

FIG. 2A

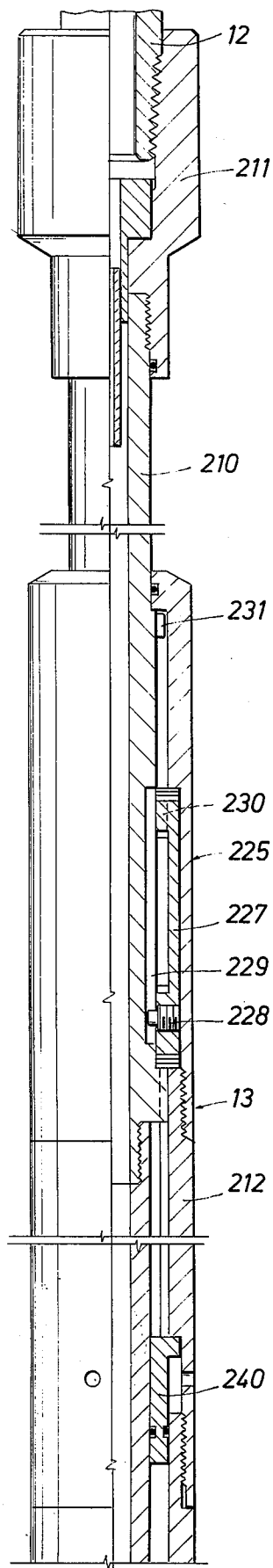


FIG. 2B

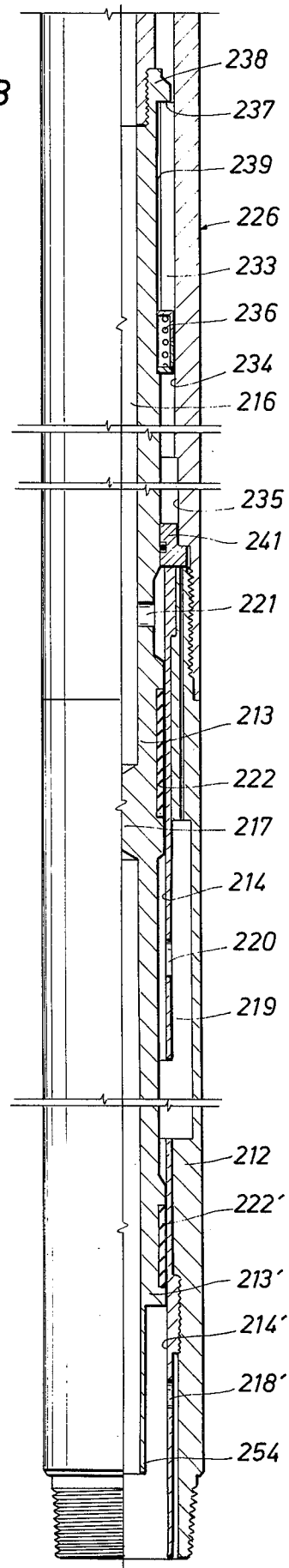


FIG. 4A

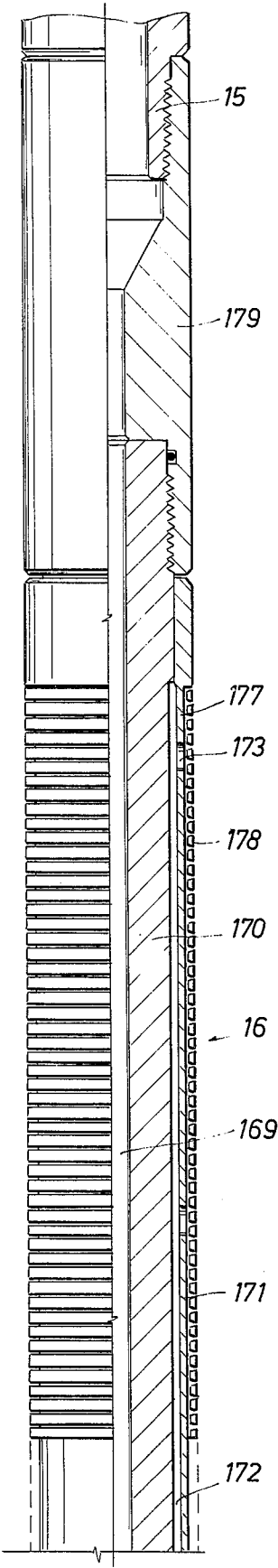


FIG. 4B

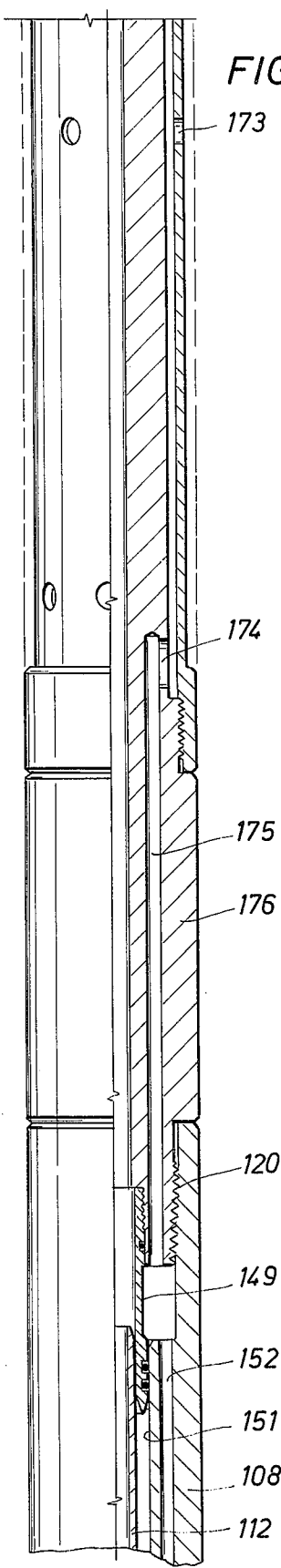


FIG. 5A

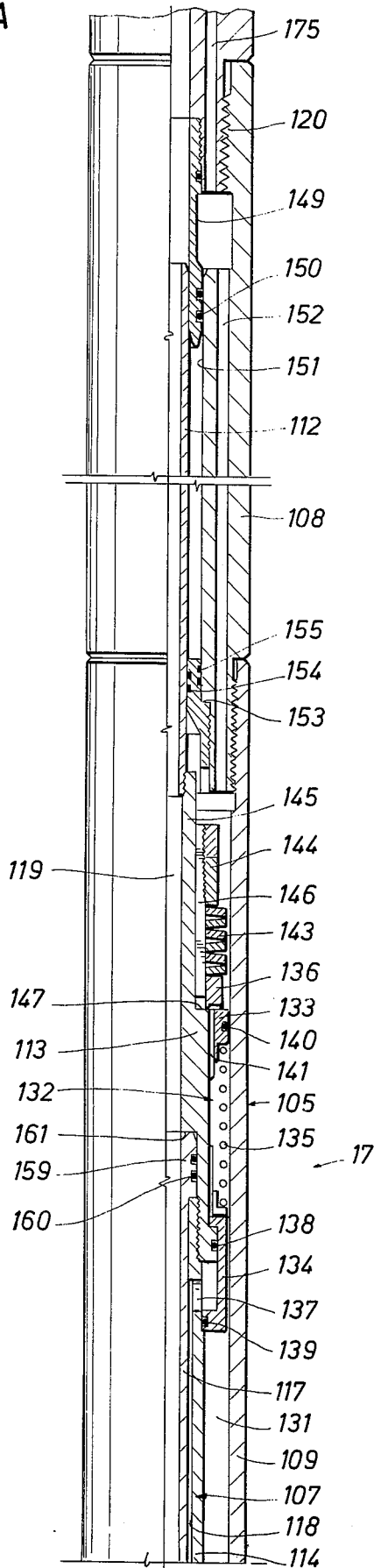


FIG. 5B

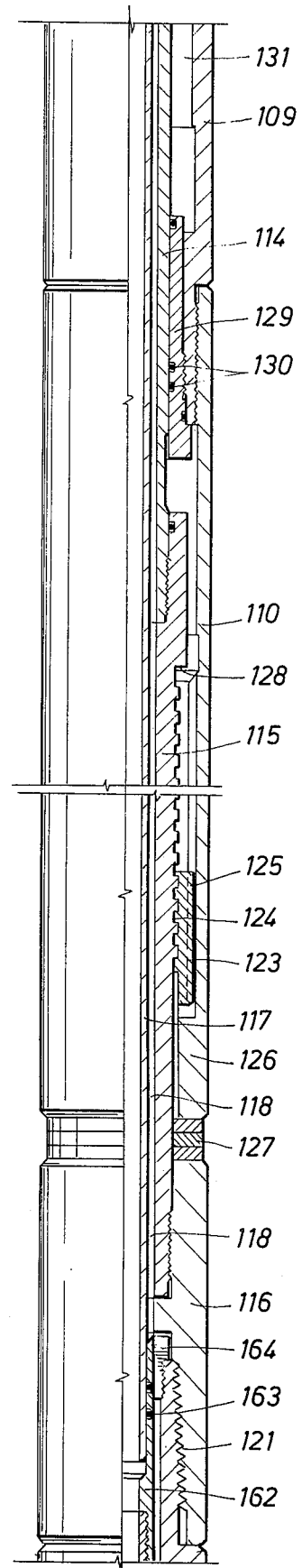


FIG. 6A

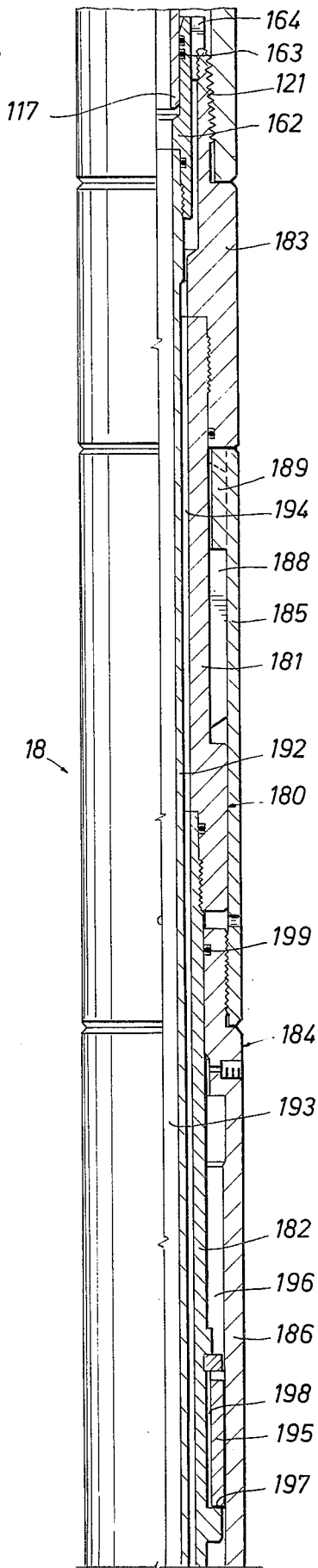


FIG. 6B

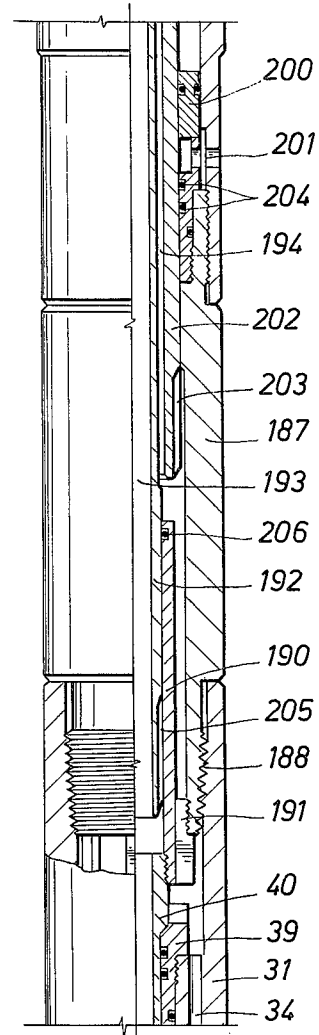


FIG. 7A

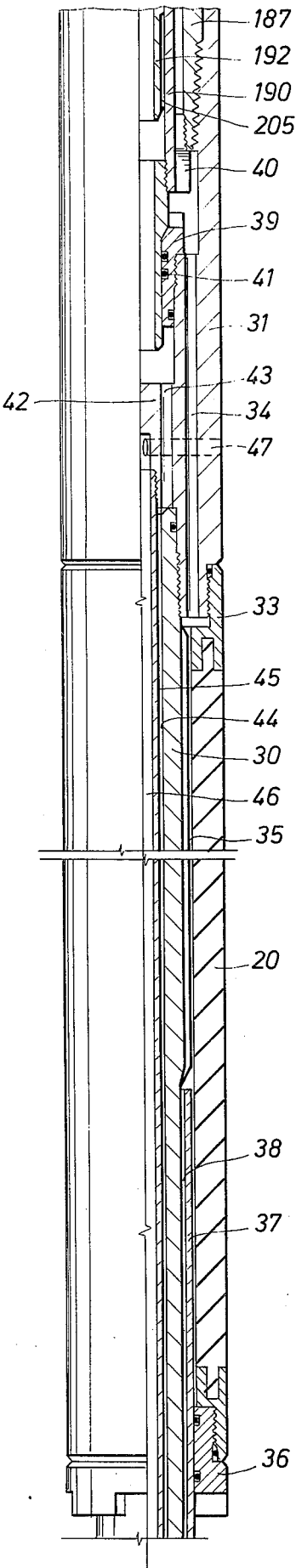


FIG. 7B

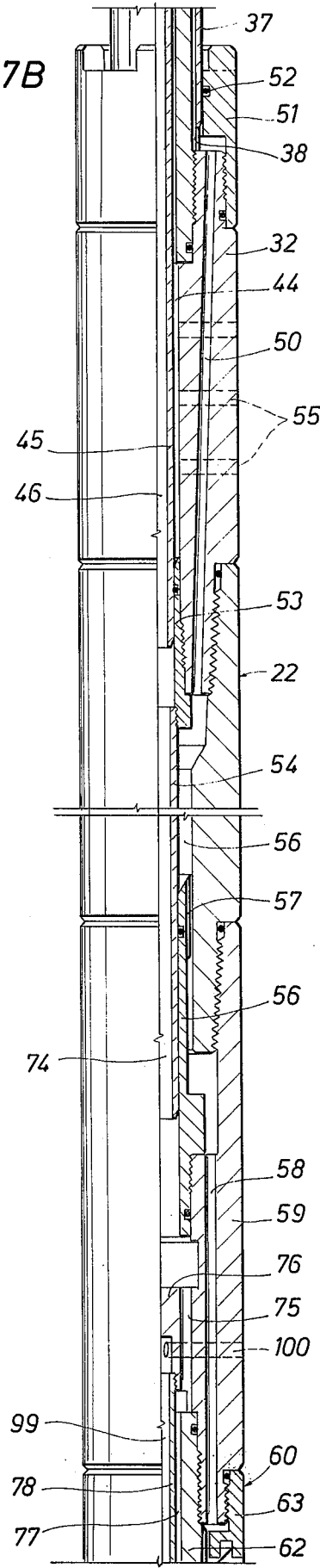


FIG. 7C

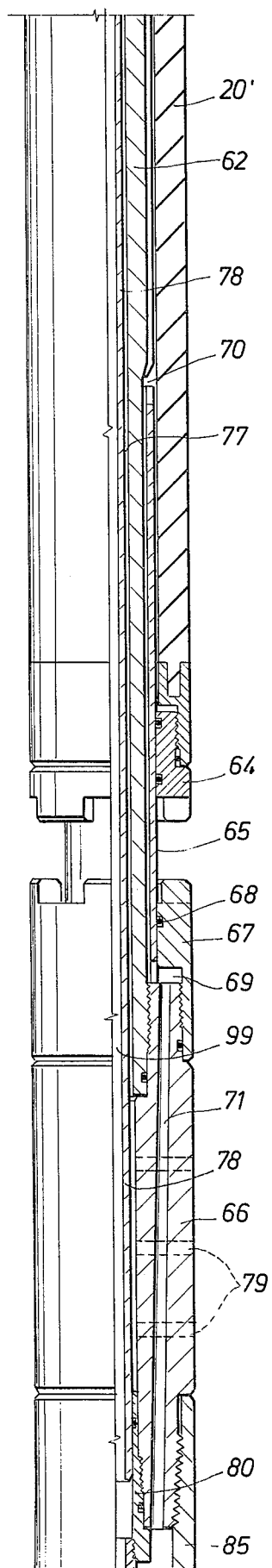


FIG. 8

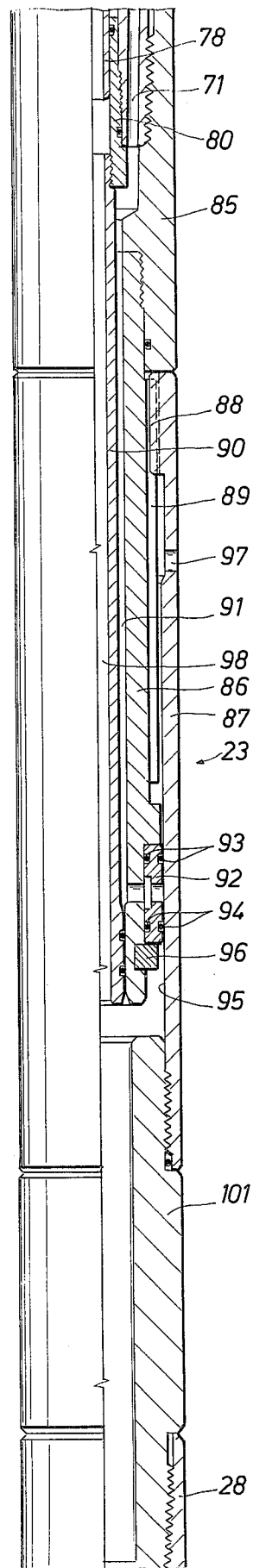
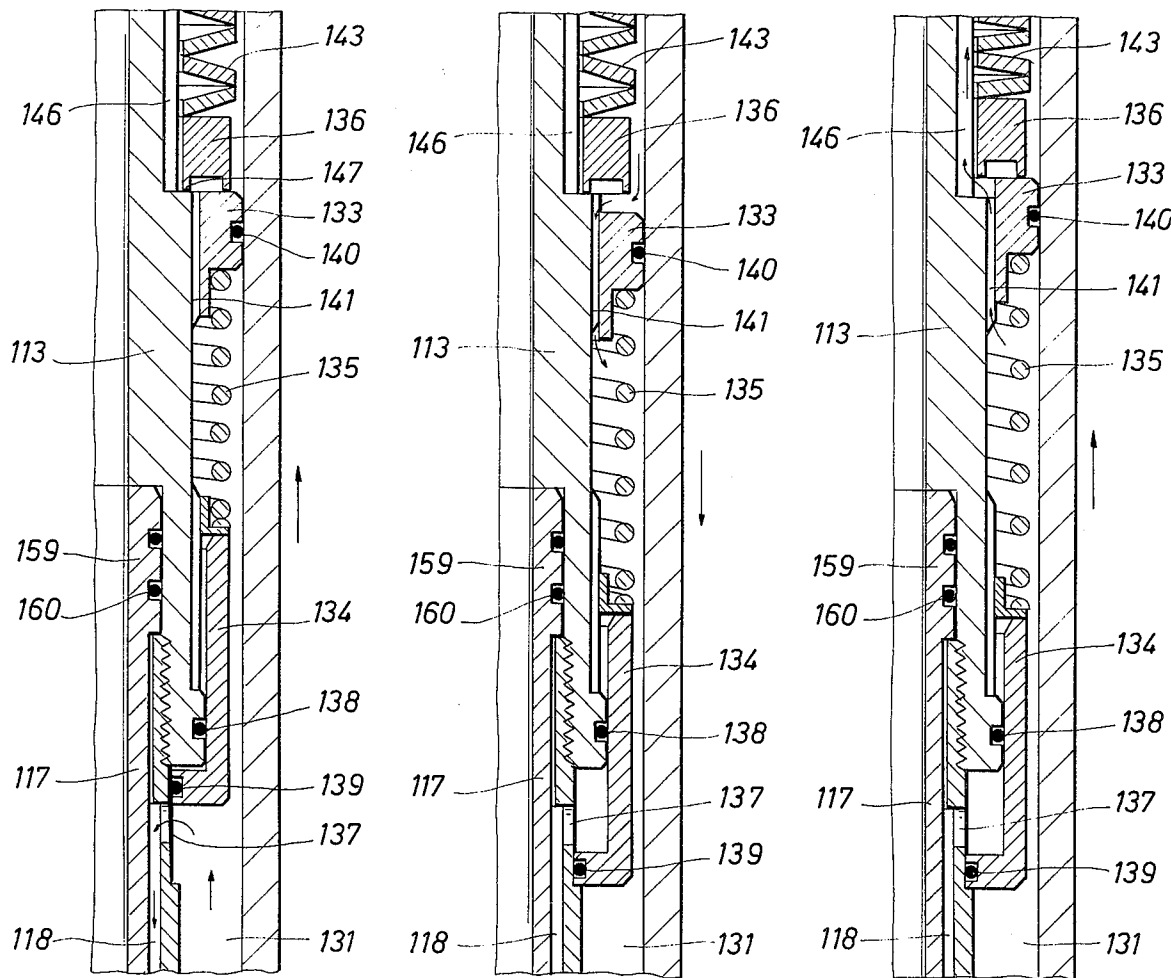


FIG. 9A

FIG. 9B

FIG. 9C



DRILL STEM TESTING METHODS AND APPARATUS UTILIZING INFLATABLE PACKER ELEMENTS

This invention relates to new and improved methods and apparatus for conducting a drill stem test of an earth formation that is traversed by a borehole. More particularly, the invention concerns unique methods for performing a drill stem test through use of spaced inflatable packer elements that function to isolate the test interval, and a pump actuated by upward and downward movement of the pipe string in a manner that enables positive surface indications of the performance of downhole equipment.

A drill stem test may be characterized as a temporary completion of a newly drilled well during which pressure measurements are made that enable various highly critical formation characteristics, such as permeability and initial reservoir pressure, to be determined. In addition, a sample of the formation fluids is taken and brought to the surface for analysis. The drill stem test is considered to be an indispensable technique for use in arriving at an informed decision on whether it will be commercially feasible to set casing and complete production from the particular zone of interest.

In certain well bore conditions such as washed out or otherwise enlarged are irregularly diametered bores, it is common practice to use test equipment that incorporates inflatable packers to isolate the interval undergoing test. The inflatable packer incorporates an elastomeric sleeve that is expanded outwardly by internal fluid pressure into sealing contact with the well bore wall, and by its nature has the capability for sealing off in a fairly wide variety of hole sizes and shapes. The pressure for inflating the packer is developed by a downhole pump that is operated in response to manipulative movements of the pipe string, either upward and downward or rotational.

One of more widely used inflatable packer systems is shown, for example, in U.S. Pat. No. 3,439,740, issued to G. E. Conover. According to the disclosure, the pump is operated in response to rotation of the pipe string which causes a transverse circular camway to reciprocate a plurality of pistons. As each piston reciprocates, well fluids are alternately drawn in from the well bore and then supplied under pressure to the interior of the pliable sleeve elements, causing them to expand into sealing contact with the well bore wall. When a predetermined inflation pressure has been generated, depending upon the number of turns or revolutions of the pipe string, a relief valve opens to limit the magnitude of the inflation pressure. However, it is very difficult if not impossible to detect at the surface when the packing elements are fully inflated, because there is no apparent change in the amount of torque required to turn the pipe when the pressure relief valves open. On the other hand it is not highly reliable to be dependent upon the number of turns of the pipe as indicating that a packer seat has in fact been attained, because the size of the borehole and thus the expansion requirement of the packers may not be known. Thus as a matter of practice, the operator will usually resort to pulling on the pipe at the surface to try to determine from the frictional restraint afforded by the packers whether or not they appear to be firmly set. Such a technique obviously involves a high degree of trial and error and uncertainty, all of which are highly undesirable.

One object of the present invention is to provide a new and improved drill stem testing apparatus that is simple and reliable in operation.

Another object of the present invention is to provide new and improved methods of utilizing inflatable packer drill stem testing apparatus in such a manner that positive surface indications are provided of the successful operation of the downhole equipment.

These and other objects are attained in accordance with the concepts of the present invention through practice of methods comprising the steps of lowering an inflatable packer having one or more expansible elements together with a pump into the borehole and positioning the elements to isolate a formation interval of interest. The pump includes relatively movable inner and outer members, one of which, for example the inner one, is connected to the packer assembly and the other of which, for example the outer member, is attached to the pipe string upon which the equipment is lowered. The packer assembly and the inner member next are anchored against downward movement in the borehole, and then the pipe string is moved upwardly and downwardly to effect corresponding reductions and expansions of the working volume of the pump which is defined in an annular space between the two members. During each upward movement, fluids under pressure are fed into the respective interiors of the inflatable elements, and during each downward movement the pump is recharged with well fluids to be supplied during the next subsequent upward movement. When a predetermined maximum inflation pressure has been developed within the elements, pressurized fluid from the working volume of the pump is automatically discharged to the well annulus. Inasmuch as the pumping power stroke is in the upward direction, it is possible for the inflation pressure to be monitored at the surface by observing the rig weight indicator during each upward movement of the pipe string. It will be recognized that the weight values shown by the indicator will increase in direct relation to the increases in pressures developed by the pump during each upward movement, so that when such increases no longer appear, but rather the weight value remains constant during several upward movements, positive indication is given that the relief valve is opening and that a predetermined inflation pressure necessary to obtain proper seating of the packer elements has in fact been developed. Operation of the pump thus can be discontinued, and the formation interval is effectively isolated to enable a drill stem test to be conducted. Thus the present invention provides a technique for isolating a well interval with inflatable packers that is much more reliable and positive than has been the case with prior art practices, particularly those involved with rotationally operable devices.

The present invention has many other objects, features and advantages that will become more clearly apparent in connection with the following detailed description of a preferred embodiment, taken in conjunction with the appended drawings in which:

FIGS. 1A and 1B are schematic views of the string of drill stem testing tools, utilizing inflatable packers suspended in a well bore;

FIGS. 2A and 2B are detailed cross-sectional views with portions in side elevation, of the formation test valve assembly, FIG. 2B forming a lower continuation of FIG. 2A;

The system includes a body member or mandrel 30 having its upper end fixed to an upper sub 31 and its lower end fixed to a lower sub 32. An inflatable packer element 20 surrounds the mandrel 30 and may be constituted by an elongated sleeve of elastomeric material such as neoprene that is internally reinforced by plies of woven metal braid or the like (not shown). The upper end of the element 20 is fixed to a collar 33 that is threaded to the upper sub 31, and may be retained with respect to the collar by means such as a frusto-conical ring that is forced against an inner surface of the element 20 by a lock nut or the like. Such structure is well known to those skilled in the art and need not be further elaborated here. One or more inflation ports or passages 34 extend vertically through the upper sub 31 and communicate with the annular space 35 between the inner wall surface of the sleeve 20 and the outer periphery of the mandrel 30. The lower end of the packer element 20 is also sealed and fixed with respect to an end cap 36 that is sealingly slidable along the mandrel 30, the lower portion of the mandrel being constituted by the combination with a passage sleeve 37 fitted around the mandrel 30 and laterally spaced therefrom to provide a continuation 38 of the passage space for inflation fluids. The upper sub 31 has a hollow seal sleeve 39 threadedly fixed therein and adapted to receive the lower end of an elongated flow tube 40 that extends upwardly within the equalizing and packer deflating valve assembly 18. The seal sleeve 39 carries seal rings 41 and is located in spaced relation above a transverse solid section 42 of the sub 31 which has, in addition to the inflation ports 34, a plurality of test ports 43 extending vertically therethrough. The ports 43 communicate with an annular fluid passage space 44 that is within the packer mandrel 30 but outside of a hollow flow tube 45 extending concentrically within the bore of the mandrel. The upper end of the flow tube 45 is threaded into the transverse section 42, and the bore 46 of the flow tube is opened to the well annulus outside the upper sub 31 by one or more laterally directed equalizing ports 47 that are angularly spaced in a transverse plane with respect to both the inflation ports 34 and the test ports 43.

The lower sub 32 as shown in FIG. 7B is threaded to the lower end of the packer mandrel 30 and has vertically extending inflation passages 50 whose upper ends are placed in communication with the annular sleeve passage 38 by a collar 51 that is threaded to the sub 32 and sealed with respect to the sleeve 37 by an O-ring 52. The flow tube 45 has its lower end received within a seal sleeve 53 that is threadedly fixed within the bore of the lower sub 32 and connected to another flow tube 54 that extends downwardly concentrically within the spacer sub 22. The annular fluid passage space 44 between the tube 45 and the mandrel 30 is communicated with the well annulus by a plurality of laterally directed ports 55 to enable formation fluids recovered during a test to enter the passage space 44 and pass upwardly through the tools. On the other hand the annular space 56 between the lower flow tube 54 and the spacer sub 22 continues a passage for inflation fluids that extend past an internal seal sleeve 56 at 57 and eventually communicates with vertically disposed inflation ports 58 in the upper sub 59 of the lower packer element assembly 20'. The lower assembly is substantially similar to the upper assembly 20 in its arrangement of an inflatable elastomeric packer element 61 (FIG. 7C) that

surrounds a mandrel 62 with the upper end of the element fixed to a collar 63 and the lower end fixed to a movable end cap 64 that is sealingly slidable on an outer sleeve 65 that surrounds the lower end portion of the mandrel. The lower end of the mandrel 62 is fixed to a lower sub 66, and a collar 67 carrying an O-ring seal 68 provides an internal recess 69 that communicates the inside 70 of the packer element 61 with one or more ports 71 that extend vertically throughout the sub 66. Thus it will be recognized that the respective interiors of the inflatable elements 20 and 20' are in continuous communication with one another so that fluid pressure applied thereto via the various intercommunicating passages 34, 35, 38, 50, 56, 58 and 70 will cause the elements to be expanded from their normally relaxed or retracted positions as shown in FIGS. 7A-7C to a substantially greater diameter where their outer peripheries come into sealing contact with an adjacent well bore wall. When expanded, the elements seal off the ends of an interval of the well bore to enable a formation test to be conducted.

Referring again to FIG. 7B, the intermediate flow tube 54 extends downwardly throughout the spacer sub 22, and its lower end extends through the seal sleeve 56 in a fluid-tight manner. Of course the bore 74 of the flow tube 56 communicates with the bore 46 of the upper flow tube 45 and thus with the well bore above the upper packing element 20 via the lateral ports 47. The lower end of the bore 74 also communicates with a series of ports 75 extending through an otherwise solid transverse section 76 of the upper sub 59, the ports 75 leading to an elongated annular flow path 77 located internally of the mandrel 62. Yet another, lower, flow tube 78 has its upper end fixed to the transverse section 76 and extends downwardly throughout the mandrel 62, with its outer wall defining the inner periphery of the annular flow path 77. The lower end of the flow path 77 is communicated with the well bore as shown in FIG. 7C by a plurality of lateral ports 79 through the wall of the lower sub 66, the lower end of the space between the tube 78 and the sub 66 being blocked by a seal sleeve 80 carrying appropriate O-rings. Accordingly, it will be recognized that the lateral ports 79 and 47 and the internal passages 46, 74, 75 and 77 provide for pressure equalization between the pressure of the fluids in the well bore above the upper packing assembly 20 and the pressure of the fluids in the well bore below the lower packing assembly 20' at all times.

The lower sub 66 of the lower packer assembly 20' is attached by a collar 85 to an inner tubular member 86 that is slidably received within an outer tubular member 87 as shown in FIG. 8, the two members being corotatively coupled by splines 88 and 89 and forming a slip joint and equalizing valve assembly 23. An inner sleeve 90 is concentrically disposed within the member 86 and is laterally spaced with respect thereto to provide a flow path 91 that communicates with the vertical ports 71 in the lower sub 66 of the packer assembly 20'. The lower end of the sleeve 90 has an outwardly directed flange that carries O-rings in sealing contact with the lower end portion of the member 86, and the flow path 91 is conducted through the wall of the member 86 by one or more ports. A ported ring 92 having upper and lower, inner and outer seals 93 and 94 is fixed between opposed shoulders of the members 86 and slidably engages the inner wall surface 95 of the

outer member 87. It will be apparent that the ring 92 forms the remote lower end of the various intercommunicated inflation passages leading to and through to the packing elements 20 and 20', and that the lower end of such passages remain closed as long as the member 86 and 87 occupy the mutually telescoped relative position shown in FIG. 8. On the other hand if the members are caused to extend, the ring 92 will be moved adjacent to a plurality of side ports 97 through the wall of the outer member 87 so that the lower end of the inflation passage is communicated with the well annulus to enable fluids to exit from the interior space of the elements 20 and 20'.

As previously mentioned, the internal sleeve 90 has its upper end threaded to the seal sleeve 80 that is fixed within the lower sub 66 of the lower packing assembly 20'. The bore 98 of the sleeve 90 is thus in fluid communication with the bore 99 of the lower flow tube 78 whose upper end is threaded into the solid section 76 of the upper sub 59 as shown in FIG. 7B. A counter-bore in the section 76 is opened to the well annulus by lateral ports 100 so that a pressure recorder housed in the carrier 28 attached to the collar 101 below the slip joint and equalizing valve 23 will "see" the pressures of fluids in the well annulus between the upper and lower inflatable packing element assemblies 20 and 20'. This pressure recorder, shown schematically in FIG. 2B, provides a second or "outside" recorder whose pressure record can be compared with the data gathered by the upper or "inside" recorder at 14.

Turning now to FIGS. 5A and 5B, a preferred embodiment of a pump assembly 17 that can be operated by manipulation of the pipe string 10 to cause expansion of the packer elements 20 and 20' is shown in greater detail. The pump 17 includes a housing 105 that extends downwardly in telescoping relation over a mandrel assembly 107 and is arranged for reciprocating motion with respect thereto between spaced longitudinal positions. The housing 105 is constituted by a series of threadedly interconnected tubular members including an upper sub 108, a cylinder section 109 and a splined section 110. The mandrel assembly 107 also comprises a number of interconnected, separate members including a flow tube 112, a valve section 113, a cylinder section 114 and a jack thread section 115 which has a pipe joint or collar 116 threaded on its lower end. Additionally, an elongated tube 117 is fixed concentrically within the members 114 and 115 and has its outer surface laterally spaced with respect thereto to provide an annular inflation fluid passage 118. The through bores of tube 117 and the mandrel sections 113 and 112 provide a central opening 119 for the passage of formation fluids through the pump assembly 17 from one end to the other. The upper sub 108 has an internal thread 120 for connection with the screen assembly 116 immediately thereabove, whereas the collar 116 has a similar thread 121 to adapt it for connection to the packer deflate and equalizing valve 18 located below the pump assembly 17.

Normally, that is when the tools are being lowered into the borehole, the housing 105 is locked in a lower position with respect to the mandrel assembly 107 by a clutch nut 123 (FIG. 5B) that is threaded at 124 to the mandrel section 115 and has a slidable spline connection 125 to the housing section 110. The clutch nut 123 engages above an inwardly extending shoulder 126 at the lower end of the housing section 110 to prevent

upward movement, and several stacked thrust washers or bearings 127 can be located between the shoulder 126 and the upper face of the collar 116 to enable rotation with relative ease. Rotation of the housing 105 with respect to the mandrel assembly 107 will cause the clutch nut 123 to feed upwardly until it comes into contact with a shoulder 128 on the mandrel, in which position the housing 105 is free to be moved upwardly and downwardly within limits along the mandrel assembly 107 in response to vertical motion of the pipe string 10 at the surface.

The lower end of housing cylinder section 109 is provided with a sleeve piston 129 that is sealed with respect to the mandrel cylinder section 114 by seal rings 130. The annular cavity 131 located above the sleeve piston 129 provides the working volume of the pump. The upper end of the cylinder space 131 is defined by a check valve system indicated generally at 132 which includes a fluid intake valve 133 and an exhaust valve 134. The intake valve 133 comprises an annular member that is pressed upwardly by a coil spring 135 against a valve seat ring 136, whereas the exhaust valve 134 is constituted by a stepped diameter sleeve that is pressed downwardly by the coil spring 135 in a lower position where it spans one or more fluid exhaust ports 137 that lead to the annular inflation passage 118 located between the hollow tube 117 and the inner surface of the mandrel cylinder section 114. Inasmuch as the valve sleeve 134 has a resultant transverse pressure area defined by the difference between the seal areas of the rings 138 and 139, it will be appreciated that a greater fluid pressure generated in the cylinder space 131 during upward movement of the housing 105 relative to the mandrel assembly 107 will shift the valve sleeve upwardly against the bias afforded by the coil spring 135 to a position uncovering the exhaust ports 137, as shown in greater detail in FIG. 9A, so that fluids under pressure can be supplied to the passage 118. On the other hand, during downward relative movement the spring 135 pushes the valve sleeve 134 closed, and a reduction in cylinder pressure below hydrostatic fluid pressure will cause the intake valve 133 to move away from the seat ring 136 as shown in FIG. 9B, thereby admitting well fluids into the cylinder space 131 and allowing it to fill during such downward relative movement. When the housing 105 reaches the bottom of its stroke, the spring 135 will push the intake valve 133 upwardly to closed position so that the pumping cycle can be repeated. As shown in FIG. 5A, the intake valve 133 carries a seal ring 140 that seals against the inner wall surface of the housing section 109, and is slidably arranged around a thickened wall portion of the mandrel section 113 which is longitudinally grooved at 141 to provide for fluid entry past the valve. The valve seat ring 139 may be provided with spaced apart, annular projections on its lower face that straddle the grooves 141 to provide a fluid tight interfit in the closed position of the valve, the inner projection resting on a mandrel shoulder 147 and the outer projection abutting the top surface of the valve element 133.

It should be noted at this point that the valve seat ring 136 is vertically movable to some extent, but normally is held in its lower position by a yieldable structure 143 that may comprise, for example, a series of Bellville washers located below an adjustable retaining nut 144 threaded on the mandrel section 113. The nut 144 and the washers 143 are located on a reduced diameter por-

tion 145 of the mandrel section, the portion 145 having circumferentially spaced, longitudinally extending grooves 146 that provide for the passage of fluids internally of the nuts 144 and the washers 143. Thus it will be recognized that when the pressure generated in the cylinder space 131 reaches a certain predetermined maximum value, the seat ring 136 can be forced upwardly together with the valve element 133 to disengage the inner projection from the shoulder surface 147 as shown in FIG. 9C to allow pressurized fluids in the cylinder space 131 to vent out of via the grooves 146. This system dictates a maximum value of inflation pressure that can be supplied by the pump assembly 17 to the inflatable packer elements 20 and 20', which valve is sufficient to fully expand them against the well bore wall while providing a protection against excessive inflation pressures that might otherwise result in damage. The magnitude of the pressure at which the seat ring 136 will move upwardly is set at a preselected value by adjustment of the preload in the washer springs 143 through appropriate vertical adjustment of the retainer nut 144.

The upper sub 108 of the housing assembly 105 provides fluids passages to the check valve system 132 and is, as previously mentioned, connected to the lower end of the screen assembly 16. As shown in FIG. 5A, a seal nipple 149 on the lower end of the screen assembly is sized to fit over the upper end of the tube 112 and carries seal rings 150 that engage the internal wall surface 151 of the sub 108. A plurality of vertically extending ports 152 serve to conduct fluids from the screen assembly 16 through the wall of the sub 108 and into the region above the check valve assembly 132. The lower portion of the sub 108 carries a seal sleeve 153 with a through bore that receives the tube 112. Seal rings 154 and 155 prevent fluid leakage between the ports 152 and the bore of the tube 112 during longitudinal relative movement. The seal rings 154 engage on a smaller diameter than do the seal rings 130 on the piston 129, so that during upward movement of the housing 105 relative to the mandrel assembly 107, a greater volume of well fluids will be brought into the pump assembly 17 than is required to fill the working volume of the pump during the next or subsequent downward movement. Thus, during each downward movement, not only is fluid supplied to fill the chamber 131, but also a certain amount of the fluids is forced back upwardly into the screen assembly 16 via the ports 152 to provide a back-flushing action to ensure that the screen assembly, to be described in detail hereinbelow, cannot become clogged by debris or other foreign matter in the well fluids.

The upper end of the lower flow tube 117 is provided with an enlarged head 159 that carries seal rings 160 and is interfitted between a shoulder 161 on the mandrel section 113 and the upper end face of the mandrel section 114. The lowermost end of the tube 117 is received by a flow coupling 162 (FIG. 5B) having seals 163 to prevent fluid leakage. The flow coupling 162 has an outwardly directed flange 164 at its upper end that is longitudinally grooved to provide for the flow of inflation fluids from the passage 118 into the annular area between the coupling and the body of the packer deflate and equalizing valve 18 connected immediately below the pump assembly 19.

The well fluids coming into the pump assembly 17 pass through the screen sub assembly 16 shown in

FIGS. 4A and 4B, wherein inner and outer members 170 and 171 are rigidly fixed and laterally spaced to provide an annular passage space 172 that is placed in communication with the well bore by a plurality of ports 173. The lower end of the passage space 172 is joined by a port 174 to a vertically disposed bore 175 that extends downwardly within the wall section of a connecting sub 176 to communicate the fluids to the interior of pump assembly 17. The seal nipple 149 is threaded to the lower end of the connecting sub 176 and sealingly interfits with the inner wall 151 of the upper sub 108 of the pump assembly 17 as previously described. The outer member 171 is provided with an external recess throughout a major portion of its length, and a screen element 178, formed of flat, spiral-wound wire or other suitable material, is positioned in the recess 177. The element 178 acts as a filter to prevent rock chips or other debris in the well fluids from coming into the pump assembly 17. A tool joint of collar 179 couples the upper end of the screen assembly 16 to the pressure recorder carrier 15 located immediately thereabove. The throughbore 169 of the member 170 continues the passage for the flow of formation fluids upwardly through the tools.

Turning now to the structural details of the pressure equalizing and packer deflating valve assembly 18 shown in FIGS. 6A and 6B, which assembly functions to enable the pressure of fluids in the isolated formation interval to equalize with the hydrostatic head of fluid immediately above the upper packer 20 upon completion of the test, as well as enabling the packer elements 20 and 20' to be deflated, so that the tools can be withdrawn from the well, the assembly comprises a mandrel 180 having an upper section 181 and a lower section 182, the upper section being provided with a collar 183 to adapt it for connection to the lower end of the pump assembly 17. The mandrel 180 is movable relatively within an outer member or housing 184 formed of threadedly interconnected sections 185, 186 and 187, the lower section or sub 187 being adapted by threads 188 for connection to the upper end of the packer assembly 19. The adjacent mandrel and housing sections 181 and 185 have interengaged splines 188 and 189 to prevent relative rotation and to provide limits for longitudinal relative movement. A valve sleeve 190 is fixed by threads 191 to the lower end portion 187 of the housing 184 and extends upwardly therein, and an elongated flow tube 192 whose upper end is connected to the flow coupling 162 extends downwardly into the valve sleeve 190. The central bore 193 of the flow tube 192 provides an upward passage for formation fluids that are recovered during the test, whereas the outer periphery of the tube is spaced inwardly of the inner wall surface of the mandrel 180 to provide a continuing inflation passage 194 leading from the pump assembly 17 to the packer assembly 19. The telescoping joint comprising the members 180 and 184 can be readily closed by downward movement of the mandrel 180, however upward movement to open position is delayed for a significant time interval by a hydraulic system including a metering piston 195 disposed within a chamber 196 located interiorly of the housing section 186. The piston 195 is sized to provide for a restricted leakage of hydraulic fluid from above to below it during upward movement, however the piston can move away from an annular seat surface 197 during movement so that hydraulic fluid can pass freely

through external grooves 198 in the mandrel section 182 behind the metering piston. The chamber 196 is closed at its upper end by a seal ring 199 and at its lower end by a floating balance piston 200 whose lower face is subject to the pressure of fluids in the well annulus via ports 201. The balance piston 200 functions to transmit the pressure of the well fluids to the hydraulic fluid below the metering piston 195 so that the pressure in this region of the chamber is never less than the hydrostatic fluid pressure in the well bore outside.

The lower end section 202 of the mandrel 180 is provided with external bypass grooves 203 that are arranged to communicate the inflation passage 194 with the well annulus via the ports 201 when the mandrel 180 is moved to its fully extended or open position with respect to the housing 184. Communication is by virtue of the fact that the upper ends of the grooves 203 will extend past the O-ring seals 204 to enable fluids to flow from the inflation passage 194 to the well annulus. Moreover the flow tube 192 is provided with similar grooves 205 that normally are positioned below a seal ring 206 on the valve sleeve 190. The upward movement that opens the inflation passage 194 to the well annulus also will position the upper ends of the grooves 205 above the seal ring 206 so that the formation fluid passage 193 is communicated with the well annulus. When this occurs, all pressures, that is to say the inflation pressure within the packer elements 20 and 20' and the pressure in the well bore interval between the packers 20 and 20' are equalized with hydrostatic pressure to enable the packers to deflate and return to their normal, relaxed positions whereby the tools can be withdrawn from the well.

The details of the test valve assembly 13 that is utilized to flow and shut-in the formation once it has been isolated by the packer assembly 19 in response to actuation of the pump 17 are shown in detail in my U.S. Pat. No. 3,308,887, to which reference is made herein. For purposes of completeness of this disclosure however, the tester as shown in FIGS. 2A and 2B includes a mandrel 210 that is connected to the pipe string 12 by a coupling 211. The mandrel 210 is telescopically disposed within a housing 212 whose lower end is threadedly connected to the upper end of the pressure relief valve assembly 14. The mandrel 210 is movable between an upper or extended position and a lower or contracted position within the housing 212 for the purpose of actuating a test valve to open and close a flow path through the tools. The valve assembly as shown in FIG. 2B comprises spaced upper and lower valve heads 213 and 213' that can simultaneously engage valve seats 214 and 214' in order to block fluid flow from within the housing below the lower valve head into the bore 216 above a transverse barrier 217 in the mandrel 210, and which are disengaged from the valve seats by downward movement in order to enable fluids to flow past the barrier via ports 218, an annular elongated sample chamber 219, and ports 220 and 221. Seals 222 and 222' prevent fluid leakage in the closed position. It should be noted that in the closed position, a sample of the fluids flowing upwardly through the tester will be trapped within the sample chamber 219 for recovery to the surface with the tools for later inspection and analysis.

In addition to the valve and sampler section described immediately above, the tester assembly 13 includes an index section 225 and a hydraulic delay sec-

tion 226. The index section 225 comprises a sleeve 227 that is mounted for rotation relative to both the housing 212 and the mandrel 210 and which carries an index pin 228 that works in a channel system 229 formed in the outer periphery of the mandrel 210. The coaction of the index pin 228 with the channel system 229 as the mandrel 210 is moved vertically within the housing 212 causes the sleeve 227 to swivel between various angular dispositions in order to position one or more internal spline grooves 230 therein in such a manner that corresponding lugs 231 on the mandrel either can or can not pass therethrough. Thus the index system 225 functions basically to provide stops to downward movement of the mandrel 210 in certain positions thereof as will be further discussed hereinbelow. The delay section 226 (FIG. 2B) includes a metering piston 233 that is mounted on the mandrel 210 and is slidable within a stepped diameter cylinder 234 in the housing 212. The piston 233 is sized transversely in such a manner that hydraulic fluid in the cylinder 234 can leak or meter past the sleeve at a controlled rate during downward movement of the mandrel 210 until the sleeve enters the enlarged diameter portion 235 of the cylinder, whereupon the mandrel 210 can move quickly downwardly to its fully contracted position. The piston 233 is biased by a spring 236 upwardly against a seat 237 provided by a shoulder 238 on the mandrel 210 so that hydraulic fluid can pass only around the periphery of the sleeve during downward movement, however the sleeve can move away from the seat during upward movement. When disengaged from the seat, hydraulic fluid can bypass through recesses 239 internally of the sleeve so that the mandrel 210 can be moved rapidly upwardly to its fully extended position. The ends of the chamber 234 are sealed off by elements 240 and 241 to provide a closed system.

As previously mentioned, an overpressure relief valve assembly 14 is connected to the lower end of the tester housing 212 as shown in FIG. 3, and includes a ported sub 245 having a stepped diameter internal bore 246. The upper end of the sub 245 is connected by a coupling to the lower threaded end of the housing 212, and the lower end of the sub is threaded at 248 for connection to the upper end of the pressure recorder carrier 15. A valve sleeve 249 is longitudinally movable within the sub 245 between an upper position where the side ports 250 provide communication between the well annulus and the bore 251 of the sub, and a lower position as shown where seals 252 and 253 are engaged to prevent fluid flow through the ports. The valve sleeve 249 is sized and arranged to be pushed downwardly to the lower position by a lower end extension 254 (FIG. 2B) of the tester mandrel 210 when the said mandrel is disposed in its lowermost position relative to the housing 212, otherwise the valve sleeve is responsive to force due to pressure differences acting across the transverse cross-sectional area bounded by the seal rings 252 and 253. Thus when the valve sleeve 249 is in the lower closed position and the hydrostatic head of the well fluids outside the ports 250 exceeds the pressure of fluids in the bore 251 of the sub 245, a downward force is developed to keep the valve closed. On the other hand if there is a greater pressure of fluids within the bore 251, upward force is developed tending to shift the valve sleeve 249 upwardly to open position.

The valve assembly 14 operates to relieve excess pressures that may be developed in the annular well

bore area between the packer elements 20 and 20' as they are inflated. It will be recognized that once the inflatable elements effect a seal with the well bore wall, and since the test valve 13 is not yet open, continued enlargement of the elements by further pumping action will tend to compress the entrapped well fluids therebetween and may raise the fluid pressure in the isolated interval to an excessive value. However, since such pressure acts upwardly on the valve sleeve 243, being communicated to the bore 251 by via the test ports 44 and the various passages 45, 43, 193 and 169, the valve sleeve is forced upwardly to vent fluid to the well annulus above the packer assembly 19 and thereby relieve such excessive pressure. Of course the valve sleeve 246 is forced downwardly to closed position by the end extension 254 of the tester mandrel 210 as the test valve is opened, and will be held in closed position throughout subsequent testing operations by the greater hydrostatic pressure in the well annulus acting through the ports 250 on the transverse pressure area of the valve element.

OPERATION

In operation, the various components of the tool string are in the end-to-end sequence as shown in FIGS. 1A and 1B of the drawings and connected to the drill string 10 preparatory to lowering into the well. The housing 105 of the pump assembly 17 is disposed in its lower position with respect to the mandrel assembly 107, with the clutch nut 123 also in its lower position where its function is to releasably lock the housing and mandrel in a mutually telescoped relationship. This disables the pump assembly 17 until such time as the clutch is released to enable relative longitudinal movement of the housing 105. Of course the inflatable packing elements 20 and 20' are both retracted, and the test valve assembly 13 is closed inasmuch as the mandrel 210 is in an upper or extended position relative to the housing 212, thereby disposing the valve heads 213 and 213' above the flow ports 220 and 218 to prohibit fluid flow. As the equipment is lowered into the borehole to setting depth, the drag springs 27 of the anchor assembly 24 frictionally engage the walls of the bore to prevent rotation as well as to provide a degree of restraint to vertical motion of the equipment. The pipe string 10 is either empty of fluids or may be provided with a column of water to act as a cushion as will be apparent to those skilled in the art. In any event, the pipe string 10 provides a low pressure region which can be communicated with an isolated section of the borehole to induce fluids to flow from the formation into the pipe string if they are capable of so doing.

When the packing assembly 19 is located opposite the formation interval to be tested, the interval is isolated by inflating the packing elements 20 and 20' into sealing contact with the surrounding well bore wall in the following manner. The pipe string 10 is appropriately manipulated to unjail the slip cage with respect to the body member of the anchor 24, and the equipment is lowered. The slips 26 are held against downward movement by the drag springs 27, so that the expander 25 shifts the slips outwardly into gripping contact with the wall of the borehole to prevent downward movement. Next the pipe string 10 is rotated to the right to feed the clutch nut 123 upwardly along the pump mandrel section 115 to the upper position where the housing 105 is free to be reciprocated with respect to the

mandrel assembly 107. As the housing 105 is elevated, it will be recognized that the weight of all of the equipment therebelow will resist upward movement of the mandrel assembly 107, so that pressure is generated within the chamber 131 above the piston 129. Such pressure will cause the check valve sleeve 134 to shift upwardly and uncover the ports 137, so that fluids under pressure are supplied via the inflation passage 118, 194 and 34 into the respective interiors of the packing elements 20 and 20'. The pressure causes the elements to inflate and bulge outwardly. When the pump housing 105 reaches the top of its stroke, thus having displaced its working volume of fluid into the inflation passage 118, the pipe string 10 is lowered to recharge the chamber 131 with well fluids. Of course the packer assembly 19 and the mandrel 10 of the pump assembly remain anchored against downward movement by the slips 26. As the housing 105 moves downwardly a reduction of pressure in the chamber 131 as it enlarges in volume during such downward movement enables the spring 135 to push the valve sleeve 134 downwardly to close off the passages leading to the packing elements 20 and 20'. As the pressure is further reduced by an increase in the working volume 131, the hydrostatic head of the well fluids present above the check valve assembly 132 forces the inlet valve 133 downwardly and away from the seat ring 136, thereby enabling the chamber to fill with well fluids as the housing 105 moves downwardly to the bottom of its stroke. When the chamber 131 is fully expanded, the absence of a pressure differential enables the spring 135 to push the inlet valve 133 closed. A second upward movement of the housing 105 will cause an additional volume of fluid under pressure to be displaced through the various inflation passages and into the packing elements 20 and 20' to increase their transverse dimension. In typical practice, depending upon hole size in relation to the relaxed diameter of the packer elements 20 and 20', a series of seven to ten cycles of the pump 17 will be sufficient to cause the respective outer peripheries of the element to engage the well bore wall as shown in FIG. 2B. Continued actuation of the pump 17 in response to upward and downward pipe motion will continually increase the inflation pressure until the desired pressure is reached. Immediately after the elements actually engage the well wall, the assembly becomes firmly anchored against upward movement due to considerable frictional restraint between the packing elements and the surrounding well bore wall.

As previously noted, the difference in seal dimensions between the piston 129 and the mandrel assembly 107 on the one hand, and the seal collar 153 and the tube 112 on the other, are such that a greater volume of well fluids is drawn in through the screen sub 16 than is required for the displacement volume of the pump chamber 131, with the result that during each downward or suction stroke of the housing 105, a certain amount of excess fluid is discharged back to the well annulus via the screen to backflush and purge the openings in the screen element 178. Thus it is practically impossible for the screen to become plugged and result in a misrun as the case for prior art devices of this type.

When a predetermined maximum inflation pressure has been developed within the inflatable elements 20 and 20' through operation of the pump assembly 17 as described above, the inlet valve seat ring 136 will be

forced upwardly and away from the mandrel shoulder 147 on each subsequent upward movement so that all the fluids in the chamber 131 are vented through the screen sub 146 to the well annulus, rather than being displaced into the inflation passage 118. Since the amount of force required at the surface to lift the pipe string 10 is directly related to the pressures developed within the chamber 131 and resisting upward movement of the piston 129, the amount of such force will increase until the pressures generated during the upward movements reach a magnitude sufficient to force the seat ring 136 upwardly, after which the force required to lift the pipe 10 during each pumping stroke will remain substantially constant. Thus the weight indicator at the rig floor can be observed by the tool operator and gives a positive indication of the performance of the downhole tools. That is to say, when the weight value stops increasing during each upward movement of the pipe string, the operator is assured that the packing elements 20 and 20' are fully expanded to the proper inflation pressure and can discontinue further operation of the pump assembly 17.

It should be noted at this point that upward movement is appropriate to open the pressure equalizing and packer deflating assembly 18, whereas downward movement is used to open the test valve 13. However, the operation of the respective hydraulic delay pistons 195 and 233 of these tools enables the pump assembly 17 to be actuated by repetitive downward and upward movements without opening the test valve or the equalizing valve because such movements occur during substantially lesser time intervals than is required for the delay pistons to meter to a released position. Thus the test and equalizing valves remain closed during operation of the pump assembly 17. Also, as previously mentioned, should an excessive squeeze fluid pressure tend to develop within the isolated interval of the well bore between the packing elements 20 and 20' due to expansion thereof subsequent to obtaining effective sealing action against the well bore wall, the excess pressure causes upward movement of the bleed valve element 249 so that the pressure is vented to the well annulus above the upper packing element 20 through the side ports 250. Of course the valve element 249 is shifted back to the lower closed position as the tester valve 13 is opened to initiate the test.

When it is desired to open the tester valve 13, the weight of the pipe string 10 is imposed upon the tools for the length of time necessary to overcome the hydraulic delay section 226. The mandrel 210 moves slowly downwardly during this time interval as the metering piston 233 approaches the enlarged diameter portion 235 of the chamber 234, and then moves rapidly downwardly to its fully contracted position. The valve heads 213 and 213' are thereby positioned below the test ports 220 and 218 to open a flow path through the sample chamber 217 and the mandrel ports 221 into the pipe string 12. Since the pipe string is initially at atmospheric or other low pressure, formation fluids in the isolated well interval between the expanded packing elements 20 and 20' will enter the ports 55 and flow upwardly through the passage 44, the ports 43, the bore 193 of the flow tube 192, through the central opening of the pump mandrel assembly 107, the bore 169 of the screen sub 16, through the pressure recorder carrier 15 and the excess pressure sub 14, and finally through the test valve assembly 13 into the pipe string

12. After a relatively short period of time necessary to drawn down the pressure in the interval of the well bore between the packing elements 20 and 20', the pipe string 10 is raised to shift the tester mandrel 210 upwardly and close the test ports 218 and 220. The formation is thereby shut-in to enable recordal by the gauge in the carrier 15 of pressure built-up data from which various formation and well fluids parameters can be determined as will be appreciated by those skilled in the art. Of course the tester valve can be repeatedly opened and closed as desired to gather further flow and shut-in pressure information, and each time the tester is closed a flowing sample of flowing formation fluids is trapped within the chamber 219. At all times during the test, of course the straddle bypass formed by the lateral ports 47, the bore 42 of the flow tube 45, the ports 75, the annulus space 77 and the later ports 79, remains open to ensure that the hydrostatic pressure of the well fluids above the upper packing element 20 is substantially equalized with the corresponding pressure of well fluids below the lower packing element 20'. The lower pressure recorder in the carrier sub 28 records the fluid pressure within the isolated interval between the elements 20 and 20' by virtue of being in communication therewith via the lateral ports 100, the bore 99 of the flow tube 78 and the bore 98 of the equalizing valve tube 90. The pressure record obtained thereby can, of course, be compared with the readings taken by the upper pressure recorder at 15.

When it is desired to terminate the test, a strain is placed in the pipe string 10, and the tension is maintained for a time sufficient to overcome the retarding action of the hydraulic delay piston 195 in the equalizing and deflate valve assembly 18. As the piston 195 reaches the upper end of the chamber 196, the equalizing grooves 203 and 205 are disposed above the respective seal rings 206 and 204 to communicate both the inflation passage 194 and the test passage 193 with the well annulus above the upper packing element 20 via the ports 201. In this manner, all the various pressures are equalized with one another, and the packing elements 20 and 20' will inherently deflate and retract to their original relaxed dimensions. Upward movement of the entire packing assembly 19 will cause extension of the lower equalizing sub 23 whereby the lowermost portion 91 of the inflation passage is communicated with the well annulus via the ports in ring 92 and the outer member ports 97. Further upward movement will unset the slips 26 of the anchor 24 from the well bore wall and cause them to be shifted inwardly by the slidable spline connections. Thus the equipment can be withdrawn intact from the well bore when the pressure records and the sample of formation fluids can be analyzed, or for that matter can be moved to another level in the well for additional tests.

Sincer certain changes or modifications may be made by those skilled in the art without departing from the inventive concepts disclosed herein, it is the aim of the appended claims to cover all such changes and modifications falling within the true spirit and scope of the present invention.

I claim:

1. A method for isolating an interval of earth formations with a packer means having at least one inflatable packing element that can be expanded in response to operation of a pump means having relatively movable inner and outer members defining a working volume,

one of said members being connected to said packer means and the other of said members being connected to a pipe string extending upwardly to the surface, comprising the steps of: releasably locking said members against relative movement to temporarily disable said pump means; lowering said packer means and pump means into a fluid filled well bore on the pipe string; at setting depth, anchoring said packer means and said one member against downward movement in the well bore and releasing said members for movement relative to each other to enable operation of said pump means; moving said pipe string upwardly and downwardly to effect corresponding movement of said other member relative to said one member; during upward movement of said pipe string and said other member discharging fluid under pressure into the interior of said packing element to inflate and expand it outwardly; and during downward movement of said pipe string and said other member drawing well fluids into said pump means for discharge during the next subsequent upward movement.

2. The method of claim 1 including the further step of venting fluid from the pump means to the well annulus when the pressure interiorly of said packing element reaches a predetermined maximum value.

3. The method of claim 2 including the further steps of providing an indication at the surface of the increase in the amount of force required to move said pipe string upwardly as the pressure interiorly of said packer element increase; and discontinuing upward and downward movement of the pipe string when the amount of force required to cause such upward movement ceases to increase and thus indicates that said fluids are being vented to the well annulus.

4. The method of claim 3 including the further steps of performing a drill stem test by flowing formation fluids from below said packing element into the pipe string for a first period of time; shutting in the formation interval for a second period of time; and instrumentally recording the pressure of the fluids in said isolated interval during said periods of time.

5. The method of claim 4 including the further steps of deflating said packer means to enable said packing element to retract to substantially its normal transverse dimension so that said packer means and pump means can be moved longitudinally through the well bore.

6. A method for isolating an interval of earth formations off the bottom of a well bore, comprising the steps of: lowering vertically spaced, upper and lower inflatable packer elements, and a pump means into the well bore on a pipe string, said pump means having a working volume provided between an inner member connected to said upper packer means and an outer member connected to said pipe string; anchoring said packer elements and said inner member against downward movement in the borehole; moving said pipe string upwardly and downward to effect corresponding movement of said outer member relative to said inner member; during each upward movement pumping fluid under pressure into the respective interiors of said upper and lower packing elements to expand them outwardly; and during each downward movement resupplying said pump means with fluids to be discharged to said packer elements during the next subsequent upward movement of said pipe string.

7. The method of claim 6 including the further step of monitoring the inflation pressure within the packing

elements at the surface, and discontinuing upward movements of the pipe string when an indication is given that the inflation pressure has reached a predetermined maximum value.

8. The method of claim 7 including the further step of exhausting fluids from the pump means to the well bore when said maximum value of inflation pressure is reached.

9. The method of claim 8 wherein the monitoring step is carried out through observation of the amount of force required to lift the pipe string during successive upward movements thereof, said discontinuing step being carried out as soon as an appreciable increase in the amount of force required to lift the pipe string during successive upward movements is no longer observed.

10. The method of claim 9 including a further step of equalizing the pressure of fluids in the well bore above the upper packing element with the pressure of fluids in the well bore below the lower packing element.

11. Apparatus for use in isolating an interval of earth formations traversed by a well bore, comprising: packer means having at least one inflatable element adapted to be expanded into sealing contact with a surrounding well bore wall; pump means for inflating said element, said pump means including relatively movable inner and outer members defining a working volume, one of said members being connected to said packer means and the other of said members being connected to a pipe string extending upwardly to the surface; releasable clutch means for preventing relative movement of said members as said apparatus is being moved longitudinally in a well bore; means for anchoring said packer means and said one member against downward movement in the well bore; first means for feeding fluid under pressure from said working volume to the interior of said packing element during upward movement of said other member relative to said one member; and second means for drawing well fluids into said working volume during downward movement of said other member relative to said one member.

12. The apparatus of claim 11 wherein said first means includes an inflation passage leading from said working volume to the interior of said packing element, and valve means for enabling fluid to flow via said passage in a direction to enable expansion of said packing element during said upward movement and for preventing the flow of fluids in the reverse direction.

13. The apparatus of claim 12 wherein said second means includes an entry passage leading from the well annulus to said working volume, and valve means for enabling fluids to enter said working volume means via said entry passage during said downward movement and for normally preventing fluid flow in the reverse direction.

14. The apparatus of claim 13 further including a normally closed vent passage for exhausting fluid from said working volume to the well annulus; and pressure responsive relief valve means for enabling fluids to vent to the well annulus via said vent passage during said upward movement of said other member only after a predetermined maximum inflation pressure has been generated within said packing element.

15. The apparatus of claim 14 further including a test passage extending generally longitudinally through said packer means and said pump means; and test valve means for selectively opening and closing said test passage to enable performance of a drill stem test.

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United States Patent [19]

Tham et al.

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[54] **SOLVENT/NON-SOLVENT PYROLYSIS OF
SUBTERRANEAN OIL SHALE**

[75] Inventors: **Min Jack Tham; Philip Joseph
Closmann**, both of Houston, Tex.

[73] Assignee: **Shell Oil Company**, Houston, Tex.

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Primary Examiner—Stephen J. Novosad

Attorney, Agent, or Firm—Harold W. Coryell

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299/5**

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[57]

ABSTRACT

In a process for recovering shale oil by injecting and producing fluid into and out of a rubble-containing cavity in an otherwise substantially impermeable subterranean oil shale, the tendency for the flow path to become plugged is reduced by injecting both a hot solvent-fluid and a non-solvent-gas at rates correlated so that the cavern remains substantially free of liquid.

6 Claims, 1 Drawing Figure

