

Feb. 14, 1950

M. F. ECKER
FLUID-OPERATED PUMP

2,497,348

Filed July 18, 1947

6 Sheets-Sheet 1

Fig. 1

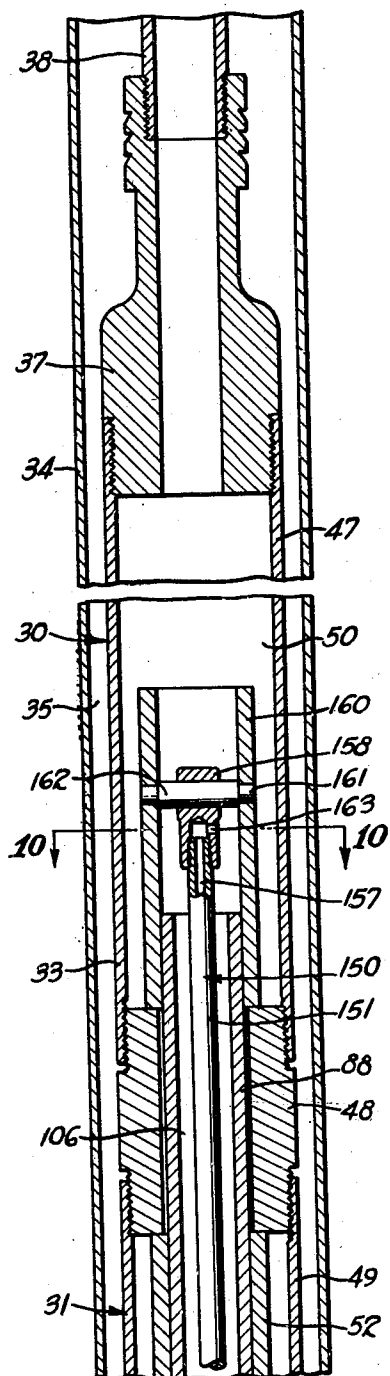
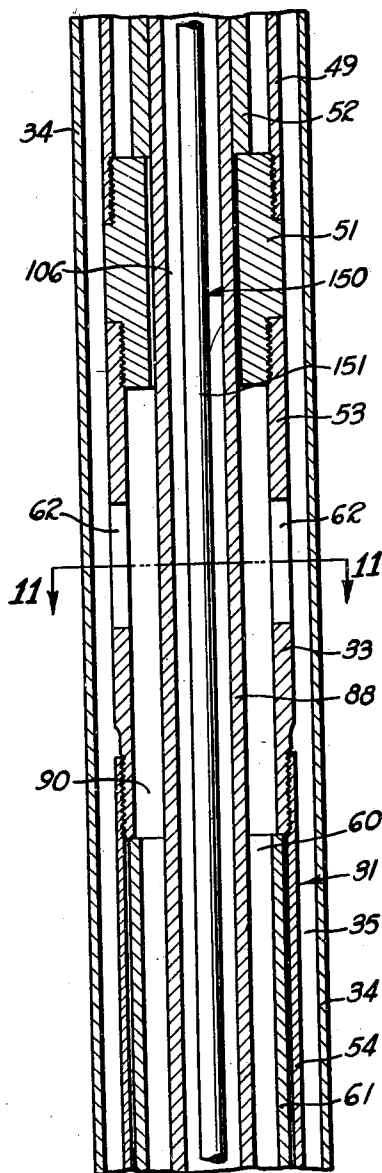


Fig. 2



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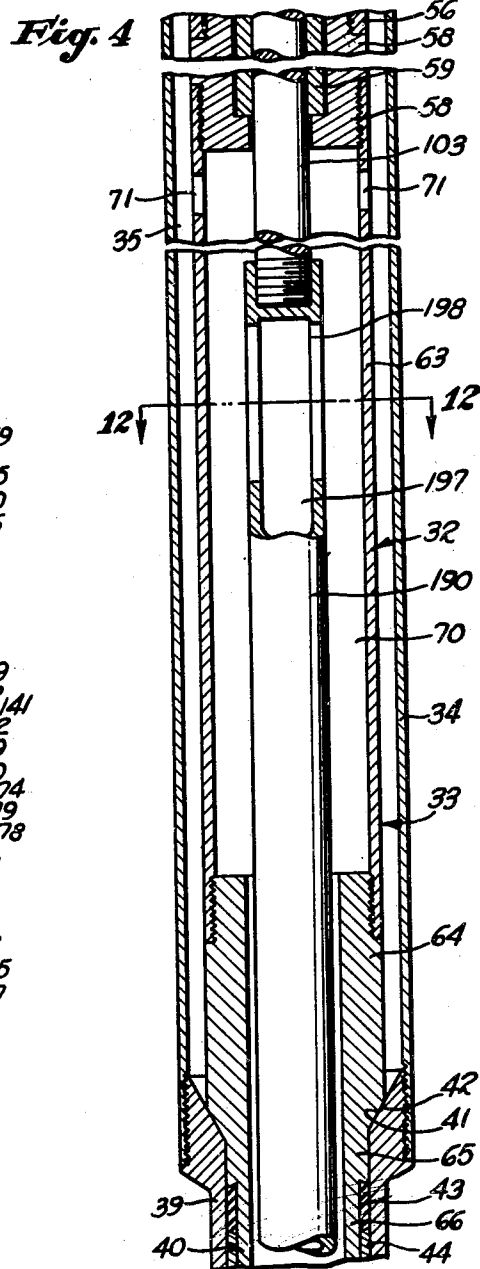
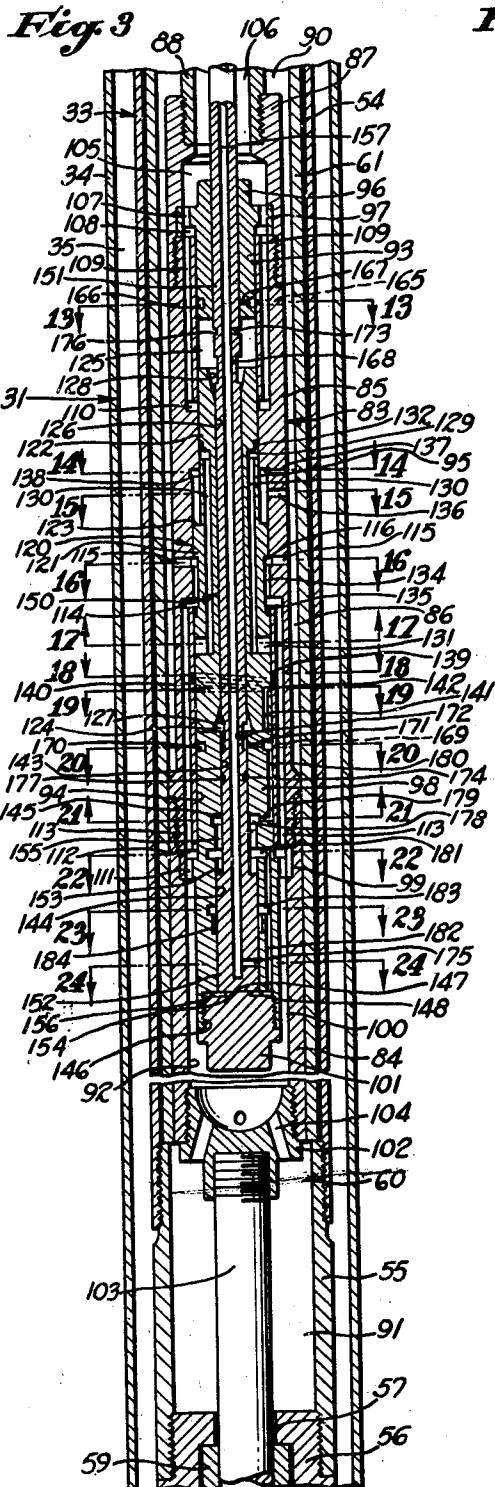
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6 Sheets-Sheet 2



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Fig. 5

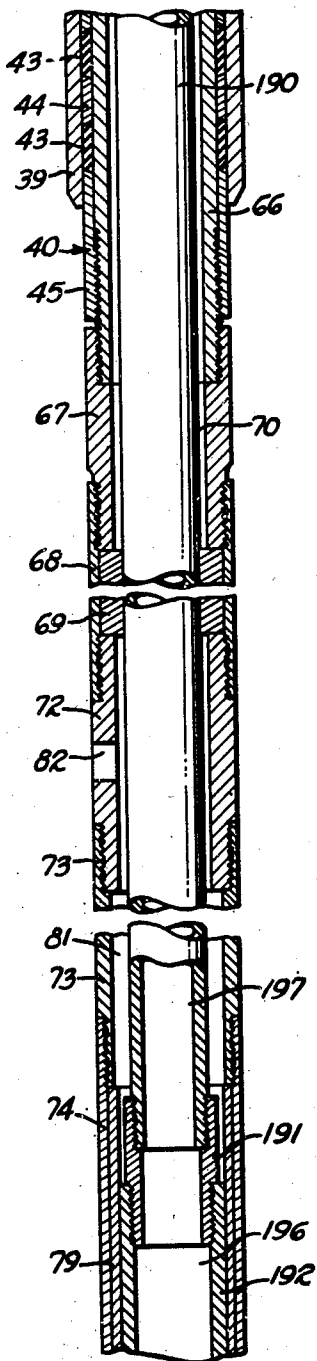


Fig. 6

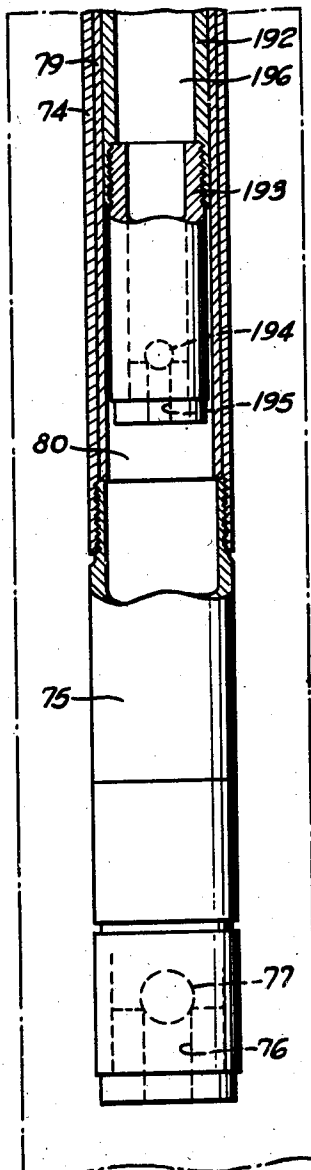


Fig. 10

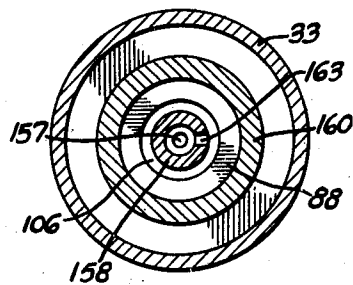


Fig. 11

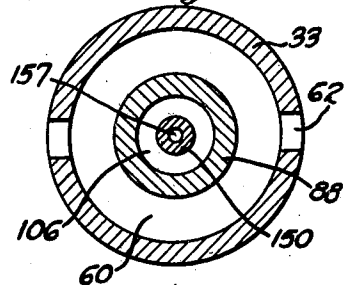
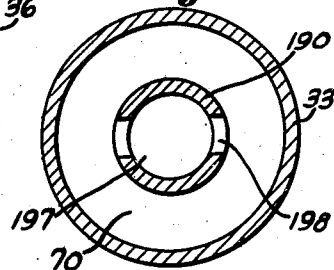


Fig. 12



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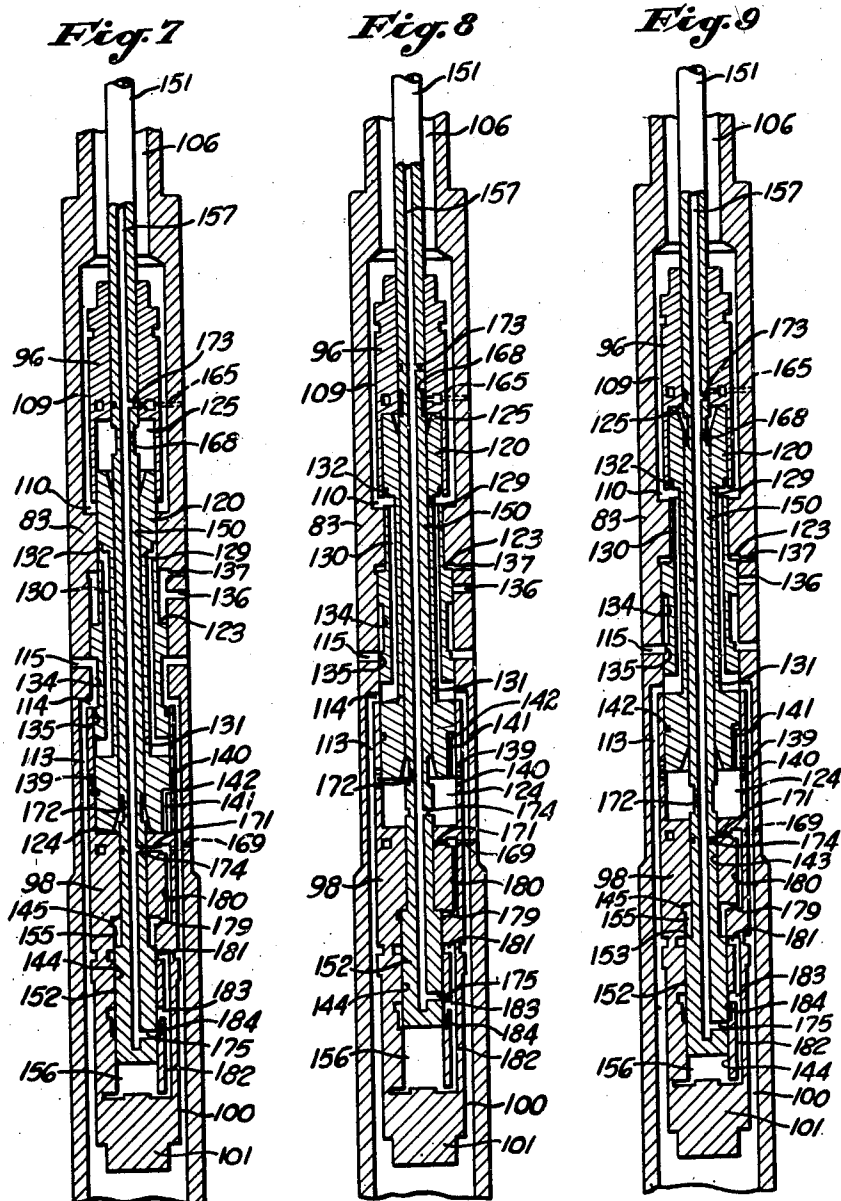
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6 Sheets-Sheet 4



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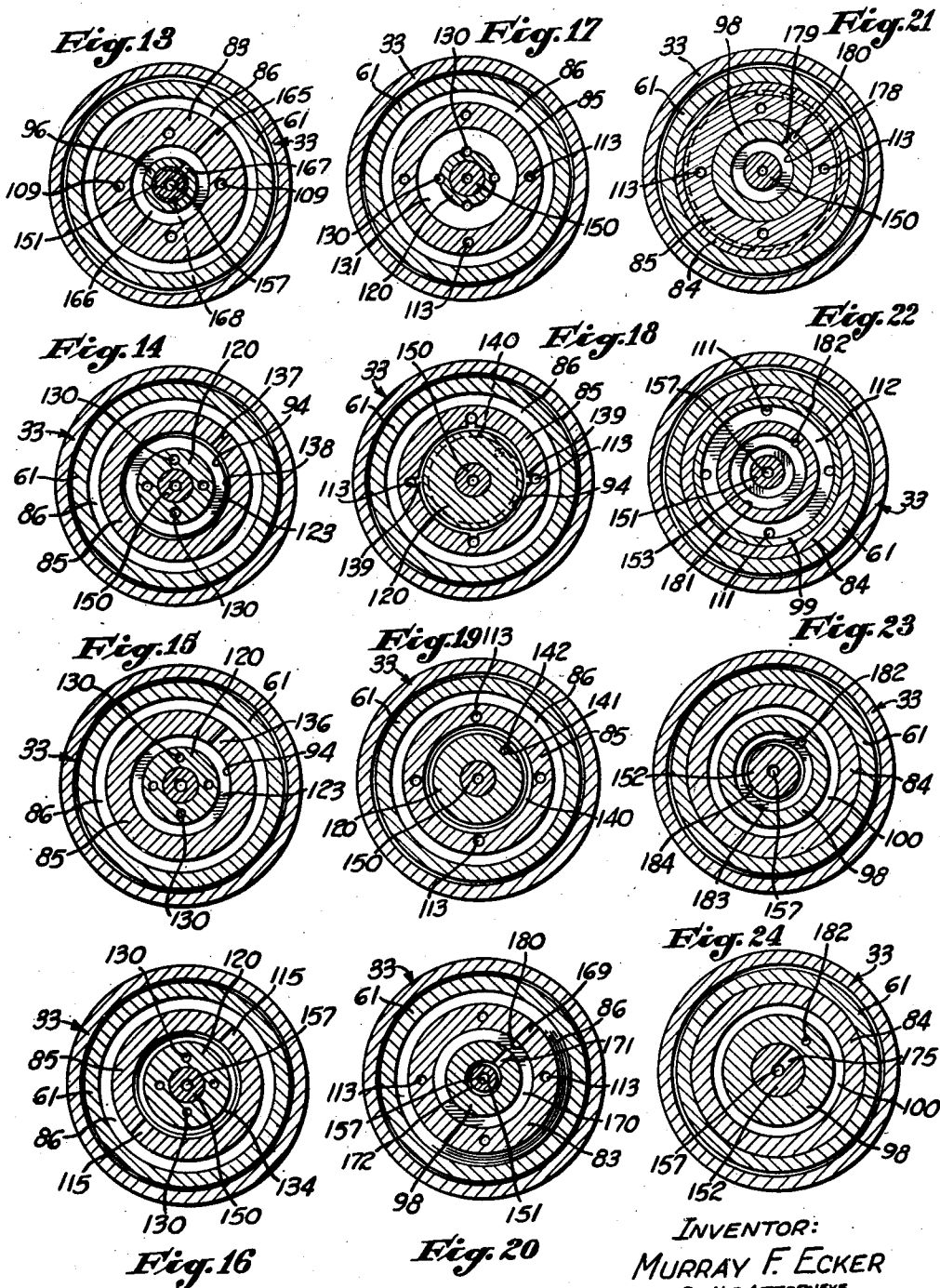
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M. F. ECKER
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6 Sheets-Sheet 5



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FLUID-OPERATED PUMP

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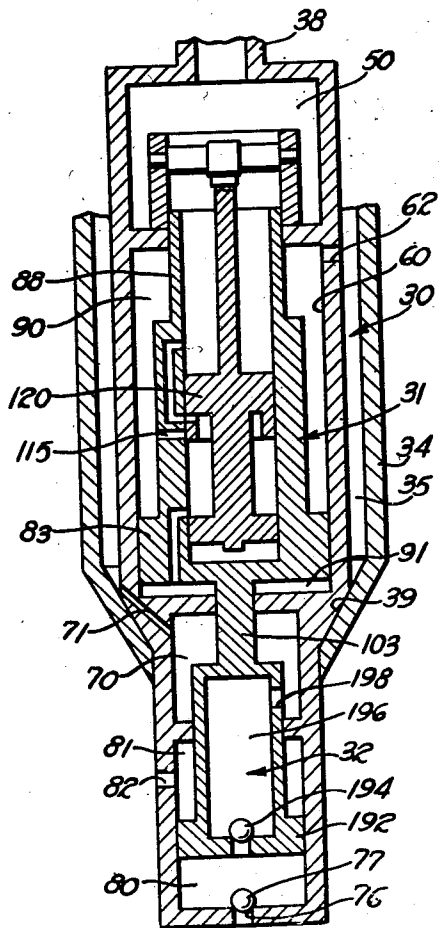
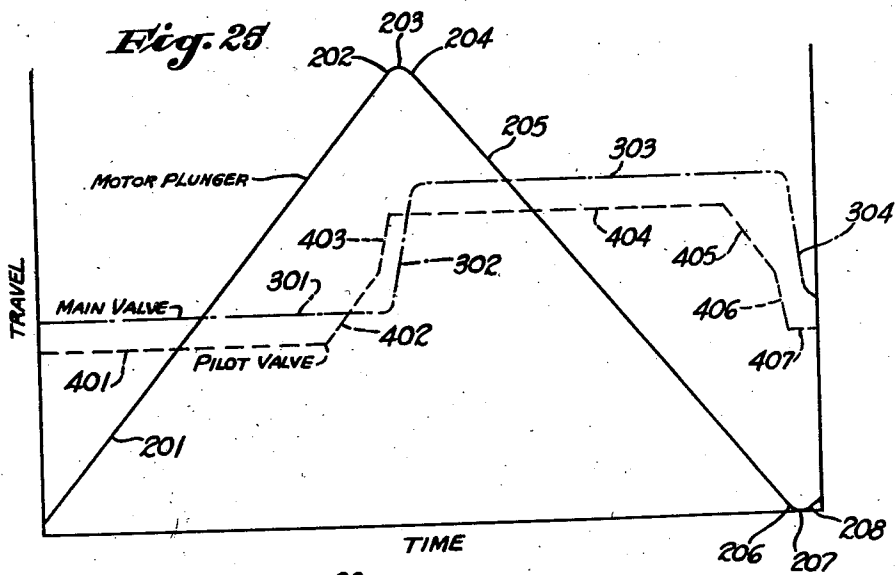


Fig. 26

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UNITED STATES PATENT OFFICE

2,497,348

FLUID-OPERATED PUMP

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Application July 18, 1947, Serial No. 761,977

18 Claims. (Cl. 103—46)

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My invention relates to fluid-operated pumps and more particularly relates to an apparatus for pumping fluid from a well, using high pressure operating fluid as motive power. Pumps of this type have a special utility in the oil industry, and my invention will accordingly be described in that connection, although its usage is not limited thereto.

Because of spatial limitations in the casing string of an oil well, designers of fluid-operated pumps have been constantly faced with problems of how to incorporate in a structure, which must of necessity be long and extremely narrow and situated in the depths of the well, many of the refinements, simplifications, and economies which are possible in pumping units which have a simple underground pump mechanically driven from a surface power unit. While fluid-operated pumps possess certain inherent advantages over mechanically driven pumps, it has been difficult to realize the full scope of these advantages. The basic fact that the fluid-operated motor was frequently in communication with well fluid containing sand or other foreign materials and was usually submerged in such fluid has either required a construction of extreme ruggedness and simplicity or the incorporation of protective devices, such as packings, which added to the friction load. Keeping the motor clear of injurious foreign matter and at the same time keeping it within narrow limits of size has involved compromises, such as constructing a pump capable of pumping in only one direction of reciprocation or incapable of high speeds because of possible injury to reciprocating parts and incapable of low speeds because of impositive valve action subject to friction. In some instances, springs have been used to assist the motor valves to pass through dead center positions, but such devices add to complexity, bulk, and the liability of mechanical failure.

A principal object of my invention is, accordingly, to provide a fluid-operated pump of simple construction, having few moving parts and so arranged as to require a minimum of cross-sectional area and to be capable of being installed in a well casing of ordinary construction and size.

Among the characteristics most sought in any pump unit is the ability to pump well fluid on both strokes of reciprocation. This ability not only increases the productivity of the pump but reduces the power consumption per unit of product by having no waste motion and by reducing the inertia of the surges of the product in the pipe line to the ground surface. It is accordingly

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another object of my invention to provide a fluid-operated pump having a double-acting pumping unit operated by a motor receiving a positive application of power coincident with each stroke of the pump.

It is a further object of my invention, also with a view to eliminating waste motion and surges, to correlate the power applicable to the motor and the discharge of spent operating fluid from the motor on each stroke thereof to the discharge of well fluid from the pump on the corresponding stroke. I accomplish this purpose by providing a reciprocating motor of the differential-area plunger type and a reciprocating pump, also of the differential-area plunger type, and connecting the plungers by a piston rod which enters into a power cylinder of the motor and into the discharge cylinder of the pump and thereby relates both the power and discharge capacity of the motor and the discharge capacity of the pump to its cross-sectional area.

Another object of my invention is to provide means for minimizing the discontinuity of flow at the end of each stroke of reciprocation of the motor and pump, and particularly for maintaining continuity of flow from the motor, with a view not only of reducing the surge effect, but of providing hydraulic rather than mechanical means of keeping the motor flushed and clear of foreign matter.

A further object of my invention is to provide hydraulically actuated valve means for causing reversal of direction of the motor and the pump whereby the movement of the valve means itself may be cushioned hydraulically, as well as the movement of the motor and pump plungers and the discharge of the fluid actuating the valve means may be utilized to supplement the total fluid discharge when the latter is at a minimum.

Yet another object of my invention is to provide main valve means entirely hydraulically actuated and therefore gentle in their operation and application, and pilot valve means mechanically, and therefore positively, actuated to assume positions in which they cause hydraulic completion of their own movement and hydraulic actuation of the main valve means.

It is also an object of my invention to provide a fluid-operated pump in which the discharge from the motor is continuous although composed of discontinuous fractions, and the discharge from the pumping unit is semi-continuous, with the two discharges joining to flow through a common conduit and so arranged that the discontinuous fractions of the motor discharge are united to

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form a continuous discharge before joining the pumping unit discharge so as to prevent the entry of the latter into the motor.

Still another object of my invention is to provide a fluid-operated motor having hydraulically operated valve means for reversing the direction of movement of a motor plunger, in which the valve means and the plunger are so constructed as to regulate hydraulically the velocity of the valve means and the deceleration and acceleration of the motor plunger consequent upon movement of the valve means.

Further objects and advantages of the invention will be made evident throughout the following specification and from consideration of the accompanying illustrative drawings, in which:

Fig. 1 is a vertical sectional view of the upper end of my invention as installed in a production tubing, showing the mechanical means for initially actuating the pilot valve of the motor;

Fig. 2 is a vertical sectional view of an intermediate portion of my invention, carried downwardly from the lower end of Fig. 1, and showing the discharge cylinder of the motor;

Fig. 3 is a vertical sectional view of a further intermediate portion of my invention, carried downwardly from the lower end of Fig. 2, and illustrative of the motor valve mechanism and the lower power cylinder of the motor;

Fig. 4 is a vertical sectional view of a further intermediate portion of my invention, carried downwardly from the lower end of Fig. 3 and showing the upper or discharge cylinder of the pump;

Fig. 5 is a vertical sectional view of a further intermediate portion of my invention, carried downwardly from the lower end of Fig. 4;

Fig. 6 is a vertical sectional view of the lower end of my invention, carried downwardly from the lower end of Fig. 5, and illustrative of the intake cylinder of the pump and the valve system thereof;

Fig. 7 is a vertical sectional semi-diagrammatic view of the motor unit of my invention, showing the pilot valve in a more advanced position of operation;

Fig. 8 is a vertical sectional semi-diagrammatic view similar to Fig. 7, showing both the pilot valve and main valve in another position of operation;

Fig. 9 is a vertical sectional semi-diagrammatic view similar to Fig. 8, showing the pilot valve in a still further advanced position of operation;

Fig. 10 is a cross-sectional view taken on the line 10—10 of Fig. 1 and on a slightly enlarged scale;

Fig. 11 is a cross-sectional view taken on the line 11—11 of Fig. 2 and on a slightly enlarged scale;

Fig. 12 is a cross-sectional view taken on the line 12—12 of Fig. 4 and on a slightly enlarged scale;

Figs. 13 to 24, inclusive, are cross-sectional views taken on the corresponding lines 13—13 to 24—24 of Fig. 3 and on a slightly enlarged scale;

Fig. 25 is a graph showing one method of the operation of my invention under normal operating conditions; and

Fig. 26 is a diagrammatic view of my pump, illustrating the main components thereof, but greatly simplified to clarify the general construction.

Referring to the drawings, I show a fluid-operated pump 30 having a fluid motor 31 (Figs. 1, 2, and 3) and a pump unit 32 (Figs. 4, 5, and 6), the outer portions of which are threadedly joined

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to form a jacket 33. The jacket 33 is of tubular form so as to fit loosely within a production tubing 34 with allowance for an annular space 35 therebetween. The production tubing 34 in turn is of such diameter as to be easily insertable in a well casing 36, indicated in broken lines in Fig. 6. As shown in Fig. 1, an upper tubular fitting 37 connects the jacket 33 to the lower end of a fluid supply tubing 38 by which operating fluid under relatively high pressure is delivered to the fluid motor unit 31.

As shown in Fig. 4, the production tubing 34 is provided at its lower end with a shoe 39 through which a reduced diameter portion 40 of the jacket 33 extends downwardly into the well casing 36. Corresponding chamfered shoulders 41 and 42 on the exterior of the jacket 33 and the interior of the shoe 39 provide a seat for the fluid-operated pump 30. The jacket 33 is sealed relative to the production tubing 34 by packing cups 43 compressible by spacer rings 44 and a gland 45 (see Fig. 5) threaded on the portion 40 of the jacket 33. It will be understood that the fluid supply tubing 38 and the production tubing 34 extend upward through the well casing 36 to the ground surface, providing, respectively, a downward conduit for operating fluid from a surface pumping unit (not shown) and an upward conduit for well fluid to which, as will be shown, the spent operating fluid is added.

The jacket 33 is constructed of a plurality of tubular parts threadedly joined so that they may be disconnected at intervals convenient for access to internal parts. As shown in Fig. 1, a tubular member 47 is threadedly secured at its upper end to the upper fitting 37 and at its lower end is secured by a nipple 48 to a tubular member 49. The upper fitting 37, tubular member 47, and nipple 48 define a high pressure chamber 50 at all times open to the fluid supply tubing 38, so as to receive high pressure operating fluid therefrom. As shown in Fig. 2, another nipple 51 is secured to the lower end of the tubular member 49 and cooperates with the nipple 48 to clamp between them a liner 52. An adapter 53 connects the nipple 51 to a tubular member 54, the lower end of which (as shown in Fig. 3) is connected in turn to a tubular element 55 which is provided at its lower end with an adapter 56 having an inwardly turned upper end flange 57. As shown in Fig. 4, a similar adapter 58 cooperates with the adapter 56 to clamp between them a liner 59 of less interior diameter than the liner 52. The nipple 51 and liner 52 define the upper end and the adapter 56 and liner 59 define the lower end of a motor cylinder 60. As shown in Figs. 2 and 3, a liner 61, of greater interior diameter than the liner 52 and held clamped between the adapter 53 and the tubular element 55, forms a sleeve for the motor cylinder 60 but, as will be seen, does not extend to either end thereof. As shown in Fig. 2, the upper end of the motor cylinder 60 is vented to the annular space 35 within the production tubing 34 by motor discharge ports 62 in the walls of the adapter 53. The liner 59 (shown in Figs. 3 and 4) separates the motor unit 31 and the pump 32.

As shown in Fig. 4, extending downwardly from the adapter 58 and secured thereto is a tubular member 63 connecting at its lower end to a seat plug 64. The seat plug 64 has a downwardly extending portion 65 of reduced diameter which forms the upper end of the reduced portion 40 of the jacket 33, and the junction of the upper and lower portions of the seat plug forms the cham-

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ferred shoulder 41 by which the jacket is seated in the shoe 39. A further reduced portion 66 of the seat plug 64 serves with the shoe 39 to form a stuffing box for holding the packing runs 43 and spacer rings 44 and (as shown in Fig. 5) is threaded at its lower end to receive the gland 45. A connecting member 67, threadedly secured to the seat plug 64 below the gland 45, has connected thereto a tubular member 68 encompassing a liner 69 of somewhat larger internal diameter than the liner 59. The liners 59 and 69, respectively, define the upper and lower limits of a pump outlet chamber 70 which (as shown in Fig. 4) is in constant communication with the annular space 35 within the production tubing 34 by ports 71 in the upper portion of the tubular member 63.

As shown in Fig. 5, the liner 69 is held clamped against the connecting member 67 by a shoulder nipple 72 secured to the lower end of the tubular member 68. Additional jacket-forming members 73, which may be of adapter or collar and nipple type, extend the jacket 33 downwardly to connection with a tubular member 74, to the lower end of which (as shown in Fig. 6) is secured a valve housing 75. The valve housing 75 has at its lower end an inlet passage 76 communicating with the well casing 36 and closed to prevent outward flow from the interior of the valve housing to the well casing by a standing valve 77. The upper end of the valve housing 75 and the lower end of the lowest jacket-forming member 73 cooperate to clamp between them a liner 79 which forms the wall of a pump inlet chamber 80 and has a larger interior diameter than the liner 69. The upper end of the liner 79 and the lower end of the liner 59 define, respectively, the lower and upper limits of an intermediate space 81 between the pump inlet chamber 80 and outlet chamber 70, which is vented to the well casing 36 by suitable vents 82 to permit well fluid to flow in and out of the space 81 as required by the hereinafter described plunger action.

As shown in Fig. 3, a motor plunger 83 is arranged to move reciprocally within the motor cylinder 60 and has a plunger head portion 84 fitting slidably within the liner 61 and a body portion 85 of smaller diameter threadedly connected thereto and proportioned to leave an annular channel 86 within the liner 61. A collar 87, of the same external diameter as the plunger body 85 and threadedly secured thereto, extends upwardly from the motor plunger 83 and is secured at its upper end to a tubular piston rod 88 which (as shown in Fig. 1) extends upwardly with a sliding fit through the liner 52 and loosely through the nipple 48 into the high pressure chamber 50. The plunger head 84 divides the motor cylinder 60 into two portions: the upper of which includes the annular channel 86 and the space between the collar 87 and the liner 52 and is constantly open to the annular space 35 through the motor discharge ports 62, and is hereinafter designated as the motor discharge chamber 90; and the lower of which includes the space 91 below the plunger head 84 and above the liner 59, and which is hereinafter designated as the alternating pressure chamber 91, for reasons to be later set forth.

The plunger head 84 and the plunger body 85 are tubular, the former having a large bore 92 and the latter having a relatively small upper bore 93, and a larger lower bore 94 separated by a shoulder 95 at their junction. The bore 93 is closed at its upper end by a tubular upper plug 96 provided with an annular flange 97 held

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clamped between the plunger body 85 and the collar 87, and the lower bore 94 is closed at its lower end by a tubular lower plug 98 provided with an annular flange 99 held clamped between the plunger body 85 and the plunger head 84. The lower plug 98 and the plunger head 84 define between them an annular space 100 communicating with the lower portion of the bore 92, and the interior of the lower plug 98 is sealed from the bore 92 by a plug 101. The lower end of the plunger head 84 is provided with an adapter 102 which threadedly connects thereto a connecting rod 103 and has passages 104 communicating between the bore 92 and the motor cylinder 60 therebelow. The bore 92 and annular space 100 thus form part of the alternating pressure chamber 91, being open to the latter at all times through the passages 104. Likewise, the annular channel 86 forms part of the motor discharge chamber 90, being always in communication therewith. So, also, the interior 105 of the collar 87 and the interior 106 of the tubular piston rod 88 form a continuation of the high pressure chamber 50.

A plurality of circumferentially spaced, vertical ports 107 in the flange 97 of the upper plug 96 lead from the interior 105 of the collar 87 to an annular groove 108 in the lower face of the flange 97 and thence communicate through a plurality of longitudinal passages 109 in the upper part of the plunger body 85 with a terminal annular groove 110 in the wall of the bore 93 below the upper plug 96. Similarly, a plurality of circumferentially spaced, vertical ports 111 in the flange 99 of the lower plug 98 lead from the annular space 100 to an annular groove 112 in the upper face of the flange 99, and thence communicate through a plurality of longitudinal passages 113 in the lower part of the plunger body 85 with a terminal annular groove 114 in the wall of the bore 94 above the lower plug 98. A plurality of radial ports 115, hereinafter called the plunger discharge ports, communicate between the annular channel 86 and an annular groove 116 in the wall of the bore 94 above the annular terminal groove 114. The high pressure chamber 50 is, therefore, potentially in communication with the alternating pressure chamber 91 through the ports 107, communicating with the interior 106 or the tubular piston rod 88, annular groove 108, upper plunger longitudinal passages 109, annular terminal groove 110, bore 93 and bore 94, annular terminal groove 114, lower plunger longitudinal passages 113, annular groove 112, ports 111, annular space 100, and passages 104. The alternating pressure chamber 91 is potentially in communication with the motor discharge chamber 90 through the ports 111, annular groove 112, lower plunger longitudinal passages 113, annular terminal groove 114, groove 94, annular groove 116, the plunger discharge ports 115, and the annular channel 86.

A main valve 120 is reciprocally carried within the plunger body 85 and has a lower portion 121 of relatively large diameter slidable within the bore 94 and an upper portion 122 of relatively small diameter slidable within the bore 93. The portions 121 and 122 have longitudinal dimensions relative to the bores in which they slide such that when the upper end of the portion 122 is in contact with the upper plug 96, the shoulder 123 at the junction of the portions 121 and 122 is not quite in contact with the shoulder 95 at the junction of the bore 93 and bore 94, and a space 124 designated as the lower main valve chamber extends between the lower end of the portion 121

and the lower plug 98. When the lower end of the portion 121 is in contact with the lower plug 98, the portion 122 extends into the bore 93, leaving therein a space designated as the upper main valve chamber 125. The main valve 120 has an axial bore 126 expanded outwardly at both ends to form conical recesses 127 and 128 which, in effect, act as extensions and minimum clearance volumes of the lower and upper main valve chambers 124 and 125.

The upper portion 122 of the main valve 120 is provided on its exterior surface with an upper annular channel 129 connected by a plurality of longitudinal valve passages 130 to a lower annular channel 131 on the exterior surface of the lower portion 121. The annular channels 129 and 131 are so spaced that when the upper annular channel 129 is in registry with the annular terminal groove 110, the lower margin of the lower annular channel 131 will be in registry with the lower margin of the annular terminal groove 114, thus providing communication as heretofore indicated from the high pressure chamber 50 to the alternating pressure chamber 91 through the longitudinal valve passages 130. The registering pairs of channels and grooves are, moreover, so placed in their respective main valve and plunger bodies that they are in registry when the upper end of the main valve 120 is in contact with the upper plug 96. The upper end of the upper annular channel 129 is provided with an annular throttling groove 132 which may preferably have the form of a groove continuously annular and of less depth than the upper annular channel 129, or may merely be intermittent segments of such a groove so as to provide an orifice of decreasing and increasing cross-sectional area as it is moved respectively downwardly or upwardly into registry with the annular terminal groove 110, in the one instance registering subsequently to the registering of the upper annular channel 129, and in the other instance in advance thereof. The lower annular channel 131 is wider than the annular terminal groove 114 with which it registers by an amount equal to the maximum width of the throttling groove 132, the excess in width being disposed on the upper side of the annular terminal groove 114 when the upper annular channel 129 and the annular terminal groove 110 are in registry. Thus, the area of registry of the lower annular channel 131 with the annular terminal groove 114 is always greater than any corresponding area of registry of the throttling groove 132 with the annular terminal groove 110, and any restriction then imposed on fluid flow through the longitudinal valve passages 130 will be imposed by the throttling groove 132 and may be calculated from the effective cross-sectional area thereof.

The lower portion 121 of the main valve 120 is further provided with a wide annular bridge channel 134 so proportioned and disposed as to open communication between the annular terminal groove 114 and the plunger discharge ports 115 when the lower end of the main valve 120 is in contact with the lower plug 98 and thereby to open the communication heretofore indicated as potential between the alternating pressure chamber 91 and the motor discharge chamber 90. The bridge channel 134 is provided with a shallow downward extension or governing groove 135, similar in form and in purpose to the throttling groove 132, by which communication with the annular terminal groove 114 may be gradually opened and closed.

The upper end of the bore 94 communicates with the annular channel 86 through a radial orifice 136 (see Fig. 15) in the plunger body 85 spaced slightly below the shoulder 95 and through a restricted radial orifice 137 (see Fig. 14) spaced more closely to the shoulder 95 and arranged to open to the bore 94 through an annular groove 138 adjacent the shoulder 95. The upper end of the bore 94 thereby forms a dashpot by which the velocity of movement of the main valve 120 both upwardly and downwardly is regulated when the shoulder 123 of the main valve is upwardly of the radial orifice 136.

Radial ports 139 (see Fig. 18) in the plunger body 85 connect each of the lower plunger longitudinal passages 113 to the lower portion of the bore 94 and there communicate with the upper end of a helical groove 140 (see Fig. 3) in the wall of the bore so disposed as to have its lower end communicate with the lower main valve chamber 124 when the upper end of the main valve 120 is in contact with the upper valve stop 96. A vertical passage 141 leads upwardly from the lower end of the main valve 120 and connects with an annular groove 142 in the outer surface of the lower main valve portion 122, disposed so as to be in registry with the lower end of the helical groove 140 when the lower end of the main valve 120 is in contact with the lower plug 98. When the main valve 120 is in this position, the vertical passage 141 and the annular groove 142 serve as a bleeder conduit to permit fluid flow between the lower plunger longitudinal passages 113 and the lower valve chamber 124, the direction of such flow, of course, depending on the relative pressures prevailing at the ends of the conduit. The helical groove 140 has a restricted cross-sectional area imposing a resistance to fluid flow therethrough substantially proportionate to the length of the helical groove through which fluid is forced to flow. This resistance is at a maximum when the main valve 120 is in contact with either the upper plug 96 or the lower plug 98, and is nil when the annular bleeder groove 142 is in registry with the radial ports 139.

The lower plug 98 has in descending order an axial minor bore 143 of the same diameter as the axial bore 126 of the main valve 120, a major bore 144 separated from the bore 143 by a shoulder 145, and a lower threaded bore 146 in which the plug 101 is retained. The plug 101 has a boss 147 on its upper face of less diameter than the major bore 144 and is inserted in the bore 146 to a depth sufficient to bring the upper face of the plug substantially level with the lower end of the major bore 144, leaving an annular space 148 around the boss 147 extending annularly into the bore 146.

A pilot valve 150 is mounted axially within the main valve 120 and the lower plug 98 and has a tubular pilot valve rod 151 fitting slidably within the axial bore 126 of the main valve and the axial bore 143 of the lower plug and a pilot valve piston head 152 fitting slidably within the major bore 144. The junction of the pilot valve rod 151 and piston head 152 is defined by a shoulder 153, and the piston head has a lower face 154 which, in the lowest position of the pilot valve (as shown in Fig. 3), comes into contact with the boss 147. The pilot valve piston head 152 delimits within the major bore 144 an upper pilot valve chamber 155 and a lower pilot valve chamber 156, the latter including the annular space 148. An axial passage 157 extends throughout the pilot valve rod 151 and into the pilot valve piston head 152 to a

position adjacent but above the face 154 of the latter. The pilot valve rod extends upwardly through the tubular upper plug 96, fitting slidably within it, and through the collar 87 and the tubular piston rod 88 with substantial clearance and (as shown in Fig. 1) protrudes from the top of the tubular piston rod 88 into the high pressure chamber 50. A fitting 158, secured to the upper end of the pilot valve rod 151, carries a striker sleeve 160 by means of a pin 161 and spacer 162. The striker sleeve 160 is designed to strike against the upper fitting 37 and against the nipple 48 to cause movement of the pilot valve 150 relative to the main valve 120 and motor plunger 83 and has sufficient downward length from the pin 161 to maintain a sliding contact with the tubular piston rod 88 in all positions of operation so as to guide the pilot valve rod axially therein. An orifice 163 in the fitting 158 permits high pressure operating fluid from the high pressure chamber 50 to enter the axial passage 157.

To permit venting of the upper main valve chamber 125 (shown in Fig. 3) so as to permit upward movement of the main valve 120, an upper vent passage 165 (best shown in Fig. 13) is provided in the motor plunger 83, radially connecting the annular channel 86 with an annular groove 166 in the outer surface of the tubular upper plug 96. A radial port 167 leads from the inner surface of the tubular upper plug 96 to the annular groove 166. A wide annular channel on the outer surface of the pilot valve rod 151 forms an upper spanning groove 168 capable of spanning between the upper main valve chamber 125 and the radial port 167 to permit the discharge of operating fluid from the chamber to the annular channel 86, this position being illustrated in Fig. 8. Similarly, to permit venting of the lower main valve chamber 124, a lower vent passage 169 (best shown in Fig. 20) is provided in the motor plunger 83 connecting the annular channel 86 with an annular groove 170 on the outer surface of the lower plug 98. A radial port 171 leads from the bore 143 of the lower plug 98 to the annular groove 170. A wide annular channel on the outer surface of the pilot valve rod 151 forms a lower spanning groove 172 capable of spanning between the lower valve chamber 124 and the radial port 171 to permit discharge of operating fluid from the chamber to the annular channel 86, as shown in Fig. 3.

The axial passage 157 in the pilot valve 150 is open to the lateral surfaces of the pilot valve by means of an upper pilot valve port 173, an intermediate pilot valve port 174, and a lower pilot valve port 175, all radial to the pilot valve. The upper pilot valve port 173 is disposed above the upper spanning groove 168 in a position permitting it to communicate with the upper main valve chamber 125 when the pilot valve 150 is lowered relative to the motor plunger 83, as shown in Fig. 3. It communicates with an annular groove 176 on the outer surface of the pilot valve rod 151, which permits it to register with the radial port 167 in all positions of rotation as it passes that port in upward and downward movement and so to communicate momentarily through the upper vent passage 165 with the annular channel 86, as shown in Fig. 7. The intermediate pilot valve port 174 is disposed below the lower spanning groove 172 in a position permitting it to communicate with the lower main valve chamber 124 when the pilot valve 150 is raised relative to the motor plunger 83, as shown in Fig. 8, and is provided with an annular

groove 177 similar to the annular groove 176 for the purpose of communicating momentarily with the annular channel 86 through the lower vent passage 169 and the radial port 171 as it passes that port in upward and downward movement, as shown in Fig. 7. The lower pilot valve port 175 is disposed adjacent the lower end of the axial passage 157 in the pilot valve piston head 152.

The bore 144 in the lower plug 98 has an annular channel 178 adjacent the shoulder 145 from which a radial orifice 179 (also shown in Fig. 21) leads to a longitudinal groove 180 in the exterior of the lower plug 98 and communicating with the annular groove 170. The upper pilot valve chamber 155 is thus always open to the annular channel 86 through the lower vent passage 169 and may also be open to the lower main valve chamber 124 through the radial port 171 and the lower spanning groove 172 and may also be open momentarily to the axial passage 157 through the radial port 171. Another annular channel 181, spaced below the annular channel 178, communicates with the annular space 148 in the lower pilot valve chamber 156 through a pilot valve by-pass passage 182. A third annular channel 183 intersects the pilot valve by-pass 182 and has a shallower annular channel 184 extending in downward continuation which serves as a control channel for governing the movement of the pilot valve 150. The lower edge of the annular channel 184 is at a distance from the shoulder 145 substantially equal to the length of the pilot valve piston head 152. The channel 184 and the lower pilot valve port 175 are so disposed in their respective containing members that when the port registers with the control channel (as illustrated in Fig. 7), the pilot valve head shoulder 153 is above the annular channel 183 and, hence, has cut off the upper pilot valve chamber 155 from communication with the pilot valve by-pass.

The connecting rod 103 fits slidably in the liner 59 through which it extends downwardly into the pump discharge chamber 70. As shown in Fig. 4, within the pump discharge chamber 70, the connecting rod 103 is threadedly connected to the upper end of a tubular pump plunger 190. The pump plunger 190 is of greater diameter than the connecting rod 103 and extends downwardly through the liner 69 (as shown in Fig. 5), fitting slidably therein, into the intermediate space 81 between the pump discharge chamber 70 and the pump inlet chamber 80, where it in turn is threadedly connected by an adapter 191 to a pump plunger head 192 having a still greater diameter. The pump plunger head 192 fits slidably in the liner 79 and extends downwardly into the pump inlet chamber 80, as shown in Fig. 6. The pump plunger head 192 is also tubular and has secured to its lower end a valve housing 193. A check valve 194, hereinafter called the traveling valve and similar to the standing valve 77, controls the passage of fluid from the pump inlet chamber 80 through an inlet passage 195 to the interior space 196 of the pump plunger head 192 and thence to the interior space 197 (seen in Fig. 5) of the pump plunger 190. As shown in Fig. 4, the upper end of the pump plunger 190 has discharge ports 198 communicating between the interior space 197 and the pump discharge chamber 70, and it will be seen that communication is always open from the traveling valve 194 through the pump plunger head and plunger to the pump discharge chamber 70

and thence through the ports 71 to the production tubing 34.

Although plungers, pistons, and rods of various ratios may be used in my invention, I preferably seek an optimum condition, hereinafter explained and described, in which the tubular piston rod 88 has a cross-sectional area equal to one-half the difference in cross-sectional area of the motor plunger head 84 and the connecting rod 103, and greater than the cross-sectional area of the latter, and in which the pump plunger 190 has a cross-sectional area equal to one-half the cross-sectional area of the pump plunger head 192 and also greater than the cross-sectional area of the connecting rod 103.

Operation

The general operation of my pump can best be understood by reference to Fig. 26. In operation, high pressure operating fluid is forced downwardly through the supply tubing 38 from a surface pumping unit (not shown) so as to actuate the fluid motor unit 31 and the pumping unit 32 connected thereto, in a manner hereinafter described in detail, but more generally describable as a double-acting cycle of reciprocation in which the fluid motor unit 31 develops power on both strokes of reciprocation, and the pumping unit 32 draws well fluid from the well by one stroke and discharges the well fluid so drawn to the production tubing 34 on both strokes. The spent operating fluid is also discharged to the production tubing 34, and, together with the well fluid, is raised to the ground surface by the action of the pumping unit. The motor plunger 83 is, in effect, of the differential-area type, the upper end thereof, in effect, having a relatively small effective cross-sectional area which is continuously exposed to the high pressure of the operating fluid in the high pressure chamber 50, and the lower end thereof being of relatively large effective cross-sectional area which is alternately exposed to the high pressure of the operating fluid. The high pressure operating fluid is alternately conveyed to the lower end of the motor plunger 83 by the operation of the main valve 120. As will be understood, when the alternating pressure chamber 91, and, consequently, the lower end of the motor plunger 83, are connected to the relatively low fluid pressure in the annular space 35, the high pressure acting on the upper end of the motor plunger will cause it to perform its downstroke, carrying with it the travelling valve 194. Upon completing the downstroke of the motor plunger 83, the main valve 120 is automatically thrown, to admit high pressure operating fluid to the alternating pressure chamber 91, which, in turn, causes the motor plunger 83 to move upwardly on its upstroke. At the end of the upstroke of the motor plunger 83, as will be understood, the main valve 120 is again mechanically thrown, to repeat the cycle.

In the following description it will be assumed that the pump has been in operation, that high pressure operating fluid fills the supply tubing 38, the high pressure chamber 50, and the tubular pilot valve 150, that well fluid fills the pumping unit 32 and is available at the standing valve 77, and that the production tubing 34 contains fluid at a pressure relatively low as compared to the pressure of the operating fluid in the supply tubing 38. It should be borne in mind that the motor discharge chamber 90 and the annular channel 86 are always in communication with the production tubing 34 through the motor discharge ports

62 and, therefore, the fluid in them which, as will be hereinafter shown, is spent operating fluid, is also at the relatively low pressure prevailing in the production tubing.

The operation of the fluid motor unit 31 will be described as a cycle of reciprocation beginning with the motor plunger 83 in raised position and about to descend, as illustrated in Fig. 3. At this stage of the cycle, both the pilot valve 150 and the main valve 120 are in their low positions relative to the motor plunger 83, with the fluid pressure in the high pressure chamber 50 exerting a downward pressure on the pilot valve so that the bottom face 154 of the pilot valve piston head 152 bears against the plug 101 of the lower plug 98. The upper pilot valve port 173 is open to the upper main valve chamber 125, and the intermediate pilot valve port 174 and lower pilot valve port 175 are closed, respectively, by the bore 143 and bore 144. In this position, high pressure fluid from within the pilot valve can, therefore, only reach the upper main valve chamber 125 through the upper pilot valve port 173 to which it is confined. The high pressure fluid also exerts a downward pressure upon the main valve 120. As the pilot valve head shoulder 153 is below the annular channel 181, the upper pilot valve chamber 155 and lower pilot valve chamber 156 are connected to each other by the pilot valve bypass 182 and are in communication through the radial orifices 179 and the longitudinal groove 180 with the lower vent passage 189 and the annular channel 86 so that the relatively low pressure of the fluid in the production tubing 34 prevails therein. Similarly, the lower main valve chamber 124 is connected to the lower vent passage 169 by the lower spanning groove 172, radial port 171, and annular groove 170, so that the relatively low pressure of the fluid in the production tubing prevails therein also. Consequently, both the pilot valve 150 and the main valve 120 are held hydraulically in their lower positions relative to the motor plunger 83 as the latter descends in its downstroke.

With the main valve 120 in its low position relative to the motor plunger 83, the motor plunger is urged hydraulically to descend. The upper annular channel 129 of the main valve, at the upper end of the longitudinal valve passages 130, is below and out of registry with the terminal annular groove 110 of the upper plunger longitudinal passages 109, and therefore the high pressure fluid in the high pressure chamber 50 is cut off from access to the lower parts of the motor plunger. The pressure of this fluid is effective upon the total cross-sectional area of the motor plunger at the liner 52, or, in other words, the cross-sectional area of the tubular piston rod 88, to urge the motor plunger downwardly. In this position, the alternating pressure chamber 91 is in communication with the motor discharge chamber 90 and thence to the motor exhaust ports 62 to the production tubing 34, by means of the passages 104, annular space 100, ports 111, lower plunger longitudinal passages 113, the plunger discharge ports 115, the main valve bridge channel 134, the annular groove 116, and the plunger discharge ports 115, so as to permit the escape to the production tubing of operating fluid forced from the alternating pressure chamber by the descending motor plunger 83. The pressure in the alternating pressure chamber 91 is therefore the relatively low pressure prevailing in the production tubing 34. It is effective upwardly against the cross-section

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tional area of the motor plunger head 84 at the liner 61, but is in part balanced by the same relatively low pressure in the motor discharge chamber 90 acting downwardly on the motor plunger and effective on an area having the cross-sectional dimensions of the annulus between the tubular piston rod 88 and the liner 61. The net area upon which the relatively low pressure acts upwardly is, accordingly, equal to the cross-sectional area of the tubular piston rod 88, and the predominating high pressure in the high pressure chamber 50, acting upon that same area, forces the motor plunger 83 downwardly.

The initial positions above described are indicated in Fig. 25 by the points of intersection of the lines therein representing movement of the motor plunger 83, the main valve 120, and the pilot valve 150 with the travel axis thereof, and it is to be understood that the positions and subsequent movements indicated for the main valve and the pilot valve in Fig. 25 are relative to the position and movement of the plunger, and not relative to the motor as a whole. In Fig. 25, the courses of the main valve and pilot valve are projected upwardly on the time axis instead of starting at the origin of coordinates.

The motor plunger 83, during its descending stroke, indicated by the sloped line 201 in Fig. 25, carries the main valve 120 and pilot valve 150 with it in initially unchanged relative positions, due to the downward pressure of the high pressure fluid in the high pressure chamber 50, the unchanged relative positions being indicated by the horizontal lines 301 and 401 in Fig. 25. At a point near the end of the descending stroke of the motor plunger 83, the lower margin of the striker sleeve 160 on the pilot valve rod 151 makes contact with the upper surface of the nipple 48, arresting the descent of the pilot valve and so mechanically causing the movement of the pilot valve relative to the motor plunger and the main valve which is indicated by the sloped line 402 of Fig. 25. It will be understood that the pilot valve is actually stationary and that the relative movement is caused by continued movement of the motor plunger. The fact that the velocity of relative movement is the velocity of the motor plunger is indicated by the parallelism of the motor plunger line 201 and the pilot valve line 402 at this stage in Fig. 25.

Until the shoulder 153 of the pilot valve piston head 152 is passed by the upper shoulder of the annular channel 181, fluid in the upper pilot valve chamber 155 will flow through the pilot valve by-pass 182 to the lower pilot valve chamber 156, and, thereafter, it will be ejected through the radial orifices 179 and the longitudinal groove 180 and the lower vent passage 169 to the production tubing 34. Immediately after the shoulder 153 of the pilot valve piston head 152 has been passed by the annular channel 181, and has thus cut off communication between the upper pilot valve chamber 155 and the lower pilot valve chamber 156, the lower pilot valve port 175 comes into registry with the pilot valve control channel 184, as shown in Fig. 7, permitting a flow of high pressure fluid to the lower pilot valve chamber 156 through the control channel 184, the annular channel 183, and the pilot valve by-pass passage 182. This high pressure fluid in the lower pilot valve chamber 156, acting in opposition to the relatively low pressure fluid in the vented upper pilot valve chamber 155, hydraulically causes upward movement of the pilot valve, disengaging the striker sleeve 160 from the

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upper surface of the nipple 48. The accelerated upward movement of the pilot valve relative to the motor plunger 83 is indicated by the steeply sloped line 403 of Fig. 25. It is, of course, of only momentary duration, as the pilot valve piston head 152 almost immediately completes its traverse of the bore 144 and comes into contact with the shoulder 145, and the pilot valve and motor plunger necessarily move thereafter in unison, as indicated by the horizontal line 404 in Fig. 25, but it serves to permit the pilot valve to actuate the main valve 120 before the motor plunger has reached the mechanical limit of its stroke, as will now be described.

As the pilot valve 150 moves upwardly relative to the motor plunger 83, the initial mechanically forced stage of this movement causes the upper pilot valve port 173, initially open to the upper main valve chamber 125, to pass within the upper plug 96 and to be closed thereby, and causes the lower spanning groove 172 to pass wholly within the lower valve chamber. Both upper and lower main valve chambers are thus momentarily closed to either ingress or egress of operating fluid, and the main valve 120 continues to move in unison with the motor plunger 83. The accelerated, hydraulically forced stage of movement of the pilot valve relative to the motor plunger 83 causes the upper spanning groove 168 to connect the upper main valve chamber 125 to the upper vent passage 165, as shown in Fig. 8, releasing the fluid in the upper main valve chamber 125 to the production tubing 34, and opens the intermediate pilot valve port 174 to the lower main valve chamber 124, admitting high pressure fluid thereto from the axial passage 157 of the pilot valve. The upwardly acting pressure differential thus created between the lower and upper main valve chambers moves the main valve 120 rapidly upward, as illustrated by the portion 302 of the graph of Fig. 25, the entire movement occurring during the latter portion of the hydraulically forced movement of the pilot valve and the initial portion of the subsequent movement in unison of the pilot valve and the motor plunger.

Although the above-described movement of the main valve is rapid and of short duration, it is, nevertheless, controlled both as to acceleration and deceleration. As shown in Fig. 7, prior to the upward movement of the main valve, the bleeder passage 141, bleeder groove 142, and the helical groove 140 form a channel of communication between the lower main valve chamber 124 and the radial ports 139 leading to the lower plunger longitudinal passages 113. This channel temporarily serves to release any high pressure fluid which may leak along the exterior of the pilot valve 150 to the lower valve main chamber 124 after the lower spanning groove 172 has ceased to communicate between the lower main valve chamber 124 and the lower vent passage 169, and so serves to prevent premature lifting of the main valve 120. As the main valve 120 begins its upward movement, the bleeder groove 142 intercepts a progressively shorter length of the helical groove 140, resulting in decreasing resistance to the release of pressure therethrough and so controlling the acceleration of the main valve. Toward the conclusion of the upward stroke of the main valve, deceleration is accomplished by dashpot action of the restricted radial orifice 137. The shoulder 123, as it ascends, forces fluid ahead of it toward the radial orifice

136 and the restricted radial orifice 137. When the shoulder 123 has passed beyond the radial orifice 136, the fluid remaining in the bore 94 above the shoulder 123 can escape only through the restricted radial orifice 137, as shown in Fig. 8, and the final upward movement of the main valve is thereby hydraulically cushioned. The ascending motion of the main valve 120 relative to the motor plunger 83 is indicated in Fig. 25 by the ascending line 302 curved terminally to illustrate the acceleration and deceleration of the valve.

The upward motion of the main valve 120 first closes communication between the alternating pressure chamber 91 and the plunger discharge ports 115, thus preventing escape of spent operating fluid from below the motor plunger 83 and arresting the descent of the motor plunger, and then opens communication between the high pressure chamber 50 and the alternating pressure chamber 91, thus permitting high pressure operating fluid to flow into the latter and to cause the motor plunger to move upwardly on its upstroke. Both of these actions are so governed as to prevent overly abrupt deceleration and acceleration of the motor plunger. As soon as the main valve 120 begins its ascent from the position shown in Fig. 7, the main valve bridge channel 134 begins to move out of registry with the lower terminal annular groove 114, reducing the opening available for the escape of spent operating fluid which is forced from the alternating pressure chamber 91 by the descending motor plunger. This closure is, however, performed gently and in the manner obviating shock because of the governing groove 135 which follows the main valve bridge channel 134 across the lower terminal groove 114 and effects a gradual closure thereof. The speed of closure is further regulated by the above-mentioned gradual acceleration of the main valve 120. The motor plunger 83 is consequently brought to a hydraulically cushioned stop as indicated by the curved line 202 in Fig. 25.

In the final stage of the upward movement of the main valve 120, the longitudinal valve passages 130 enter into registry with the upper and lower plunger longitudinal passages 109 and 113, respectively, as shown in Fig. 8, and permit the flow of high pressure fluid from the high pressure chamber 50 to the alternating pressure chamber 91. This opening of communication is gradual because the velocity of the main valve 120 is decelerated by the dashpot action of the restricted radial orifice 137, as heretofore described, and also because the initial opening is effected by registering of the throttling groove 132 with the upper terminal annular groove 110.

With high pressure fluid admitted to the alternating pressure chamber 91, the motor plunger 83 now has high pressure fluid and low pressure fluid acting upon it in both upward and downward directions. High pressure is exerted downwardly, as before, on the cross-sectional area of the tubular piston rod 88, but is more than offset by high pressure in the alternating pressure chamber 91 exerted upwardly on an annulus having the cross-sectional area of the motor plunger head 84 less the cross-sectional area of the connecting rod 103. Low pressure is exerted upwardly on the connecting rod 103, but is more than offset by low pressure in the motor discharge chamber 90 exerted downwardly on an annulus having the cross-sectional area of

the motor plunger head 84 less the cross-sectional area of the tubular piston rod 88. The net, or unbalanced, area affected by upwardly exerted high pressure equals the net, or unbalanced, area affected by downwardly exerted low pressure, and the net effect is, of course, to cause the motor plunger 83 to begin its ascending stage of the cycle of reciprocation.

It will be seen that with the pilot valve piston head 152 engaged by the shoulder 145 of the lower plug 98 so that the pilot valve 150 moves in unison with the motor plunger 83, as indicated by the horizontal line 404 of Fig. 25, the descending stroke of the motor plunger 83 would be limited by contact of the striker sleeve 160 with the upper surface of the nipple 48. However, the action of the main valve 120 is such that, normally, even though terminal movement of the main valve is cushioned, high pressure fluid is admitted to the alternating pressure chamber 91 in time to reverse the direction of movement of the motor plunger 83 before the mechanical limitation is effective. Theoretically, a momentary pause would occur at the end of the motor plunger stroke, indicated in Fig. 25 at 203, having a duration equal to the time of travel of the main valve 120 from the position in which the discharge of spent operating fluid through the lower plunger longitudinal passages 113 is cut off to the position in which high pressure operating fluid is admitted to the lower plunger longitudinal passages. In practice, it will be found that due to inertia of the moving parts, or to compressibility of the operating fluid, no such pause occurs, or at most it is of practically imperceptible duration, and the motor plunger passes smoothly from the decelerating movement indicated at 202 to the accelerating movement of the reverse stroke indicated at 204, produced by the above-described gradual admission of high pressure fluid to the lower plunger longitudinal passages 113 and then to its ascending stroke indicated by the line 205 in Fig. 25.

As the motor plunger 83 starts upwardly, the pilot valve 150 and main valve 120 accompany it, due to high pressures existing in the lower pilot valve chamber 156 and lower main valve chamber 124, and to low pressures existing in the lower and upper vent passages 169 and 165 to which the upper pilot valve chamber 155 and the upper main valve chamber 125 are then open. The absence of relative movement is indicated by the horizontal lines 404 and 303 in Fig. 25. At a point near the end of the ascending stroke of the motor plunger 83, the striker sleeve 160 strikes the upper tubular fitting 37 and is arrested thereby, so mechanically causing the movement of the pilot valve relative to the motor plunger and the main valve, which is indicated by the sloped line 405 in Fig. 25. As illustrated in Fig. 9, as the motor plunger 83 and the main valve 120 continue to ascend, the lower pilot valve port 175 passes downwardly beyond the lower end of the pilot valve control channel 184 and is closed by the bore 144. The upper shoulder 153 of the pilot valve piston head 152 at once comes into registry with the annular channel 181, allowing the fluid in the lower pilot valve chamber 156 to escape through the pilot valve by-pass 182 and the upper pilot valve chamber 155 to the lower vent passage 169. Until then this fluid has been forced by the descending pilot valve to return to the axial valve passage 157. During this mechanically forced movement of the pilot valve, the intermediate pilot

valve port 174 passes downwardly out of registry with the lower main valve chamber 124 and is closed by the bore 143 in the lower plug 98.

With the fluid in the lower pilot valve chamber 156 free to escape through the lower vent passage 169, the high pressure operating fluid in the high pressure chamber 50 urges the pilot valve 120 downwardly. The striker sleeve 160 is disengaged from the upper tubular fitting 37, and the pilot valve is hydraulically moved downwardly, while the motor plunger continues to move upwardly. The accelerated movement of the pilot valve relative to the motor plunger is indicated by the steeply sloped line 406 of Fig. 25, and the relative positions of the valves and motor plunger at the instant that hydraulic actuation of the pilot valve begins are shown in Fig. 9. As in the case of the upward, hydraulically urged motion of the pilot valve, hereinbefore described, this accelerated downward movement of the pilot valve is of brief duration, and the pilot valve piston head 152 comes into contact with the plug 101, causing the pilot valve and the motor plunger to move thereafter in unison, as indicated by the horizontal line 407 of Fig. 25, and completing the cycle of the pilot valve.

The hydraulically actuated downward movement of the pilot valve 150 brings the upper pilot valve port 173 into registry with the upper main valve chamber 125, admitting high pressure operating fluid thereto from the axial valve passage 157. The lower spanning groove 172 is immediately thereafter brought into communicating position between the lower main valve chamber 124 and the lower vent passage 169, releasing the fluid below the main valve 120 and permitting the main valve to descend in response to the fluid pressure above it. It should be noted that, while the main valve 120 has been in its raised position, shown in Figs. 8 and 9, the lower main valve chamber 124 has been in communication with the lower plunger longitudinal passages 113, which, for the moment, contain high pressure fluid, through the helical groove 140 and the radial ports 139. As long as the intermediate pilot valve port 174 is open to the lower main valve chamber 140 are equal, but when the intermediate pilot valve port is closed by the descent of the pilot valve, the helical groove 140 provides pressure from the lower plunger longitudinal passages 113 to compensate for any leakage from the lower main valve chamber to the lower vent passage 169 until flow through the lower spanning groove 172 overcomes it. The main valve 120 is thus protected against a premature descent, but the pressure upholding it may be quickly overcome when the operating cycle so requires because of the resistance provided by the helical groove 140.

The main valve 120 now descends in response to the high pressure above it, its course being indicated in Fig. 25 by the curved line 304. For the moment, the velocity of the main valve is retarded by the dashpot action in the bore 94 exerted by the shoulder 123, which, until it passes and permits opening of the radial orifice 136, creates a partial vacuum through the restricted radial orifice 137. Thereafter, the main valve descends rapidly until the annular bleeder groove 142 is in registry with the radial ports 139. The effective flow areas of the annular bleeder groove 142 and the bleeder passage 141 are greater than the effective flow area of the radial port 171 connecting them with the lower vent passage 169. A dashpot effect is thereby imposed, and high pres-

sure from the lower plunger longitudinal passages 113 builds up pressure in the lower main valve chamber 124 faster than pressure is released therefrom through the lower spanning groove 172 and the vent passages connected thereto. Consequently, the descending movement of the main valve 120 is momentarily decelerated. This feature of the invention has special importance if the pump load is suddenly lightened, as by the advent of gas in the well fluid, as it prevents unduly rapid acceleration of the motor plunger 83 under such circumstances.

During the initial accelerating stage of the descent of the main valve 120, the longitudinal valve passages 130 are moved out of registry with the upper and lower plunger longitudinal passages 109 and 113, respectively, cutting off the supply of high pressure operating fluid to the alternating pressure chamber 91. The rate of flow is decreased gradually by the accelerating movement of the main valve and by the gradual closure of the upper terminal groove 110 by the throttling groove 132. The resultant deceleration of the upward movement of the motor plunger 83 is indicated by the curved line 206 in Fig. 25. The motor plunger then theoretically pauses, as indicated at 207, while the main valve moves rapidly to the position in which the main valve bridge channel 134 connects the lower plunger longitudinal passages 113 to the plunger discharge ports 115, the pause being practically imperceptible because of the inertia of the motor plunger. The connection between the lower plunger longitudinal passages 113 and the plunger discharge ports 115 is made gradually, both because of the deceleration of the main valve at this stage of its movement and because communication is initially opened by the governing groove 135. Consequently, the motor plunger 83 accelerates gradually, as indicated at 208 in Fig. 25, as it begins to repeat the described cycle.

The pump unit 32 reciprocates in unison with the motor unit 31, being attached thereto by the connecting rod 103, but its cycle of reciprocation will be described in the reverse order of strokes. On the upstroke of the motor plunger 83, the pump plunger head 192 is drawn upwardly in the pump inlet chamber 80, creating a partial vacuum therein and causing compression within the pump plunger 190 and the pump discharge chamber 70, and thereby causing the travelling valve 194 to close and the standing valve 77 to open. Well fluid already in the pump discharge chamber 70 is discharged therefrom through the discharge ports 71 to the production tubing 34, the reduction in capacity of the pump discharge chamber being proportionate to the differential in cross-sectional area of the pump plunger tube 190 entering the pump discharge chamber and the connecting rod 103 withdrawn therefrom. Well fluid is drawn into the pump inlet chamber 80 from the well casing 36 through the standing valve 77, the increase in capacity of the inlet chamber being proportionate to the cross-sectional area of the pump plunger head 192. On the reverse or downward stroke of the pump plunger, the standing valve 77 is closed by back pressure, and the travelling valve 194 is opened. Well fluid is forced from the pump inlet chamber 80 through the travelling valve 194 into the interior space 196 of the pump plunger head 192 and into the interior space 197 of the pump plunger 190 and thence through the discharge ports 198 into the pump discharge chamber 70. As the decrease in capacity of the pump inlet

chamber 80 on the downward stroke of the pump is proportionate to the cross-sectional area of the pump plunger head 192, and the increased capacity of the pump discharge chamber is proportionate only to the cross-sectional area of the pump plunger 190 less the cross-sectional area of the connecting rod 103, well fluid is necessarily forced from the pump discharge chamber to the production tubing 34 by the downward stroke of the pump plunger as well as by the upward stroke thereof. A discharge of well fluid from the discharge ports 71 will occur on both strokes of the pump, provided the increased capacity of the discharge chamber on the downward stroke of the pump is less than the reduced capacity of the inlet chamber on that stroke.

It will be seen, therefore, that the operation of my pumping apparatus is double-acting for both the motor and the pump. Both strokes of the motor are power strokes, and both strokes of the pump are discharge strokes. Both strokes of the motor also result in the discharge of spent operating fluid to the production tubing. Both the motor and the pump have differential type reciprocating plungers. The chambers respective to each of the plungers are alternately disconnected and in connected series and are so arranged that the last cylinder in each series is continuously open to the production tubing and delivers thereto a substantially continuous, although pulsating, discharge of fluid so as to maintain, in combination, a rapid and efficient flow in the production tubing.

As will be seen from Fig. 25, during a major part of the pump cycle, the motor plunger and, consequently, the pump plunger are moving at a uniform rate and therefore are discharging uniformly, and the periodic decrease in the combined discharge at the end of each stroke is of relatively short duration. It will also be seen from Fig. 25 that the pilot valve 150 and the main valve 120 are stationary relative to the motor plunger 83 during the period of maximum fluid discharge from the motor and from the pump, and that they are moved and therefore the fluid actuating them is discharged at the brief period of minimum discharge from the motor plunger and the pump. This action lessens the amplitude of the pulsations in the production tubing and is thereby conducive to conservation of power. It is supplemented by jets of high pressure operating fluid discharged from the upper and intermediate pilot valve ports 173 and 174 through the upper and lower vent passages 165 and 169 as those ports pass those passages in their upward and downward movements. The discharge of operating fluid outwardly through the motor discharge ports 62 to the production tubing 34 is continuous, and well fluid cannot enter the ports 62 against this discharge. This prevents the entry of sand or other foreign materials into the working parts of the motor, which is an important feature of my invention. If foreign matter were able to enter the ports 62, it could not have access to the working parts of the motor except through the narrow annular channel 86, and this annular channel is continuously flushed upwardly toward the ports 62 as it receives spent operating fluid from the plunger discharge ports 115 during downward movement of the motor plunger and is reduced in capacity by upward movement of the motor plunger and receives fluid from the vent passages 165 and 169 at each end of the plunger stroke.

The combined action of the double-acting differential fluid-operated motor with the double-

acting differential plunger pump thus not only economizes on power by providing a relatively steady flow of fluid toward the ground surface, but assures a maximum outflow of clean operating fluid through the motor discharge ports 62 coincident with passage across that port of each peak pulsation of the well liquid discharged by the pump. The hydraulically actuated main valve 120 and the partly hydraulically actuated pilot valve 150 provide continuity to the outflow of operating fluid through the motor discharge ports. The discharge from these valves is potentially of higher pressure than the spent operating fluid discharged through the plunger discharge ports 115, as it has less work to perform, and, in conjunction with the high pressure jets emitted through the vent passages 165 and 169 as the latter are passed by the pilot valve ports 173 and 174, it maintains a substantial velocity of the fluid through the annular channel 86 and the motor discharge ports 62 at periods when the velocity would otherwise be at a minimum.

Also, as will now be shown, the combination of a differential type motor with a pump of the differential plunger type, hereinbefore described, permits proportionment of the pump discharge and the fluid-operated motor discharge so as to readily obtain the greatest economy of operation in wells of different depths, pressures, and rates of flow.

The ratio of power generated by the motor unit 31 to the volume of operating fluid supplied thereto at a given pressure may be altered by changing the cross-sectional areas of the tubular piston rod 88 and the connecting rod 103 with reference to the cross-sectional area of the motor plunger head 84, the latter being considered more or less determined by spatial limitations. Likewise, the apportionment between upward and downward pump strokes of the double-stroke discharge of the pump unit 32 may be altered by changing the cross-sectional areas of the connecting rod 103 and the pump plunger 190 with reference to the cross-sectional area of the pump plunger head 192 which determines the double-stroke discharge for a given length of stroke. It will be seen that the cross-sectional area of the connecting rod 103 is a factor in both of these alterations. It will also be seen that the tubular piston rod 88, motor plunger head 84, connecting rod 103, pump plunger 190, and pump plunger head 192 are threadedly connected and that the liners through which they slide are held by the clamping action of adjacent parts of the jacket 33. It is, therefore, a relatively simple operation to alter the power and discharge characteristics of my invention to suit well conditions by the substitution of motor plunger parts, connecting rods, and pump plunger parts of the desired size, with concomitant changes in the liners.

While regulation of power ratios and fluid discharge ratios may be made in the above-described manner by changes in cross-sectional areas which will suggest themselves to those skilled in the art as being suitable to local conditions, an optimum condition of equal power application to both strokes of the motor unit 31 will prevail when the cross-sectional area of the tubular piston rod 88 is one-half of the difference in cross-sectional area of the motor plunger head 84 and the connecting rod 103, a situation which may be met by various mathematical combinations which will in turn vary the speed of the pump and the quantity of work done thereby. This optimum situation provides that the net, or unbalanced, area affected

by high pressure operating fluid and spent operating fluid is always equal to the cross-sectional area of the tubular piston rod 88 on both upward and downward strokes of the motor, and the power so derived is consequently equal on both strokes. The cross-sectional area of the connecting rod 103 should always be less than that of the tubular piston rod 88 in order to provide a continuous discharge of operating fluid from the motor unit 31.

It will be found that when a condition of balanced power prevails on the upward and downward strokes of the motor unit 31, the discharge of operating fluid from the motor unit will not be balanced, but will be greater on the upward stroke than on the downward stroke by an amount equal to twice the maximum displacement of the connecting rod 103 in the alternating pressure chamber 91. To secure a uniform speed on both strokes of reciprocation, the work performed or the total discharge of the motor unit 31 and the pump unit 32 must also be balanced on upward and downward strokes. This may be achieved by providing a pump plunger 190 having a cross-sectional area equal to one-half the cross-sectional area of the pump plunger head 192 and ignoring the displacement effect of the connecting rod 103 in the pump discharge chamber 70. A discharge of the pump unit 32 is thus obtained, unbalanced by twice the maximum displacement of the connecting rod 103, which will combine with the unbalanced discharge of the motor unit 31 to provide a balanced total discharge under conditions of balanced application of power.

While irregularity in the speed of the pump, caused by unbalanced power and load factors, has no serious consequences during the major portion of each stroke, it may be detrimental if permitted to affect the rate of deceleration and acceleration, and, obviously, the ratios of motor power and pump load may be temporarily changed by the entry of gas instead of liquid into the pump. However, as the rate of reversal of both the main valve 120 and the motor plunger 83 is, as hereinbefore described, controlled independently of the degree of power applied to the motor plunger, the power may be proportioned to the pump load as desired, without danger. Each of these factors—the control of the rate of reversal and the control of speed during the major portion of each stroke—is independent of the other and is an important feature of my invention.

With a pumping unit as herein described, wherein the moving parts, such as valves and plungers, are free of friction-creating packing rings and the motor is self-protecting against infiltration of dirt, and in which the deceleration and acceleration at the end of each stroke are governed by a hydraulically moved main valve subject to dashpot action to control its speed, and the main valve is in turn actuated by a pilot valve having mechanical initiation of movement and hydraulic acceleration, an exceptional range of speed is possible. A speed as low as two strokes per minute may be attained without stalling or binding. On the other hand, thirty to forty strokes per minute are possible without endangering the rapidly reciprocating parts.

Although I have herein shown and described a simple and practical embodiment of my invention, it will be understood that numerous details of construction, proportion, and arrangement may be modified without departing from the spirit of my invention, and I do not intend to be limited to these details as herein disclosed, but intend

my invention to be accorded the full scope of the following claims.

I claim as my invention:

1. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a pumping unit having a reciprocable differential-type pump plunger and adapted to discharge fluid into said conduit means on both strokes of reciprocation; a reciprocating differential-type fluid-operated motor operably connected to said pump plunger to cause reciprocation of the same and having a discharge chamber for receiving spent operating fluid and outlet means from said discharge chamber to said conduit means, said motor being adapted to cause a discharge of spent operating fluid through said outlet means on both strokes of reciprocation; hydraulically movable valve means for causing reversal of said motor adapted to discharge spent operating fluid to said discharge chamber at the end of each stroke of reciprocation of said motor so as to cause continuous discharge of said spent operating fluid through said outlet means to said conduit means; means for controlling the rate of operation of said valve means; and means for controlling the deceleration and acceleration of said motor.

2. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a pumping unit having a reciprocable pump plunger and adapted to discharge fluid into said conduit means on both strokes of reciprocation; a reciprocating fluid-operated motor operably connected to said pump plunger to cause reciprocation of the same and having a discharge chamber for receiving spent operating fluid and outlet means from said discharge chamber to said conduit means, said motor being adapted to cause a discharge of spent operating fluid through said outlet means on both strokes of reciprocation; and hydraulically movable valve means for causing reversal of said motor adapted to discharge spent operating fluid to said discharge chamber at the end of each stroke of reciprocation of said motor so as to cause continuous discharge of said spent operating fluid through said outlet means to said conduit means.

3. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a pumping unit having a reciprocable pump plunger and adapted to discharge fluid into said conduit means on both strokes of reciprocation; and a reciprocating fluid-operated motor operably connected to said pump plunger to cause reciprocation of the same and having a discharge chamber for receiving spent operating fluid and outlet means from said discharge chamber to said conduit means, said discharge chamber and said outlet means forming a flow channel of substantial length between said motor and said conduit means, and said motor being adapted to cause a continuous discharge of spent operating fluid through said flow channel.

4. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a pumping unit having a reciprocable differential-type pump plunger and adapted to

discharge fluid into said conduit means on both strokes of reciprocation; a reciprocating differential-type fluid-operated motor operably connected to said pump plunger to cause reciprocation of the same and having a discharge chamber for receiving spent operating fluid and outlet means from said discharge chamber to said conduit means spaced from said motor, said motor being adapted to cause a discharge of spent operating fluid through said outlet means on both strokes of reciprocation; and means for discharging operating fluid to said discharge chamber at the end of each stroke of reciprocation of said motor so as to cause continuous discharge of operating fluid through said outlet means to said conduit means.

5. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a pumping unit having a reciprocable differential-type pump plunger and adapted to discharge fluid into said conduit means on both strokes of reciprocation; a reciprocating differential-type fluid-operated motor operably connected to said pump plunger to cause reciprocation of the same and adapted to discharge spent operating fluid to said conduit means synchronously with the discharge of fluid thereto by said pumping unit; and means for discharging additional operating fluid from said motor at the end of each stroke of reciprocation thereof so as to cause continuous discharge of operating fluid therefrom to said conduit means.

6. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a pumping unit having a reciprocable differential-type pump plunger and adapted to discharge fluid into said conduit means on both strokes of reciprocation; a fluid-operated motor including a reciprocating differential-type motor plunger operably connected to said pump plunger to cause reciprocation of said pump plunger and adapted to discharge spent operating fluid from said motor to said conduit means during each stroke of reciprocation; and fluid-operated valve means for causing reversal of the direction of movement of said motor plunger adapted to discharge operating fluid at the end of each stroke of reciprocation of said motor plunger in commixture with the operating fluid discharged by said motor plunger and to cause a continuous flow of the so commixed operating fluid from said motor to said conduit means.

7. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a fluid-operated motor including, in alignment, a high pressure chamber communicating with said supply means, a discharge chamber communicating with said conduit means, and a third chamber forming a motor cylinder jointly with said discharge chamber; a motor plunger reciprocable in said motor cylinder having a piston extending from its one side into said high pressure chamber and a rod extending from its other side through the distal end of said third chamber; and valve means for opening said third chamber alternately to communication with said high pressure chamber and said discharge chamber so as to cause reciprocation of said motor plunger, said piston having a cross-sectional area

less than that of said motor plunger and greater than that of said rod, whereby reciprocation of said motor plunger in either direction causes the contents of said discharge chamber to flow to said conduit means.

8. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a fluid-operated motor including, in alignment, a high pressure chamber communicating with said supply means, a discharge chamber communicating with said conduit means, and a third chamber forming a motor cylinder jointly with said discharge chamber; a motor plunger reciprocable in said motor cylinder; and valve means for opening said third chamber alternately to communication with said high pressure chamber and said discharge chamber so as to cause reciprocation of said motor plunger, said valve means and said motor plunger forming restricted passage means for said operating fluid adapted to cause gradual opening and closing of communication between said third chamber and said discharge chamber so as to cause gradual acceleration and deceleration of said motor plunger when said motor plunger is moved toward said third chamber.

9. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a fluid-operated motor including, in alignment, a high pressure chamber communicating with said supply means, a discharge chamber communicating with said conduit means, and a third chamber forming a motor cylinder jointly with said discharge chamber; a motor plunger reciprocable in said motor cylinder; and valve means for opening said third chamber alternately to communication with said high pressure chamber and said discharge chamber so as to cause reciprocation of said motor plunger, said valve means and said motor plunger forming restricted passage means for said operating fluid adapted to cause gradual opening and closing of communication between said high pressure chamber and said third chamber so as to cause gradual acceleration and deceleration of said motor plunger when said motor plunger is moved toward said high pressure chamber.

10. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a fluid-operated motor including, in alignment, a high pressure chamber communicating with said supply means, a discharge chamber communicating with said conduit means, and a third chamber forming a motor cylinder jointly with said discharge chamber; a motor plunger reciprocable in said motor cylinder; and valve means for opening said third chamber alternately to communication with said high pressure chamber and said discharge chamber so as to cause reciprocation of said motor plunger, said valve means and said motor plunger forming restricted passage means for said operating fluid adapted to cause gradual opening and closing of communication between said third chamber and said discharge chamber so as to cause gradual acceleration and deceleration of said motor plunger when said motor plunger is moved toward said third chamber and forming additional restricted passage means for said operating fluid adapted

to cause gradual opening and closing of communication between said high pressure chamber and said third chamber so as to cause gradual acceleration and deceleration of said motor plunger when said motor plunger is moved toward said high pressure chamber.

11. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a fluid-operated motor including, in alignment, a high pressure chamber communicating with said supply means, a discharge chamber communicating with said conduit means, and a third chamber forming a motor cylinder jointly with said discharge chamber; a motor plunger reciprocable in said motor cylinder; fluid-operated reciprocating valve means for opening said third chamber alternately to communication with said high pressure chamber and said discharge chamber so as to cause reciprocation of said motor plunger; and means forming dashpots at each end of said valve means for so delaying the movement of said valve means in each direction of reciprocation as to require substantially a predetermined period of time for the completion of said movement.

12. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a fluid-operated motor including, in alignment, a high pressure chamber communicating with said supply means, a discharge chamber communicating with said conduit means, and a third chamber forming a motor cylinder jointly with said discharge chamber; a motor plunger reciprocable in said motor cylinder having a piston extending from its one side into said high pressure chamber and a rod extending from its other side through the distal end of said third chamber; and valve means for opening said third chamber alternately to communication with said high pressure chamber and said discharge chamber so as to cause reciprocation of said motor plunger, said piston having a cross-sectional area less than that of said motor plunger and greater than that of said rod and equal to one-half the difference in cross-sectional area of said motor plunger and said rod.

13. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a reciprocating pumping unit having an inlet chamber and a pump discharge chamber; a pump plunger reciprocable in said inlet chamber; inlet means for said inlet chamber; outlet means in said pump discharge chamber communicating with said conduit means; valve means operable to permit fluid flow through said inlet means to said inlet chamber and from said inlet chamber to said pump discharge chamber; an extension on said pump plunger having a cross-sectional area equal to one-half the cross-sectional area of said pump plunger and extending from said pump plunger into said pump discharge chamber; a fluid-operated motor including, in alignment, a high pressure chamber communicating with said supply means, a motor discharge chamber communicating with said conduit means, and a third chamber forming a motor cylinder jointly with said motor discharge chamber; a motor plunger reciprocable in said motor cylinder; a piston extending from one side of

said motor plunger through said motor discharge chamber and into said high pressure chamber; a rod extending from the other side of said motor plunger through the distal end of said third chamber and into said pump discharge chamber and there operatively connected to said extension to cause reciprocation of said pump plunger, said piston having a cross-sectional area greater than that of said rod and less than that of said extension and equal to one-half the difference in cross-sectional area of said motor plunger and said rod; and valve means for opening said third chamber alternately to communication with said high pressure chamber and said motor discharge chamber so as to cause reciprocation of said motor plunger.

14. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a fluid-operated motor including, in alignment, a high pressure chamber communicating with said supply means, a discharge chamber communicating with said conduit means, and a third chamber forming a motor cylinder jointly with said discharge chamber; a motor plunger reciprocable in said motor cylinder having a piston removably connected to its one side and extending into said high pressure chamber, and a rod extending from its other side through the distal end of said third chamber; and valve means for opening said third chamber alternately to communication with said high pressure chamber and said motor discharge chamber so as to cause reciprocation of said motor plunger.

15. In a fluid-operated pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, the combination of: a pumping unit having a reciprocable differential-type pump plunger and adapted to discharge fluid into said conduit means on both strokes of reciprocation; a fluid-operated motor including, in alignment, a high pressure chamber communicating with said supply means, a discharge chamber communicating with said conduit means, and a third chamber forming a motor cylinder jointly with said discharge chamber; a motor plunger reciprocable in said motor cylinder having a piston connected to its one side and extending into said high pressure chamber, and a rod extending from its other side through the distal end of said third chamber and into said pumping unit and there operatively connected to said pump plunger to cause reciprocation thereof, said pumping unit having a pump discharge chamber adapted to receive said rod, and said pump plunger having a portion of greater cross-sectional area than said rod extending into said pump discharge chamber and there connected to said rod; and valve means for opening said third chamber alternately to communication with said high pressure chamber and said motor discharge chamber so as to cause reciprocation of said motor plunger.

16. A fluid-operated motor for a pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, comprising: cylinder means including a discharge chamber open to said conduit means; a differential-type plunger reciprocable in said cylinder means in response to the pressure of said operating fluid and adapted to cause a discharge of spent operating fluid from said discharge cham-

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ber on both strokes of reciprocation; a fluid-operated main valve for causing reciprocal movement of said plunger; and a pilot valve for supplying fluid to actuate said main valve, responsive to movement of said plunger to move through an initial stage of movement to a position in which it is adapted to hydraulically actuate its own further movement, and then responsive to such hydraulic actuation to move at increased velocity to a position in which it is adapted to actuate said main valve.

17. A fluid-operated motor for a pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit means for conveying a product therefrom, comprising: cylinder means including a discharge chamber open to said conduit means; a differential-type plunger reciprocable in said cylinder means in response to the pressure of said operating fluid and adapted to cause a discharge of spent operating fluid from said discharge chamber on both strokes of reciprocation; fluid-operated reciprocable valve means for causing reciprocal movement of said plunger; and means forming dashpots at each end of said valve means for so delaying the movement of said valve means in each direction of reciprocation as to require substantially a predetermined period of time for the completion of said movement.

18. A fluid-operated motor for a pump having supply means for supplying relatively high pressure operating fluid thereto and having conduit

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means for conveying a product therefrom, comprising: cylinder means including a discharge chamber open to said conduit means; a differential-type plunger reciprocable in said cylinder means in response to the pressure of said operating fluid and adapted to cause a discharge of spent operating fluid from said discharge chamber on both strokes of reciprocation; and valve means interconnecting said cylinder means for causing said operating fluid to actuate said plunger, said valve means and said plunger forming restricted passage means for causing a gradual increase and decrease in the rate of flow of said operating fluid at the beginning and end of each reciprocating stroke of said plunger so as to cause gradual acceleration and deceleration of said plunger.

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