

[54] METHOD AND APPARATUS FOR FLOWING
CRUDE OIL FROM A WELL[76] Inventor: **Johnnie A. Elfarr**, P.O. Box 901,
Palestine, Tex. 75801[22] Filed: **Sept. 19, 1973**[21] Appl. No.: **398,571**[52] U.S. Cl. **417/54**, 166/68, 166/314,
417/118[51] Int. Cl. **F04f**, E21b[58] Field of Search 166/68, 105, 244 R, 314;
417/54, 55, 118[56] **References Cited****UNITED STATES PATENTS**

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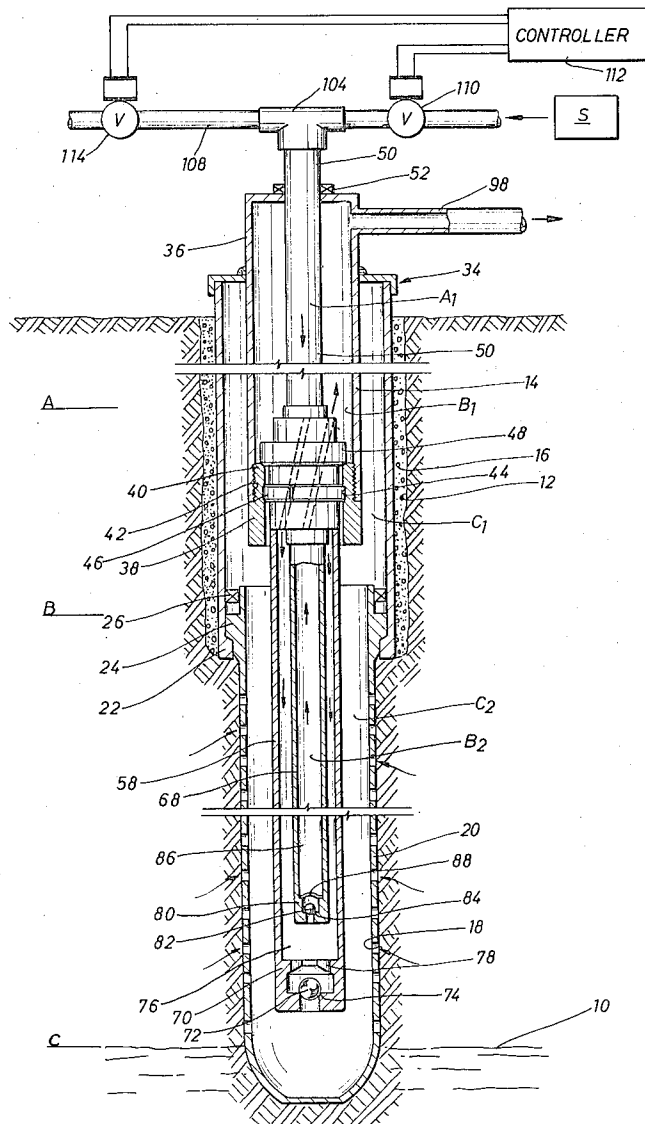
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[57]

ABSTRACT

Method and apparatus for flowing crude oil from wells wherein a fluid is injected into the oil bearing earth formation for the purpose of reducing the viscosity of the oil and causing it to migrate under induced formation pressure to one or more production wells. The apparatus and method are employed in the production wells in such manner that flashing of high temperature water to steam is selectively induced in the apparatus and in the well casing in which the apparatus is located for lightening the fluid column in the apparatus and causing a flowing action to occur and for selectively condensing the steam to its liquid state for liquid transportation of oil within the apparatus. The apparatus is received in the well casing in such a manner that the apparatus and the inner conduit to which it is connected may be removed from the well casing substantially free of any of the hot liquid that is present in the apparatus in the operative condition thereof.

18 Claims, 5 Drawing Figures

SHEET 1 OF 3

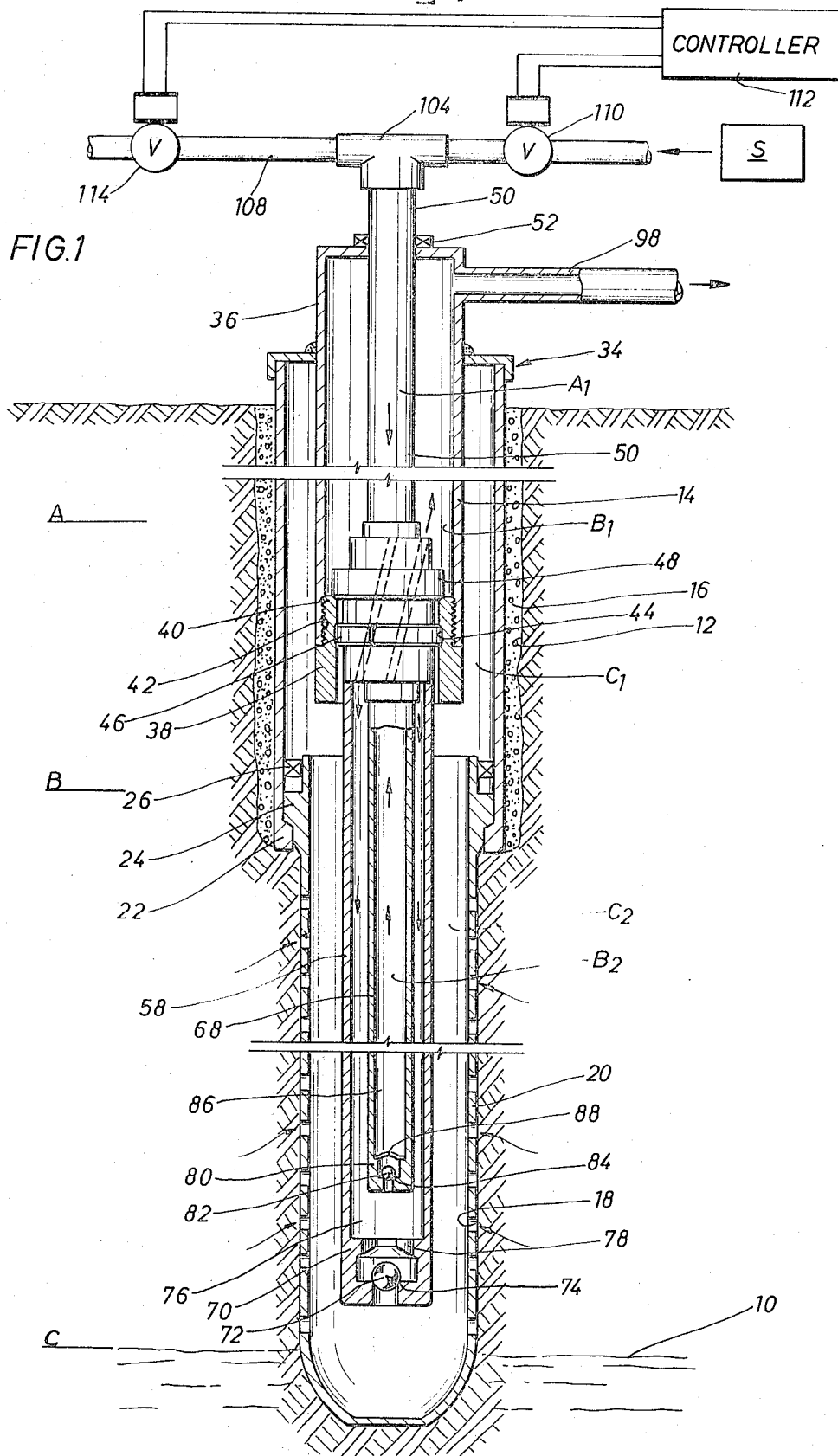


FIG. 2

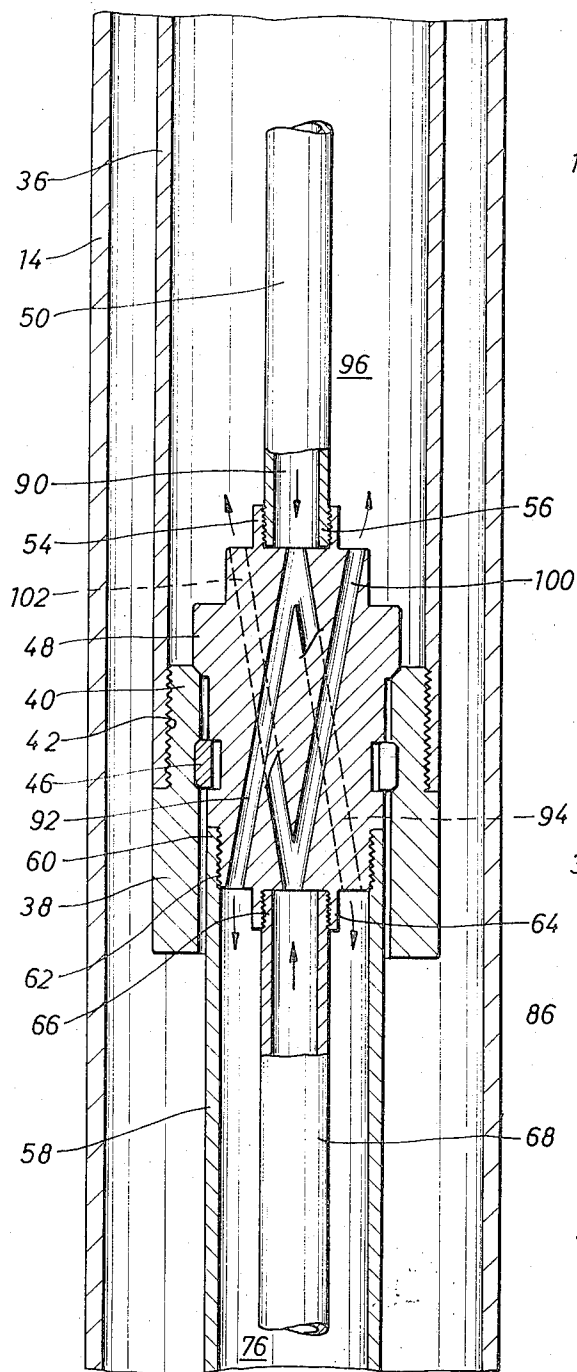
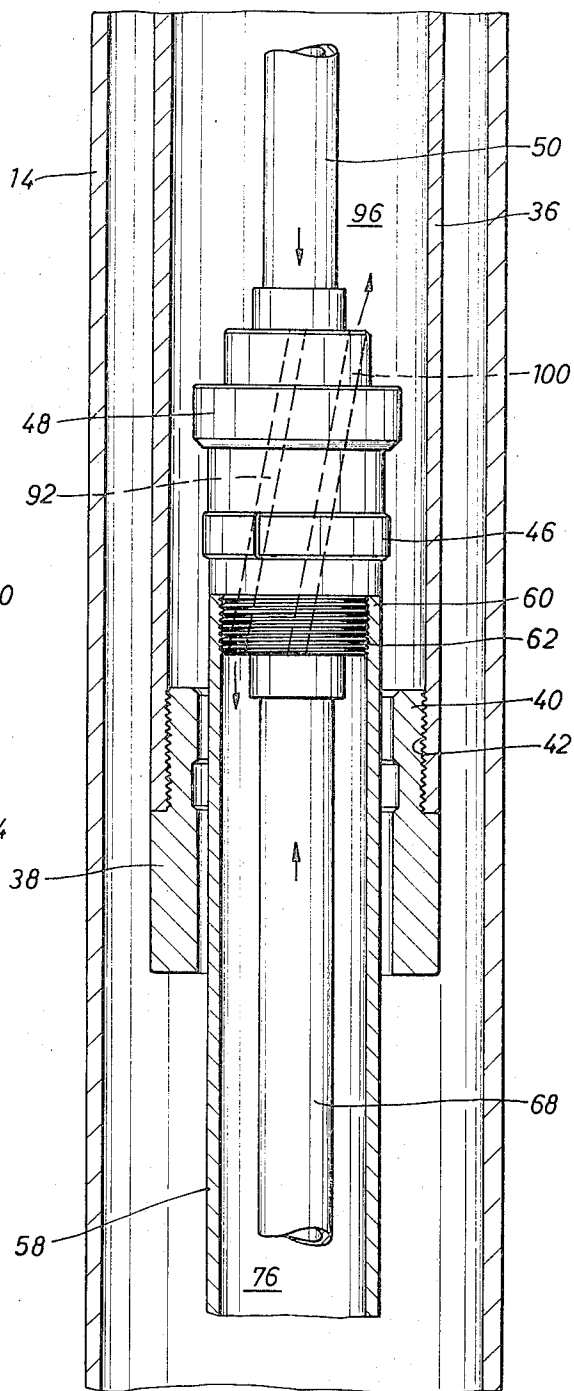


FIG. 3



METHOD AND APPARATUS FOR FLOWING CRUDE OIL FROM A WELL

FIELD OF THE INVENTION

This invention is directed generally to apparatus for production or secondary recovery of crude oil from earth formations having insufficient formation pressure for raising the crude oil to the surface of the earth and wherein the crude oil within the earth formation is of sufficient viscosity to prevent it from readily migrating to production wells. More particularly the invention is directed to a pneumatic displacement method of primary or secondary recovery of crude oil wherein air or steam is injected into the formation to reduce the viscosity of the crude oil and to develop a formation pressure that causes migration of the oil to production wells. Where steam is injected into the oil bearing formation, the steam may be selectively condensed and vaporized simply by varying the pressure thereof. Specifically, the invention is directed to the provision of a method and apparatus for pneumatic displacement pumping, incorporating a down-hole valve mechanism and a surface located control facility that cooperate to inject a pressurized gas into the well to cause selective vaporization and condensation of hot water within the pumping mechanism to produce controlled displacement pumping of the crude oil entering the production well from the formation.

BACKGROUND OF THE INVENTION

While the invention will be explained for purposes of simplicity with regard to its application to production of oil from oil bearing earth formations having little or no formation pressure, it is considered obvious that the invention may be utilized effectively for displacement of other fluids that may or may not be located within earth formations. The present invention will be discussed in its application solely for the production of oil from oil bearing earth formations for purposes of simplicity and to facilitate ready understanding of the invention. It is in no way intended to limit the present invention solely to use in connection with production of oil.

When oil bearing earth formations are discovered that have insufficient formation pressure for gas energized production of oil found in the formation, or when a pressurized oil bearing formation loses a substantial amount of its formation pressure, it will become necessary to provide for recovery of the oil by methods other than production by formation pressure flowing. One acceptable method for producing low pressure or zero pressure oil bearing earth formation has been the use of mechanically energized pumps that simply mechanically elevate the oil to the surface of the earth for production by conventional reciprocating pump mechanisms. These pumps are generally restricted to production of oil from very shallow oil bearing earth formations and are not capable of pumping a viscous crude oil because viscous crude oil, in absence of formation pressure, will not be capable of migrating through the earth formation to the well bore.

Another method, successfully utilized in production of otherwise unproducable oil wells, has been the use of pneumatic displacement pumps, which may be also referred to as "gas lift valves." These pumps or valves may be energized by compressed air, compressed inert gases, steam, or compressed natural gas and are effective

to achieve production of oil bearing formations that are of substantial depth. U.S. Pat. Nos. 1,326,338 to Gregory, 1,754,945 to Haskell, and 3,106,170 to Gray, each disclose pneumatic displacement type devices for flowing or pumping oil wells.

Typically, pneumatic displacement pumps inject a gas into a pumping mechanism disposed below the fluid level within the well which gas serves a piston like function to raise liquid in the production tubing in the form of a slug or segment. A small amount of the gas, of course, mixes with the liquid to some extent, thereby lightening the load of the column and allowing the column of liquid to be transported to the earth surface for production.

Where steam is injected into the earth formation, for the purpose of providing sufficient heat to reduce the viscosity of the crude oil entrapped in the earth formation and thereby allowing the crude oil to migrate toward one or more production wells, typically a number of production wells surround a steam injection well. The steam injected into the formation will condense to its liquid form, because of the pressure under which it is maintained, whereupon the liquid form will also migrate through the oil bearing earth formation toward the production well. The water at the level of the oil sand in the production wells will be in the order of 250° to 350°F. Since the water temperature is above the boiling point of water at atmospheric pressure, reduction of pressure within the well bore at the formation level will cause immediate vaporization of the water to steam. This vaporization is typically referred to in the industry as "flashing" and will be so referred to in the present application.

Where steam is injected into oil bearing earth formation, for the purpose of reducing the viscosity of the crude oil contained therein and causing it to migrate to production wells, and air or other gases are injected into production wells for the purpose of lifting the crude oil or a mixture of crude oil and water to the surface of the earth for production, each time the pumping mechanism operates the water contained in the production fluid at the bottom of the well, being in the order of 250° to 350°F will flash to steam, thereby interfering with effective production of the oil. In fact, the efficiency of producing crude oil in this manner is typically in the order of 12 percent, thereby rendering pneumatic displacement pumping of hot production fluid having a water content to be quite expensive and thereby reducing the commercial feasibility of recovery of oil in this manner. It is therefore considered desirable to utilize the pressure generated by the water content of the hot production fluid to assist in production of the crude oil. It is also desirable to utilize, as efficiently as possible, the energy that is required to produce steam and inject it into the oil bearing formation for production purposes.

One problem presented by the use of pneumatic type fluid displacement pumps or flowing devices is the physical dimension of the well casing within which the pump mechanisms must be received. Because of the substantial physical size of most pneumatic displacement pumps, it is necessary to provide a well bore and well casing of substantial dimension to allow sufficient space within which the pump may be received. Well bores of substantial size are expensive to drill and therefore detract from the commercial feasibility of pneumatic displacement pump type oil recovery sys-

tems. It is desirable therefore to provide a pneumatic displacement pump type pumping mechanism that is of relatively small cross-sectional dimension and which will be efficiently received within a well bore without any requirement for enlargement of the well bore beyond the normal dimension required for receiving conventional well production tubing.

Another problem with some pneumatic displacement pump mechanisms occurs when the pumping mechanisms are extracted from the well for repair or replacement. During steam injection for the purpose of enhancing formation pressure and simultaneously increasing the temperature of the formation, thereby reducing the viscosity of the crude oil contained in the formation and enhancing the ability of the oil to flow from the formation to the production tubing, the formation is heated to a temperature near the temperature of superheated steam and, consequently, and liquid that is trapped within the well tubing as it is extracted from the well is quite hot and poses a dangerous condition for workmen accomplishing the well servicing operation. In most pneumatic well pumping mechanisms, there is present at the lowermost portion of the well tubing, one or more check valve mechanisms that seal responsive to the hydrostatic head of the liquid contained within the tubing, thereby causing the tubing to be pulled from the well full of hot production fluid trapped therein. The hazardous condition of such repair operations is enhanced because the trapped production fluid frequently spills when the tubing is separated and presents a safety hazard because of the likelihood of fire and the generally unsafe conditions that result from oil spills. Moreover, when the production fluid is extremely hot, because of the steam or fire flooding operations that provide the formation pressure for production and provide heat for reducing the viscosity of the oil to allow it to migrate in the formation, the hot oil/water mixture presents a safety hazard to workmen involved in disassembly of sections of tubing that are filled with the hot fluid. Hot production fluid spilling from fluid filled sections of tubing presents a safety hazard due to the possibility of causing hot fluid burn injuries to the workmen separating the tubing. It is therefore very desirable to remove tubing strings from the well that are not filled with hot liquid.

Accordingly, it is a primary object of the present invention to provide a novel method of accomplishing pneumatic displacement of high temperature fluid from a well which effectively utilizes pressure generated by high temperature flashing of water into steam for assisting in elevation of production fluid from a fluid bearing earth formation to the surface of the earth for production.

It is a further object of the present invention to provide a novel method of pneumatic displacement pumping of high temperature water containing fluid from a well wherein the water content of the fluid is caused to selectively flash into steam and condense into its water form for the purpose of controlled release of pressure that assists in production of the fluid from the well.

It is an even further object of the present invention to provide a pneumatic displacement type pumping mechanism for flowing oil or any other production fluid from a well that obviates any necessity for lifting oil filled tubing strings from the well during repair of replacement operations.

It is an even further operation of the present invention to provide pneumatic displacement type pumping apparatus having down-hole valves that may be removed for repair or replacement simply by removing the intermost light-weight tubing string from the well.

Another object of the present invention involves the provision of novel pneumatic displacement type pumping apparatus for flowing high temperature production fluid from wells which includes valve apparatus and valve seat structures that may be completely removed from the well in a single operation, simply by removing the centermost light-weight tubing string from the well.

Among the several objects of the present invention is contemplated the provision of novel pneumatic displacement type pumping apparatus that may be effectively utilized in oil wells of relatively small casing dimension.

It is also an important object of the present invention to provide novel pneumatic displacement type pumping apparatus employing a simple cross-over mechanism that promotes efficient pumping operation of the apparatus by cooperating with other structure of the displacement pumping mechanism to cause selective development of pressure changes within the pumping mechanism and within the casing to cause selective flashing of the hot water content of the production fluid into steam and causes selective condensation of steam into water and utilizes the energy of the steam to assist in transportation of production fluid to the surface of the earth.

It is an even further object of the present invention to provide novel pneumatic displacement type pumping apparatus for flowing high temperature water containing oil from a well, which apparatus is simple in nature, reliable in use, and low in cost.

Other and further objects, advantages and features of the present invention will become apparent to one skilled in the art upon consideration of the written specification, the attached claims and the annexed drawings. The form of the invention, which will now be described in detail, illustrates the general principles of the invention, but it is to be understood that this detailed description is not to be taken as limiting the scope of the present invention.

SUMMARY OF THE INVENTION

A preferred embodiment of the present invention may comprise a well casing extending through a drilled bore in the earth to an oil bearing earth formation which well casing may be provided with a well head at its upper extremity and with a perforated element, typically referred to as a screen, at its lower extremity. Oil, or water contained oil, typically referred to as production fluid, may be forced by formation pressure, either induced naturally or artificially and may enter the well casing through the perforations of the screen and may rise to a level within the casing. Inner and outer conduits may be removably suspended from a well head at the surface of the earth and may extend to the production zone within the casing. The outer conduit may be provided with a landing nipple at its lower extremity and a landing adapter, connected to the inner tubing string, may be received and locked within the landing nipple in such manner that a sealed relationship is established between the landing nipple and the landing adapter.

An outer pump conduit may extend downwardly from the landing adapter and may have a check valve disposed at the lower extremity thereof to allow unidirectional flow of production fluid from the well casing into an outer pump chamber. An inner pump tubing may extend downwardly from the landing adapter and may be disposed within the outer pump conduit and may have a check valve disposed at its lower extremity to allow unidirectional flow of production fluid from the outer pump chamber to an inner pump chamber.

The outer pump chamber may be communicated by restricted crossover passages to the inner tubing strong supported by the well head and may cooperate with the intertubing string to define a pressure imposing chamber wherein pressurized gas is introduced into the well in order to cause a pneumatic pumping action to occur. The outer chamber below the crossover mechanism may constitute an outer pumping chamber wherein hot water disposed therein may be caused to vaporize into steam and provide a motive force that causes the flow of oil or oil water mixture disposed within the outer pumping chamber to flow through a check valve into the inner pumping chamber. The inner pumping chamber is communicated through restricted passages formed in the crossover mechanism to a flow chamber defined by the annulus between the inner and outer tubing strings within the well bore which annulus is, in turn, communicated with a flow line to conduct produced fluid from the well to a handling or storage facility. The restricted passageways from the inner pumping chamber to the flow chamber allow the development of pressure changes to cause flashing of water into steam in the flow chamber which develops a pressure condition that assists in transporting fluid within the flow chamber upwardly through the outer tubing string to the flow line.

The inner tubing string is communicated with a pressurized source of actuating gas such as compressed air, compressed natural gas, or steam, which may be introduced into the well to provide a motive or control force for pneumatic displacement pumping of liquid from the level of the oil bearing earth formation to surface for production through the flow line extending from the well head.

In employing the method of pneumatic type displacement pumping in accordance with the present invention, a gas may be introduced into the inner conduit or injection chamber at much lower temperature than the temperature of the production fluid within the well. The cool gas causes condensation of at least a part of the steam present within the inner conduit at the start of a pumping cycle. The condensed water will flow through the crossover mechanism into the outer pumping chamber and steam within the outer pumping chamber will also condense. Pressure within the inner conduit will then be reduced by venting the inner conduit, thereby causing flashing of a portion of the water content within the inner conduit and through the crossover passages will cause vaporization of a part of the water content of the production fluid within the outer pumping chamber, thereby creating sufficient pressure to induce liquid within the outer pumping chamber to flow through the check valve mechanism into the inner pumping chamber. The liquid within the inner pumping chamber will then flow through the restricted passages of the crossover mechanism into a much larger flow chamber defined by the annulus between the inner and

outer conduits. This chamber, being of much larger dimension, of course, causes sudden pressure reduction of the liquid exiting from the restricted passages of the crossover mechanism and causes a portion of the water content of the liquid so exiting to vaporize or flash immediately to steam. The steam, in addition to producing a pressure that induces upward flow of production fluid within the flow chamber to the flow line at the well head, also serves to lighten the column of fluid as to cause an upward flowing action to occur, thereby transporting oil contained in the mixture to the well head where it is conducted away through the flow line. With less than 50 pounds of flow line pressure, the fluid, so produced, will be transported through the flow line to a storage or handling facility.

The control valves are then manipulated to vent the inner conduit and the outer pumping chamber in order to reduce pressure therein. As the pressure reduces below the formation pressure, the lower check valve of the outer pumping conduit will open because of the pressure differential thereacross and will communicate the low pressure condition of the outer pumping chamber to the well casing and to the formation. A portion of the water content of the hot production fluid within the casing will flash into steam and will force production fluid from the casing into the outer pumping chamber and through the crossover mechanism into the inner tubing string. Because there is more steam available than can be exhausted through the crossover mechanism into the inner conduit, a back pressure develops within the outer pumping chamber and within the casing outwardly of the pumping mechanism. When pressure conditions across the lower check valve become substantially balanced, the lower check valve will seat thereby entrapping the production fluid within the outer pumping chamber. Also, because of the increased pressure developed by the back pressure condition, the steam begins to condense within the outer pumping chamber and within the casing outwardly of the pumping mechanism. When enough of the steam has condensed and sufficiently lowered the pressure within the outer pumping chamber and the inner conduit, the condensed water will flash again to steam and force fluid again into the inner pumping chamber, thereby initiating a subsequent pumping cycle.

The valve mechanism, including the crossover mechanism and the upper and lower check valve assemblies may be extracted from the inner conduit simply by unlocking the landing adapter from the landing nipple and raising the inner conduit relative to the outer conduit. When this occurs, fluid within the inner conduit will be drained through the crossover passages into the outer conduit and the inner conduit may be raised completely free of any hot liquid that might otherwise be disposed above the crossover mechanism. The check valves will of course retain a small quantity of fluid below the crossover mechanism. The outer tubing may also be removed completely free of fluid since its lower extremity is completely open after removal of the crossover mechanism.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features, advantages and objects of the present invention, as well as others, which will become apparent, are attained and can be understood in detail, more particular description of the invention, briefly summarized above,

may be had by reference to the embodiments hereof which are illustrated in the appended drawings, which drawings form a part of this specification.

It is to be noted, however, that the appended drawings illustrate only typical embodiments of the invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

In the Drawings:

FIG. 1 is a sectional view of a well casing extending through a well bore in the earth's surface to an oil bearing earth formation and also illustrating in simple mechanical terms the provision of a pneumatic displacement type pump mechanism constructed in accordance with the present invention within the casing structure in position for pumping production fluid from the well.

FIG. 2 is a fragmentary sectional view of the well and pumping mechanism of FIG. 1 illustrating the landing nipple and landing adapter structures with the cross-over passages formed therein, showing the mechanism seated at its operative position.

FIG. 3 is a fragmentary sectional view of the mechanism of FIG. 2 illustrating the liquid pumping mechanism of the present invention as being unseated and moved upwardly relative to the landing nipple for extraction of the same from the well.

FIG. 4 is a schematic view of an oil production system wherein an injection well is provided which injection well is surrounded by a number of production wells, each of which being capable of producing oil that migrates outwardly away from the injection well because of the formation pressure that is created at the injection well by fire flooding operations or by injection of steam into the formation.

FIG. 5 is a fragmentary sectional view of the upper extremity of a fluid pumping mechanism constructed in accordance with the present invention and illustrating a modified well head structure and its valved connection to a flow line.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the drawings for a more detailed understanding of the present invention and referring specifically to FIG. 1, there is depicted in partial section a typical earth formation having a well bore drilled in intersecting relation with an oil bearing stratum of the formation. As shown in FIG. 1 of the drawings, A represents overburden of the formation while B represents a porous oil bearing portion of the formation, typically referred to as oil sand. The oil sand may be quite thin, in the order of 4 to 5 feet thick or it may well be 50 to 100 feet in thickness or greater. In shallow oil wells the oil sand will typically be in the order of 4 to 10 feet in thickness. Below the oil sand B there typically exists another earth formation C, referred to as water sand, which contains either fresh or salt water depending upon the particular environment involved and an oil water contact level or interface 10 will typically exist.

The well bore 12 in the earth formation will typically be drilled to sufficient depth for setting of a casing 14 in the earth formation, which casing may extend slightly below the upper level of the oil sand. Ordinarily, a cement 16 is employed to firmly secure the casing 14 to the wall structure defining the bore 12 in the earth formation. As the casing is cemented, a plug of cement is formed at the bottom of the casing and,

subsequent to setting of the cement, the plug will be drilled out and a bore 18 will be drilled or otherwise formed through the oil sand B and slightly into the water sand C below the level of the oil/water interface 10. A perforated element 20, typically referred to as a screen, may then be inserted through the casing 14 to a position within the bore 18 with the lower perforations of the screen substantially at the oil/water interface. If desired, the lower portion of the casing 14 may be provided with an internal landing flange 22 cooperating with an external flanged portion 24 formed on the screen 20 for supporting the screen in proper position relative to the casing. A packer 26 may be interposed between the screen and casing to retain the screen in position relative to the casing and to establish a sealed relationship between the screen and the casing.

As shown in FIG. 4, an injection well 28 and a plurality of production wells 30 are drilled in the earth to the oil bearing formation or oil sand B and each of the wells may have a casing and screen structure essentially as depicted in FIG. 1. The injection well 28, however, will be suitably connected to a generating facility 32 capable of generating the compressed gaseous medium that is to be employed in order to both heat and pressurize the oil bearing earth formation and cause migration of the oil away from the injection well 28 toward the production wells 30.

At this point it should be understood that the crude oil that is typically produced in flooding operations, where such operations be fire flooding or steam flooding, is a viscous crude petroleum product which, cannot be efficiently produced from the formation by pumping because the viscous crude oil will not flow through the formation of its own accord in order that it may be pumped by mechanically driven pumps. It is typical for such oil bearing formations to be under little or no formation pressure and, therefore, the oil will not be caused to migrate by pressure toward the reduced pressure area defined by a production well. It is necessary, therefore, in order to produce viscous crude oil of such nature, to heat the crude oil and thereby reduce its viscosity to a readily flowable nature and to provide artificial formation pressure in order that the oil contained within the formation may be caused by such pressure to migrate toward a production well, where it may be produced by any number of acceptable methods. One suitable method of developing heat and pressure necessary for production of viscous crude oil from shallow earth formations is typically referred to as "fire flooding." In fire flooding operations heat in the oil bearing earth formation is created by actual burning of some of the crude oil that is locked within the formation and such burning, in addition to developing a formation pressure because of the expansion of gases during the burning operation, also produces sufficient heat to reduce the viscosity of the crude oil to a consistency where flowing will readily occur. Air or any other gasiform fluid medium containing a controlled amount of oxygen to support combustion of the crude oil is injected into the oil bearing earth formation through an injection well. The air is injected at sufficient pressure to cause combustion of a small amount of the crude oil that is locked in the earth formation.

Another acceptable method of generating heat and pressure for production of viscous crude oil is known as "steam flooding" where superheated steam is injected into the oil bearing earth formation through an

injection well. The steam when generated may be in the order of 400°F and may be in the order of 250° to 350°F when entering the oil bearing earth formation and the steam may be injected into the well at a pressure in the order of 300 psi. The steam will migrate through the oil bearing earth formation and cause the oil entrapped therein to be reduced in viscosity such that it migrates along with the steam to the production wells surrounding the injection well. As the oil migrates outwardly away from the injection well due to the formation pressure that is developed by the steam, it is simultaneously drawn toward the production wells due to the low pressure condition that is developed as migrating oil and steam enter the production wells and is pumped to the surface.

Ordinarily, fluid displacement type pumping mechanisms that are employed to produce wells wherein heat and pressure are induced by steam or fire flooding operations employ pumping mechanisms that must be placed at a considerable level above the oil/water interface that is established at the level of the screen, because vaporization or flashing of excessive amounts of the water content of the production fluid into steam will interfere with the pumping operation. When the water content of the production fluid vaporizes into steam, which vaporization is typically referred to as "flashing," the steam vapor may establish a vapor locked condition between the check valves of the apparatus. When this occurs, pressure changes within the pumping mechanism merely achieve compression of the vapor between the check valves but the check valves will remain closed and prevent any fluid from passing through the pumping mechanism. It is therefore considered necessary to place the pumping mechanism sufficiently above the oil/water contact level within the well that a hydrostatic head of fluid within the well will prevent flashing of the water content of the oil into steam.

The present invention, however, is specifically designed to utilize flashing or vaporization of the water content of the oil into steam for the purpose of providing a motive force that causes a flowing condition to exist within the pumping mechanism. In accordance with the present invention, one suitable fluid displacement type pumping mechanism that utilizes vaporization of the water content of the production fluid for assistance in production of fluid from the well may conveniently take the form illustrated in FIG. 1 where a well head, illustrated generally at 34, is disposed at the upper extremity of the casing 14 and provides a physical structure for supporting a pumping mechanism within the well. An outer conduit 36 may be removably supported by the well head 34 and may extend downwardly through the casing to a level slightly above the upper extremity of the screen 20. A landing nipple 38 having an externally threaded portion 40 may be received by internal threads 42 defined within the lower extremity of the outer conduit 36. An internal locking groove 44 may be formed in the landing nipple 38 and may receive a locking mechanism 46 of a landing adapter 48 that may be secured in any suitable manner to the lower extremity of an inner conduit 50 that is also removably supported adjacent the upper extremity thereof by the outer conduit 36 and a sealed relationship may be established between the inner and outer conduits by means of a packing device 52.

As illustrated in detail in FIGS. 2 and 3, the landing adapter 48 may be provided with an internally threaded connector flange 54 that may receive the externally threaded portion 56 of the inner conduit 50, thereby causing the inner conduit to support the landing adapter and the pump mechanism carried thereby.

Again referring to FIG. 1 and also referring to FIGS. 2 and 3, an outer pump conduit 58 may be provided having an internally threaded upper extremity 60 that may be threadedly secured to the landing adapter by external threads 62 formed on a reduced diameter portion of the landing adapter. An internally threaded flange 64 may depend from the landing adapter and may receive the externally threaded upper extremity 66 of an inner pump conduit 68 thereby supporting the inner pump conduit from the landing adapter.

It will be desirable to control the flow of production fluid from the formation into the casing and into the pump mechanism and to provide such control the present invention may incorporate a valving mechanism essentially as depicted in FIG. 1 of the drawings where the outer pump conduit 58 may be provided with a valve seat and cage structure 70 at the lower extremity thereof. A valve ball 72 may be disposed within the valve cage structure and may ordinarily rest in engagement with a circular valve seat 74 to provide a seal that separates an outer pumping chamber 76 from the casing. The ball 72 serves a check valve function and will be moved upwardly from the seat 74 by pressure differential across the ball 72 in order to allow production fluid to enter into the chamber 76 from the formation. A cage 78 will prevent the ball 72 from being completely displaced from the valve and cage assembly but will allow production fluid to flow freely past the valve ball when such flow is initiated.

A ball and cage assembly 80 is likewise disposed at the lower extremity of the inner pump conduit 68 having a ball type check valve 82 that engages a seat 84 to restrict downward flow of production fluid and to respond to upward flow of production fluid caused by a predetermined pressure differential to move upwardly from its seat 84 and allow the flow of production fluid into an inner pumping chamber 86. A cage element 88 prevents the valve ball 82 from being completely displaced from the check valve and cage assembly 80.

The inner conduit 50 may represent an injection chamber through which a pressurized medium is introduced into the well to cause controlled pumping actuation. It is desirable that communication be established between the injection chamber 90 and the outer pumping chamber 76 and such communication may be conveniently established by intersecting crossover passages 92 and 94 that may be formed in the landing adapter 48.

The annulus between the outer conduit 36 and the inner conduit 50 may define a flow passage 96 that serves to conduct produced fluid from the pumping mechanism to the well head structure where it may be conveniently carried from the well head by means of a flow conduit 98 to any suitable storage or handling facility. It is desirable that the flow passage 96 be in fluid communication with the inner pumping chamber 86 and such communication may be conveniently established by means of intersecting crossover passages 100 and 102, also defined within the landing adapter 48.

To provide for controlled actuation of the pumping mechanism it will be desirable to selectively communi-

cate the pumping mechanism with a source S of pressurized medium such as air and to selectively vent the injection chamber 90. Accordingly, the inner conduit 50 may be provided with a T-connection 104 at the upper extremity thereof, which T-connection may be connected to an actuating fluid supply conduit 106 and a vent conduit 108. Pressurized fluid such as air may be injected from the source S into the injection chamber 90 defined by the inner conduit 50 under control of an automatic valve 110 that is selectively energized by a controller mechanism 112. The controller mechanism also actuates an automatic vent valve 114 that serves to vent the injection chamber 90 to the atmosphere or to any other suitable receiver for the vented fluid from the injection chamber.

OPERATION

Steam assisted operation of the pumping mechanism may be characterized by venting of the injection chamber 90 through the vent conduit 108 with the valve 114 in its open condition at the end of an operative cycle of the pumping mechanism. After the inner and outer pumping chambers and the flow chamber have become filled to a suitable level with production fluid entering from the formation, which formation flow of production fluid will be discussed hereinbelow a pumping cycle will be initiated by the controller 112 which causes closure of the vent valve 114 and simultaneously opens the injection valve 110 thereby causing pressurized medium to flow from the source S to the conduit 106 and into the injection chamber 90 defined by the inner conduit 50. When steam assisted pumping operation is employed, the injected fluid will be air or any other suitable gas which will be at a much lower temperature than the temperature of the superheated steam present in the pumping mechanism and within the chamber 90.

As the low temperature medium is injected into the chamber 90 it condenses the steam vapors that are present in the injection chamber and the water, so condensed, descends to the level of the crossover passages 92 and 94 in the landing adapter 48, whereupon the water will flow through the crossover passages into the outer pumping chamber 76. When the water that has resulted from the condensation within the chamber 90 passes through the crossover passages into the chamber 76, an immediate pressure change occurs due to forcing of the water through the restricted passages 92 and 94 and due to the much larger dimension of the chamber 76. The pressure drop occurring as the superheated water enters the outer pump chamber causes at least a portion of the water content of the fluid to flash into steam, creating enough of an explosive effect that causes the liquid within the outer pumping chamber to be forced through the check valve mechanism 80 into the inner pumping chamber 86 and simultaneously causes liquid in the inner pumping chamber to be forced through the crossover passages 100 and 102 into the flow chamber 96.

Because the flow chamber 96 is of much larger dimension than the dimension of the inner pumping chamber 86 and because the liquid is forced through the restricted crossover passages 100 and 102 a pressure drop will be developed within the chamber 96 causing a portion of the water content of the production fluid flowing into the chamber 96 to immediately flash into steam. The steam serves to lighten the liquid

column within the chamber 96 and cause an upward flowing effect thereby carrying the liquid upwardly within the flow chamber to the well head structure where it exits through the flow conduit 98. With less than 50 pounds of flow line pressure the fluid moves to a storage facility such as a tank battery, where it is stored under atmospheric conditions until it is transported away for further handling.

At this time the injection valve 110 will be closed and the vent valve 114 will be opened thereby venting the injection chamber 90 through the conduit 108 to the atmosphere or to any other suitable receiver for the vented gaseous medium. When this occurs the outer pumping chamber 76 will also be communicated to the atmosphere through the crossover passages 92 and 94 and the inner conduit 50. As such venting decreases the pressure condition within the outer pumping chamber below the pressure of the liquid disposed in the annulus between the screen and the outer pump conduit 58. When this occurs the pressure differential across the contact area between the valve ball 72 and the valve seat 74 will cause the ball to move upwardly thereby communicating the screen chamber with the outer pumping chamber 76 thereby venting the screen annulus through the outer pumping chamber, the restricted crossover passages 100 and 102 and the injection chamber 90 to the vent conduit 108. As the pressure decreases in the screen annulus, the water content of the fluid within the screen annulus, because of its high temperature, in the order of 250° to 350°F will immediately flash to steam, thereby creating steam pressure within the screen annulus that forces liquid contained therein through the check valve assembly and into the outer pumping chamber 76. In view of the fact that steam is continuously generated while the vent valve 114 is open, the steam in traversing the restricted crossover passages 100 and 102 will develop a back pressure within the outer pumping chamber 76 and within the annulus between the screen and the outer pump conduit 58. After the pressure induced by the steam has increased to a predetermined level, the steam will begin to condense within the screen annulus and liquid will be forced through the check valve mechanism 70 into the outer pumping chamber 76 completing the pumping cycle. The next pumping cycle will be initiated simply by the controller 112 which reverses the surface valves opening the valve 110 and closing the vent valve 114 in the manner discussed above.

Although the controller may be utilized for cyclically introducing a pressurized cool gas into the injection chamber 90 and venting the injection chamber to cause displacement type pumping actuation in the manner described above, it has been determined that displacement pumping of production fluid will occur automatically without cyclic operation of the valves after the pumping operation has been initiated. As long as steam is continuously introduced into the formation through an injection well and enters the well bore through the oil sand along with migrated crude oil, the pump mechanism will automatically pump production fluid from the oil bearing formation and conduct it to the flow conduit 98 as long as a back pressure of less than 50 psi is maintained on the flow conduit. It has been determined that a back pressure less than 50 psi in the flow conduit will allow the pumping operation to be automatically accomplished without cyclic operation of the valves 110 and 114 as long as the pump mechanism

within the well is disposed at a sufficient level relative to the screen to prevent a hydrostatic head from developing above the screen to the point that flashing of steam is prevented in the annulus between the screen and the outer pump conduit 58. With the control valves closed condensation will occur naturally within the injection passage 90 and the condensed fluid in the injection passage will flow through the restricted crossover passages into the outer pump chamber where flashing of the steam content of the liquid will occur because of the pressure differential caused by flow across the restricted passages and the flashing will force liquid within the outer pumping chamber into the inner pumping chamber and through the restricted crossover passages 100 and 102 into the flow chamber 96. Flashing of steam will occur in the flow chamber because of the pressure differential existing across the restricted passages 100 and 102 thereby causing the liquid column within the flow passage to be lightened and forced upwardly where it is produced through the flow conduit.

In order for the pumping actuation to occur automatically without cycling of the valves, it is necessary that the water content of the production fluid be quite high. It is therefore desirable to place the lower extremity of the pump mechanism as close as conveniently possible to the oil water contact level within the well and such can be accomplished in accordance with the present invention by placing the lower extremity of the pumping mechanism within the screen as shown in FIG. 1. It is also necessary in order for pumping actuation to be conducted automatically that back pressure on the flow conduit and flow chamber be as low as conveniently possible. It has been determined that back pressure should be below 50 psi in order to achieve automatic operation of the pumping mechanism without cycling of the valves.

It has also been determined that displacement pumping will occur when the valves are cycled and yet when no pressurized gaseous medium is introduced into the injection chamber 96 but only after injection induced cycling has occurred for a particular period of time. Flashing of the steam as it is forced in the form of high temperature water through the restricted crossover passages in the landing adapter will occur automatically and will induce pressurized fluid movement within the pumping mechanism to produce an oil water mixture in the flow conduit even though cycling of the valves by the controller does not induce injection of a pressurized gaseous medium into the injection chamber 90.

Referring now to FIG. 5 there is disclosed a modified embodiment of the well head structure wherein a well head illustrated generally at 116 includes conduits 118 and 120 that extend from the casing and are controlled respectively by valves 122 and 124. An outer conduit 126 may be supported by the well head and may extend into the well casing in similar manner as illustrated in FIG. 1. An inner conduit 128 may be supported by the outer conduit 126 and may extend downwardly into the outer conduit in the same manner as shown in FIG. 1 with a sealed relationship between the inner and outer conduits being established by means of a stuffing box 130. An injection conduit 132 controlled by an injection valve 134 may control introduction of pressurized gaseous medium from a source S' similar to the source S illustrated in FIG. 1. An exhaust conduit 136 con-

trolled by an exhaust valve 138 may also be disposed in communication with the conduit 128 in order to exhaust an injection chamber in similar manner as discussed above in connection with FIG. 1.

A flow conduit 140 may extend from the outer conduit 126 and may be controlled by means of a flow valve 142 to conduit produced fluid to a suitable storage facility. The flow conduit 140 may communicate with the conduit 120 and may further be provided with a pressure gauge 146 in order to monitor the pressure of the flow conduit.

A controller 148 may be provided for control of the automatic valves 134 and 138 in the manner discussed above in connection with FIG. 1 in order to cause pressure induced cycling of the pumping mechanism or to cause cycling of the valves as appropriate in order to achieve automatic actuation of the pumping mechanism. The pumping mechanism of the well structure set forth in FIG. 5 will function in identical manner to that illustrated in FIG. 1.

In view of the foregoing it is clearly apparent that I have provided a novel displacement type pumping mechanism that provides the capability of fluid pressure induced or automatic fluid displacement pumping of a production fluid from an oil bearing earth formation. It is apparent that the present invention is one well adapted to attain all of the objects hereinabove set forth together with other advantages which will become obvious and inherent from a description of the apparatus itself. It will be understood that certain combinations and subcombinations are of utility and may be employed without reference to other features and subcombinations. As many possible embodiments may be made of the invention without departing from the spirit or scope thereof, it is to be understood that all matters herein set forth or shown in the accompanying drawings are to be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. Apparatus for flowing liquid from a well bore extending from the surface of the earth to a liquid bearing earth formation, said apparatus comprising:

casing means extending into said well bore and defining a well head at the upper extremity thereof, said casing being in fluid communication with said liquid bearing earth formation;

outer conduit means being supported by said well head and extending into said casing;

a landing nipple being coupled to the lower extremity of said outer conduit means and defining support means;

inner conduit means being removably supported by said well head and extending into said outer conduit means, said inner conduit means cooperating with said outer conduit means to define flow chamber means;

landing adapter means being coupled to said inner conduit means and being releasably and sealingly engaged with said landing nipple;

outer pump conduit means being supported in sealed relation by said landing adapter means and depending therefrom, said outer pump conduit defining a pressure imposing chamber;

first valve means being carried by said outer pump conduit means and allowing unidirectional flow of said production liquid from said casing means into said pressure imposing chamber;

inner pump conduit means being supported by said landing adapter means, said inner pump conduit means extending into said pressure imposing chamber and being in fluid communication with said outer conduit means;

second valve means being carried by said inner pump conduit means and allowing unidirectional flow of said production liquid from said pressure imposing chamber to said flow chamber means;

means for selectively introducing pressurized fluid into said pressure imposing chamber; and means for conducting produced liquid from said flow chamber means.

2. Apparatus as recited in claim 1, wherein: said pressure imposing chamber is in fluid communication with said inner conduit means; and said flow chamber means is in fluid communication with said outer conduit means, outwardly of said inner conduit means.

3. Apparatus as recited in claim 1, wherein: said landing adapter means has first crossover passage means formed therein communicating said inner conduit means with the annulus between said inner and outer pump conduit means and second crossover passage means communicating said inner pump conduit means with the annulus between said inner and outer conduit means.

4. Apparatus as recited in claim 1, wherein: said landing nipple is connected to the lower extremity of said outer conduit means; said landing adapter is connected to the lower extremity of said inner conduit means; and said inner and outer pump conduit means are connected to the lower extremity of said landing adapter.

5. Apparatus as recited in claim 1, including: perforated means secured to the lower extremity of said casing means and having perforations formed therein communicating said liquid bearing earth formation with said casing means.

6. Apparatus as recited in claim 5, wherein: at least a portion of said inner and outer pump conduit means extend into said casing to a level disposing said first valve means below the level of production liquid within said casing and perforated means.

7. A method of displacement pumping of a production fluid including crude oil and water from an oil bearing earth formation wherein production and injection wells are formed in the earth and are in communication with said formation and at least one injection well continuously injects steam into said oil bearing earth formation and wherein said production wells each have apparatus defining an injection chamber, a production fluid supply chamber being open to said formation and receiving production fluid from said formation, a first pumping chamber having valved communication with said production fluid supply chamber, a second pumping chamber having valved communication with said first pumping chamber and a flow chamber being disposed in communication with said second pumping chamber, said method comprising the steps of:

causing production fluid including steam, water and crude oil to enter said first pumping chamber from said production fluid supply chamber; condensing at least a portion of said steam in said first pumping chamber into water;

causing flashing of a portion of the water content of said production fluid into steam in said first pumping chamber and causing steam pressure forcing of liquid and steam from said first pumping chamber to said second pumping chamber;

condensing at least a portion of the steam content of said production fluid in said second pumping chamber into water;

causing flashing of a portion of the condensed water of said liquid in said second pumping chamber to steam and causing steam pressure forcing of said liquid and steam from said second pumping chamber to said flow chamber;

condensing at least a portion of the steam content of said production fluid in said flow chamber into water; and

causing flashing of a portion of the condensed water of said production fluid in said flow chamber to lighten the column of the liquid in said flow chamber and to cause steam forcing of liquid from said flow chamber for production.

8. The method of claim 7, wherein:

said condensing of said steam in said first pumping chamber is accomplished by injecting a fluid under pressure into said injection chamber at a lower temperature than the temperature of the steam within said injection chamber.

9. The method of claim 7, wherein: said injected fluid is air.

10. The method of claim 7, wherein:

steam entering said production fluid supply chamber from said formation is caused to condense in said production fluid supply chamber by controlled modification of the steam generated pressure condition within said production fluid supply chamber.

11. The method of claim 8, wherein the steps of claim 7 occur repetitively to induce cyclic displacement pumping actuation and including the steps of:

discontinuing injection of fluid into said injection chamber after cyclic displacement pumping actuation of said pumping has been conducted in accordance with the steps of claim 7 for a predetermined period of time;

continuing with cyclic displacement pumping actuation in accordance with the steps of claim 7 in absence of injection of said fluid medium; and

maintaining a predetermined back pressure on said flow chamber after discontinuing injection of fluid into said injection chamber to allow controlled and substantially continuous flashing of at least a portion of the water content of said production fluid into steam within said flow chamber.

12. Apparatus for flowing production fluid including a mixture of oil and water from an oil bearing earth formation wherein the earth formation is heated and pressurized by injection of a fluid into the formation and at least one production well bore extends to the formation, said apparatus comprising:

casing means extending into said well bore and defining a well head at the upper extremity thereof, said casing means being in fluid communication with said oil bearing earth formation;

means communicating said casing means with said formation;

pump means being disposed within said casing and defining an injection chamber, a flow chamber and first and second pumping chambers, said pump

means defining first restricted passage means communicating said injection chamber and said first pumping chamber and defining second restricted passage means communicating said second pumping chamber and said flow chamber;

first valve means controlling the flow of production fluid from said casing into said first pumping chamber, said inlet of said valve means being disposed sufficiently near the oil/water contact within said casing to prevent the hydrostatic head of the column of fluid within said well from interfering with flashing of the water content of said production fluid into steam;

second valve means controlling the flow of production fluid from said first pumping chamber to said second pumping chamber; and

means for selectively controlling injection of a pressurized medium into said injection chamber and venting of said injection chamber.

13. Apparatus as recited in claim 12, wherein:

said means for defining said flow chamber comprises outer conduit means suspended within said casing by said well head; and

said means defining said injection chamber comprises an inner conduit means suspended by said well head within said outer conduit means.

14. Apparatus as recited in claim 12, wherein:

said means communicating said casing means with said formation is perforated means disposed at the lower extremity of said casing means, said perforated means having been perforated along the length thereof to allow production fluid to enter said casing means from said formation, the lower extremity of said perforated means extending below the oil/water level within said formation.

15. Apparatus as recited in claim 13, wherein:

said first valve means is disposed in juxtaposed relation with said oil/water level.

16. Apparatus as recited in claim 14, wherein:

said pump means extends at least partially within said perforated means.

17. Apparatus as recited in claim 12, including:

means for maintaining a minimum of back pressure on the production fluid flowing through said flow chamber to allow continuous flashing of the water content of said production fluid into steam.

18. Apparatus for flowing production fluid including a mixture of oil and water from an oil bearing earth formation wherein the earth formation is heated and pres-

surized by injection of a fluid into the formation and at least one production well bore extends to the formation, said apparatus comprising:

casing means extending into said well bore and defining a well head at the upper extremity thereof, said casing means being in fluid communication with said oil bearing earth formation;

first and second casing valves communicating said casing with a flow line and with a vent conduit, respectively, said casing valves being closed during operation of said apparatus and being opened to balance the pressure conditions in said flow chamber and said casing;

pump means being disposed within said casing and defining an injection chamber, a flow chamber and first and second pumping chambers, said pump means defining first restricted passage means communicating said injection chamber and said first pumping chamber and defining second restricted passage means communicating said second pumping chamber and said flow chamber, said flow chamber being in communication with said flow line;

flow valve means connected in said flow line and controlling flow of production fluid from said flow chamber;

first check valve means controlling the flow of production fluid from said casing into said first pumping chamber, said inlet of said first check valve means being disposed sufficiently near the oil/water contact within said casing to prevent the hydrostatic head of the column of fluid within said well from interfering with flashing of the water content of said production fluid into steam;

second check valve means interposed between said first and second pumping chambers and controlling the flow of production fluid from said first pumping chamber to said second pumping chamber;

a source of pressurized medium;

injection conduit means interconnecting said source and said injection chamber;

valve means in said injection conduit for selectively controlling injection of pressurized medium from said source into said injection chamber;

an exhaust conduit being communicated with said injection chamber; and

valve means in said exhaust conduit being controllable for venting of said injection chamber.

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