

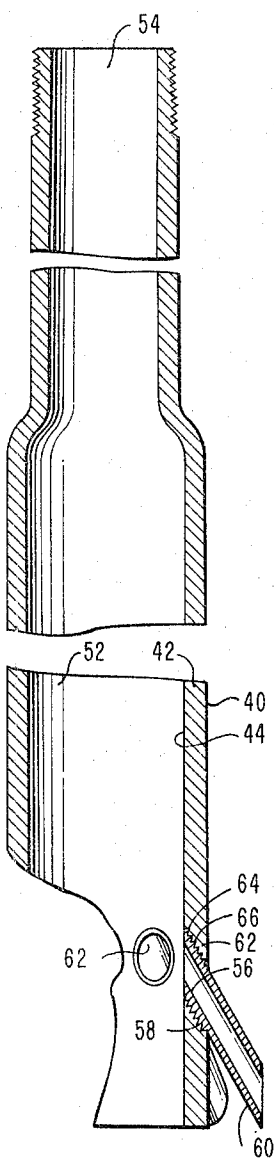
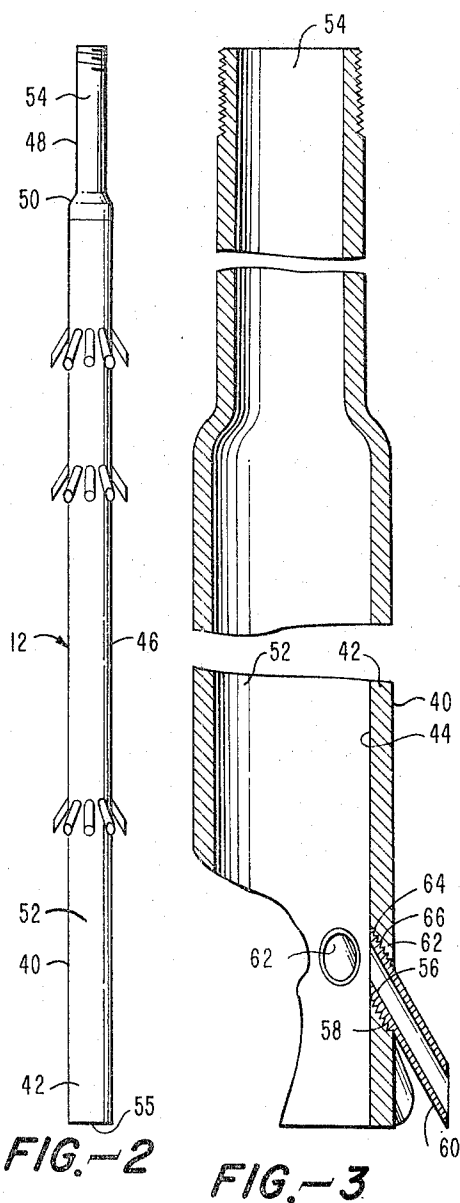
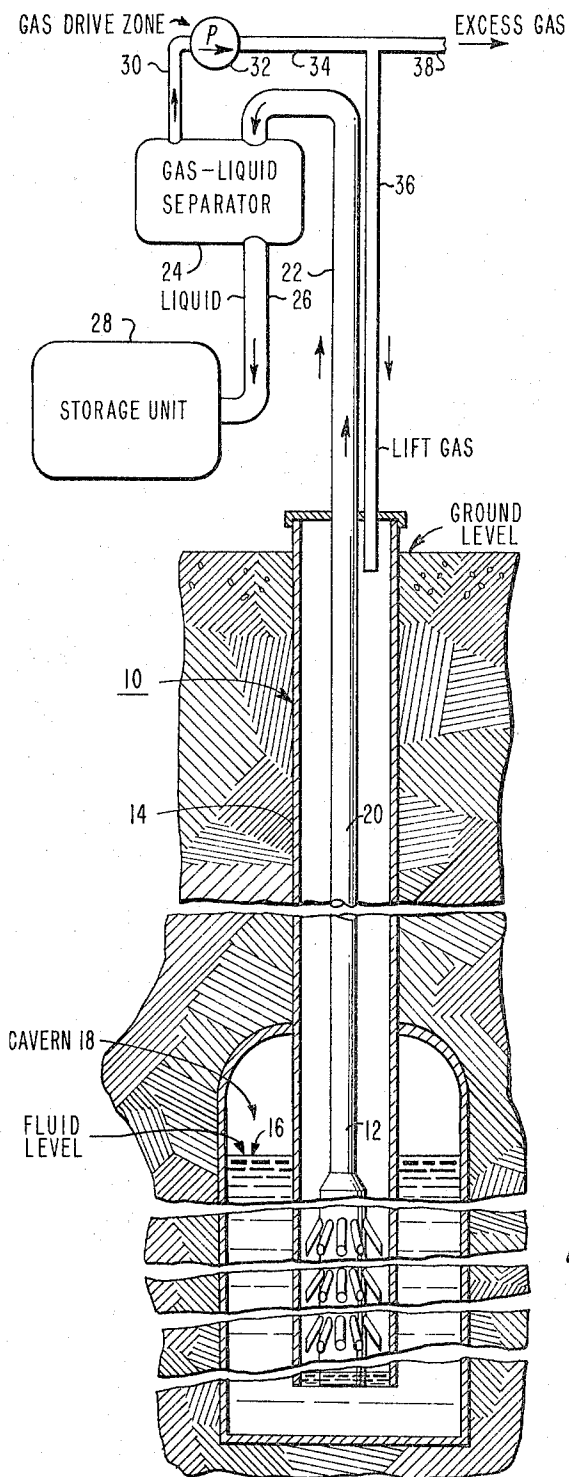
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LIQUID RECOVERY

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LIQUID RECOVERY

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The present invention generally relates to liquid recovery and more particularly relates to an improved gas lift process and an improved gas lift tube for use in a gas lift process.

Attempts have been made to reduce the cost of operating conventional gas lift processes, but the most successful attempts still require a considerable initial outlay for apparatus and a considerable input of power in order to effectively lift a reasonable volume of fluid from an underground cavern per unit time. In this regard, it is conventional in many of such processes to employ an above-ground compressor unit to impel the lift gas under high pressure down into the well annulus and into the underground cavern. If such motive gas is condensable, a considerable proportion thereof may be lost through condensation to liquid form.

Certain conventional gas lift devices which have been designed to provide improved control over the gas lift process have resulted in increasing the lift gas pressure requirements due to constrictions, packings, etc., in the flow path or across the flow path of the lift gas. These constrictions also complicate the inspection problem for the gas lift apparatus and generally increase the cost of cleaning, repair and replacement of components of the apparatus.

Accordingly, it would be highly desirable to provide a simplified gas lift process which could be operated efficiently on a continuous basis for the recovery at low cost from an underground cavern of large volumes of stored liquid per unit time. Preferably, such process should employ apparatus of simplified design and of low initial cost and maintenance cost. Also, it would be desirable to employ a process wherein the power requirements could be minimized and wherein the lift gas would not be condensed to an appreciable extent in the process.

Furthermore, certain conventional gas lift processes employ lift gas which must be carefully separated from the liquid to be recovered from the underground cavern. It would be more desirable to provide an economical gas lift process which could employ to advantage the gas phase of vaporizable liquid to be recovered from an underground cavern so that contamination of the liquid with the lift gas would be avoided. Preferably, such process also should be capable of recovering without malfunction those contaminants which are normally present in and which accumulate in the liquid in the cavern, that is such contaminants as water, sulfur-bearing gases and the like. Many conventional gas lift processes cannot operate effectively if more than a trace concentration of water builds up in the liquid to be recovered from the cavern.

Accordingly, the principal object of the present invention is to provide improvements in gas lift systems.

It is also an object of the present invention to provide an improved gas lift process.

It is a further object of the present invention to provide an improved gas lift tube for use in a gas lift process.

It is a still further object of the present invention to provide an improved economical, inexpensive gas lift process capable of employing the vapor phase of a vaporizable liquid to be recovered from an underground cavern as the lift gas and capable of operating under low power requirements and in a continuous manner.

It is a still further object of the present invention to provide an improved gas lift process capable of recover-

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ing vaporizable liquid from an underground cavern, which liquid may contain considerable concentrations of non-condensable, non-vaporizable or difficultly vaporizable liquids, such as water and the like.

It is also an object of the present invention to provide improved gas lift apparatus initially inexpensive and also inexpensive to repair, inspect, maintain, clean and replace.

It is a still further object of the present invention to provide an improved apparatus and a gas lift process which minimizes the pressure required for forcing lift gas into and through a cavern and for lifting a given volume of vaporizable liquid from an underground cavern for recovery thereof and which minimizes or eliminates contamination of liquid being lifted from an underground cavern by a lift gas.

These and other objects are accomplished in accordance with the present invention by providing an improved gas lift process. In accordance with the process, liquid is recovered from an underground cavern, preferably through the use of an improved gas lift apparatus comprising a gas lift tube of novel construction and design. More specifically, the present improved gas lift process comprises continuously passing a gas down into the annulus of a well or borehole running to an underground cavern containing a vaporizable liquid, the gas comprising the gas phase of the liquid in the cavern. Thus, the gas is passed down between a well casing and a gas lift tube disposed concentrically in the casing. Such lift gas is under a drive pressure just sufficient to cause it to pass down to the liquid level in the casing (i.e. cavern liquid level) to a point where the gas can enter the lift tube along the periphery thereof and at a low angle. Thus, at least a major proportion of the lift gas enters the lift tube in this manner, with, at most, a minor proportion of the cavern liquid to be lifted. At most, a minor proportion of the lift gas passes through the liquid in the cavern and into the open unrestricted bottom end of the gas lift tube in admixture with a major proportion of the cavern liquid to be lifted.

Since the lift gas depresses the liquid level in the region between the well casing and lift tube to below the liquid level outside the casing in the cavern, a hydraulic pressure differential is established which results in lifting of the cavern liquid by suction up the gas lift tube from the open bottom end thereof. Thus, a mixture of lift gas (minor proportion) and cavern liquid (major proportion) to be produced or recovered from the cavern passes continuously upward in the lower gas lift zone (lower part of the gas lift tube) and is accelerated in an upward direction by the simultaneous and continuous injection of the major proportion of the lift gas through a plurality of smaller, unrestricted upwardly directed flow paths intersecting the upwardly moving column or mass of lift gas liquid. Such upwardly directed flow paths are disposed at the liquid level in the area between the casing and lift tube, and below the liquid level in the cavern outside the casing, and are sufficiently long to provide a substantial pressure drop and resultant substantial acceleration in the upward movement of the lift gas-liquid mixture contacted in the lift tube, that is, in the lower portion of the gas lift zone, and preferably at a relatively low angle. This rate of movement is further accelerated by passing the mixture of lift gas and liquid up into and through a necked-down intermediate gas lift zone and then into and through an upper unrestricted gas lift zone of substantially smaller cross-section than the lower gas lift zone. A Venturi effect is created thereby.

The mixture of the lift gas and the liquid recovered from the cavern is continuously passed from the upper gas lift zone (upper end of the gas lift tube) into a gas-liquid separating zone disposed above the surface of

the ground wherein the lift gas is separated from the recovered liquid. Such lift gas is then continuously passed through a gas drive zone which is maintained at a pressure just sufficient to impart the necessary drive pressure to the lift gas but which is insufficient to substantially condense the lift gas, such driven lift gas then being passed, by means of such drive pressure, again down the previously described flow path and into the liquid in the cavern in order to effect recovery of further amounts of liquid from the cavern in the previously described manner.

The gas lift process is facilitated to a substantial extent through the use of an improved gas lift tube which comprises a substantially cylindrical hollow riser tube having a lower portion and an upper portion integrally connected thereto by a necked down intermediate portion, the upper portion having a substantially smaller cross-section than the lower portion so that the riser tube creates the described Venturi effect in a simplified manner for gas-liquid mixtures passing upwardly from the lower portion into and through the upper portion of the gas lift tube. The lower end of the gas lift tube is left completely unobstructed and wholly open, so that the central cavity thereof has a cross-section about identical with that of the remainder of the lower portion of the riser tube, and is immersed well below the surface of the liquid in the cavern.

As previously noted, the lift gas for the system is preferably the vapor phase of the vaporizable liquid which is to be recovered from the cavern so that there is no problem of contamination of the recovered liquid by the lift gas. The upward acceleration of the gas-liquid mixture through the riser tube is obtained through the use of a plurality of symmetrically disposed hollow injection tubes having central passageways of small cross-section, the tubes being of sufficient length to provide a substantial pressure drop from outer end to inner end thereof. Each injection tube is connected through the wall of the riser tube adjacent the lower end thereof so that the central passageway of the injection tube communicates with the central cavity of the lower portion of the riser tube. Moreover, the inner end of each injection tube preferably is flush with the inner surface of the wall defining the central cavity of the riser tube, and each injector tube extends outwardly from said inner surface through said riser tube wall at a downwardly directed angle.

Accordingly, the lift gas passing through the injection tubes intersects the liquid in the riser tube at a low angle, i.e. along an upwardly and inwardly directed path so as to add thrust to such gas-liquid mixture and accelerate the rate of rise thereof. Preferably, the entire wall defining the central cavity of the riser tube and the wall defining the opening within each of the injection tubes is kept smooth, essentially continuous and unrestricted so that a minimal amount of drive pressure is necessary to result in adequate upward movement of the gas-liquid mixture through the gas lift tube for efficient recovery of the liquid from the cavern. Moreover, the smooth, uncomplicated, simplified design of the gas lift tube minimizes initial cost and facilitates cleaning, inspection, repair and replacement of components thereof so as to further minimize the cost of operating the gas lift process.

A further feature is that the present process may be practiced by passing the annular space between the well casing and gas lift tube, which space is sufficiently large so that the lift gas exhibits laminar flow. When the annular space is small and the gas velocity is high, laminar flow is not obtained. With laminar flow, the heat transfer between the motive gas (lift gas), and the mixed phase stream moving upwardly in the gas lift tube is materially reduced since a layer of motive gas forms around the outside of the lift tube and acts as a thermal shield, thus eliminating the need of an insulating pipe

string. Accordingly, condensation and resulting waste of the motive (lift) gas during passage to the cavern are minimized, even though the gas is at about its dew point. In addition, excessive vaporization of the mixed phase stream is avoided. Therefore, the stabilized conditions of the process are maintained.

Further features of the present invention will be apparent from a study of the following detailed description and the accompanying drawings of which:

FIG. 1 is a schematic flow diagram depicting one embodiment of the gas lift process of the present invention in operation, and including a schematic representation of the gas lift tube of the present invention;

FIG. 2 is a schematic side elevation of a portion of a preferred embodiment of the gas lift tube of the present invention; and,

FIG. 3 is an enlarged fragmentary longitudinal cross-section of the gas lift tube of FIG. 2, illustrating the specific arrangement of injection tubes and riser tube adjacent the bottom end of the gas lift tube of FIG. 2.

Now referring more particularly to FIG. 1 of the accompanying drawings, suitable apparatus 10 is schematically illustrated for operating the gas lift process of the present invention in accordance with the flow diagram of FIG. 1. Such apparatus 10 includes an improved gas lift tube 12 in accordance with the present invention, disposed within a well annulus or casing 14, both the tube 12 and casing 14 extending down to below the liquid level 16 in an underground cavern 18 containing a vaporizable fluid in the liquid state. The gas phase of such fluid is utilized as the lift gas for the process.

Also as shown in FIG. 1 of the accompanying drawings, the gas lift tube 12 can be connected to similar sections of pipe 20, which sections 20 may be part of the gas lift tube 12 itself and which extend to above ground and connect to a transfer line 22 which runs into a gas-liquid separation unit 24. In said unit 24, the lift gas is separated from the recovered liquid, the latter passing from the separation unit 24 through a line 26 to a storage unit 28 which, if desired, can be part of the unit 24. The lift gas passes from the separation unit through a line 30 and into a gas drive zone 32 wherein only sufficient pressure is applied to the gas to rapidly move the gas into the well annulus 14 through lines 34 and 36 and down the well annulus 14 to force the liquid in the well annulus to a point below the liquid level 16 in the cavern 18 and equal to the level of ingress of the lift (motive) gas into the tube 20. Line 38, which may be valved (not shown), is provided for bleeding off excess amounts of lift gas.

The components illustrated in FIG. 1 can be of conventional construction, except the gas lift tube 12, which forms a part of the invention. The gas drive zone 32 may comprise any suitable gas impelling apparatus, such as a compressor operating at low compression ratio. However, zone 32 preferably comprises a non-lubricated compressor operated at, for example, 110 p.s.i. discharge when propane gas is the lift gas in a 95 p.s.i. propane recovery system. It will be understood that the present process does include the use of a gas drive zone at pressure insufficient to condense a substantial proportion of the lift gas but sufficient to move the lift gas down to and force the liquid in the well annulus or casing 14 to a level below that of the liquid in the cavern external of well annulus or casing 14, as described.

A schematic representation of a preferred embodiment of the gas lift tube 12 of the present invention is set forth in side elevation in FIG. 2 and in enlarged fragmentary longitudinal cross-section in FIG. 3. The gas lift tube 12 comprises a hollow substantially cylindrical riser tube 40, the annular wall 42 thereof having a smooth interior surface 44. The lift tube is divided into a lower portion 46 and an upper portion 48 of smaller cross-section than the lower portion and integrally connected to the lower portion by a stepped or neck-

ed-down intermediate portion 50. The central cavity 52 in the lower portion 46 of the riser tube is of larger diameter than the central cavity 54 in the upper portion 48 of the riser tube 40 and extends into full communication with the liquid in the cavern 18 through an open bottom 55, the cross-sectional dimensions of the central cavity 52 thereof being at least about equal to the cross-sectional dimensions of the cavity 52 at other points in the lower portion 46 of the riser tube 40. If desired, the bottom 55 can be flared to facilitate ease of entry of cavern liquid into the tube 40.

The riser tube can be fabricated from any suitable material, such as steel, stainless steel, non-ferrous metals, such as brass, etc., reinforced plastic, cement or concrete, or other materials and is preferably generally circular in cross-section, as described. Moreover, it can be of relatively uniform diameter throughout the upper portion 48. Preferably, the necked-down intermediate portion 50 interconnecting the upper and lower portions of the riser tube 40 provides gradual reduction in cross-section of the cavity 52 to that of the cavity 52, proceeding upwardly from the lower portion 46 to the upper portion 48 of the riser tube 40. The intermediate portion 50 can be connected to the upper end of the lower portion 46 of the riser tube 40 and the lower end of the upper portion 48 of the riser tube by any suitable means, as by welding, threading on, sweating on, etc. The reduction in cross-section in the upper portion of the riser tube from that in the lower portion of the riser tube creates, as previously indicated, a Venturi effect on the upwardly moving turbulent stream or column of lift gas and liquid from the cavern, so as to accelerate that rate of movement. As shown particularly in FIG. 3, the inner surface 44 of the annular wall 42 defining the central cavity of the riser tube is relatively smooth, featureless and restrictionless so that cleaning rods can be passed down through the entire riser tube without difficulty, in contrast to many conventional riser tube configurations. Furthermore, the riser tube can be visually or otherwise inspected the length thereof so as to discover defects, etc., without the usual difficulties attendant riser tubes of complex internal configuration. Repairs and replacement of various sections of the riser tube of the invention can be made easily, due to the simple and uniform nature of the tube 40.

As shown more particularly in FIG. 3, the gas lift tube 12 of the present invention also includes a plurality of hollow injection tubes 56 which are smaller than the riser tube 40 and each of which comprises a generally annular wall 58 defining a central passageway 60 in communication with the central cavity 52 in the lower portion 46 of the riser tube 40. The passageway 60 is also in communication with liquid below the liquid level in the cavern 18. Each such injection tube 56 is of simplified design, preferably generally circular in cross-section, and capable of providing a Venturi effect which increases the gas lift efficiency of the gas lift tube. Yet, each injection tube provides smooth uncomplicated unrestricted flow for the lift gas passing therethrough.

Each injection tube 56 is disposed within an opening 62 in the wall 42, which opening extends from the inner surface 46 to the outer surface of the wall 42. Each injection tube is secured to the wall 42 of the riser tube 40 in any suitable manner, as by welding or the like. Preferably, each injection tube 56 is releasably secured to the wall 42, as by a threaded inner end portion 64 of the tube 56 and a mating threading portion 66 of the wall 42 defining the opening 62, so that the tube 56 is more readily replaceable upon erosion, corrosion or the like. The inner end of each injection tube 56 preferably terminates flush with the inner surface 44 of the annular wall 42 of the riser tube 40 so that the flow path for the lift gas-liquid mixture passing upwardly in the lower portion of the riser tube is essentially unrestricted.

As will be more particularly noted in FIG. 3 of the

accompanying drawings, each injection tube 56 extends from the inner surface 44 of the annular wall 42 outwardly and downwardly at any desired angle, for example, between about 10° and about 75°, preferably about 60°, from the longitudinal surface of the riser tube 10, and each tube 56 is sufficiently long so that it extends well out into the path of movement (laminar flow) of the lift (motive) gas below the liquid level in the cavern external of the annulus. Moreover, each injection tube 56 is sufficiently long so as to establish a directional flow pattern and provide a measurable pressure drop across the length thereof for lift gas passing upwardly and inwardly therethrough and into communication with the main turbulent lift gas and cavern liquid rising through riser tube 40. The maximum length of the injection tubes is that which is just short enough to allow the gas lift tube to be inserted into a given well annulus when the injection tubes 56 are in place in the riser tube 40, as in FIGS. 2 and 3. Thus, the injection tubes 56 act as guide means for the gas lift tube 12.

The plurality of injection tubes 56 provide a plurality of flow paths for at least the major proportion of the lift gas and not more than a minor proportion of the cavern liquid which is lifted. This arrangement results in effective acceleration of the rate of upward movement of the main body or column of lift gas-liquid mixture in the riser tube 40. Usually, at least about four injection tubes are provided, with such tubes equally spaced at 90° angles from one another around the lower portion of the riser tube 40 a short distance above the bottom end thereof. During operation of the gas lift, motive (lift) gas is forced down the well annulus 14 under a sufficient pressure to push the liquid level in the annulus to below that of the injection tubes, the motive gas thereupon flowing into and through the injection tubes, as shown in FIG. 1. Preferably, at least 8 injection tubes 56 are provided as a first set, equally spaced around the circumference of the riser tube and all at a given level. In order to facilitate further acceleration of the lift gas-liquid mixture moving upwardly in the lower portion of the riser tube 40, a second set of, for example, 8 injection tubes 56 is preferably disposed a short distance below the uppermost set, as shown in FIG. 3, and a third set of, for example, 8 injection tubes 56 can be disposed a short distance below the second set, also as shown in FIG. 3. Preferably, all three sets contain the same number of injection tubes. In such an event, the motive gas preferably is used to push the liquid level in the annulus to below that of the lowermost set of injection tubes.

As shown in FIG. 3, each set may contain 8 injection tubes disposed at 45° angles from one another around the circumference of the lower portion of the riser tube. Also as shown in FIG. 3, the middle set of 8 injection tubes can be offset at an angle of about 22.5° from the first and third sets so as to maximize uniformity of injection of the lift gas into the rising turbulent column of lift gas-liquid mixture in the riser tube. In the event the liquid level in the annulus is not forced to below the level of the lowermost set of injection tubes, cavern liquid will pass into the riser tube in a greater proportion along with the lift (motive) gas.

As a specific example of an improved steel gas lift tube 12 in accordance with the present invention, the tube 12 includes a riser tube 40, the lower portion 46 of which is fabricated from 8.625 inch outer diameter, 0.32 inch thick cylindrical steel pipe having a central cavity approximately 7.98 inches in diameter. The pipe is 18 feet, 6 inches in length with open upper and bottom ends. The upper end of the lower portion of the riser tube 40 is connected, as by welding, to a generally cylindrical 6 inch long necked-down steel reducer ring 50, which provides for reduction from the dimensions of the 8.625 inch diameter tube to a 6.625 inch diameter tube

having a 6.1 inch diameter central cavity and walls 0.31 inch thick. The upper end of the reducer ring is connected, as by welding, to the lower end of the upper portion 48 of the riser tube which comprises a cylindrical 6.625 inch outer diameter, 6.1 inch central cavity diameter steel pipe. This upper pipe can be any suitable length, for example, about 14 inches long, and can be provided with an upper threaded end for releasably coupling it with a mating threaded portion of pipe (not shown) which may be a continuation or extension, in effect, of the gas lift tube for the required distance, i.e. to above the surface of the ground as one or a plurality of such releasably interconnected tubes. Such tubes may have, for example, the same external and internal diameter as the upper portion of the riser tube proper.

The gas lift tube of this specific example further includes three sets of eight injection tubes 56 each. The lowermost set of injection tubes comprises 8 generally cylindrical hollow steel tubes 56, each about 4 inches long, with a wall thickness of about 0.125 inch and an internal diameter of 1.25 inch. The inner end of each injection tube is set flush with the inner surface of the lower portion of the riser tube 40 and is secured in place by means of welding, as shown in FIG. 3. Each tube 56 extends outwardly and downwardly through an opening in the wall of the riser tube at an angle of about 60° from the external surface of the riser tube. The outer end of each injection tube 56 is trimmed off so as to be essentially parallel with the outer surface of the riser tube 40 and with the well annulus or casing 14 in which the gas lift tube is to be inserted.

The lowermost (first) set of injection tubes 56 is disposed at a level of about 6 feet, 9 inches above the bottom end of the riser tube 40, i.e., the top surface of each injection tube in the set intersects the outer surface of the riser tube at that level. The second set of 8 injection tubes 56 is disposed approximately 8 feet above the first (lowermost) set and each injection tube thereof depends at approximately the same angle downwardly from the riser tube 40 and is the same size and shape as the injection tubes of the first set. However, the second set of injection tubes is offset approximately 22.5° from the first set of injection tubes. An uppermost or third set of injection tubes 56 is disposed approximately 24 inches above the second set of injection tubes 56 and comprises 8 injection tubes substantially identical in design to those of the first and second sets. The injection tubes of the third set are aligned with those of the first set of injection tubes and therefore are offset 22.5° from those of the second or intermediate set of injection tubes. With such an arrangement, the flow of lift gas through the injection tubes and into the rising column of lift gas-liquid mixture in the lower portion of the riser tube is made uniform substantially around the periphery of that column. It will be noted from FIG. 3 of the accompanying drawings, that both the riser tube 40 and the injection tubes 56 are all simple, straight hollow pipes, of substantially uniform cross-section throughout the length thereof.

The following examples more particularly illustrate certain features of the present invention.

EXAMPLE I

Gas lifting of liquid propane utilizing propane gas as the lift gas is carried out by the present process utilizing apparatus substantially as set forth in FIGS. 1 to 3 and as previously described. The following conditions as set forth in Table I below are utilized:

Table I

Cavern conditions:	
Depth—	600 ft.
Contents—	liquid propane, with water as a contaminant.
Storage pressure—	95 p.s.i.
Temperature—	50° F.

Gas lift separator:

Pressure—80 p.s.i.

Temperature—40° F.

Gas compressor:

Capacity—4.0 MM C.F.D.

Brake horse power—74.

The present process is initiated by starting up the compressor and forcing propane lift gas under a force of 110 p.s.i. and at a rate of 2,800 s.c.f./in. down into the well annulus so as to depress the liquid level in the well annulus about 60 ft. that is, to just below the lowermost of 3 sets of 8 injection tubes each, set an angle of 60° from the vertical. The remainder of the construction of the gas lift tube also conforms to that set forth in the previously described specific example of a gas lift tube. Substantially all of the propane gas passes through the 3 sets of injection tubes and into the central cavity in the riser tube where it contacts a rising column of water. Thus, the accumulated heavy layer of water present as a separate phase is gas lifted before the lighter liquid propane layer is gas lifted.

The water is sucked into the open bottom of the riser tube and is gas lifted at a pumping rate of 40 g.p.m., aided in part by the Venturi effect created by the injection tubes and by the necked-down intermediate riser tube section and the upper small diameter rise tube section and also aided by the uniform injection of the lift gas at a low angle of attack at 3 different levels in the riser tube and substantially uniformly around the periphery of the riser tube. Laminar flow of the lift gas provides a thermal shield over the outer surface of the riser tube, preventing substantial loss of heat through the riser tube wall to the rising column of water, and thereby inhibiting condensation of the lift gas, even though such gas is at about the dew-point thereof.

The mixture of lift gas and water passes out of the upper end of the gas lift tube and into the separator, wherein the propane lift gas is removed and passed to the compressor or drive zone, while the water is bled off as waste. The lift gas again passes down into the well annulus from the drive zone, substantially no loss of the lift gas occurring by compression thereof in the drive zone.

The described pumping procedure continues for about 1 hour, whereupon the liquid propane-water interface in the cavern is reached, and the system automatically begins to gas lift liquid propane at the rate of 220 g.p.m. by the previously described procedure. Water is simultaneously gas lifted with the liquid propane at the rate of 2 g.p.m., this water being the normal influx into the cavern. The liquid propane which is gas lifted is present in turbulent mixture with the propane lift gas in the rising column in the riser tube, which propane lift gas passing down the well annulus is in laminar flow heat shielding against loss of heat therefrom and into the rising column. Accordingly, condensation of the lift gas passing down the well annulus and evaporation of liquid propane being gas lifted in the column are inhibited so that the high efficiency of operation of the gas lift is maintained at a low power consumption.

The column of liquid propane and gaseous propane passes from the upper end of the gas lift tube and into the separator, wherein the liquid propane is separated from the gaseous propane and passes to storage. The gaseous propane is passed to and through the drive zone (compressor) in substantially unaltered form, sufficient force being imparted thereto so as to move it into and down the well annulus for reuse, such gas maintaining the liquid level in the well annulus depressed to below the lowermost set of injection tubes. This procedure is operated eight hours for the recovery of 105,000 gallons of liquid propane, after which the system is shut down by cutting off the compressor.

The described process works efficiently on a continuous basis, regardless of whether contaminant water and/or liquid propane is being gas lifted from the cavern. The

equipment is durable, efficient, easily assembled, maintained, inspected and repaired, and the process is economical because of low power consumption per gallon of gas-lifted liquid propane.

EXAMPLE II

The process of Example I is carried out utilizing the same equipment, but substituting ethane gas for gaseous propane as the lift gas. In the process, liquid ethane is gas lifted from an essentially contaminant-free cavern. The conditions of operation are set forth in Table II below:

Table II

Cavern conditions:	
Depth—	600 ft.
Cavern liquid—	ethane.
Storage pressure—	430 p.s.i.
Temperature—	50° F.
Gas lift separator:	
Pressure—	415 p.s.i.
Temperature—	48° F.
Gas compressor:	
Capacity—	4.0 MM l.f.d.
Brake horsepower required—	40.
Pumping rate:	
220 g.p.m. of liquid ethane.	
Total liquid ethane gas lifted—	105,000 gallons.

The process is found to be highly efficient, utilizing low power consumption for the continuous gas lifting of liquid ethane with ethane gas as the lift gas.

The preceding examples clearly illustrate that by the present gas-lift process readily vaporizable liquid can be efficiently recovered from an underground cavern utilizing the improved gas lift tube of the present invention and utilizing as the lift gas the vapor phase of the liquid to be recovered from the cavern. The preceding examples also clearly illustrate that the present process can be carried out in a manner which provides Venturi effects which help to reduce power requirements to a low level. Moreover, laminar flow of the lift gas down the well annulus further reduces power losses. The process is capable of continuous operation even when an appreciable proportion of water is being recovered before or with the vaporizable liquid from the cavern. In contrast, accumulated water tends to materially interfere with recovery of stored liquid from underground caverns in many conventional gas lift processes.

The preceding examples further illustrate that the present process employs only a low drive pressure, that is, just sufficient to cause the lift gas to depress the liquid level in the well annulus to below that in the cavern, i.e. to the level of the lowermost set of injection tubes. The process is best practiced by passing the lift gas from the separator through a drive pressure-imparting zone which condenses, at most, an insignificant proportion of the lift gas. Accordingly, power requirements are minimized throughout the process. Moreover, the present process is equally adaptable for the recovery of large volumes per unit time of various types of readily vaporizable liquids such as propylene, methane, ethylene and other hydrocarbons, from underground caverns which are disposed at any given depth below the surface of the ground.

The preceding examples additionally illustrate that the improved gas lift tube in accordance with the present invention can be easily fabricated from conventional materials and is durable and inexpensive to construct and to maintain, inspect, clean, repair and replace. Packing between the well annulus and the gas lift tube is neither required nor desirable, and the injection tubes of the gas lift tube aid in centering the gas lift tube within the well annulus for easy insertion and withdrawal. Moreover, any given plurality of injection tubes can be arranged in any suitable configuration so as to maximize the desired acceleration of the upward movement of the

liquid within the gas lift tube. Inasmuch as the improved gas lift tube has a uniformly smooth, restriction-free inner surface, both in the riser tube section and the injection tube sections, plugging problems do not occur and cleaning is easily carried out. Other advantages of the present invention are set forth in the foregoing.

Various modifications, changes, alterations, and additions can be made in the present process and in the present gas lift tube. All such modifications, changes, alterations and additions which are within the scope of the accompanying claims form a part of the present invention.

What is claimed is:

1. A continuous process for recovering readily vaporizable liquid from an underground cavern, which process comprises carrying out in sequence and on a continuous basis the steps of passing a lift gas comprising the gas phase of a readily vaporizable liquid down a well annulus and into contact with a readily vaporizable liquid in an underground cavern, said lift gas being under a drive pressure just sufficient to cause said lift gas to depress the liquid level in said annulus to below that in said cavern external of said annulus, the lift gas being passed into said cavern at about the dew point of said lift gas but at a rate sufficient to substantially maintain said gas in uncondensed form during said gas lifting, establishing and maintaining laminar flow of said lift gas in said annulus whereby a thermally insulative layer of said lift gas is formed around a plurality of gas lift zones to prevent condensation of said lift gas in said annulus and evaporation of said cavern liquid in said gas lift zones, injecting at least a major proportion of said lift gas containing a minor proportion of said liquid through a plurality of unrestricted upwardly directed flow paths and into contact with the periphery of a lower gas lift zone of said plurality of gas lift zones, passing at least a mixture comprising a major proportion of said liquid and a minor proportion of said lift gas into the bottom of said lower gas lift zone and upwardly in said lower gas lift zone, said smaller unrestricted flow paths intersecting said upwardly moving liquid mixture in said lower gas lift zone to form a turbulent mixture therewith, whereby the rate of upward movement of said liquid in said lower gas lift zone is accelerated and laminar flow is inhibited in said gas lift zones, passing said liquid in mixture with said injected lift gas upwardly into and through an upper unrestricted gas lift zone of smaller cross section than the cross section of said lower gas lift zone, whereby upward movement of said gas and liquid is further accelerated, passing said mixture from said upper gas lift zone and into a gas-liquid separating zone and separating said gas from said liquid therein, passing said gas through a gas drive zone, and thereafter returning said gas from said drive zone down said flow path for gas lifting further liquid from said cavern.

2. The process of claim 1 wherein a necked-down intermediate gas lift zone interconnects said lower gas lift zone and said upper gas lift zone, wherein said liquid is continuously passed from said gas-liquid separating zone to a liquid storage zone and wherein substantially none of said lift gas is liquified in said gas drive zone.

3. The process of claim 2 wherein essentially all of said lift gas passes into said lower gas lift zone through said smaller unrestricted flow paths, wherein said smaller unrestricted flow paths are of sufficient length to provide a pressure drop thereacross and are of diameter smaller than that of said upper gas lift zone, and wherein said smaller unrestricted flow paths comprise a plurality of vertically spaced sets, each of said sets including a plurality of said flow paths substantially uniformly distributed around said periphery.

4. The method of claim 3 wherein said liquid comprises normally gaseous hydrocarbon, wherein said lift gas comprises the vapor phase of said liquid, wherein said cavern is disposed at an underground level sufficiently deep to maintain said petroleum in the form of

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a liquid, and wherein said gas-liquid separating zone and said lift gas is liquified in said gas drive zone. atmospheric pressure.

5. The method of claim 4 wherein said gas comprises propane and wherein said liquid comprises condensed propane which includes a minor proportion of water.

6. The method of claim 4 wherein said lift gas comprises propylene and wherein said liquid comprises condensed propylene which includes up to a minor proportion of water.

7. The method of claim 4 wherein said lift gas comprises methane and wherein said liquid comprises condensed methane which includes up to a minor proportion of water.

8. The method of claim 4 wherein said lift gas comprises ethane and wherein said liquid comprises condensed ethane which includes up to a minor proportion of water.

9. The method of claim 4 wherein said lift gas comprises ethylene and wherein said liquid comprises condensed ethylene which includes up to a minor proportion of water.

10. An improved gas lift tube for a gas lift apparatus, which gas lift tube includes a riser tube having a substantially smooth annular wall defining an essentially restriction-free central cavity extending the length of said tube, said riser tube having open upper and lower ends, and comprising a lower portion and an upper portion integrally connected thereto by an intermediate necked-down portion, the cross-section of the cavity of said upper portion being of uniform diameter and smaller than that of said lower portion, the cross section of the cavity in said lower portion also being of uniform diameter and a plurality of spaced injection tubes releasably connected to said riser tube adjacent the bottom end

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thereof and extending into communication with said central cavity, each of said injection tubes having a substantially smooth annular wall defining a uniform diameter restriction-free central passageway extending the length thereof and of smaller cross-section than that of the central cavity in said upper portion of said riser tube, the length and diameter of each of said injection tubes being such as to provide a pressure drop when lift gas is utilized therewith at conventional lift gas flow rates, each of said injection tube having open inner and outer ends, the inner end of each of said tubes being flush with the inner surface of the riser tube which defines said central cavity, each of said injection tubes extending downwardly and outwardly from the annular wall of said riser tube and being adapted to act as guide means for said riser tube when said riser tube is inserted into a well annulus.

11. The gas lift tube of claim 10 wherein said injection tubes are disposed in a plurality of vertically spaced sets, the injection tubes of each set being disposed symmetrically around substantially the entire circumference of said riser tube.

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