Aug. 27, 1968 H. H. FISHER, JR., ET AL 3,398,796

MULTIPLE INJECTION WELL PACKER APPARATUS

Filed Nov. 26, 1965 4 Sheets-Sheet 1

FIG. 1a.

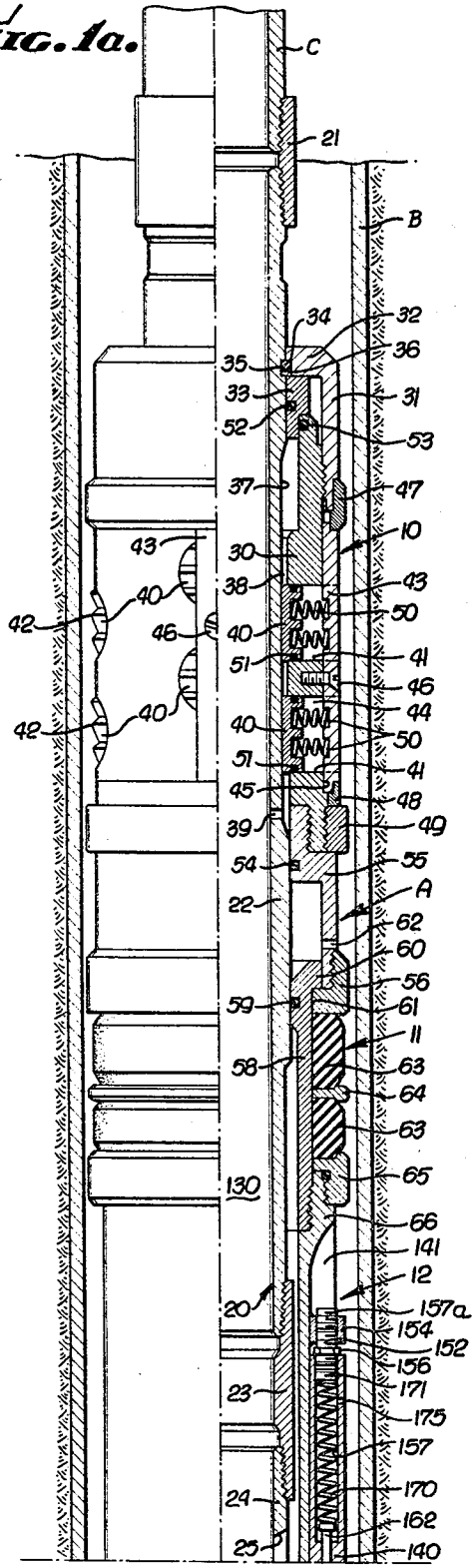

FIG. 1b.

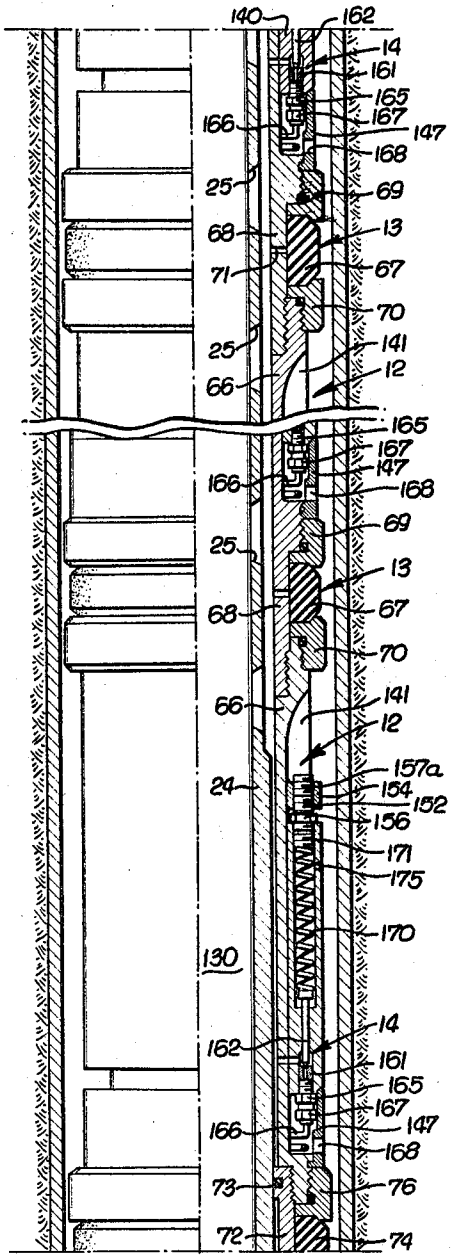

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FIG. 1c.

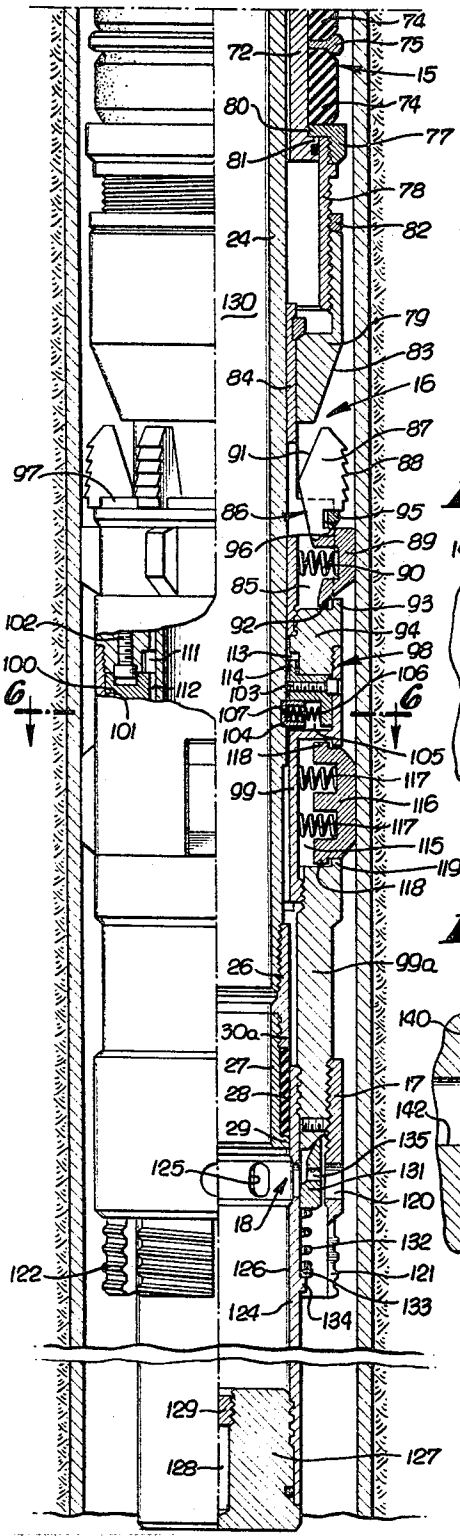


FIG. 2.

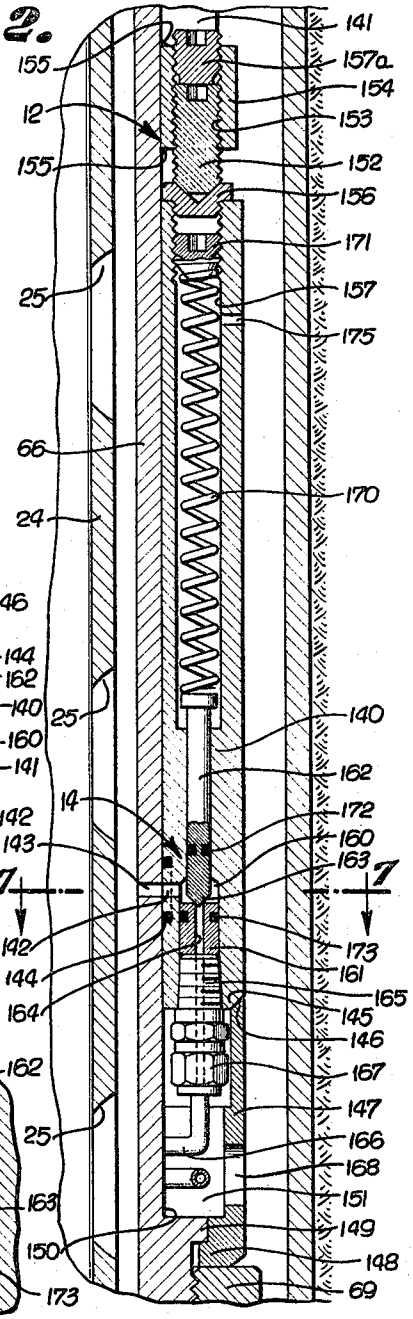


FIG. 7.

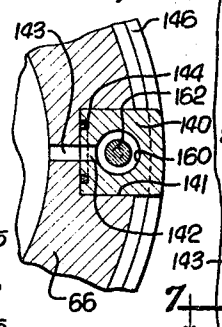
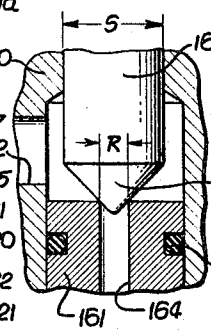


FIG. 8.



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MULTIPLE INJECTION WELL PACKER APPARATUS

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FIG. 3a.

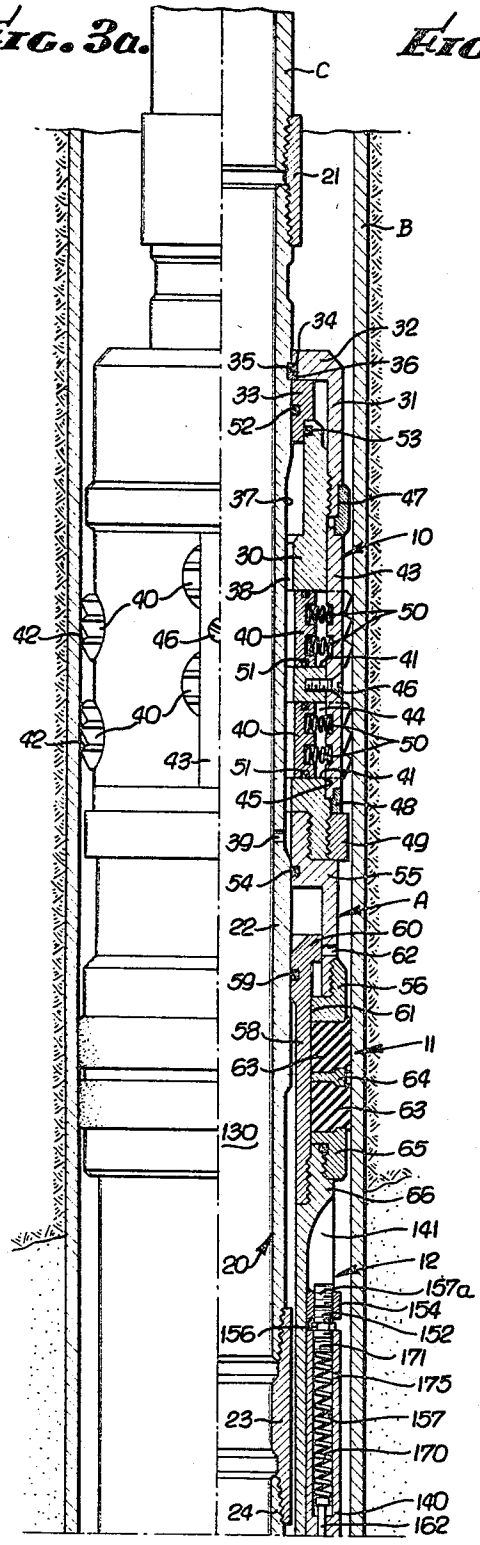
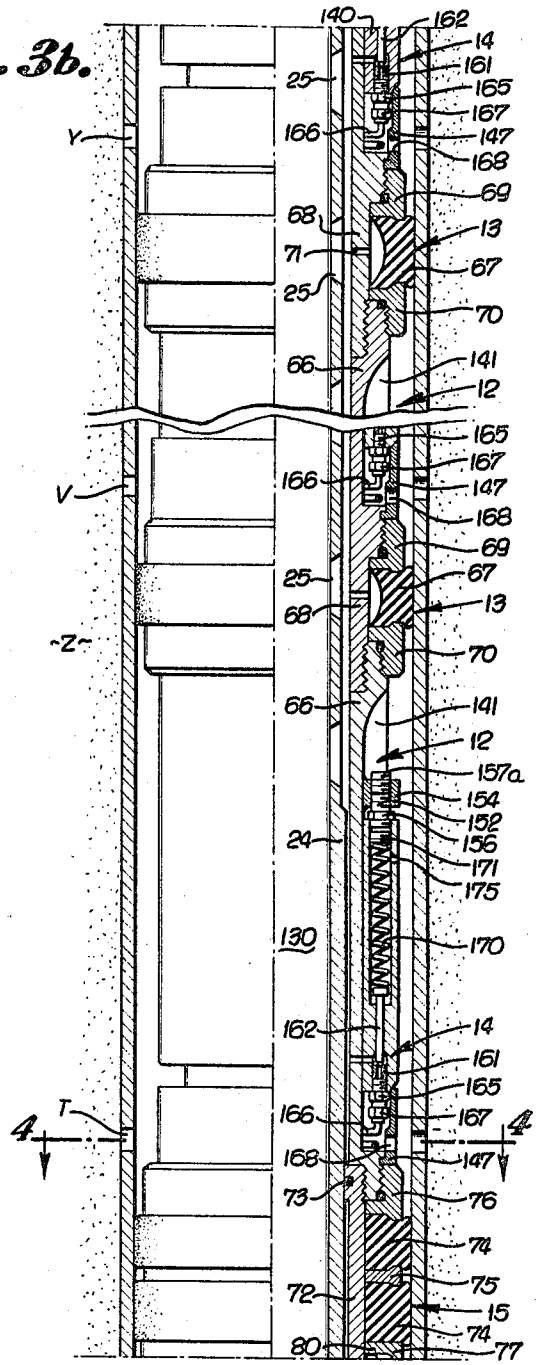


FIG. 3b.



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MULTIPLE INJECTION WELL PACKER APPARATUS

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FIG. 3c.

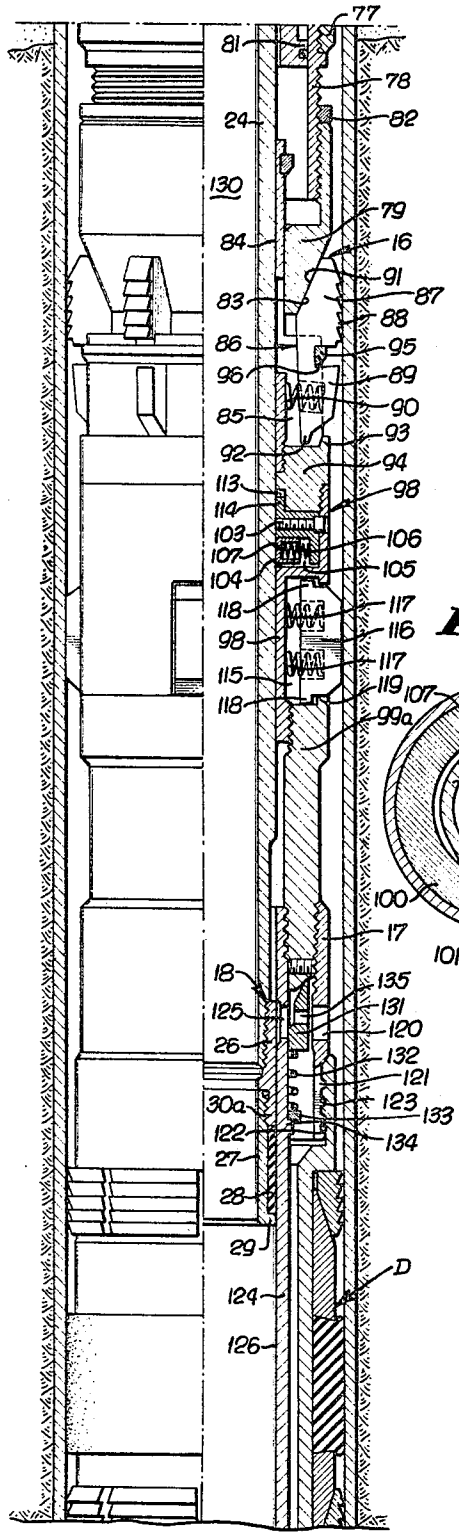


FIG. 4.

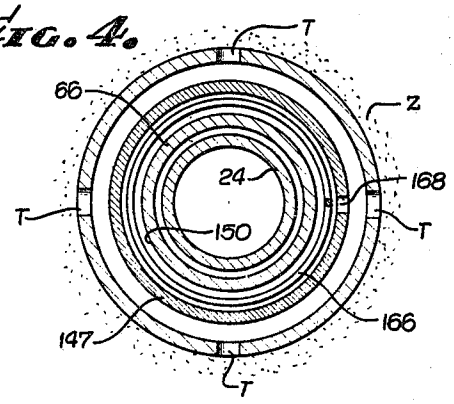


FIG. 5.

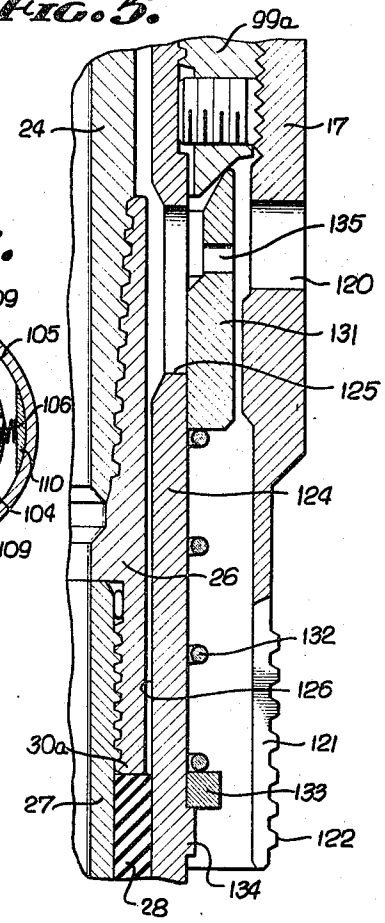
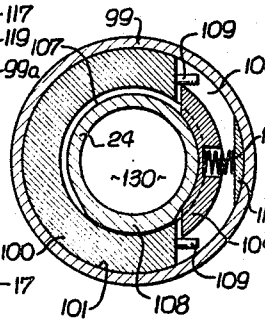


FIG. 6.



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United States Patent Office 3,398,796
Patented Aug. 27, 1968

3,398,796

MULTIPLE INJECTION WELL PACKER APPARATUS

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Filed Nov. 26, 1965, Ser. No. 510,001
16 Claims. (Cl. 166—120)

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 straddling the casing perforations, a separate flow path being provided from a body passage to each zone, which flow path includes elongate 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 is 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 disel 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 opposite 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 thereabove, 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.

Referring to the drawings:

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

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

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

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

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. 1*c*;

FIG. 7 is a cross-section taken along the line **7**—**7** on FIG. 2;

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 initially 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. 3*c*. 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 threadedly secured to a coupling **21**, which is, in turn, threadedly 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 threadedly attached to a coupling **23**, which is, in turn, threadedly 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 or a portion 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 **30***a* of the coupling thereabove.

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** slidable 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 thereinto 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 B. 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 or 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 piston grooves **44** and bearing 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 section **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. This upper abutment bears against the upper end of a rubber or rubber-like packing element **63** surrounding an upper connector sleeve **58** within which the mandrel **20** is slidable, leakage of fluid

between the connector sleeve and mandrel being prevented by a seal ring **59** on the upper portion of the connector sleeve engaging the periphery of the mandrel. This connector sleeve has an upper flange **60** overlying an inwardly 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 bleeder 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 packing structure **11** consists of a plurality of packing elements **63**, **63** surrounding the connector sleeve **58** and separated by an intervening spacer ring **64**, the lower packing element engaging a lower thrust ring or abutment **65** threadedly secured to the upper end of an upper module body **66** that is threadedly attached 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 element **67** surounding 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 hereinbelow. 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 elements **74**, of rubber or rubber-like material, surround 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 element **74** engaging a lower thrust ring or abutment **77** threadedly attached 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 each of which a slip **86** is disposed, the slip including an upper anchor portion **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. 1*c*.

When the expander **79** is moved downwardly 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 **87** outwardly into full engagement with the wall of the well casing B, and the drag portions **89** inwardly of the wall of the well casing, as disclosed in FIG. 3*c*. 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** threadedly attached to the lower end of the slip sleeve **84**. A ring **95** encompasses the slips **86** between their drag and anchor portions, being disposed in grooves **96** separating such portions of the slips and also being engageable by an outwardly directed flange **97** of the slip sleeve that overlies 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 **99***a*. 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 circumferentially around the mandrel, as, for example, about 270 degrees. The base of the groove **107** extends gradually outwardly to the periphery of the mandrel, the portion of the mandrel between the ends of the groove constituting 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 finger **110**. The extent of 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 counterbore **113** in the lower portion of the coupling **94**, the ring **100** having a stop finger **114** extending upwardly into this counterbore. 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** outwardly, 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 circumferential 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 circumferentially 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 terminals **118** with companion overlapping stop portions **119** on the drag block housing **99** and on the upper portion of the connector sleeve **99***a* 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**

therethrough and which has spring-like arms or dogs **121** at its lower portion which are formed collectively with an external thread **122** having upper 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 operation is to take place, as described hereinbelow.

The upper end of a tubular receptacle and valve body **124** is threadedly secured to a lower portion of the connector sleeve **99***a*, 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** threaded 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 **99***a*, 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 large 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** through the latter.

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 surrounding its 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. This ratio tube protector **147** is disposed around an externally reduced diameter portion **150** of the body **66** to provide an annular space **151** therebetween.

The valve housing **140** is urged downwardly so that its lower tapered end **145** engages the companion upper taperede 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 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 **157***a* 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 slidable. Leakage of fluid downwardly along the exterior of the valve seat **161** is prevented by a side 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 2,000 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 2,000 p.s.i. lower than the fluid

pressure within the mandrel. Accordingly, the pressure of the fluid injected into the formation zone will always be substantially 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 packer of a known type, is set in the well casing B below the lowermost end of the formation zone (FIG. 3*c*). 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 bullets or 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 removed 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. 1*c*, the expander **79** being in its upper position and engaging a snap ring **79***a* 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 its 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 turned to cause 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**, and from the latter through the upper 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. Since 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 V, T, so that 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 members **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 wall of 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 protectors **147**, passing outwardly through the port or ports **168** in the latter into the well casing B 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 therethrough. 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 down through the tubing string C and into the mandrel **20** will result in the liquid passing through the module mechanism **12** and through their ratio tubes **166** into the 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, without otherwise 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 tubing string C and the mandrel **20**, the mandrel shifting upwardly 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 therearound 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 the pistons 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 actuatable 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 convenient 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 actuatable 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 module assembly **12**. Although the lower 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 against said 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 means 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 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 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.

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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