measure it is obvious that underground storage offers less of a fire hazard than a similar volume of above ground storage.

The withdrawal of L.P.G. to the surface, however, prevents certain difficulties. Any withdrawal method based on the pressure differential between the cavern and the surface of the earth must cope with the volatility of L.P.G. under reduced pressure. A conventional centrifugal pump is normally preferred for pumping liquids because the horsepower required varies directly with the demand. Thus, the more the outlet of the pump is throttled, the less is the power used, which is not true of other types of pumps. The operation of a centrifugal pump, however, depends on the pressure at the outlet of the suction line being lower than that at the base; with L.P.G. this unavoidably results in partial vaporization of L.P.G. in the pump suction pipe. This tends to "vapor lock" the pump, halting its transfer of fluid. The general approach to this problem in the prior art has been to seek means for eliminating the vaporization in the pump suction pipe, see e.g. U.S. 2,021,394.

Another problem arises when the L.P.G. contains water. This is a common situation in the initial operation of underground storage caverns prepared by dissolving out the interior of salt domes with water. It has been my experience that such a cavern requires numerous changes of L.P.G. to remove all the water therefrom. The undesirable presence of water during the elevation of L.P.G. to the surface by any means involving a substantial amount of vaporization in the riser can result in the formation of a solid L.P.G.-water hydrate therein. This is in the nature of ice, being formed as the temperature of the withdrawn liquid approaches 32° F. due to the cooling effect accompanying the aforesaid vaporization of L.P.G. in the line. These hydrates can partly or entirely plug the line, requiring shutting down and resorting to various expedients to

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decompose the hydrates. This problem is discussed at some length in Chem. & Met. Engineering, vol 49, No. 5 (1942) pp. 136-137.

The present invention overcomes the problems of preventing vaporization in the outlet line and of hydrate formation therein by making positive use of the vaporization of L.P.G. during its elevation to the surface of the ground. This invention is based on the recognition that the aforesaid vaporization can make possible a natural gas lift to assist in the elevation of the L.P.G. to the surface. A gas lift, basically, is a method of lifting a liquid by means of gas under pressure. In a natural gas lift all of the gas used to lift the liquid is supplied by the vaporization of the liquid itself, the expanding gas serving to lighten the liquid and to raise it. In applying this principle to the present invention the outlet pipe or riser from the underground storage cavern is connected directly or through an above ground separating tank to a compressor means. The latter reduces the pressure of the L.P.G. in the riser, thus causing vaporization of part of the liquid to take place. The pressure differential between the compressor unit and the liquid in the cavern, and the gas lift effect caused by the decreasing specific gravity of the L.P.G. as it rises, causes a flow of L.P.G. liquid and vapor from the cavern to the top of the outlet pipe. Where a separation tank is used the fluid mixture is first collected therein. The liquid phase is then pumped from the separator tank to an above-ground storage tank, fuel system, process, or elsewhere as desired. The vapors, which are removed from the separator tank by the compressor, may be condensed and recombined with the liquid or returned to the cavern in such a manner as to effect heat exchange with the liquid rising to the surface.

For the removal of L.P.G. from shallow underground storage tanks and caverns the separator tank, vapor compressor and liquid pump may be replaced with any pump capable of handling L.P.G. vapor and liquid in combination, such as the rotary plastic vane type. In this modification the pump operates as a combination compressor, condenser, and pump, condensing the vapors within the pump when the pressure of the pump exceeds that of the underground cavern or tank.

The principal object of this invention is to provide a novel means and method for removing L.P.G. from an underground storage tank or cavern. A further object is to effect this removal by using the vaporization in the riser pipe to effect a natural gas lift in the L.P.G. during its elevation to the surface. A further object is the prevention of solid L.P.G.-hydrate formation in the riser during the elevation of L.P.G. from underground storage to the surface of the earth.

The accompanying drawings illustrate schematically the operation of the invention. Figure 1 illustrates a combination of an underground storage cavern and above ground compressing and separating equipment. Figure 2 is a modification of Figure 1 showing spray means to condense surface vapors. Figure 3 shows a modification wherein the compressing and separating units are combined in a rotary vane pump to draw L.P.G. from an underground storage tank.

Referring to Figure 1, 1 is an underground storage cavern containing L.P.G. A riser pipe 2 extends from within the L.P.G. to the surface of the earth where it is connected to a separator tank 3. A pipe 4 connects the base of separator 3 with pump 5 in line 4 emptying

into receiver 10. A pipe 6 connects the top of separator 3 with the suction side of a gas compressor 7, the discharge of which is connected via line 8 through condenser 9 (optional) to receiver 10. A line 10a drains receiver 10 and leads to suitable loading equipment. A portion of the gas discharge from compressor 7 may be recycled through line 12 to the vapor space in the top of cavern 1, line 12 annularly enclosing the vertical portion of riser 2. The division of gas flow through lines 8 and 12, or its complete diversion to one of these lines, is effected by proper setting of valves 17 and 18 in lines 8 and 12, respectively. Separator 3 is provided with a liquid level controller 11 which acts through either control line 13 to adjust valve 14 or through control line 15 to adjust valve 16. While both control lines are delineated it should be understood that only one is actually installed, the choice of which one depending on the relation between pump capacity and compressor capacity. If compressor 7 is oversize in capacity as compared to pump 5 it will tend to over-fill separator 3. In this situation the increased liquid level would operate through liquid level controller 11 and control line 13 to throttle valve 14. This reduces the vapor flow to the compressor and hence reduces the flow of liquid and vapor to the separator 3. With the pump flow constant the liquid level will be brought back to the proper level. On the other hand, the pump 5 may be oversize as compared to the compressor volume. It will then tend to pump separator 3 dry. In this case the limiting factor is the compressor and the other control system would be used to throttle the pump. When the liquid level in the separator falls below the proper value liquid level controller 11 via control line 15 would throttle discharge valve 16 until the compressor catches up.

In starting up the described system separator 3 will be empty, valve 14 will be open, and with an oversize pump valve 16 will be closed. Assuming that some moisture is present in the cavern, valve 18 would be open and valve 17 closed. On supplying power to the electrical circuit the action of compressor 7 will create a pressure differential between the compressor and the liquid in the cavern, this pressure differential ultimately becoming sufficient for the vapor pressure in the cavern to force L.P.G. liquid and vapor up through riser 2 into the separator 3. Liquid phase is withdrawn from the latter through line 4 and pump 5 into receiver 10. The pressure in separator 3 being appreciably lower than that in the cavern produces evaporation in the riser. The resulting vapors when withdrawn through compressor 7 are heated by the work of compression and, when returned to the cavern through line 12, effect considerable heat exchange with riser 2. This serves to maintain the temperature of the latter above the temperature of the L.P.G.-water hydrate formation. In addition, it increases vaporization of L.P.G. in the riser, lowering the density of the elevated L.P.G. and thus permitting a faster flow rate. In the absence of water vapor in the stored L.P.G. valves 17 and 18 are set so as to reliquify compressed vapors in condenser 9; the condensate is then combined with the liquid entering receiver 10. If the liquid column in riser 2 were free of entrained vapors it is evident that the system would be in static equilibrium when the vapor pressure in the cavern balances the back pressure of the vapor in the separator plus the hydrostatic head of the liquid column between the two liquid levels. The present invention, however, is based on the recognition that since the liquid in the column contains considerable vapor it can exceed this theoretical valve without necessarily increasing the cavern pressure as by the recycle of vapors thereto through line 12.

Figure 2 is a modification of Figure 1 wherein the liquid L.P.G. pumped into the receiver 10 through line 4 is equipped with a sprayer 20 to dissolve the L.P.G. vapor trapped above the liquid level. Otherwise this vapor becomes compressed as the receiver fills, making further

filling difficult; in extreme cases the pressure buildup could burst the tank. In the present case some vapor enters through line 8 since even when condenser 9 is used a certain amount of light ends will pass through it without being condensed. The function of receiver 10 is to provide a mixing zone for L.P.G. and its vapors, hence the use of the sprayer 20 contributes to this function. If such a receiver were omitted and the fluids in lines 4 and 8 combined directly in line 10a, it would result in considerable hammering in this line. This is eliminated by the use of a receiver, especially in combination with a jet spray, to effect better liquid-vapor contact and better dissolving of the vapor in the liquid.

Figure 3 illustrates another modification wherein a riser pipe 22 extends from within the underground storage tank 21 to the surface of the ground and connects there with a pump 23. The latter discharges directly to a suitable transport or storage means. Pump 23 combines the function of both the compressor and the condenser in Figures 1 and 2 and also eliminates the need for a separator and a receiver. Pump 23 must therefore be designed to efficiently pump both liquids and vapors and to compress the vapor portion into the liquid so as to discharge only liquid L.P.G. This requires that pump 23 be of the positive displacement type and preferably of the rotary vane type. This modification also eliminates the return line to the underground storage chamber since this type of installation is limited to shallow tanks, say 25 to 35 feet deep, where the problem of hydrate formation does not develop.

The use of the gas lift effect in accordance with this invention makes it possible to pump L.P.G. from much greater depths than would be possible otherwise. For example, in a cavern 1100 feet deep and at a temperature of 80° F., liquid commercial propane has a vapor pressure of about 167 p.s.i.g. With this vapor pressure a homogeneous column of liquid propane (constant specific gravity) would be lifted 684 feet against atmospheric pressure. However, the use of an above ground compressor arrangement effects a gradual reduction in the apparent specific gravity of the liquid column due to vaporization of the liquid. This vaporization, as already explained, results from the decreasing pressure on the column as its height above the cavern liquid level increases. Thus, the effective specific gravity at a height of 1100 feet above reservoir level is only 0.04 as compared to a specific gravity of 0.45 in the cavern and 0.09 half way up (550 feet). In this particular case one pound of commercial propane will be composed of 0.22 pound vapor and 0.78 pound liquid at the 1100 foot level. Consequently, the weight of the column is lowered so that the entire 1100 foot column can be supported under the conditions stated (a cavern temperature of 80° F. and a vapor pressure of 167 p.s.i.a.) as compared to the 684 feet obtainable without the gas lift effect. In fact, it is theoretically possible to pump from as deep as 2000 feet by this method; however, the size of the compressor required for such a lift makes its cost almost prohibitive.

As a practical matter the riser pipe must be dimensioned according to the desired pumping rate. If the riser pipe is too large in diameter there is slippage of vapors around the edge of the liquid column and a resultant loss of gas lift. If the pipe diameter is too small there is excessive friction loss. In the case of the 1100 foot column just described, if a flow rate of 200 gallons/minute is desired the lower portion of the riser should theoretically be 3½ inches in diameter and the upper portion 4½ inches diameter. A 4-inch pipe all the way would, however, be satisfactory in this case.

It can be seen that the present invention resides basically in treating as an asset rather than a liability the in situ vaporization of L.P.G. as it is elevated from a cavern to the surface of the earth. The several embodiments of this invention described in the foregoing specification and drawings should be considered as illustrative and not

exclusive of equivalent modifications which could be devised by those skilled in the art.

I claim:

1. In a system comprising an underground cavern for the storage of volatile liquid, a riser extending from the lower portion of the cavern to the surface for lifting the stored volatile liquid, means connected to the upper end of said riser for separating the volatile liquid from its vapors, and a compressor communicating with the separator means and adapted to compress the separated volatile liquid vapors, in combination, means for recycling a portion of the gas discharged from said compressor to the cavern in heat exchange relationship with the riser, and means for condensing a portion of said gas discharge for above ground use.

2. In a system comprising an underground storage cavern, an above ground closed receiver, and fluid conveying means connecting the lower portion of the cavern with the receiver, in combination, a closed separator tank and a compressor arranged in that order above ground and ahead of the receiver, a conduit connecting the aforesaid elements, said compressor operating to draw volatile liquid from the cavern into the separator tank wherein it separates into a liquid and gaseous phase, the gaseous phase being drawn through the compressor and discharged therefrom into the receiver, and a liquid line connecting the lower portion of the separator with the receiver to permit draining the liquid phase in the separator directly into the receiver.

3. In a system comprising an underground storage cavern, a closed separator tank, a compressor, a condenser, and a closed liquid receiver arranged in that order above ground, a first conduit connecting the aforesaid elements, and a second conduit connecting the base of the separator tank directly with the receiver, said compressor operating to draw volatile liquid from the cavern into the separator tank wherein it separates into a liquid and gaseous phase, the liquid phase being drained through said second conduit into the receiver and the gaseous phase being drawn overhead through the compressor and condenser and the condensate emptied into the receiver, in combination, means for returning the compressed but uncondensed vapors to the cavern in heat exchange relationship with the volatile liquid being drawn therefrom, said means including a down pipe annularly surrounding a portion of said first conduit.

4. In a system comprising an underground storage cavern, an above ground closed receiver, and a segmented conduit connecting the lower portion of the cavern with the receiver, in combination, a closed separator tank, a compressor, and a condenser connected by said conduit segments and arranged in that order above ground and ahead of the receiver, the compressor operating to draw volatile liquid from the cavern into the separator tank wherein it separates into a liquid and gaseous phase, the gaseous phase being drawn through the compressor and condenser and the condensate emptied into the receiver, a liquid line connecting the lower portion of the separator with the receiver, whereby the liquid phase in the separator can be discharged directly into the receiver, and spray means at the discharge end of the liquid line, said spray means functioning to dissolve the vapors present in the condensate entering the receiver through the aforesaid conduit.

5. The method of removing a volatile liquid from underground storage to an outlet located at a higher level, wherein the vertical distance from the storage zone to said outlet is greater than the maximum height of a column of unvaporized liquid that could be supported by the vapor pressure in the storage zone, comprising establishing a pressure differential between said storage zone and said outlet tending to elevate the liquid toward said outlet, and maintaining conditions of temperature and pressure on the liquid being elevated such that the pressure diminishes with approach to said outlet and the

liquid volatilizes, thus lowering the density of said liquid by creating a vapor-liquid mixture, said mixture being more readily elevated by the aforementioned pressure differential.

6. The method of removing a volatile liquid from underground storage to an outlet located at a higher level, wherein the vertical distance from the storage zone to said outlet is greater than the maximum height of a column of unvaporized liquid that could be supported by the vapor pressure in the storage zone, comprising establishing a pressure differential between said storage zone and said outlet tending to elevate the liquid toward said outlet, maintaining conditions of temperature and pressure on the liquid being elevated such that the pressure diminishes with approach to said outlet and the liquid volatilizes, thus lowering the density of said liquid by creating a vapor-liquid mixture, said mixture being more readily elevated by the aforementioned pressure differential, compressing the vapor-liquid mixture at the outlet and conveying the resultant liquid to a receiver.

7. The method of removing a volatile liquid from underground storage to an outlet located at a higher level, wherein the vertical distance from the storage zone to said outlet is greater than the maximum height of a column of unvaporized liquid that could be supported by the vapor pressure in the storage zone, comprising establishing a pressure differential between said storage zone and said outlet tending to elevate the liquid toward said outlet, maintaining conditions of temperature and pressure on the liquid being elevated such that the pressure diminishes with approach to said outlet and the liquid volatilizes, thus lowering the density of said liquid by creating a vapor-liquid mixture, said mixture being more readily elevated by the aforementioned pressure differential, separating the vapor-liquid mixture at the outlet into a vapor phase and a liquid phase, compressing said vapor phase, and recycling the compressed vapors to the underground storage zone in heat exchange relationship with the liquid being elevated so that the heat of compression is transferred to said liquid increasing its rate of vaporization.

8. The process of claim 7 wherein the volatile liquid is L.P.G. and the heat of compression transferred to the liquid being elevated serves to prevent the formation of solid L.P.G.-water hydrates in the liquid being elevated.

9. The method of removing a volatile liquid from underground storage to an outlet located at a higher level, wherein the vertical distance from the storage zone to said outlet is greater than the maximum height of a column of unvaporized liquid that could be supported by the vapor pressure in the storage zone, comprising establishing a pressure differential between said storage zone and said outlet tending to elevate the liquid toward said outlet, maintaining conditions of temperature and pressure on the liquid being elevated such that the pressure diminishes with approach to said outlet and the liquid volatilizes, thus lowering the density of said liquid by creating a vapor-liquid mixture, said mixture being more readily elevated by the aforementioned pressure differential, separating the vapor-liquid mixture at the outlet into a vapor phase and a liquid phase, compressing said vapor phase, recycling a portion of the compressed vapors to the underground storage zone in heat exchange relationship with the liquid being elevated so that the heat of compression is transferred to said liquid increasing its rate of vaporization, conveying said liquid phase from the separation zone to a receiver, and condensing a portion of the compressed vapors and conveying this portion to a receiver.

10. A method of preventing solid hydrate formation in a withdrawal conduit of an underground storage zone wherein volatile hydrocarbon is stored which comprises elevating said volatile hydrocarbon through said conduit under conditions of decreasing pressure with increasing elevation thereby volatilizing and tending to cool said

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hydrocarbon during said elevating, said hydrocarbon containing sufficient water to form solid hydrate upon cooling during elevation in said conduit, heating vapors of said hydrocarbon, returning said vapors thus heated to said zone along said conduit in contact therewith thereby placing said heated vapors in indirect heat exchange relationship with said hydrocarbon being elevated, thereby maintaining the temperature of said hydrocarbon being elevated sufficiently high to prevent formation of said solid hydrate.

11. The method of claim 10 wherein the volatile hydrocarbon is L.P.G.

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