



(11)

EP 1 916 380 A1

(12)

## EUROPEAN PATENT APPLICATION

(43) Date of publication:  
30.04.2008 Bulletin 2008/18

(51) Int Cl.:  
*E21B 43/12 (2006.01)*      *F04B 47/12 (2006.01)*

(21) Application number: 06255476.1

(22) Date of filing: 24.10.2006

(84) Designated Contracting States:  
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR  
HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI  
SK TR**  
Designated Extension States:  
**AL BA HR MK RS**

(71) Applicant: **BP EXPLORATION OPERATING  
COMPANY LIMITED  
Sunbury-on-Thames, Middlesex TW16 7BP (GB)**

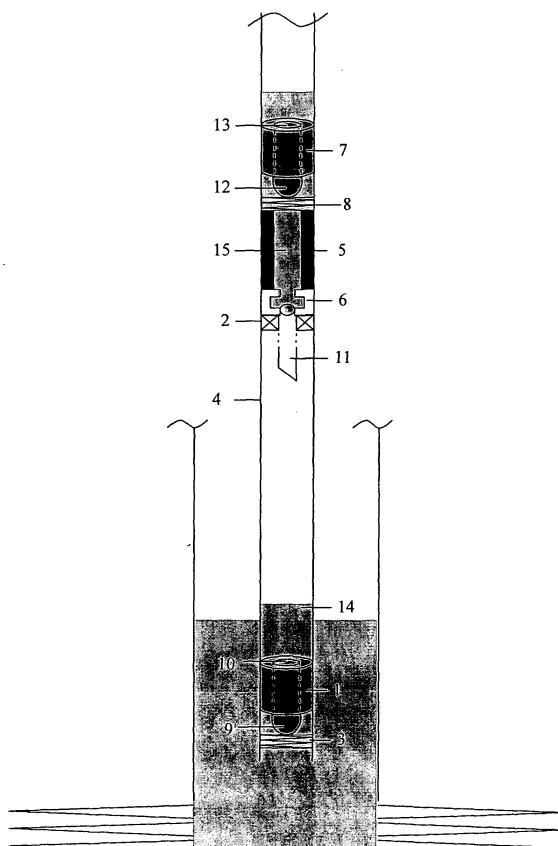
(72) Inventor: **The designation of the inventor has not yet been filed**

(74) Representative: **Collins, Frances Mary et al  
BP International Limited,  
Group Patents and Agreements,  
Chertsey Road  
Sunbury-on-Thames,  
Middlesex TW16 7LN (GB)**

### (54) Method and apparatus for removing liquid from a gas well

(57) A method of removing liquid from a gas well having a production tubing with a restriction therein run into the upper portion thereof and wherein a plunger lift system is arranged within the production tubing, the plunger lift system comprising an upper limiting means, a lower limiting means, a plunger that is capable of moving between the upper and lower limiting means, and a one-way valve situated at or above the upper limiting means that is capable of allowing fluid passage therethrough in an upward direction but not in a downward direction.

FIG.



EP 1 916 380 A1

## Description

**[0001]** The present invention relates to a method and system for removing liquid from gas wells.

**[0002]** Most gas wells during their lifetime produce liquids. Liquids may occur in gas wells as a result of condensation, which takes place when the reservoir pressure is insufficient for particular components to remain in the gaseous state; such components are known as "condensables" and include water, propane, butane, pentane, propylene, ethylene and acetylene. A further source of liquids in gas wells may be water encroachment into the gas producing formation from aquifers or other water-bearing zones.

**[0003]** Gas wells which produce liquids are susceptible to liquid loading, whereby a liquid column accumulates at the bottom of the well. Liquid loading takes place when the flow rate of the produced gas is insufficient to naturally carry liquids to the surface. Liquids are naturally carried to the surface both as entrained droplets and as a liquid film on the inner surface of the production tubing. However, as the pressure of gas in the reservoir decreases over time gas flow rate also decreases. If the flow rate drops below the minimum flow rate at which liquids can be lifted out of a particular well by the flowing gas stream - the critical velocity - fall back of liquid occurs and liquid loading begins. Although gas may, for some time, pass through a liquid column as bubbles or slugs, eventually a hydrostatic equilibrium is reached between the reservoir pressure and the back pressure exerted by the accumulated liquid column. At this point the well is "dead" i.e. it no longer produces gas, although there are still associated reserves. It is therefore necessary to remove the liquid in order to maintain gas production.

**[0004]** Gas wells which experience liquid loading may be low pressure wells, which may sustain liquid loading as soon as production commences. Alternatively, gas wells which undergo liquid loading may be depleted wells, in which the gas flow rate had initially been sufficient to carry liquids to the surface naturally and where production of gas from the gas well has resulted in the reservoir pressure decreasing to such an extent that liquid loading has commenced.

**[0005]** A widely employed means of removing liquid from gas wells is plunger lift. Plunger lift is a cyclic operation wherein a plunger (i.e. a piston) moves reciprocally between two longitudinal positions within a well-production tubing, typically between the lower end of the well production-tubing and a position immediately below, at or immediately above the wellhead. Generally, the plunger travels from the lower end of the production tubing towards the wellhead under the propulsion of gas which has built up in the well and below the plunger. Gas may build up in the well naturally, or may be injected into the well from the surface. As the plunger travels towards the wellhead it lifts a liquid column which has accumulated thereabove. This liquid is then removed at the wellhead, for example via outlet pipes. Typically, the well is shut-

in (i.e. production is stopped) thereby providing an enclosed system and the plunger is allowed to fall through the production tubing under the influence of gravity. When the plunger reaches a column of liquid at the lower

5 end of the production tubing the liquid bypasses the plunger via an annulus between the plunger and the inner-surface of the production tubing and/or through a longitudinal channel through the plunger and accumulates above the plunger. The well is then put back into production, and the pressure that has built up below the plunger lifts the plunger and the liquid column towards the well-head. The annulus between the plunger and the inner surface of the tubing is such that although liquid bypass is tolerated when the plunger falls through the liquid column, on lift of the plunger there is sufficient gas turbulence in the annulus to create a liquid seal which prevents, at least to some extent, fallback of liquid from above the plunger.

**[0006]** Various types of plunger may be employed in 20 a plunger lift system. Two-piece plungers, for example, are particularly common. Two-piece plungers comprise two members which, when coupled together, are capable of lifting liquids. The two members of the plunger are capable of independently falling through an upwardly 25 moving stream of gas or a multiphase stream of gas and liquid without substantially impeding the upward flow of the stream. Thus, a two-piece plunger can be dropped into a gas well whilst the well is in production, thereby reducing the period for which the well must be shut in, or 30 eliminating the need for shutting in the well. This may significantly speed up plunger lift cycles.

**[0007]** Various other means of removing liquids from 35 gas wells are available; however, all have associated disadvantages.

**[0008]** For example, reducing the size of the production tubing, thereby reducing the cross-sectional flow area, can increase the gas flow rate in a given gas well. However, replacing tubing is an expensive procedure and further tubing reduction may be required as the pressure of gas declines over time.

**[0009]** Various down-hole pumping devices are also 45 available to remove liquids from gas wells; however, this requires energy input and expensive equipment for operation. Further, pumps can be readily damaged by solids, such as sand, which may be present in the gas well. However, such down-hole pumping devices experience problems with free gas which interferes with pumping the liquids.

**[0010]** Alternatively, a surfactant or mixture of 50 surfactants may be injected into a gas well to form a foam, which reduces the surface tension of the liquid such that the foam may be lifted at a lower critical velocity than is required for lifting the "un-foamed" liquid. However, although surfactants are useful in de-watering gas wells, 55 liquid hydrocarbons do not foam well and the produced liquid may require continual agitation to maintain foaming. A disadvantage of injecting a surfactants or mixture of surfactants into a gas well is the cost of the chemicals

and potential technical problems associated with the deployment of these chemicals. Also, the installation of a permanent injection facility can be costly and technically challenging. Furthermore, batch treating (dumping surfactant into a well) adds to the hydrostatic liquid column resulting in a limited "time-window" in which the treatment is effective.

**[0011]** Plunger lift systems are advantageous because they can operate without the input of energy and their installation is relatively cheap. In addition, there are methods available to determine whether plunger lift will work in a particular well prior to installation. Also, if, for some reason, a plunger lift system fails to work, it can be relatively easily removed from the well by, for example, wire-line retrieval methods.

**[0012]** Existing plunger lift systems do, however, suffer from at least one significant disadvantage: since the plunger must be able to move between the lower and upper limiting means, the production tubing that is run into the well must not comprise any restrictions which would prevent this. Thus, existing plunger lift systems may not be employed in any gas well where the production tubing has such a restriction. Such restrictions may include down-hole valves, or narrowing of the production tubing. In particular, existing plunger lift systems may not be employed in gas wells where a sub-surface safety valve is present in the production tubing.

**[0013]** There remains a need for an apparatus and method which overcome or at least mitigate these problems. In particular, there remains a need for an improved apparatus and method for removing liquid from gas wells which have a restriction within the production tubing.

**[0014]** According to a first aspect of the present invention there is provided a method of removing liquid from a gas well having a production tubing with a restriction therein run into the upper portion thereof and wherein a plunger lift system is arranged within the production tubing, the plunger lift system comprising an upper limiting means, a lower limiting means, a plunger that is capable of moving between the upper and lower limiting means, and a one-way valve situated at or above the upper limiting means that is capable of allowing fluid passage therethrough in an upward direction but not in a downward direction; the method comprising the steps of:

- a) allowing liquid to accumulate in the gas well with the plunger held at the upper limiting means until a column of liquid forms in the production tubing above the lower limiting means;
- b) releasing the plunger such that it falls towards the lower limiting means through the column of liquid until it engages with the lower limiting means;
- c) allowing gas pressure to build up in the gas well below the plunger until the plunger and column of liquid are forced towards the upper limiting means such that the plunger engages with the upper limiting means and at least a portion of the column of liquid passes through the one-way valve; and

d) repeating steps a) to c).

**[0015]** It is envisaged that gas pressure may also build up, in step c), in the annulus between the production tubing and the casing of a cased gas well.

**[0016]** The method of the present invention may be employed in a deviated well provided that the angle of deviation of the well from the vertical is less than 60°, preferably less than 30°, such that the plunger is capable of falling under gravity through the production tubing.

**[0017]** The upper and lower limiting means are simply means which prevent the plunger travelling further than required. However, it is preferred that the upper and lower limiting means do not impede fluid flow in the production tubing.

**[0018]** The one way-valve may be situated either above or below the restriction in the production tubing, preferably immediately below the restriction. It is also envisaged that the one-way valve may be situated at the upper limiting means, and may in fact act as the upper limiting means. Where the restriction in the production tubing is a downhole valve, such as a sub-surface safety valve of an off-shore gas well, the one-way valve may be incorporated into the downhole valve. Accordingly, the downhole valve may be the restriction in the production tubing and also act as the upper limiting means and as the one-way valve; this provides for relatively easy access if maintenance is required.

**[0019]** Where the one-way valve lies above the upper limiting means, it is preferred that the volume of the column of liquid that forms in the production tubing above the lower limiting means is substantially greater than the volume of the production tubing between the upper limiting means and the one way-valve such that the plunger forces a substantial portion of the column of liquid through the one-way valve. It is therefore preferred that the one-way valve lies immediately above the upper limiting means.

**[0020]** Preferably, the plunger forces at least 75% of the column of liquid through the one-way valve, preferably, at least 95%.

**[0021]** Preferably, the lower limiting means is located within the production tubing at or near the lower end thereof.

**[0022]** During step (a), the gas well is in production. However, a gas stream or a multiphase stream of gas and liquid is capable of by-passing the plunger that is retained at the upper limiting means via an annulus between the plunger and the inner surface of the production tubing. The gas stream or multiphase stream then passes through the one-way valve and to the wellhead of the gas well.

**[0023]** Preferably, the gas well is shut-in during step (b). Preferably, the gas well is opened-up during step (c).

**[0024]** The one-way valve of the plunger lift system prevents the liquid that has been forced therethrough from falling back down the production tubing. As would be well known to the person skilled in the art of deliqui-

fication, the volume of gas increases with decreasing depth due to expansion of the gas at lower pressures. Accordingly, the velocity of the gas that has passed through the one way valve may be higher than the velocity of gas in the lower end of the production tubing. This can lead to the phenomenon that, in upper parts of a gas well, the velocity of the gas may exceed the critical velocity. Where the velocity of the gas stream or of the multiphase stream that passes through the one-way valve is above the critical velocity, liquid will be naturally lifted from above the one-way valve to the wellhead.

**[0025]** Where the flow rate of the gas stream or of the multiphase stream that passes through the one-way valve is below the critical velocity, liquid will accumulate above the one-way valve. Initially, this liquid may be sufficiently agitated to allow for the passage of gas. However, artificial lift may eventually be required to remove the liquid that accumulates in the production tubing above the one-way valve. Owing to the potential increased velocity of the gas stream or the multiphase stream above the one way valve and/or the decreased distance to lift the liquid, the chosen method of artificial lift that is employed is likely to be more effective and/or economical when used in combination with the method of the present invention than if that artificial lift method was used alone to lift liquid from the lower end of the production tubing.

**[0026]** It is therefore envisaged that the method of the present invention may further comprise the step of artificially lifting liquid that accumulates in the production tubing above the one-way valve to the wellhead of the gas well. For example, a surfactant or a mixture of surfactants may be added to any liquid which accumulates above the one-way valve thereby forming a foam which is lifted to the wellhead by the flow of the gas stream or multiphase stream that passes through the one way valve.

**[0027]** Alternatively, a further plunger lift system may be employed to lift any liquid that accumulates in the production tubing above the one way valve. Accordingly, the method of the present invention may further comprise the following steps:

- e) arranging a further plunger lift system within the production tubing above the restriction in the production tubing and above the one-way valve, the further plunger lift system comprising an upper limiting means situated at, immediately above or immediately below the wellhead, a lower limiting means situated at or above the restriction within the production tubing and at or above the one-way valve, and a plunger that is capable of moving between the upper and lower limiting means;
- f) allowing a further column of liquid to accumulate above the restriction within the production tubing and above the one way-valve with the plunger of the further plunger lift system held at the upper limiting means;
- g) releasing the plunger of the further plunger lift system such that the plunger falls towards the lower

limiting means of the further plunger lift system and through the further column of liquid until it engages with the lower limiting means of the further plunger lift system;

5 h) allowing gas pressure to build up below the plunger of the further plunger lift system until the plunger of the further plunger lift system and the further column of liquid are forced towards the upper limiting means of the further plunger lift system such that the plunger engages with the upper limiting means and removing at least a portion of the column of liquid at the wellhead; and

10 i) repeating steps e) to h).

15 **[0028]** Preferably the gas well is shut-in during step (g). As would be evident to the person skilled in the art, the gas well is opened-up during step (h).

**[0029]** According to a second aspect of the present invention, there is provided an apparatus for removing 20 liquids from a gas well having a production tubing with a restriction therein run into the upper portion thereof, the apparatus comprising a plunger lift system arranged within the production tubing wherein the plunger lift system comprises: an upper limiting means, a lower limiting 25 means, a plunger that is capable of moving between the upper and lower limiting means, and a one-way valve that is capable of allowing fluid passage therethrough in an upward direction but not in a downward direction characterised in that the one-way valve is situated at or above 30 the upper limiting means, the upper limiting means is situated at or below the restriction in the production tubing, and the lower limited means is situated at location where, during production of gas from the gas well, a column of liquid accumulates in the production tubing.

35 **[0030]** The upper limiting means of the plunger lift system is preferably the restriction in the production tubing. Alternatively, the upper limiting means may be a separate restriction within the production tubing.

**[0031]** The plunger lift system may further comprise a 40 retaining means for holding the plunger at or near the upper limiting means until it is required to fall. For example, such retaining means may be a mechanically or electrically actuated retaining-means, controllable from the surface. Alternatively, the upper limiting means may comprise an electromagnetic retaining means, also controllable from the surface. Electricity may be supplied to such retaining means by batteries, or by an electrical cable run, for example, through an annulus between the production tubing and the well-casing and then through the 45 wall of the production tubing.

**[0032]** The plunger lift system may further comprise a 50 means for detecting when the volume of the column of liquid (liquid loading) is sufficiently high that the plunger is required to fall towards the lower limiting means and through the column of liquid until it engages with the lower limiting means. Such means, may, for example, be a pressure measurement device, located at the lower limiting means, wherein the pressure measurement is cor-

related with liquid loading. Thus, the higher the pressure difference between the wellhead pressure and the down-hole pressure at the lower limiting means, the more liquid is present in the production tubing.

**[0033]** The plunger lift system may further comprise means for detecting when the plunger has reached the lower limiting means. Such means include, for example, electro-magnetic detectors, impact detectors, and acoustic detectors.

**[0034]** As discussed above, the one-way valve may be situated above or below the restriction in the production tubing. Preferably the one-way valve is situated below the restriction. More preferably the one-way valve acts as the upper limiting means. Also, as discussed above, the one-way valve may act as the restriction in the production tubing.

**[0035]** In order to prevent damage to the plunger and/or the production tubing, the plunger lift system may further comprise shock absorber means for absorbing shock when the plunger impacts upon the lower and upper limiting means. The shock absorber means may act as the upper and/or lower limiting means. For example, the upper and/or lower limiting means may be a resilient bumper, such as a bumper spring. Alternatively one or both of the shock absorbers may be attached, either directly or indirectly, to the plunger itself, for example a bumper spring may be attached to the upper and/or lower surfaces of the plunger.

**[0036]** Typically, the plunger of the plunger lift system is cylindrical in shape where the longitudinal axis of the cylinder is aligned with the longitudinal axis of the production tubing. Suitably, the plunger is composed of a dense material, such as galvanised titanium or steel. Frequently the cylindrical surface of the plunger is provided with ribs or grooves in order to aid turbulence in the annulus between the plunger and the production tubing. Typically, the cylindrical surface of the plunger is provided with circumferential or helical ribs or grooves.

**[0037]** Preferably the plunger of the plunger lift system of the present invention is a two-piece plunger. Two-piece plungers generally comprise a cylindrical first member, having a channel extending longitudinally therethrough; and a second member, which sealingly engages with the cylindrical first member thereby sealing the channel, such that passage of fluids through the channel is either prevented or is substantially reduced. The channel may be arranged centrally in the cylindrical first member or may be offset. It is preferred that the longitudinal axis of the channel is aligned with the longitudinal axis of the cylindrical first member. In use, the two-piece plunger is arranged in the production tubing with the longitudinal axis of the cylindrical first member aligned with the longitudinal axis of the production tubing. Generally, the cylindrical first member is arranged above the second member in the production tubing. Preferably, the lower surface of the cylindrical first member is shaped to complement the shape of the second member, for example, the second member may be spherical and the lower sur-

face of the cylindrical first member may be concave - this ensures that sealing engagement of the first and second members can be readily achieved. Alternatively, the second member may be a rod which fits inside the channel of the cylindrical first member. Such rods may be provided with stabilisers, for example a series of outwardly extending arms at the base of the rod, such that the rod remains aligned with the channel of the cylindrical first member.

**[0038]** In use, the cylindrical first member of the two-piece plunger is held by retaining means at the upper limiting means while the second member falls down the production tubing toward the lower limiting means. As the second member falls, a gas stream or a multiphase stream of gas and liquid is able to flow upwardly around it. Thus, the second member may be allowed to fall through the production tubing while the gas well remains in production. When required, the cylindrical first member may be released from the retaining means. As the cylindrical first member falls down the production tubing it allows upward flow of a gas stream or a multiphase stream of gas and liquid through the channel. Accordingly, the cylindrical first member may also be released from the retaining means while the gas well remains in production. When the cylindrical first member reaches the column of liquid that has accumulated above the lower limiting means, liquid will be forced through the channel of the cylindrical first member in addition to by-passing the plunger via an annulus between the cylindrical first member and the inner surface of the production tubing. When the cylindrical first member reaches the lower limiting means it sealingly engages with the second member, substantially preventing any flow of fluids through the channel of the cylindrical first member. The first and second members will then remain coupled at the lower limiting means until sufficient gas pressure has built up below the two-piece plunger to lift both the two-piece plunger and the liquid column above the two-piece plunger up the production tubing towards the upper limiting means such that at least a portion of the column of liquid passes through the one-way valve. There may be sufficient gas pressure for lifting the two-piece plunger and associated liquid column as soon as the first member reaches the lower limiting means. Alternatively, the well may be shut-in until sufficient gas pressure has built up.

**[0039]** Typically the upper limiting means is provided with a decoupling means for decoupling the sealingly-engaged first and second members of the two-piece plunger thereby unsealing the channel of the cylindrical first member. It is preferred that the decoupling means does not prevent upward passage of fluids through the channel of the cylindrical first member of the two-piece plunger. Typically, the decoupling means protrudes downwardly from the upper limiting means and is capable of being inserted through the channel of the first member to decouple the two-piece plunger by forcing the second member away from sealing engagement with the channel of the cylindrical first member. Typically, the downwardly

protruding decoupling means is a pipe having a length greater than the length of the channel in the cylindrical first member. Alternatively, the downwardly protruding decoupling means may be a rod, which is of narrower diameter than the channel and has a length that is greater than the length of the channel of the cylindrical first member. Initially, the gas flow rate may be too high for the second member of the two piece plunger to fall through the production tubing. Thus, the second member may be held by gas flow adjacent the channel through the cylindrical first member. However, the second member does not block the channel, as the rod has forced the second member away from sealing engagement with the channel such that fluid can flow around the second member and through an annulus between the wall of the channel and the rod. Where the downwardly protruding decoupling means is a pipe, it is preferred that the lower end of the pipe is shaped so as to mitigate the risk of the second member blocking the channel in the cylindrical first member to flow of fluid therethrough, for example, the lower end of the pipe may be cut at an angle, or there may be perforations in the lower end of the pipe. As gas flow declines, owing to the accumulation of the column of liquid in the production tubing, the second member will fall toward the lower limiting means of the plunger lift system.

**[0040]** Suitably the apparatus of the present invention may comprise a further plunger lift system comprising an upper limiting means situated at or near the wellhead and a lower limiting means situated at or above the restriction within the production tubing and at or above the one-way valve. Where the one-way valve is situated below the restriction in the production tubing, the lower limiting means of the further plunger lift system is suitably the restriction. Where the one-way valve is situated above the restriction in the production tubing, the lower limiting means of the further plunger lift system is suitably the one-way valve. Preferably the further plunger lift system additionally comprises a retaining means for holding the plunger at or near the upper limiting means. Preferably the further plunger lift system also includes a means of detecting when sufficient liquid has accumulated above the one-way valve such that the plunger is required to fall. A means of detecting when the plunger of the further plunger lift system has reached the lower limiting means is preferably provided. The further plunger lift system may also comprise shock absorbing means, as described above. Preferably the plunger of the further plunger lift system is a two-piece plunger of the type described above in which case, the upper limiting means of the further plunger lift system is provided with a decoupling means.

**[0041]** Where a gas well comprises more than one restriction within the production tubing, a corresponding number of plunger lift systems according to the invention may be employed, for successively lifting liquid past each of the restrictions within the production tubing and to the wellhead.

**[0042]** Where the apparatus of the present invention

comprises at least one further plunger lift system, it is envisaged that the apparatus may further comprise a timing device. Such a timing device may allow the plungers of the systems to be released at different times. This may

5 prevent the unnecessary lifting of one of the plungers, in particular when a plunger has little, or no, liquid above it.

**[0043]** The invention will now be described by way of example only and with reference to the Figure which represents, in simplified cross-section, a production tubing

10 of an off-shore gas-well having an apparatus according to the invention arranged therein.

**[0044]** Referring to the Figure, the apparatus comprises: a first and a second plunger lift system arranged within a production tubing (4) below and above a sub-surface

15 safety valve (5) respectively. The first plunger lift system comprises a plunger (1), an upper limiting means (2), a lower limiting means (3), and a one-way valve (6) situated above the upper limiting means (2) and below the sub-surface safety valve (5). The second plunger lift system

20 comprises a plunger (7), an upper limiting means (not shown) and a lower limiting means (8), situated above the sub-surface safety valve (5). The plunger (1) of the first plunger lift system is a two-piece plunger comprising a cylindrical first member (1) and a spherical second

25 member (9) wherein the cylindrical first member (1) has a channel (10) extending longitudinally therethrough and a concave lower surface (not shown). The upper limiting means (2) of the first plunger lift system is provided with a decoupling means (11) for releasing the spherical second member (9) of the two-piece plunger from sealing

30 engagement with the concave lower surface of the cylindrical first member. The decoupling means (11) is a pipe that extends downwardly from the upper limiting means (2) and has its lower end cut at an angle. A retaining

35 means (not shown) - preferably a mechanical tool that is triggered by pressure - is provided for holding the first member of the two-piece plunger (1) at or near the upper limiting means (2). The lower limiting means (3) of the first plunger lift system is optionally provided with a shock

40 absorbing means. The plunger (7) of the second plunger lift system is also a two-piece plunger (7), comprising a cylindrical first member (7) and a spherical second member (12) wherein the cylindrical first member (7) has a channel (13) extending longitudinally therethrough and

45 a concave lower surface (not shown). The upper limiting means (not shown) of the second plunger lift system is the wellhead or may be located near the wellhead and the upper limiting means is provided with a decoupling means (not shown), for example, a rod protruding downwardly from the wellhead; and a retaining means (not shown) for holding the first member of the two-piece

50 plunger of the second plunger lift system at or near the upper limiting means (not shown) of the second plunger lift system. Preferably, the retaining means is a conventional lubricator type arrangement. The lower limiting means (8) of the second plunger lift system is optionally provided with a shock-absorbing means.

**[0045]** In use, a column of liquid (14) is allowed to ac-

cumulate above the lower limiting means (3) of the first plunger lift system while the cylindrical first member (1) of the two-piece plunger is held at the upper limiting means (2) by the retaining means (not shown). When the volume of the column of liquid (14) reaches a critical volume at which gas production declines to an unacceptable level, the gas well is generally shut-in and the first member (1) of the two-piece plunger is released from the retaining means (not shown) and is allowed to fall. As the first member (1) falls, gas or a multiphase mixture of gas and liquid passes through the channel (10). When the cylindrical first member (1) reaches the column of liquid (14), liquid is forced through the channel (10) and through an annulus between the plunger (1) and the inner surface of the production tubing (4) until the first member (1) sealingly engages with the second cylindrical member (9) of the two-piece plunger. Gas pressure is then allowed to build up below the two-piece plunger (1 & 9) and, if applicable, in the annulus between the production tubing and casing of a cased gas well, until the two-piece plunger (1 & 9) and the column of liquid (14) are forced towards the upper limiting means (2). Generally, the two-piece plunger is forced towards the upper limiting means (2) when the well is opened (offset by the initial pressure drop when opening up the well). As the two-piece plunger (1 & 9) approaches the upper limiting means (2) at least a portion of the liquid column above the plunger will pass through the one-way valve. When the two-piece plunger (1 & 9) of the first plunger lift system reaches the upper limiting means (2), the second member of the two-piece plunger (9) will be forced away from the first member (1) by the decoupling means (11) and the retaining means for holding the plunger at the upper limiting means (not shown) is actuated. If the gas flow rate is initially too high for the second member (9) of the two-piece plunger to fall, the angled end of the downwardly protruding pipe (11) will prevent the second member (9) of the two-piece plunger blocking the pipe (11) to passage of gas or multiphase fluid. As gas flow rate declines (for example due to further liquid loading) the second member (9) of the two-piece plunger will fall to the lower limiting means (3) of the first plunger lift system. The cycle may then be repeated.

**[0046]** Liquid which is lifted through the one-way valve (6) by the first plunger lift system will accumulate above the one-way valve as a liquid column (15). Once the volume of the liquid column (15) above the one-way valve (6) exceeds a certain critical volume at which gas production declines to an unacceptable level, the first member (7) of the two-piece plunger of the second plunger lift system is released from the retaining means (not shown) and allowed to fall. When the first member (7) of the plunger of the second plunger lift system reaches the column of liquid (15), liquid is forced through the channel (13) extending longitudinally through the first member (7) and through an annulus between the plunger (7) and the inner surface of the production tubing (4) until the first member (7) sealingly engages with the second member

(12) of the two-piece plunger of the second plunger lift system. Gas is then allowed to build up below the plunger (7 & 12) of the second plunger lift system until the plunger and the column of liquid (15) are forced towards the upper limiting means (not shown) of the second plunger lift system. When the plunger of the second plunger lift system arrives at the wellhead, liquid is removed at the well head (not shown) by an outlet pipe. On the plunger's arrival at the well head, the retaining means for holding the first member (7) at the well head (not shown) can be actuated and the protruding rod forces the spherical second member (12) of the two-piece plunger away from sealing engagement with the channel of the cylindrical first member, such that the second member (12) may fall to the lower limiting means (8). The cycle may then be repeated.

**[0047]** Optionally the retaining means may be connected to a timer device (not shown) such that the first members (1 & 7) of the first and second plunger lift systems may be allowed to fall at different times.

## Claims

1. A method of removing liquid from a gas well having a production tubing with a restriction therein run into the upper portion thereof and wherein a plunger lift system is arranged within the production tubing, the plunger lift system comprising an upper limiting means, a lower limiting means, a plunger that is capable of moving between the upper and lower limiting means, and a one-way valve situated at or above the upper limiting means that is capable of allowing fluid passage therethrough in an upward direction but not in a downward direction; the method comprising the steps of:
  - a) allowing liquid to accumulate in the gas well with the plunger held at the upper limiting means until a column of liquid forms in the production tubing above the lower limiting means;
  - b) releasing the plunger such that it falls towards the lower limiting means through the column of liquid until it engages with the lower limiting means;
  - c) allowing gas pressure to build up in the gas well below the plunger until the plunger and column of liquid are forced towards the upper limiting means such that the plunger engages with the upper limiting means and at least a portion of the column of liquid passes through the one-way valve; and
  - d) repeating steps a) to c).
2. A method as claimed in Claim 1 wherein the gas well has a casing and in step c) gas pressure builds up in the annulus formed between the casing and the production tubing.

3. A method as claimed in any one of the preceding  
Claims which further comprises the steps of:

e) arranging a further plunger lift system within the production tubing above the restriction in the production tubing and above the one-way valve, the further plunger lift system comprising an upper limiting means situated at, immediately above or immediately below the wellhead, a lower limiting means situated at or above the restriction within the production tubing and at or above the one-way valve, and a plunger that is capable of moving between the upper and lower limiting means; 5

f) allowing a further column of liquid to accumulate above the restriction within the production tubing and above the one way-valve with the plunger of the further plunger lift system held at the upper limiting means; 15

g) releasing the plunger of the further plunger lift system such that the plunger falls towards the lower limiting means of the further plunger lift system and through the further column of liquid until it engages with the lower limiting means of the further plunger lift system; 20

25

h) allowing gas pressure to build up below the plunger of the further plunger lift system until the plunger of the further plunger lift system and the further column of liquid are forced towards the upper limiting means of the further plunger lift system such that the plunger engages with the upper limiting means and removing at least a portion of the column of liquid at the wellhead; and 30

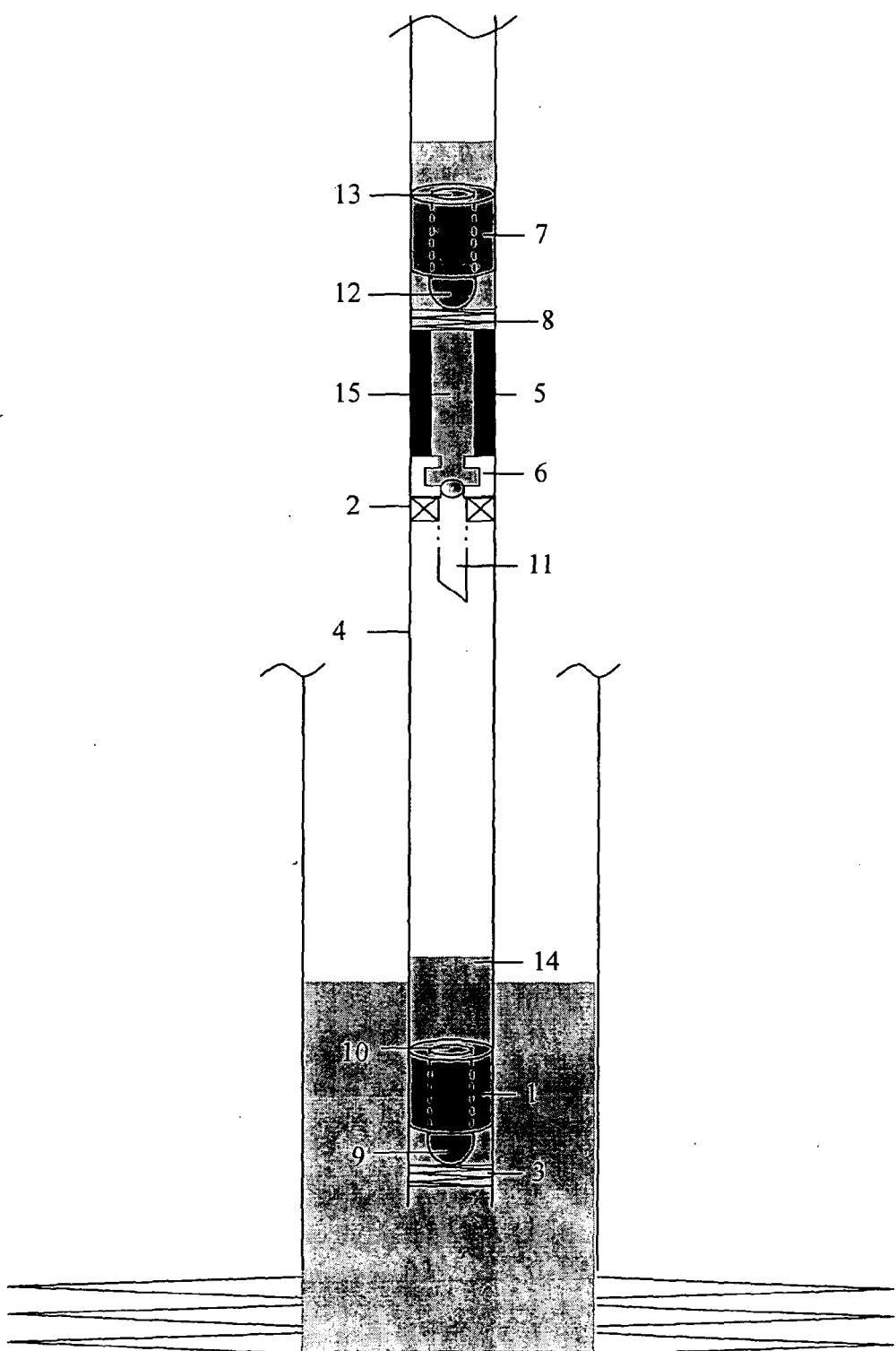
i) repeating steps e) to h). 35

4. An apparatus for removing liquids from a gas well having a production tubing with a restriction therein run into the upper portion thereof, the apparatus comprising a plunger lift system arranged within the production tubing wherein the plunger lift system comprises: an upper limiting means, a lower limiting means, a plunger that is capable of moving between the upper and lower limiting means, and a one-way valve that is capable of allowing fluid passage therethrough in an upward direction but not in a downward direction **characterised in that** the one-way valve is situated at or above the upper limiting means, the upper limiting means is situated at or below the restriction in the production tubing, and the lower limited means is situated at location where, during production of gas from the gas well, a column of liquid accumulates in the production tubing. 40

45

50

FIG.





DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (IPC)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
X	US 2 160 291 A1 (SCOTT CLARENCE N) 30 May 1939 (1939-05-30) * page 4, column 1, line 42 - page 5, column 1, line 59 * * figures 1-6 *	4	INV. E21B43/12 F04B47/12
Y	-----	1-3	
X	US 2 676 547 A1 (KNOX DONALD G) 27 April 1954 (1954-04-27) * column 4, line 61 - column 5, line 48 * * figures 1-4 *	4	
Y	-----	1-3	
X	US 7 080 692 B1 (KEGIN KEVIN L [US]) 25 July 2006 (2006-07-25) * the whole document *	4	
	-----		
			TECHNICAL FIELDS SEARCHED (IPC)
			E21B F04B
<p>3 The present search report has been drawn up for all claims</p>			
Place of search		Date of completion of the search	Examiner
The Hague		13 March 2007	Schouten, Adri
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			
T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ..... & : member of the same patent family, corresponding document			

ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.

EP 06 25 5476

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

13-03-2007

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2160291	A1	NONE	
US 2676547	A1	NONE	
US 7080692	B1	25-07-2006	US 7080691 B1 25-07-2006