Apparatus and methods for well pumping utilizing a submersible system comprising a pump body having a pump chamber and a hydraulic chamber. A diaphragm is disposed within the pump chamber and divides the pump chamber into a pumped fluid chamber and a hydraulic fluid chamber. A piston is disposed within the hydraulic chamber such that movement of the piston within the hydraulic chamber creates a differential pressure across the diaphragm. A coupling is connected to the piston and operable to connect the piston to a rod extending from the top of the well.
MECHANICALLY ACTUATED DIAPHRAGM PUMPING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

0001 Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

0002 Not Applicable.

BACKGROUND

0003 The present invention relates generally to methods and apparatus for submersible pumping systems. More particularly, the present invention relates to methods and apparatus for submersible pumps used in artificial lift systems for producing low flow rate oil, gas and coal bed methane wells.

0004 Hydrocarbons, and other fluids, are often contained within subterranean formations at elevated pressures. Wells drilled into these formations allow the elevated pressure within the formation to force the fluids to the surface. However, in low pressure formations, or when the formation pressure has diminished, the formation pressure may be insufficient to force the fluids to the surface. In these cases, a pump can be installed to provide the required pressure to produce the fluids.

0005 The volume of well fluids produced from a low pressure well is often limited, thus limiting the potential income generated by the well. For wells that require pumping systems, the installation and operating costs of these systems often determine whether a pumping system is installed to enable production or the well is abandoned. Among the many significant costs associated with pumping systems are those for installing, maintaining, and powering the system. Reducing these costs may allow more wells to be produced economically and increase the efficiency of wells already having pumping systems.

0006 The operation of a downhole pumping system depends on providing energy, which is converted to hydraulic power that lifts fluid from the well. Thus, the transmission of hydraulic power between the surface and a downhole pump is one of the key elements that determines the efficiency, size, and operating characteristics of a downhole pumping system. For example, a rod pump, which is the dominate means of pumping fluids from oil and gas wells, uses a reciprocating steel rod as the means to transmit energy from the surface to the downhole pump. Rod pumps, although plentiful, suffer serious limitations, especially under harsh conditions. Most of the problems stem from wear in the pump due to the interaction of the pumped fluid with the pressure generating (piston-cylinder) portions of the pump.

0007 There remains a need to develop lower cost, more efficient methods and apparatus for pumping fluids from a low pressure wellbore that overcome some of the foregoing difficulties while providing more advantageous overall results.

SUMMARY OF THE PREFERRED EMBODIMENTS

0008 The embodiments of the present invention are directed toward apparatus and methods for well pumping utilizing a submersible system comprising a pump body having a pump chamber and a hydraulic chamber. A diaphragm is disposed within the pump chamber and divides the pump chamber into a pumped fluid chamber and a hydraulic fluid chamber. A piston is disposed within the hydraulic chamber such that movement of the piston within the hydraulic chamber creates a differential pressure across the diaphragm. A coupling is connected to the piston and operable to connect the piston to a rod extending from the top of the well.

0009 In certain embodiments, a well pumping system comprises a rod extending into a tubing string disposed in a well. A submersible pump is disposed in the well and coupled to the rod. The submersible pump comprises a pump body having a pump chamber and a hydraulic chamber, where a diaphragm is disposed within the pump chamber and divides the pump chamber into a pumped fluid chamber and a hydraulic fluid chamber. A piston is disposed within the hydraulic chamber such that movement of the piston within the hydraulic chamber creates a differential pressure across the diaphragm. An inlet valve selectively controls the flow of fluid from the well into the pumped fluid chamber and an outlet valve selectively controls the flow of fluid from the pumped fluid chamber into an annular region between said rod and the tubing string.

0010 In some embodiments, a method for installing an operating a well pumping system comprising connecting a submersible pump to a rod and extending the rod into a tubing string disposed in a well. The submersible pump is connected to the tubing string. The pump is operated by actuating the rod so as to reciprocate a piston that is disposed within a hydraulic chamber of the submersible pump. Fluid pressure is transferred from the hydraulic chamber to a pump chamber of the submersible pump, wherein a diaphragm divides the pump chamber into a pumped fluid chamber and a hydraulic fluid chamber so that as pressure within the hydraulic fluid chamber decreases, fluid is pulled into the pumped fluid chamber from the well and as pressure within the hydraulic fluid chamber increases fluid is moved from the pumped fluid chamber into an annular area between the rod and the tubing string.

0011 Thus, the present invention comprises a combination of features and advantages that enable it to overcome various problems of prior devices. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description of the preferred embodiments of the invention, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

0012 For a more detailed description of the preferred embodiment of the present invention, reference will now be made to the accompanying drawings, wherein:

0013 FIG. 1 is a schematic view of one embodiment of a reciprocating rod-driven submersible pumping system utilizing a boot seal;

0014 FIG. 2 is a schematic view of a submersible pump utilizing a bottom hold down system;

0015 FIG. 3 is a schematic view of a submersible pump utilizing a top hold down system;
FIG. 4 is a schematic view of a submersible pump mounted on production tubing;

FIG. 5 is a schematic view of one embodiment of a reciprocating rod-driven submersible pumping system utilizing wiper seals; and

FIG. 6 is a schematic view of one embodiment of a rotating rod-driven submersible pumping system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows a submersible pump 10 coupled to a reciprocating rod 12 via connecting rod 14 and couplings 16. Pump 10 comprises body 18, inlet valve 20, diaphragm 22, pump chamber 24, outlet valve 26, hydraulic cylinder 28, piston 30, and boot seal 32. Inlet valve 20 controls the flow of fluid through inlet 34 and comprises ball 36 and seat 38. Outlet valve 26 controls the flow of fluid through outlets 40 and comprises ball 44 and seat 42. Diaphragm 22 is disposed within pump chamber 24 and provides a flexible membrane allowing the transfer of hydraulic forces, i.e., pressure, but not fluid between the pumped fluid from the wellbore and the hydraulic fluid in the pump.

Pumped fluid flows from the wellbore, through inlet valve 20, and into pump chamber 24. The fluid exits pump chamber 24 through outlet valve 26 and into the tubing string above pump 10. Pump chamber 24 is a constant volume chamber and has rigid boundaries. Diaphragm 22 divides pump chamber 24 into a pumped fluid chamber 46, which is connected to valves 20 and 26, and a hydraulic fluid chamber 48, which is in fluid communication with hydraulic cylinder 28.

Piston 30 is moveably disposed within hydraulic cylinder 28. Seals 47 engage the wall of cylinder 28 and divide the cylinder into an upper chamber 50 and a lower chamber 52. Both upper chamber 50 and lower chamber 52 are filled with a fixed volume of hydraulic fluid that is preferably a clean, dry hydraulic oil. Upper chamber 50 is isolated from the wellbore by boot seal 32 which sealingly engages pump body 18 and piston 30 and allows for volumetric changes in the upper chamber. Lower chamber 52 is fluidly connected to hydraulic fluid chamber 48.

Piston 30 is coupled to reciprocating rod 12 via connecting rod 14 and couplings 16. As piston 30 is moved upward by reciprocating rod 12, hydraulic fluid is drawn from hydraulic fluid chamber 48 into lower chamber 52. This decreases the fluid volume in hydraulic fluid chamber 48 and causes diaphragm 22 to expand. The expansion of diaphragm 22 closes outlet valve 26, opens inlet valve 20, and draws fluid through inlet 34 into the diaphragm. The upward movement of piston 30 also causes boot seal 32 to expand.

Once reciprocating rod 12 has reached the upward limit of its stroke it reverses direction and moves downward. As piston 30 is moved downward by reciprocating rod 12, hydraulic fluid is pushed back into hydraulic fluid chamber 48 from lower chamber 52. This increases the fluid volume in hydraulic fluid chamber 48 and causes diaphragm 22 to contract. The contraction of diaphragm 22 closes inlet valve 20, opens outlet valve 26, and pushes fluid through out of the diaphragm and through outlets 40. The downward movement of piston 30 also causes boot seal 32 to contract.

Thus, the reciprocation of hydraulic fluid into and out of hydraulic fluid chamber 48 causes pumped fluid to move through valves 20 and 26 and into and out of the diaphragm 22, causing a pumping action. Boot seal 32 and diaphragm 22 provide static seals that help to assure a complete seal and long life for the pump. This arrangement also assures that pumped fluid never comes into contact with dynamic seals 46 located on piston 30. The linear movement of reciprocating rod 12 and piston 30 is preferably designed such that diaphragm 22 is substantially emptied on each stroke. In certain embodiments, piston 30 is designed to have a potential stroke distance that is about 50% larger than the actual stroke of reciprocating rod 12 so as to accommodate mechanical alignment and rod stretch.

Pump dynamics are also improved as the delivery stroke is the downstroke rather than the upstroke as in conventional rod pumps. This allows the weight of the reciprocating rod 12, rather than the lifting force provided by the surface unit, to be the driving force delivering fluid from pump 10 to the surface. The use of a viscous hydraulic fluid to transmit pressure between hydraulic cylinder 28 and the pump chamber 24, with appropriate restrictions 43 between the two, can eliminate rod pound by providing slowing of the downward motion of the reciprocating rod 12 when pumping gas. Such a viscous connection provides increased resistance to the movement of piston 30 when high velocities may be encountered due to a lack of resistance that may occur, such as when gas is drawn into diaphragm 22.

In certain embodiments, pump assembly 10 is installed downhole on reciprocating rod 12. Referring now to FIG. 2, the lower end of pump 10 is fitted with a mechanical, or cup-type, bottom hold down system 56 to attach the pump to landing nipple 56 in tubing string 54. This embodiment is installed in the same way as a standard insert rod pump, and can directly replace almost any standard downhole rod pump. FIG. 3 illustrates an alternate hold down system for pump 10 where the pump is coupled to tubing string 60 via the engagement of top hold down system 64 with landing nipple 62. Both top and bottom hold down systems are well known in the art.

As shown in FIGS. 2 and 3, pump 10 may further comprise check valve 70 disposed on piston 30. Check valve 70 comprises seat 72, ball 74, and biasing member 76. Check valve 70 provides selective fluid communication between upper chamber 50 and lower chamber 52. Biasing member 76 urges ball 74 into sealing engagement with seat 72 preventing fluid communication between upper chamber 50 and lower chamber 52. As piston 30 moves downward, pressure within lower chamber 52 increases. As the fluid within lower chamber 52 reaches a predetermined pressure, the differential pressure across ball 74 will compress biasing member 76. The compression of biasing member 76 opens check valve 70 and allows fluid communication between lower chamber 52 and upper chamber 50 so that the pressure within the chambers will equalize.

Check valve 70 and biasing member 76 are selected such that the valve opens at a predetermined pressure that is less than the failure pressure of diaphragm 22. Thus, valve 70 prevents damage to diaphragm 22 due to overpressurization. Check valve 70 compensates for pump setting variations, and other variations in volume of fluid due
to leakage, thermal expansion, or other factors. In other embodiments, a small orifice through piston 30 may be used in place of check valve 70.

[0029] Referring now to FIG. 4, a tubing-mounted pump 100 is shown. Pump 100 comprises body 118, inlet valve 120, diaphragm 122, pump chamber 124, outlet valve 126, hydraulic cylinder 128, piston 130, check valve 131, and boot seal 132. Pump 100 is attached to tubing string 102 and installed into a well with the tubing string. Reciprocating rod 112 is then run into tubing string 102 and connected to piston 130 via releasable coupling 116. Coupling 116 may be a mechanical hold down assembly, such as Harbison-Fischer part number 7381H1b, engaging a standard F-type seating nipple. Coupling 116 is designed to remain connected until the pulling force exceeds a selectable maximum, at which time, the coupling disengages, allowing the reciprocating rod 112 to be pulled from the well separately from tubing string 102.

[0030] The reciprocating movement of rod 112 operates pump 100 in the same manner as described in relation to pump 10 above. In general, as piston 130 moves upward, hydraulic fluid is drawn into hydraulic cylinder 128 from pump chamber 124, expanding diaphragm 122 and drawing fluid through inlet valve 120. As piston 130 moves downward, hydraulic fluid is forced back into pump chamber 124, collapsing diaphragm 122 and pushing fluid into tubing string 102 through outlet valve 126. Check valve 131 provides fluid communication across piston 130 so as to limit the fluid pressure acting on diaphragm 122. Mounting pump 100 to tubing string 102 allows for a larger diameter pump to be used which in turn allows for a larger diaphragm 122 and an increased pumping capacity.

[0031] Referring now to FIG. 5, submersible pump 150 is coupled to a reciprocating rod 162 via connecting rod 164 and couplings 166. Pump 150 comprises body 168, inlet valve 170, diaphragm 172, pump chamber 174, outlet valve 176, hydraulic cylinder 178, piston 180, piston seals 182, and wiper seal 184. As with pump 10, as piston 180 moves upward, hydraulic fluid is drawn into hydraulic cylinder 178 from pump chamber 174, expanding diaphragm 172 and drawing fluid through inlet valve 170. As piston 180 moved downward, hydraulic fluid is forced back into pump chamber 174, collapsing diaphragm 172 and pushing fluid through outlet valve 176.

[0032] Wiper seal 184 provides an effective seal that engages piston 180 and minimizes the loss of hydraulic fluid. Wiper seal 184 may preferably be used in less severe environments where fluid loss and seal wear is not expected on the wiper. Although the boot seal of pump 10 may form a better seal, wiper 184 will, in many environments, effectively accomplish the same job while being less complicated and more compact.

[0033] Some current wells utilize rotating rods, as an alternative to reciprocating rods, to provide power to submersible pumps. FIG. 6 illustrates a submersible pump 200 configured for use with a rotating rod 212. Pump 200 comprises body 218, inlet valve 220, diaphragm 222, pump chamber 224, outlet valve 226, expansion element 227, hydraulic cylinder 228, piston 230, check valve 231, and barrel cam 232. Pump 200 is connected to rotating rod 212 by coupling 216. A non-contact coupling, such as a magnetic coupling, can be used to seal the pump assembly without the use of dynamic seals.

[0034] The rotation of rod 212 causes barrel rod 234 to rotate and barrel body 236 and piston 230 to reciprocate within hydraulic cylinder 228. As piston 230 moves upward, hydraulic fluid is drawn into hydraulic cylinder 228 from pump chamber 224, expanding diaphragm 222 and drawing fluid through inlet valve 220. Expansion element 227 is constructed from an expandable material so as to compensate for the change in volume of chamber 228 as piston 230 moves. As piston 230 moves downward, hydraulic fluid is forced back into pump chamber 224, collapsing diaphragm 222 and pushing fluid through outlet valve 226. Check valve 231 provides fluid communication across piston 230 so as to limit the fluid pressure acting on diaphragm 222.

[0035] Although the submersible pump systems shown and described herein use sucker rods activated by existing drive systems, such as reciprocating rod pump drive heads or progressing cavity rotating rod drive heads to operate the pump, other methods, such as using a cable and weight system to operate a reciprocating pump, are also possible. The embodiments shown and described herein provide a mechanically actuated hydraulic diaphragm pump that can utilize the motion of a rotating and/or reciprocating rod string to operate the pump. The preferred pump systems isolate the pumped fluid from the working fluid with one or more flexible diaphragms and/or seals. The systems can be designed to work in the same way, and use the same infrastructure, e.g. surface units, rod strings, hold down systems, balls and seats, installation methods, etc., as conventional rod pump bottom hole assemblies, but operate using a diaphragm pump instead of a conventional piston-cylinder pump or progressing cavity pump.

[0036] While preferred embodiments of this invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the scope or teaching of this invention. The embodiments described herein are exemplary only and are not limiting. Many variations and modifications of the system and apparatus are possible and are within the scope of the invention. For example, the relative dimensions of various parts, the materials from which the various parts are made, and other parameters can be varied, so long as the apparatus retain the advantages discussed herein. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims.

What is claimed is:
1. A well pumping system comprising:
   a pump body comprising a pump chamber and a hydraulic chamber, wherein said pump body is dispos: able within a well;
   a diaphragm disposed within the pump chamber, wherein said diaphragm divides the pump chamber into a pumped fluid chamber and a hydraulic fluid chamber;
   a piston disposed within the hydraulic chamber, wherein movement of said piston within the hydraulic chamber creates a differential pressure across said diaphragm; and
   a coupling connected to said piston and operable to connect said piston to a rod extending from the top of the well.
2. The well pumping system of claim 1 further comprising a hold down system that is operable to attach said pump body to a tubing string disposed within the well.

3. The well pumping system of claim 1 wherein said piston has a first portion disposed within the hydraulic chamber and a second portion extending outside of said pump body.

4. The well pumping system of claim 3 further comprising a seal member sealingly engaged with said piston and said pump body, wherein said seal member forms a barrier between the hydraulic chamber and the well.

5. The well pumping system of claim 4 wherein said seal member is a static seal.

6. The well pumping system of claim 5 wherein said seal is a boot seal.

7. The well pumping system of claim 5 wherein said seal is a wiper seal.

8. The well pumping system of claim 1 wherein the rod extending from the top of the well reciprocates.

9. The well pumping system of claim 1 wherein the rod extending from the top of the well rotates.

10. The well pumping system of claim 9 further comprising a cam that converts rotation of the rod into movement of said piston within the hydraulic chamber.

11. The well pumping system of claim 1 further comprising a check valve selectively providing fluid communication across said piston so as to limit the differential pressure across said diaphragm.

12. A well pumping system comprising:

   a rod extending into a tubing string disposed in a well; and
   a submersible pump disposed in a well and coupled to said rod, wherein said submersible pump comprises:
   a pump body comprising a pump chamber and a hydraulic chamber;
   a diaphragm disposed within the pump chamber, wherein said diaphragm divides the pump chamber into a pumped fluid chamber and a hydraulic fluid chamber;
   a piston disposed within the hydraulic chamber, wherein movement of said piston within the hydraulic chamber creates a differential pressure across said diaphragm;
   an inlet valve that selectively controls the flow of fluid from the well into the pumped fluid chamber; and
   an outlet valve that selectively controls the flow of fluid from the pumped fluid chamber into an annular region between said rod and the tubing string.

13. The well pumping system of claim 12 further comprising a hold down system that connects said pump body to the tubing string.

14. The well pumping system of claim 12 wherein said piston has a first portion disposed within the hydraulic chamber and a second portion extending from said pump body into the tubing string.

15. The well pumping system of claim 14 further comprising a seal member sealingly engaged with said piston and said pump body, wherein said seal member forms a barrier between the hydraulic chamber and the annular region between said rod and the tubing string.

16. The well pumping system of claim 15 wherein said seal member is a static seal.

17. The well pumping system of claim 16 wherein said seal is a boot seal.

18. The well pumping system of claim 16 wherein said seal is a wiper seal.

19. The well pumping system of claim 12 wherein said rod reciprocates.

20. The well pumping system of claim 12 wherein the rod rotates.

21. The well pumping system of claim 20 further comprising a cam that converts rotation of the rod into movement of said piston within the hydraulic chamber.

22. The well pumping system of claim 12 further comprising a check valve selectively providing fluid communication across said piston so as to limit the differential pressure across said diaphragm.

23. A method for installing an operating a well pumping system comprising:

   connecting a submersible pump to a rod;
   extending the rod into a tubing string disposed in a well;
   connecting the submersible pump to the tubing string;
   reciprocating a piston disposed within a hydraulic chamber of the submersible pump, wherein the piston is reciprocated by actuating the rod; and
   transferring fluid pressure from the hydraulic chamber to a pump chamber of the submersible pump, wherein a diaphragm divides the pump chamber into a pumped fluid chamber and a hydraulic fluid chamber so that as pressure within the hydraulic fluid chamber decreases, fluid is pulled into the pumped fluid chamber from the well and as pressure within the hydraulic fluid chamber increases fluid is moved from the pumped fluid chamber into an annular area between the rod and the tubing string.

24. The method of claim 23 wherein the submersible pump is connected to the tubing string by a hold down system.

25. The method of claim 23 wherein the piston has a first portion disposed within the hydraulic chamber and a second portion extending into the tubing string.

26. The method of claim 25 further comprising a seal member engaged with the piston and forming a barrier between the hydraulic chamber and the annular region between the rod and the tubing string.

27. The method of claim 26 wherein said seal member is a static seal.

28. The method of claim 27 wherein said seal is a boot seal.

29. The method of claim 27 wherein said seal is a wiper seal.

30. The method of claim 23 wherein actuating the rod comprises reciprocating the rod.

31. The method of claim 23 wherein actuating the rod comprises rotating the rod.

32. The method of claim 31 wherein the submersible pump comprises a cam that converts rotation of the rod into reciprocation of the piston within the hydraulic chamber.

33. The method of claim 21 further comprising providing fluid communication across the piston so as to limit the pressure within the hydraulic fluid chamber.

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