MULTIPLE INJECTION WELL PACKER APPARATUS

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ABSTRACT OF THE DISCLOSURE

Apparatus for injecting fluid through perforations in a subsurface well casing, a plurality of spaced packings on a supporting body being adapted to seal against the casing to form a plurality of separated zones isolated from one another and surrounded by casing perforations, a separate flow path being provided from a body passage to each zone, which flow path includes an elastomeric tubing for controlling the rate at which fluid discharges into each zone, a limit valve also being provided in each flow path for limiting the maximum fluid pressure that can be imposed in each zone and on the surrounding well formation.

The present invention relates to subsurface well bore apparatus, and more particularly to subsurface apparatus for injecting fluids into well bore, such as synthetic resins, water, steam, acids, and the like.

In the injecting of fluids into a formation zone in a well bore by subjecting the fluids in the well bore to pressure, the desired injection of the fluids along the length of the zone is difficult to secure at the required rate. Assuming a length of a formation zone to be treated, it may break down at different pressures along its length, resulting in weaker regions of the zone receiving more of the injecting fluid than other regions. It has been proposed heretofore to provide an apparatus for injecting fluids into a formation along a desired length in which substantially the same amount of fluid will be injected along the length of the formation regardless of the fact that the breakdown pressures along the length of the formation might vary. The apparatus can be adjusted to inject the same amount of fluid into each interval of the formation being treated, or, for that matter, to deliver a different but known amount of fluid to each or any section of the treated interval.

In well bores that produce substantial quantities of sand, it is desirable to employ a sand consolidation process along the length of the producing formation. One such process includes the injecting of a flushing fluid into the sand to displace most of the formation crude and brine, followed by the injection of acetone to miscibly displace the residual brine and the remaining crude. The sand near the injection area is then resaturated with diesel oil. A calculated volume of a synthetic resin, which may, for example, be an epoxy resin, is pumped into the formation at a low rate, the resin fully saturating the interstices between the sand grains, because it has a greater viscosity than diesel oil, and preferentially wetting the said grains. Diesel oil is again injected into the resin saturated sand and this oil immiscibly displaces the resin, leaving the sand grains covered with resin and the interstices filled with diesel oil. A diesel oil containing an activator is then injected into the sand, the activator reacting with the resin film on the sand surfaces to initiate polymerization or setting of the resin and the strong adherence of the sand grains to one another. The resulting body is strong and rigid, one having a high degree of permeability, but which is incapable of shifting into the well bore.

It is highly desirable to secure a substantially uniform injection of various fluids into the well bore regardless of the fact that the particular fluids being injected are of different viscosities. Apparatus has been suggested for accomplishing this purpose. Fluids having lower viscosities, such as flushing fluid, are injected at a much greater rate than relatively higher viscosity fluids, such as the epoxy resin.

The length of the formation zone into which the fluids are to be injected is divided into definite lengths by use of multiple packing elements sealed against the casing and spaced apart a desired distance, such as two feet, four feet, etc., the casing having perforations between each pair of packing elements. Each fluid used in the formation treating operation is pumped through a flow regulator or control device between each pair of packing elements into the casing and through the casing perforation or perforations therebetween into the surrounding formation or zone.

The present invention contemplates a multiple injection well packer apparatus for separating a length of formation to be treated into individual sections through use of multiple packing elements, but in which assurance is had that the overall straddled zone has been packed off at its opposes ends. Such pack-off of the apparatus within the well casing at each end of the straddled zone can occur in the absence of fluid pressure within the apparatus. In fact, a packing or sealing off of the packing elements at each end of the straddled zone can be secured without reliance upon fluid pressure for expanding the initially retracted packing elements against the wall of the surrounding well casing. With the packer apparatus described hereinbelow, it cannot be moved longitudinally in the well casing by fluid pressure applied through the apparatus.

The apparatus incorporates a comparatively simple device for discharging fluids having different viscosities into the surrounding formation at different flow rates, while still maintaining the rate of flow into the different separated regions of the formation zone into which the fluid is to be injected substantially the same; that is to say, fluids having relatively low viscosity will be injected at a different rate and uniformly along the length of the overall formation at a substantially higher rate than fluids having relatively greater viscosities, there being a substantially even distribution of each injected fluid into the zone to be treated along its entire length.

The apparatus incorporates a safety feature to prevent fracturing a tight interval of the formation by precluding the application of a fracturing fluid pressure thereto. It also incorporates a circulation valve that allows fluid to be spotted around the well packer apparatus and for equalizing pressure around the apparatus after the formation treating operation has been completed. Despite the presence of the circulation valve, which is in an open condition when raising or lowering the apparatus through the fluid in the well casing, it incorporates a device that limits the rate at which fluid can flow through the apparatus and into the tubing string, while it is being lowered in the well bore, to prevent inadvertent expansion of the packing and other expandable elements of the apparatus. Despite such limitation in the flow of fluid through the apparatus and into the tubing string, elevation of the tubing string can occur with fluid allowed to drain relatively freely therefrom. This prevents the build-up of pressures in the apparatus that might otherwise inadvertently expand packing and other elements against the wall of the surrounding well casing.

This invention possesses many other advantages, and has other purposes which may be made more clearly apparent from a consideration of a form in which it may
be embodied. This form is shown in the drawings accompanying and forming part of the present specification. It will now be described in detail, for the purpose of illustrating the general principles of the invention; but it is to be understood that such detailed description is not to be taken in a limiting sense, since the scope of the invention is best defined by the appended claims.

Refiguring to the drawings:

FIGURES 1a, 1b and 1c together constitute a combined side elevational and longitudinal sectional view through apparatus embodying the invention, with the parts in condition for moving the apparatus through a surrounding well casing, FIGS. 1b and 1c being lower continuations of FIGS. 1a and 1b, respectively;

FIG. 2 is an enlarged longitudinal section through one of the flow control or regulator devices embodied in the apparatus;

FIGS. 3a, 3b and 3c are views corresponding to FIGS. 1a, 1b and 1c, illustrating the apparatus set in packed-off condition in the well casing, FIGS. 3b and 3c being lower continuations of FIGS. 3a and 3b, respectively;

FIG. 4 is a cross-section taken along the line 4-4 on FIG. 3b;

FIG. 5 is an enlarged fragmentary vertical section of the lower valve portion of the apparatus in a closed position;

FIG. 6 is a cross-section taken along the line 6-6 on FIG. 4c;

FIG. 7 is a cross-section taken along the line 7-7 on FIG. 5;

FIG. 8 is an enlarged view of part of the limit valve portion of the regulator device.

The multiple injection well packer apparatus A illustrated in the drawings can be lowered through a string of well casing B from the top of a well bore by means of a tubing string C to the desired position of use where the casing has been perforated at predetermined spaced intervals along the length of the formation zone into which fluid or fluids are to be injected. The apparatus includes an upper hydraulic anchor or hold-down device 10, below which is located an intially retracted and mechanically expandable packing structure 11 to be shifted into sealing engagement with the wall of the well casing. Below the mechanically expandable packing elements are located a desired number of identical intermediate injection module assemblies 12 on which are mounted hydraulically inflatable packing devices 13 and which include flow regulators or controllers 14. The number of these intermediate module assemblies 12 can be varied depending upon the perforated interval of the formation zone to be treated. A lower mechanically expandable packing structure 15 is secured to the lowermost module assembly, below which a set-down type of expander and slip device 16 is provided for anchoring the apparatus against downward movement in the well casing. To this lower portion of the apparatus, an indexing or latching device 17 is secured for appropriately relating the apparatus to a lower locating tool D previously set in the well casing B, such as a well packer of a known type disclosed at the lower portion of FIG. 5c. The apparatus also incorporates a lower circulation valve 18 to allow fluid to flow into and out of the apparatus A and through the tubing string C during its lowering and raising through the liquid in the well casing or well bore.

As more specifically illustrated in the drawings, the apparatus includes an inner or central mandrel 20 extending substantially throughout its entire length, the upper end of the mandrel being threaded secured to a coupling 21, which is, in turn, threaded attached to the lower end of the tubing string C that extends to the top of the well bore. This mandrel includes an upper section 22, the lower end of which is threaded attached to a coupling 23, which is, in turn, threaded attached to a lower slotted or perforate mandrel section 24, the slots 25 preferably being relatively narrow so as to function as a screen for preventing the injection of solids from the mandrel that might tend to plug or otherwise interfere with the proper operation of the apparatus and thereof. The lower end of the lower mandrel section 24 is connected through a coupling 26 to a terminal mandrel section 27 constituting part of the circulation valve, there being a suitable rubber or rubber-like seal ring 28 on the terminal section retained between a lower flange 29 of the terminal section and the lower end 30a of the coupling thereon.

The anchor or hold-down portion 10 of the apparatus surrounds the upper mandrel section 22. It includes a body 30, the upper portion of which is threadedly secured to an adapter housing 31 having an upper flange 32 extending inwardly to the periphery of the upper mandrel section. The upper end of the body 30 also engages an adapter 33 slideable along the upper mandrel section and which engages the lower side of the housing flange and also a split ring 34 confined within a peripheral groove 35 in the mandrel section and within a counterbore 36 in the housing flange. The downward thrust of the mandrel 20 is transferred through the ring 34 and the adapter 33 to the upper end of the body 30. Upward thrust and movement of the mandrel is transferred through the split ring 34 to the housing flange 32 and to the body 30.

Below the adapter 33, the body 30 has a length 37 of reduced diameter to provide an annular passage 38 between the body and housing which can receive fluid under pressure from the interior of the mandrel 20 that passes thither into through one or more mandrel side ports 39. The fluid in the annular passage 38 can act upon the inner surfaces of piston or hydraulic anchoring elements 40 mounted in cylindrical body bores 41, the fluid under pressure forcing the piston elements outwardly to embed their wickers or teeth 42 into the wall of the well casing. The pistons 40 are maintained properly oriented in their bores 41 by longitudinal retainer bars 43 extending across vertical grooves 44 in the pistons, the retainer bars extending into body grooves 45 and being secured to the body 30 by one of more screws 46. The upper ends of the bars are held against the body by an upper ring 47 surrounding them and also encompassing the adapter housing 31, the lower ends of the bars being held inwardly by a lower retainer ring 48 encompassing them which surrounds the lower portion of the body, the ring and bar assembly 47, 43, 48 being clamped against one another and against the adapter housing 31 by a clamp ring 49 threaded on the lower portion of the body 30 and bearing against the lower retainer ring 48.

The bars 43 also function as seats for helical compression springs 50 located in the grooves of the pistons 40 for springing against the pistons 40, tending to hold them in a retracted position. However, fluid under pressure of a sufficient value can act on the inner ends of the pistons 40 and shift them outwardly against the force of the compression springs 50. These springs will retract the piston anchoring elements 40 when the fluid under pressure is relieved or reduced to a low value. Leakage of fluid between each piston and the wall of its cylinder bore is prevented by a suitable seal ring 51 mounted on the piston. Upward leakage of fluid from the anchor body 30 is prevented by a seal ring 52 on the adapter 33 sealingly engaging the periphery of the mandrel and by a seal ring 53 on the body sealingly engaging the adapter 33. Similarly, leakage of fluid in a downward direction from the body is prevented by a seal ring 54 on a connector 55 sealingly engaging the periphery of the mandrel and by a seal ring 56 on the connecting body portion 22, the upper end of the connector being threadedly attached to the lower end of the anchor body 30.

The lower end of the connector 55 is threadedly attached to an upper thrust ring or abutment 56 forming a portion of the upper mechanically expanded pack-off portion 11 of the apparatus, there being a suitable rubber or rubber-like packing element 63 surrounding an upper connector sleeve 58 within which the mandrel 20 is slideable, leakage of fluid
between the connector sleeve and mandrel being pre-
vented by a seal ring 89 on the upper portion of the con-
ector sleeve engaging the periphery of the mandrel. This
connector sleeve has an upper flange 60 overlying an in-
w ardly directed flange 61 of the upper abutment 56, the
space between the upper end of the connector 55 and the
sleeve communicating with the exterior of the apparatus
through a bleed port 62, to prevent fluid from being
trapped within the connector as a result of its downward
movement along the upper connector sleeve 58.
As disclosed, the upper mechanically expandable pack-
ing structure 11 consists of a plurality of packing ele-
ments 63, 63 surrounding the connector sleeve 58 and
separately by an intervening spacer ring 64, the lower
packing element engaging a lower thrust ring or abut-
ment 65 threadedly secured to the lower portion of the upper
connector sleeve 58. This module body of the upper injection module assembly 12 carries a
hydraulically expandable packing structure 13 which
includes an expandable rubber or rubber-like packing ele-
ment 67 surrounding the lower reduced diameter portion
68 of the body 66, with its upper end engaging an upper
gauge ring 69 threadedly secured to the body 66 and its
lower end engaging a lower gauge ring 70 threadedly
secured to the upper end of the body 66 of a module 12
therebelow, which is threadedly attached to the lower
end of the module body 66 thereabove. The hydraulically
actuatable packing element 67 is expandable by fluid
under pressure passing from the interior of the mandrel
and its perforations 25 through a port 71 in the body 66
into the element 67.
Each injection module assembly 12 is substantially the same and its details will be described hereinaf-
ower. The module assemblies in any required number are connected to one another with the body 66 of the lowermost module assembly 12 being threadedly secured to the upper end of a lower connector sleeve 72 forming a portion of the lowermost pack-off structure 15, this lower connector sleeve carrying a seal ring 73 relatively slidable against
the periphery of the mandrel below its perforations 25.
One or a plurality of inherently retractable packing ele-
ments 74, of rubber or rubber-like material, surrounding
the lower connector sleeve, being spaced apart by a suitable
spacer 75, the upper packing element engaging an upper
abutment 76 threadedly attached to the lower end of the
module body 66 thereabove, and the lower packing ele-
ment 74 engaging a lower thrust ring or abutment 77 to
the tie sleeve 78, to a tie sleeve 78, which is, in turn,
threadedly and adjustably secured to the upper portion
of an expander 79. The lower thrust ring 77 has an
inwardly directed flange 80 overlying an outwardly directed
flange 81 at the bottom portion of the lower connector
sleeve 72, the expander 79 being retained in appropriate
adjusted relation to the tie sleeve 78 by a suitable lock
nut 82 threaded on the latter and bearing against the
upper end of the expander.
The expander 79 has an external surface 83 tapering in a
downward and inward direction, and it is slidable along
the upper portion of a slip sleeve 84 surrounding the
mandrel 20 and along which the mandrel is movable.
This slip sleeve has a plurality of circumferentially spaced
longitudinal grooves 85 therein in which each of a slip
86 is disposed, the slip including an upper anchor por-
tion 87 having external teeth 88 adapted to engage and
embed in the wall of the well casing B, and a lower drag
portion 89 for frictionally engaging the wall of the well
casing. A helical compression spring 90 is disposed in
each groove 85 behind the drag portion 89 of each slip,
bearing against such drag portion and against the base
of the groove to urge the drag portion into full surface
engagement with the wall of the casing, at which time the
anchor portion 87 will be retracted from the wall of the
well casing as disclosed in FIG. 1c.
When the expander 79 is moved downward within
the slips 86, its tapered surface 83 will engage companion
tapered surfaces 91 on the anchor portions of the slips
to rock such portions hard against the wall of the well casing B, and the drag portions
89 inwardly of the wall of the well casing, as disclosed
in FIG. 3c. The outward movement of each drag portion
89 toward the well casing is limited by lower terminals
92 of each slip engaging an upwardly extending lip 93 of
a coupling 94 threaded to the lower end of the slip sleeve 84. A ring 95 encompasses the slips
86 between their drag and anchor portions, being dis-
posed in grooves 96 separating such portions of the slips
and also being engageable by an outwardly directed
flange 97 of the slip sleeve that overrules the ring 95. Thus,
downward movement of the slip sleeve 84 will cause the
flange 97 to engage the ring 95, which will, in turn, engage
the slips 86 and move them jointly downwardly in the
well casing B. Upward movement of the slip sleeve will
cause the coupling 94 to engage the lower ends of the
slips and move them upwardly jointly in the well casing.

The ability of the mandrel 20 to move longitudinally
with respect to the parts that surround it is determined
by a control device 98 which is specifically illustrated as
being of the type shown in U.S. Patent No. 2,802,534. As
shown, this control device includes a drag block housing
99 surrounding the mandrel 20, the upper end of which
is threadedly attached to the coupling 94, and the lower
end of which is threadedly secured to a connector sleeve
99a. A clutch limit ring 100 is mounted in a counterbore
101 in the upper portion of the drag block housing,
being prevented from turning by a screw 102 attached
to the coupling 94 and by a screw 103 extending into the
housing 99. A clutch segment or dog 104 is disposed in a ring groove 105, being urged inwardly by a helical
compression spring 106 against the mandrel and into
a peripheral groove 107 in the latter which extends cir-
cumferentially around the mandrel, as, for example, about
270 degrees. The base of the groove 107 extends gradu-
ally outwardly to the periphery of the mandrel, the portion
of the mandrel between the ends of the groove consti-
tuting a bridge piece 108 which can cam the clutch segment
104 outwardly and hold it outwardly so that the mandrel
can move longitudinally therealong. The segment is
guided in its radial movement by guide pins 109 affixed
to the limit ring 100. The spring 106 bears against the
dog 104 and against a ring groove 105. The turning of
the mandrel 20 within the drag block housing 99 and the clutch ring 100 is determined by a key 111 in a
keyway 112 in the mandrel and extending into a counter-
borc 113 in the lower portion of the coupling 94, the ring
109 having a stop finger 114 extending upwardly into
this countereor. When the key 111 engages one end of
the finger 114, the bridge portion 108 of the mandrel
will have cammed the clutch segment or dog 104 out-
wardly, permitting longitudinal movement of the mandrel
20 with respect to the clutch parts surrounding it. When
the key engages the opposite end of the finger, the mandrel
can be brought to a position of alignment of its circum-
ferential clutch groove 107 with the dog 104, the spring
106 shifting the dog thereinto to couple the mandrel and
the surrounding clutch parts to one another against
relative longitudinal movement.
The drag block housing 99 has a plurality of circum-
ferentially spaced grooves 115 receiving drag blocks 116
urged outwardly into frictional engagement with the wall
of the well casing B by helical compression springs 117
bearing against the blocks and against the bases of the
grooves. The extent of outward shifting of the blocks
is limited by engagement of their upper and lower ter-
minals 118 with companion overlapping stop portions 119
on the drag block housing 99 and on the upper portion
of the connector sleeve 99a threadedly secured to the lower
end of the drag block housing. The lower end of this
connector sleeve is threadedly secured to the latch
sleeve 17, which has circumferentially spaced ports 120
This ratio tube protector 147 is disposed around an externally reduced diameter portion 150 of the body 66 to provide an axis for the mandrel and lower tapered faces and which are adapted to mesh with companion internal left-hand threads 123 on the upper portion of the locator or well packer D previously set in the well casing B below the point at which the formation treating opening is to take place, as described hereinbelow.

The upper end of the tubular receptacle and valve body 124 is threadedly secured to a lower portion of the connector sleeve 99c which has circumferential ports 125 therethrough and a cylindrical valve seat 126 below the ports. The lower end of the receptacle is closed by a plug 127 thread therein, which may have a central well 128 to receive a thermometer (not shown), or the like. The well cavity can be closed by a suitable pipe plug 129.

Fluid can flow between the central passage 130 of the mandrel and through the ports 125 to the exterior of the apparatus. However, in lowering the apparatus in the well bore, it is desired to restrict the flow of well bore fluid upwardly into and through the mandrel 20 and into the tubing string C. Accordingly, a valve ring 131 is provided that surrounds the receptacle or valve body 124 and which is guided by the latter below the ports, its upper position being determined by its engagement with the lower end of the connector sleeve 99c, the valve member 131 being urged in the upward direction by a helical spring 132 bearing against its lower end and also resting upon a spring seat 133 which rests upon a valve body flange 134. The valve member 131 has a plurality of circumferentially spaced ports 135 of relatively small area, so as to constitute orifices.

During lowering of the apparatus A through the fluid in the well bore, the latter must pass through the orifices 135 in the choke valve ring 131 before passing through the valve body ports 125 and into the interior 130 of the mandrel 20, flow of fluid through the ports 125 being greatly restricted. However, in the event that fluid is to be pumped down through the mandrel, the valve member 131 is shifted by the pressure of the fluid downwardly against the force of the spring 132 to a location clear of the valve body ports 125 so that fluid can flow freely from the mandrel through the larger ports 125 to the exterior of the apparatus. Similarly, during elevation of the apparatus through the fluid in the well casing, the fluid can drain relatively freely from the tubing string C, since it will shift the valve member 131 downwardly along the valve body 124 to a position exposing the ports 125 to the fluid.

Each injection module assembly 12 includes the flow controller or regulator 14 that will govern the rate of discharge of fluid from the module and into the well casing between a pair of adjacent packing elements, when they are expanded outwardly against the wall of the well casing. Such flow controller can also limit the pressure applied to the formation, which is always held to a predetermined differential below the pressure of the fluid within the mandrel 20. The flow controller or regulator 14 for each module includes a valve housing 140 disposed within a longitudinal groove 141 formed in the module body 66 (see FIG. 2). This valve housing has an inlet port 142 communicating with a port 143 extending from the interior of the module body to the base of its longitudinal groove 141, leakage of fluid between the valve housing and base of the body groove being prevented by a suitable gasket or seal ring 144 mounted on the housing and port 142, and adapted to seal against the base of the groove. The housing is maintained in firm position against the base of its groove by causing a lower tapered housing end 145 to engage a companion tapered end 146 on a valve housing wedge and ratio tube protector 147 which has a lower flange 148 clamped against a body flange 149 by an upper gauge ring 69 or 76 of a module therebelow.

The valve housing 140 is urged downwardly so that its lower tapered end 145 engages the companion upper taperend surface 146 of the wedge and protector 147 by a clamp screw 152 threaded within a bore 153 in a thrust block 154 mounted in the upper portion of the longitudinal body groove 141 and suitably secured thereto to as by welding material 155. This clamp screw 152 bears against a screw seat 156 threaded in the upper end of a central passage 157 extending downwardly from the upper end of the valve housing 140. Thus, by turning the clamp screw 152 and forcing it against the screw seat 156, the valve housing 140 is forced downwardly of the body 66 and against the housing wedge 147 and inwardly against the base of the body groove 141. Assurance is had that the clamp screw 152 will remain in its tightened condition by threading a lock screw 157a in the thrust block bore 153 and bearing it against the clamp screw.

Fluid under pressure from within the mandrel 20 can pass through its narrow slots 25 to the interior of the module housing 66, then flowing outwardly through its port 143 and the aligned port 142 of the valve housing 140 into a bore 160 of the latter in which a valve seat 161 is disposed. The fluid under pressure will engage a valve stem 162 and shift it upwardly so that its lower tapered end 163 does not engage the valve seat, the fluid then flowing downwardly through the valve seat passage 164 and into a connector 165 threaded in the lower end of the valve housing 140. The upper end of a ratio tube 166, of stainless, copper, or the like, is suitably secured to the connector, as by means of a coupling nut 167 (in a known manner), and this ratio tube of a suitable length is coiled around the reduced diameter portion 150 of the module body, the tube having a predetermined length. The fluid discharging from the tube can pass through a port 168 in the ratio tube protector 147 to the exterior of the apparatus between packing elements.

The valve stem 162 is urged downwardly into engagement with the valve seat 161 to close the passage 164 of the latter by a helical compression spring 170 mounted in the bore 157 of the valve housing, the upper end of the spring engaging an adjustable spring seat 171 threaded in the upper end of the valve housing. Leakage of fluid upwardly along the valve stem 162 is prevented by a seal ring 172 on the stem engaging the wall of the companion housing bore in which the stem is splidable. Leakage of fluid downwardly along the exterior of the valve seat 161 is prevented by a seal ring 173 on the latter engaging the wall of the surrounding housing bore. The spring seat 171 is adjusted in the housing to provide a required compressive force on the spring 170 when its tapered head 163 engages its companion seat 161, so that the valve stem will move away from its seat to open the passage 164 only upon the exertion of a predetermined pressure on the annular area of the valve head (FIG. 8), which is the area S of the valve stem minus its smaller central area R sealed against the seat, so that a greater differential pressure is required to initially open the valve stem 162 by shifting it away from its companion seat 161 than is required to hold the valve stem in its open position by acting upon the full area S of the stem. However, since the fluid pressure must overcome the force of the spring 170, the pressure of the fluid discharging through the valve seat passage 164 will be at a substantially lower value than the pressure within the mandrel 20. As an example, the spring may exert a force corresponding to 2000 p.s.i. when the valve stem is in its open position. Accordingly, the fluid pressure on the downstream side of the ratio tube 166, when the valve stem 162 is in its open position, will always be 2000 p.s.i. lower than the fluid pressure.
pressure within the mandrel. Accordingly, the pressure of the fluid injected into the formation zone will always be considerably lower than the pressure of the fluid in the mandrel.

The well bore fluid is allowed to enter the spring chamber through a vent port 175 extending through the valve housing between its exterior and the chamber. Thus, the hydrostatic head of fluid acting on the valve stem 162 is balanced, the valve stem being shifted upwardly to an open position in response to fluid pressure above that of the hydrostatic head of fluid in the well casing.

When the apparatus is used for injecting fluids into a formation zone along a desired length of the latter, the indexing or locating member D, such as a well packing of a known type, is set in the well casing B below the lowermost end of the formation zone (FIG. 3c). A suitable perforating tool, such as a perforating gun (not shown), is then lowered in the well casing into engagement with the locator D. This perforating gun will have bullet-shaped charges located at required spaced intervals along its length, so as to perforate the casing at specified spaced locations with respect to the indexing device D. The gun is fired and the perforations T, V, Y produced in the well casing B that open into the formation zone Z to be treated.

The gun is withdrawn from the casing and the multiple injection well packer apparatus A run in the well casing. This apparatus will have its latch or indexing sleeve 17 appropriately spaced below the packing elements, and the packing elements of the apparatus spaced longitudinally from one another by an appropriate distance, such that when the apparatus has been lowered on the tubing string C to the locator D, the latch 17 can be snapped into the threaded box 123 of the locator, in view of the ability of the dogs or spring arms 121 to snap inwardly and the fact that the lower faces of the threads 122 are tapered. During lowering of the apparatus in the well casing, the anchor portions 87 of the slips 86 will be in their retracted position disclosed in FIG. 1c, the expander 79 being in its upper position and engaging a snap ring 79a mounted on the upper portion of the slip sleeve 84. At this time, the clutch dog 104 is disposed in the mandrel groove 107, so that the lowering movement of the mandrel 20 cannot effect a setting of the mechanically expandable portions of the apparatus.

During lowering of the apparatus A through the fluid in the well bore, it can pass into the apparatus only at a restricted rate through the orifice ports 135. As a result, a fluid pressure differential will not be built up within the mandrel 20 and within the interior of the module bodies 66 and the anchor body 30 that might expand the inflatable packing elements 67 and the pistons 40 outwardly against the wall of the well casing. Instead, the pressure flowing around the exterior of the apparatus, as a result of fluid being lowered in the well casing, will be greater than the pressure within the apparatus, retaining the packing elements 67 and anchor elements 40 in their inward or retracted positions.

After the latch sleeve 17 has been snapped into the locator D, the mandrel 20 is caused to turn its bridge portion 108 to cam the clutch segment 104 outwardly, and the tubing string C and mandrel can then be lowered. The friction drag blocks 116 and the drag portions 89 of the slips will resist downward movement of the drag body 99 and the slip sleeve 84, the downward movement of the mandrel being transmitted through the split ring 35 and adapter 33 to the anchor body housing 30, within the slips 86 from the latter through the slip packing structure 11 to the upper module body 66, the downward effort being transmitted through the several module bodies and through the lower packing structure 15 to the expander 79, the expander moving downwardly along the slip sleeve 84 and behind the anchor portions 87 of the slips 86, expanding the latter outwardly against the wall of the well casing B. A continuation of the downward thrust on the tubing string C and the mandrel 20 will be transmitted to the members above the expander 79 so that the expander 79 cannot move downwardly to any further extent, the lowermost module body 66 will shift the upper gauge ring 76 of the lower packing structure toward the lower gauge ring or abutment 77, shortening the packing elements 74 and expanding them outwardly against the wall of the well casing.

Once the lowermost packing elements 74 have been set against the wall of the well casing, the module bodies 66 are prevented from moving downwardly to any further extent. As a result, a continuation of the downward movement of the tubing string C and mandrel 20 will result in the anchor body 30, connector 55, and upper thrust ring or abutment 56 of the upper mechanically set packing structure 11 moving downwardly towards the lower thrust ring or abutment 65, shortening the uppermost packing elements 63 and compressing and expanding them outwardly into anchoring engagement with the wall of the well casing. At this time, the upper packing elements 63 are disposed above the uppermost perforations Y produced by the perforating gun, and the lower mechanically set packing elements 74 are disposed below the lowermost perforations T produced by the perforating gun. The hydraulically expandable packing elements 67 are then disposed between the perforations Y, V, and T, so that the expansion of the hydraulic packing elements against the well casing B will result in a pair of adjacent packing elements being disposed on opposite sides of each set of perforations, in order to divide the casing into isolated regions into which fluids are to be injected.

Prior to downward movement of the mandrel 20, for the purpose of setting the slips and the packing elements against the casing, a desired fluid may be spotted around the well packer apparatus A. Thereafter, upon releasing of the clutch 98 and shifting the mandrel downwardly within the parts that surround it to expand the slips and upper and lower packing structures, the lower seal ring or sleeve 28 is shifted downwardly below the valve body ports 125 and into sealing engagement with the cylindrical valve seat 126 to close the lower circulation valve 18. Accordingly, the pumping of fluid under pressure down through the tubing string C will cause such pressured fluid to pass through the mandrel slots 25 to the interior of the module bodies 66. Since the limit valve 14 will only open upon being subjected to a predetermined pressure differential, which, for example, may be about 2,000 p.s.i., pressure built up within the mandrel will pass through the module body ports 71 to the interior of the hydraulic packing elements 67, inflating the latter and expanding them outwardly against the well casing. When the fluid pressure acting on the valve stems 162 is sufficient to overcome the resisting force of the springs 170, the valve stems are shifted from their valve seats 161, and such fluid can then pass through the valve seats and through the ratio tubes 166 into the interior of the tube protector 147, passing outwardly through the port or ports 168 in the latter into the well casing 20 between the pairs of spaced packing elements, which may, for example, be spaced about two feet apart. The fluid will then pass through the casing perforations T, V, Y straddled by each pair of packers into the surrounding formation zone Z.

The rate at which fluid will pass outwardly from each ratio tube 166 will depend upon the fluid pressure within the mandrel 20, the viscosity and density of the fluid, the diameter of the valve seat passage or orifice 164, the length of each ratio tube, its inside diameter, and the formation injection pressure. The longer the tube 166, the greater will be its frictional resistance to fluid flow through it. The more viscous the liquid being pumped through the tube 166, the greater will be the resistance to flow, with a preselected length, a less viscous fluid will pass through the tube at a greater rate for discharge into the casing B.
and for passage through its perforations into the surrounding well bore. Thus, the pumping of a flushing liquid downward through the tubing string C and into the mandrel 20 will result in the liquid passing through the module formation Z at a much greater rate than a comparatively viscous liquid, such as an epoxy resin, which can be used in performing a sand consolidation operation. The proper selection of the length of ratio tubes 166 ensures modifying the equipment, can determine the pressure differential across the modules, to determine the rate at which a fluid will flow from each of the modules, and such rate of fluid will be substantially equal for each module. As a result, assurance is had that fluid will be injected through each set of straddled perforations at substantially the same rate, so that each length of formation straddled by each set of adjacent packings will receive substantially the same quantity of fluid. Accordingly, a uniform distribution of the fluid pumped from the mandrel along the entire length of the straddled formation Z will be secured.

When the well treating operation has been completed, which may be a sand consolidation operation described above, the apparatus can be released from the well casing simply by relieving the fluid pressure and pulling up on the upper anchor C and the mandrel 20, the mandrel springing upward to open the lower circulation valve 18 and to dispose the mandrel groove 107 opposite the clutch dog 104, which will then be forced by its spring 106 into the groove, relocking the parts in their retracted position.

Opening of the circulation valve 18 will insure the equalizing of the pressure internally and externally of the apparatus, allowing the hydraulic packing elements 67 and pistons 40 to retract. The upward movement of the mandrel 20 will pull the anchor body 30 upwardly to shift the upper abutment 56 away from the lower abutment 65, allowing the upper set of mechanically expandable packing elements 63 to inherently retract. The flange 61 of the upper thrust abutment will engage the flange 60 of the upper connector sleeve 58 to pull such sleeve upwardly, the upward motion being transmitted through the several module bodies 66 to the upper gauge ring or abutment 76 of the lower set of mechanically expanded packing elements 74, this upper abutment being shifted upwardly away from the lower abutment 77, permitting the lowermost packing elements 74 to retract inherently. The upward movement of the lower connector sleeve 72 will cause its flange 81 to engage the lower abutment 77 and act through the tie sleeve 78 to pull the expander 79 upwardly relative to the slips 86, allowing the springs 90 to shift their drag portions 89 outwardly and rocking the anchor portions 87 inwardly from the well casing B.

If desired circulating fluid can be pumped down through the apparatus A and thereaund in order to clear it of treating liquids, after which the apparatus can be pulled upwardly, the tapered upper faces of the latch threads 122 camming against the locator threads 123 and shifting the spring arms 121 inwardly to detach the apparatus A from the lower locator D. The apparatus A can then be elevated by the tubing string C and removed completely from the well bore.

During the forcing of fluid under pressure into the formation, such fluid under pressure is prevented from shifting the tool A upwardly in the well casing B, since the pressure within the mandrel 20 will pass through the ports 39 and act on the anchor buttons 40, shifting them outwardly to embed their teeth 42 in the wall of the well casing, thereby preventing upward shifting of the anchor body 30, as well as of the parts therebelow. The relieving of the pressure in the mandrel allows the springs 50 to return to their original positions or anchor elements inwardly to their retracted position.

It is apparent that a packer apparatus has been provided in which assurance is had that the hydraulically actuable packing elements 67 will not be inadvertently expanded against the well casing during lowering of the apparatus through the liquid in the well bore. Assurance is had that the formation zone Z to be straddled by the apparatus is packed off at each of its ends, inasmuch as the uppermost and lowermost sets of packing elements 63, 74 are firmly expanded outwardly against the well casing prior to the subjecting of the apparatus and the formation to fluid pressure. The ratio tubes 166 provide a simple and constant means of insuring the pumping of a less viscous fluid from the apparatus at a much greater rate than a more viscous fluid; whereas, the check valves 14 will insure the expansion of the hydraulically actuable packing elements against the well casing prior to discharge of any treating liquid from the apparatus, and they will also insure that the formation cannot be subjected to an inordinately high pressure that might result in its fracture. The pressure applied to the formation is always much less than the pressure within the apparatus A itself, which, in the example given above, can be about 2,000 p.s.i. less.

In some processes where only a single fluid is to be injected into the formation, the ratio tubes 166 need not be used, since fluid will pass through the orifice passages 164 of the valve seats 161 at a regulated rate, substantially the same rate of flow of fluid occurring through each of the orifice passages 164. The orifice device 131 limits upward flow of well bore fluid into the apparatus, it is forced clear of the circulation ports 125 when fluid is to be circulated through and around the apparatus, and also during upward movement of the apparatus A through the liquid in the well casing B. We claim:

1. In subsurface apparatus for injecting fluid through perforations in a conduit string disposed in a well bore: body means having a fluid passage and adapted to be disposed in the conduit string; a plurality of packing means on said body means for sealing against the conduit string to form a plurality of separated zones in the conduit string isolated from one another and straddling the perforations in the conduit string; means providing a separate flow path from said fluid passage to each of said separated zones externally of said body means; each of said flow paths including an unobstructed elongate tubing through which fluid flows at a controlled rate and discharges into the well bore externally of said body means.

2. In subsurface apparatus as defined in claim 1; in which said elongate tubing is disposed circumferentially around said body means.

3. In subsurface apparatus as defined in claim 1; a valve in each flow path on the upstream side of said tubing adapted to open in response to fluid pressure in said passage for reducing the pressure of the fluid in said passage flowing to said tubing.

4. In subsurface apparatus as defined in claim 3; each valve comprising a valve seat and a valve member engageable with said seat, said valve member having an area acted upon by fluid pressure in said passage when said valve member is disengaged from said seat which is substantially greater than the area of said valve member which can be acted upon by fluid pressure in said passage when said valve member engages said seat, whereby a substantially greater fluid pressure is required to shift said valve member from said seat than to maintain said valve member disengaged from said seat.

5. In subsurface apparatus as defined in claim 3; each valve comprising a valve seat, a valve member having a forward surface subject to the pressure of fluid in said passage and engageable with said seat, said valve member having a rearward surface subject to the pressure of fluid externally of said body means between a pair of packing means, and a spring bearing the valve member to engage its forward surface with said seat.

6. In subsurface apparatus as defined in claim 3; each valve comprising a valve seat, a valve member having a forward surface subject to the pressure of fluid in said
passage and engageable with said seat, said valve member having a rearward surface subject to the pressure of fluid externally of said body member in a pair of packing means, and a spring bearing against said valve member to engage its forward surface with said seat; the area of said forward surface acted upon by fluid pressure in said passage when said surface is disengaged from said seat being substantially greater than the area of said forward surface acted upon by fluid pressure in said passage when said forward surface engages said seat, whereby a substantially greater fluid pressure is required to shift said valve member from said seat than to maintain said valve member disengaged from said seat.

7. In subsurface apparatus as defined in claim 1; said plurality of packing means being initially retracted; means for expanding said plurality of packing means against the conduit string, comprising hydraulically operable means responsive to fluid pressure in said passage for expanding one or more of said plurality of packing means against the conduit string.

8. In subsurface apparatus as defined in claim 1; said plurality of packing means being initially retracted; means for expanding said plurality of packing means against the conduit string, comprising hydraulically operable means responsive to fluid pressure in said passage for expanding one or more of said plurality of packing means against the conduit string; and mechanically actuated means for expanding the uppermost and lowermost of said plurality of packing means against the well conduit.

9. In subsurface apparatus for injecting fluid through perforations in a conduit string disposed in a well bore: body means having a fluid passage and adapted to be disposed in the conduit string; a plurality of packing means on said body means for sealing against the conduit string to form a plurality of separated zones in the conduit string isolated from one another and straddling the perforations in the conduit string; means providing a separate flow path from said fluid passage to each of said separated zones externally of said body means; a valve in each flow path adapted to open in response to fluid pressure in said passage and to close in response to the pressure differential of the fluid in said passage and the exterior of said body means tending to drop below a predetermined value; each valve comprising a valve seat, a valve member having a forward surface subject to the pressure of the fluid in said passage and engageable with said seat, said valve member having a rearward surface subject to the pressure of the fluid externally of said body means and between a pair of packing means, a spring bearing against said valve member to engage its forward surface with said seat; the area of said forward surface acted upon by fluid pressure in said passage when said surface is disengaged from said seat being substantially greater than the area of said forward surface acted upon by fluid pressure in said passage when said forward surface engages said seat, whereby a substantially greater fluid pressure is required to shift said valve member from said seat than to maintain said valve member disengaged from said seat.

10. In subsurface apparatus for injecting fluid through perforations in a conduit string disposed in a well bore: body means having a fluid passage and adapted to be disposed in the conduit string; a plurality of packing means on said body means for sealing against the conduit string to form a plurality of separated zones in the conduit string isolated from one another and straddling the perforations in the conduit string; means providing a separate flow path from said fluid passage to each of said separated zones externally of said body means; said plurality of packing means being initially retracted; means for expanding said plurality of packing means against the conduit string comprising hydraulically operable means responsive to fluid pressure in said passage for expanding one or more of said plurality of packing means against the conduit string, and mechanically actuated means for expanding the uppermost and lowermost of said plurality of packing means against the well conduit.

11. In subsurface apparatus as defined in claim 10; a valve in each flow path adapted to open in response to fluid pressure in said passage for reducing the pressure of the fluid in said passage discharging into the conduit string externally of said body means.

12. In subsurface apparatus as defined in claim 11; each valve comprising a valve seat and a valve member engageable with said seat, said valve member having an area acted upon by fluid pressure in said passage when said valve member is disengaged from said seat which is substantially greater than the area of said valve member which can be acted upon by fluid pressure in said passage when said valve member engages said seat, whereby a substantially greater fluid pressure is required to shift said valve member from said seat than to maintain said valve member disengaged from said seat.

13. In subsurface apparatus as defined in claim 11; each valve comprising a valve seat, a valve member having a forward surface subject to the pressure of the fluid in said passage and engageable with said seat, said valve member having a rearward surface subject to the pressure of the fluid externally of said body means and between a pair of packing means, and a spring bearing against said valve member to engage its forward surface with said seat.

14. In subsurface apparatus as defined in claim 11; each valve comprising a valve seat, a valve member having a forward surface subject to the pressure of the fluid in said passage and engageable with said seat, said valve member having a rearward surface subject to the pressure of the fluid externally of said body means and between a pair of packing means, and a spring bearing against said valve member to engage its forward surface with said seat; the area of said forward surface acted upon by fluid pressure in said passage when said surface is disengaged from said seat being substantially greater than the area of said forward surface acted upon by fluid pressure in said passage when said surface is engaged from said seat; the area of said forward surface acted upon by fluid pressure in said passage when said surface is engaged from said seat being substantially greater than the area of said forward surface acted upon by fluid pressure in said passage when said surface is disengaged from said seat; the area of said forward surface acted upon by fluid pressure in said passage when said surface is engaged from said seat being substantially greater than the area of said forward surface acted upon by fluid pressure in said passage when said surface is disengaged from said seat; the area of said forward surface acted upon by fluid pressure in said passage when said surface is engaged from said seat being substantially greater than the area of said forward surface acted upon by fluid pressure in said passage when said surface is disengaged from said seat.

15. In subsurface apparatus as defined in claim 7; slip means for anchoring said body means in the well conduit against downward movement therein; and anchoring means responsive to the fluid pressure in said passage to be expanded thereby into engagement with the conduit string to anchor said body means against upward movement therein.

16. In subsurface apparatus as defined in claim 1; in which said elongate tubing is disposed externally of said body means.

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