METHOD AND APPARATUS FOR GRAVEL PACKING AND PERFORATING A WELL IN A SINGLE TRIP

The present invention relates generally to methods and apparatus for gravel packing a well, and, more specifically relates to methods and apparatus for gravel packing a well with only a single trip of the tool string into the wellbore, which method may also provide for the perforating of the well on such single trip.

Techniques are well known in the oil and gas industry for controlling sand migration into wells penetrating unconsolidated formations by gravel packing the wells. Such gravel packing typically consists of depositing a quantity, or "pack", of gravel around the exterior of a perforated liner and screen, with the pack preferably extending into the perforations in the unconsolidated formation. The gravel pack then presents a barrier to the migration of the sand while still allowing fluid to flow from the formation. In placing the gravel pack, the gravel is carried into the well and into the formation in the form of a slurry, with the carrier fluid or workover fluid being returned to the surface, leaving the gravel in the desired location.

Attempts have been made in the past to minimize the number of trips of the tool string into the well. Each trip of the tool string into a well takes an appreciable amount of time, and therefore incurs significant costs in terms of rig and crew time. As will be readily apparent,

these costs are dramatically increased if the tool string is tripped to a great depth in a well.

Previous attempts to minimize trips into the borehole for gravel packing have only allowed the actual gravel packing operation to be performed in a single trip, but have not allowed the well to be placed on production at the end of that trip. Thus, with conventional so-called "one-trip" techniques, after a single trip into the borehole for gravel packing, the tubing and at least a portion of the tool string would have to be tripped out of the hole, and other equipment, such as a seal assembly or extension tripped into the hole to stab into the production packer to place the well on production. Examples of such prior art techniques are disclosed in U.S. Patent No. 4,372,384, issued January 10, 1983, and U.S. Patent No. 4,566,538, issued January 28, 1986.

Accordingly, the present invention provides new methods and apparatus whereby a well may be gravel packed and placed on production with a single trip of the tool string and tubing into the wellbore. Additionally, the well may first be perforated on this same, single, trip into the wellbore.

More specifically, the invention provides a gravel pack assembly for use in a tool string for gravel packing an annular area of a wellbore surrounding at least a portion of said tool string in said wellbore, said assembly adapted to be placed in said wellbore by being suspended from a tubing string; comprising: a packer assembly; a crossover assembly, said crossover assembly being selectively operable from a first state in which fluid communication is precluded between an interior bore of said crossover assembly and said annulus, and a second state wherein a first flow path is

established communicating an upper interior portion of said crossover assembly with said annulus, and further being selectively manipulable to establish a second flow path from a lower interior portion of said crossover assembly to a wellbore annulus above said packer; a gravel pack screen disposed around a portion of said gravel pack assembly; a selectively operable valve member operable to allow fluid communication from the annulus in said wellbore exterior to said screen to a lower interior portion of said crossover assembly; and an operating mechanism selectively engageable with said crossover assembly to occlude fluid flow through said interior bore of said crossover assembly, at least in a first direction, and to operate said crossover assembly between said first and second states.

The invention also provides a method for gravel packing a wellbore using the above apparatus.

Preferred embodiments of the method and apparatus of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figures 1A-C depict a perforating/gravel pack assembly in accordance with the present invention; the assembly is depicted in Figure 1A as disposed in a wellbore, and is depicted in part in Figures 1B and C in different stages of a perforating/gravel pack operation.

Figures 2A-E depict the packer/crossover assembly of Figure 1, illustrated partially in vertical section.

Figure 3 depicts a portion of the packer/crossover assembly of Figure 2, having a probe assembly disposed therein, at one stage of operation, illustrated partially in vertical section.

Figure 4 depicts the differential pressure operated valve and tell-tale screen assembly of Figure 1, illustrated partially in vertical section.

Figure 5 depicts the crossover sleeve assembly of Figure 1, illustrated partially in vertical section.

Figure 6 depicts an upper portion of the packer/crossover assembly in Figure 2 in one stage of manipulation, illustrated partially in vertical section.

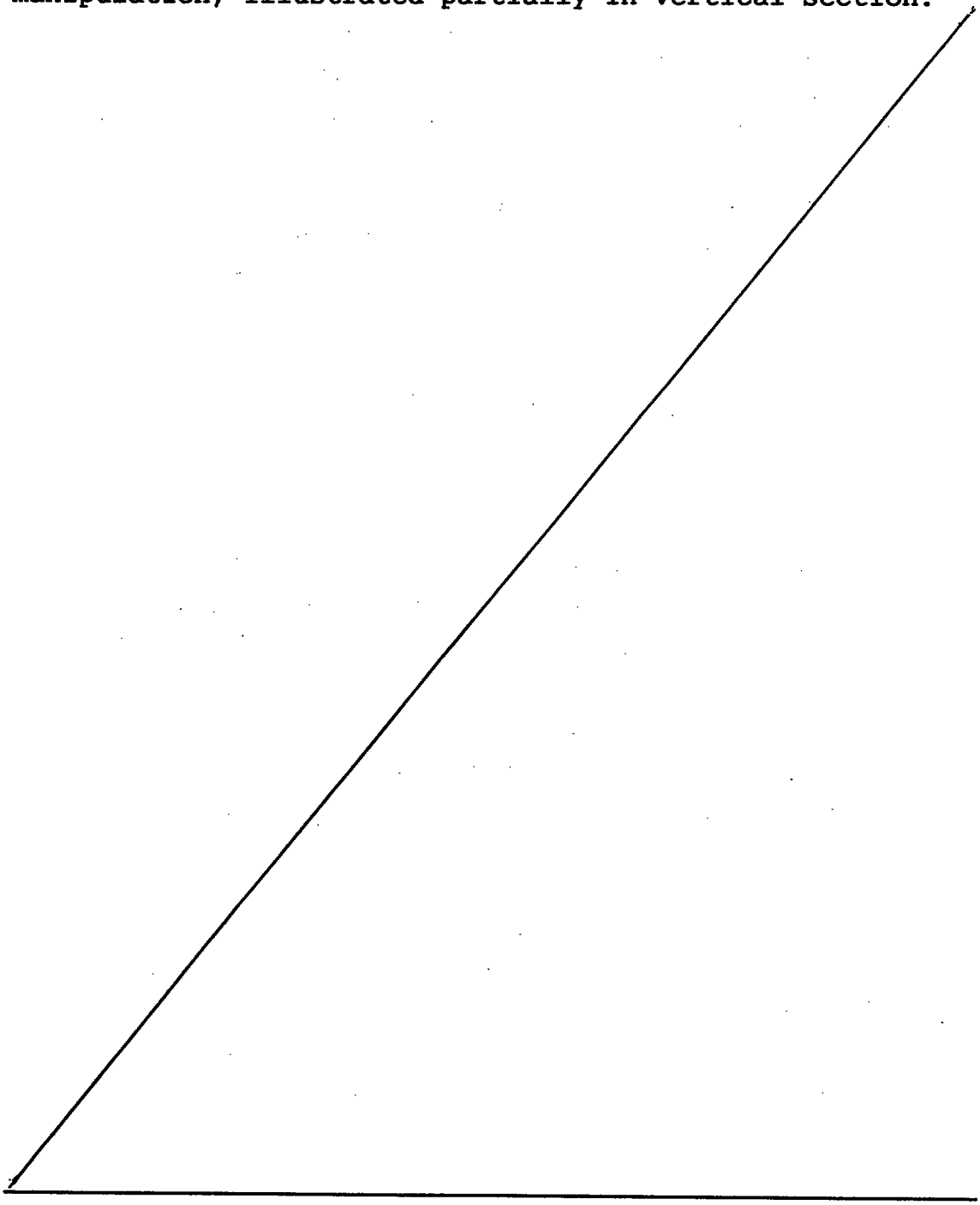


Figure 7 depicts a second portion of the packer/crossover assembly of Figure 2, at the same stage of manipulation as depicted in Figure 6, illustrated partially in vertical section.

Figure 8 depicts a portion of the service tool assembly of the packer/crossover assembly of Figures 2A-E at one stage of operation, illustrated partially in vertical section.

Figure 9 depicts an alternative embodiment of the sliding sleeve valve of the perforating/gravel pack assembly of Figure 1, illustrated partially in vertical section.

Figures 10A-B depict an alternative embodiment of a multipurpose running tool and a closure assembly suitable for use with the present invention, and illustrated partially in vertical section.

Figure 11 depicts the apparatus of Figure 10A at one stage during the operation prior to use of multi-position running tool to set the packer, illustrated partially in vertical section.

Referring now to the drawings in more detail, and particularly to Figures 1A-C, therein is depicted in Figure 1A an exemplary perforating/gravel pack apparatus 10 in accordance with the present invention. Perforating/gravel pack apparatus 10 is shown disposed within a cased wellbore 12. Casing 14 is placed and secured in the borehole 16 by conventional cementing techniques. Perforating/gravel pack apparatus 10 is shown disposed in wellbore 12 at a depth which positions perforating gun 18 adjacent a zone of interest 20. Perforating gravel pack apparatus 10 is suspended from a

tubing string 22. As will be apparent from the discussion to follow, tubing string 22 is a production tubing, since at the completion of the perforating and gravel packing operation, the well is then placed directly on production.

Perforating gravel pack apparatus 10 includes a packer/crossover assembly 24. Packer/crossover assembly 24 includes a packer 26. Packer 26 is preferably a hydraulically set packer such as the Versa-Trieve retrievable Packer manufactured and sold by Otis Engineering Corporation. Coupled to packer 26 is a crossover assembly 28 which will be described in more detail later herein. Beneath crossover assembly 28 is a non-rotating shear sub 30. Coupled in perforating/gravel pack apparatus 10 beneath shear sub 30 is primary gravel pack screen 32. Gravel pack screen 32 is secured around housing 34 in a conventional manner. Coupled within housing 34 is at least one sleeve valve 36 as will be described in more detail later herein. Sleeve valve 36 is preferably a sliding sleeve type valve which allows selective opening of a port 38 to allow fluid communication, through screen 32, between wellbore 12 and the interior of housing 34.

Coupled in exemplary perforating/gravel pack apparatus 10 is also an optional differential pressure operated circulating valve 40. Housing assembly 34 extends through screen 32, and through tell-tale screen 42. Tell-tale screen is secured a short distance beneath primary gravel pack screen 32. Within tell-tale screen 42, housing assembly 34 includes a sliding sleeve valve 44. Sliding sleeve valve 44 is preferably a ball-operated valve, which includes a seating surface to receive a

sealing ball, by which the sleeve may then be moved by application of hydraulic pressure. Beneath valve 44 is packer 46. Packer 46 is preferably a mechanically-set retrievable packer, such as the Perma Lach packer manufactured and sold by Otis Engineering Corporation. Perforating equipment located in perforating/gravel pack apparatus 10 beneath packer 46 may be of virtually any conventional type, including various types of vent assemblies, as desired. In the illustrative embodiment depicted, the perforating equipment includes a ported sub 48 to allow fluid communication between a lower annulus 50, located beneath packer 46, and the interior of housing assembly 34 and tubing string 22. Perforating equipment also includes an appropriate firing head 52 such as a mechanically-actuated firing head. However, as will be readily apparent, annulus or tubing pressure actuated firing heads could also be utilized. Firing head 52 is operably coupled to perforating gun 18, which may consist of one or more guns of virtually any conventional type.

Referring now to Figures 2A-E, therein is depicted packer and crossover assembly 24 in greater detail. Packer 26 may be of any appropriate type, but preferably is a hydraulically actuated packer. Packer 26 is shown in combination with a multi-position service tool, indicated generally at 60, also such as is manufactured and sold by Otis Engineering Corporation. The structure and operation of multi-position service tool 60 is described and illustrated in U.S. Patent No. 4,832,129, issued May 23, 1989, to Sproul, et al. and assigned to Otis Engineering Corporation. U.S.

Patent No. 4,834,175 discloses an exemplary embodiment of a Versa-Trieve packer suitable for use with the present invention.

Briefly, multi-position service tool 60 attaches to packer 26 in such a way as to enable the packer to be run and set, and for the tool to be released from the packer, all without rotation of service tool 60. Packer 26 will be set in response to the application of hydraulic pressure, which causes movement of an actuation piston which shears restraining shear pins and causes the setting sleeve of multi-position service tool 60 to bear against a guide on the packer, moving the outer parts of the packer relative to a packer mandrel, thereby expanding packer seals 100 and setting packer slips 102.

The structure and operation of multi-position service tool 60 in combination with packer 26 will be outlined briefly. A group of separation shear pins 62 having a shear strength sufficient to, at a minimum, support the packer assembly hang weight connect the packer mandrel 64 to service tool mandrel 66. During run-in, packer 26 is mechanically locked in an unset condition by separation shear pins 62.

Separation shear pins 62 are decoupled with respect to run-in handling forces by a transfer support assembly, indicated generally at 67. Transfer support assembly 67 includes a plurality of transit support lugs 68 carried by a collet assembly 70 which is selectively movably mounted relative to service tool mandrel 66. Transit support lugs 68 carry the weight of the packer and any weight of equipment hanging therefrom so that the hang weight of that equipment is not applied to separation shear pins 62 during the run-in procedure.

Transit support lugs 68 are engaged against an annular flange 75 which is formed on a tube guide extension 74. Transit support lugs 68 engage an underside 61 of annular flange 75, with the upper surface 73 of flange 75 being aligned for engagement with a setting sleeve 76, and to serve as a stop therefore. The hang weight of packer and crossover assembly 24 is communicated through tube guide extension 74 and through transit lugs 68 and collet assembly 70 to service tool mandrel 66. This described system isolates the handling forces arising during the run-in procedure from separation shear pins 62.

Service tool mandrel 66 includes a locking flange 78 with a recess which is engaged by a shoulder portion 71 of collet 70. Shoulder portion 71 limits the upward movement of collet 70. Collet 70 includes finger portions 70a having enlarged radially inwardly extending head portions 70b. Collet head portions 70b are retained in a detent groove 67 in multi-position tool mandrel 66. Detent groove 67 is located above the portion of locking flange 78 engaged by shoulder portion 71 of collet 70. Head portion 70b of collet 70 is engaged and prevented from deflecting by a piston shoulder 80a on an annular piston 80. Piston 80 is adapted for sliding movement along service tool mandrel 76.

Transit lugs 68 are released, and the packer is set, by pressurizing fluid within the interior of the tubing string. Pressurized fluid within the tubing will be communicated through a port 88 in tool mandrel 66 to act upon piston 80 to cause setting of packer 26, after closing the bore of the tubing string, such as through use of a probe or "dart" assembly 220, as will be described in more detail later herein. Once a downward path through the tubing string is closed, fluid may be pressurized within the tubing. This fluid traverses port 88 to

annulus 72 and acts upon piston 80. Pressure on piston 80 will cause shearing of transit shear pins 94, and subsequent downward movement of piston 80, as depicted in Figure 8. Piston 80 is coupled to an extension sleeve 81 which, in turn, is coupled to tool mandrel locking flange 78 through transit shear pins 94. Upon shearing of transit shear pins 94, piston 80 will drive service tool piston mandrel 76 downwardly against shoulder 73 of tube guide extension 74. Collet 70 remains in place as the piston is driven downwardly. Piston shoulder 80a will clear collet head 70, thereby allowing it to deflect, and also permitting the collet transfer assembly to move downwardly along the locking flange 78; and permitting the spring loaded support lugs 68 to retract inwardly. As transit support lugs 68 retract, the hang weight of the packer is transferred from transit support lugs 68 to separation shear pins 62.

Tube guide extension 74 is moveable relative to packer mandrel 64. Upper seal 100 and slips 102 are connected to tube guide extension 74 by a connecting sub 96. An internal locking slip ring assembly 98 is restrained within an annulus 97 between connecting sub 96 and packer mandrel 64. Slip ring assembly 98 is biased by a coil spring 99. Slip ring assembly 98 functions as an internal slip which prevents reverse movement of tube guide extension 74 relative to packer mandrel 64. Accordingly, tube guide extension 74 will move downwardly relative to packer mandrel 64 in response to continued extension of piston 80 and attached extension sleeve 81. As piston 80 nears the limit of its extension along tool mandrel 66, slips 102 and seals 100 will engage the casing and set packer 26 against the inside bore of the well casing.

Because packer mandrel 64 is anchored onto tool mandrel 66 by separation shear pins 62, guide tube extension 74 continues its downward movement relative to packer mandrel 64. Once the desired slip setting pressure has been achieved and packer 26 is securely anchored in place, service tool 60 can be released from packer 26 by increasing hydraulic pressure, and/or by pulling tubing string 22 upwardly, to cause shearing of separation shear pins 62. Once separation shear pins 62 are sheared, transfer support lugs 68 may retract radially inwardly, thereby permitting service tool 60 to be reciprocated freely within the bore of packer 26.

Referring now primarily to Figure 2E, therein is depicted a portion of the mechanism for selectively closing bore 121 of packer and crossover tool assembly tool 24. A closing mandrel 120 is secured, such as by a shear pin 122 within multi-position service tool mandrel 66. Multi-position service tool mandrel 66 includes seals 124, 126 located on opposite sides of a radial aperture 128. Seals 124 and 126 are adapted to engage the exterior of closing sleeve 120, so as to isolate radial aperture 128. Radial aperture 128 is longitudinally aligned with a radial aperture 130 in crossover sleeve 132 and radial aperture 134 in crossover housing member 136. A closing probe, or "dart assembly" 220 is depicted in dashed lines within closing sleeve 120. The structure and operation of dart assembly 220 is depicted later herein in connection with the description of the operation of perforating/gravel pack assembly 10.

Also coupled to closing sleeve 120 is a shearable stop block assembly, indicated generally at 138. Shearable stop block assembly 138 includes stop block 140 which is coupled by a shear pin 142 to closing sleeve 120.

The purpose of shearable stop block assembly 138 will be described in more detail later herein.

As can also be seen in Figure 2E, beneath radial aperture 130 in crossover sleeve 132 is a stop ledge 144 which will selectively engage and restrict downward movement of stop block assembly 138. Beneath stop ledge 144 is a radially inset sleeve portion 146 of crossover mandrel 132. Radially inset sleeve portion 146 provides sufficient clearance in annular area 148 to accommodate a bow-type collet spring assembly, indicated generally at 150. Bow-type collet spring assembly 150 preferably includes a mechanism, such as two radially inwardly extending shoulders 152a, 152b which engage either side of a radially outwardly extending ledge 154 on sleeve portion 146. Bow-type collet spring assembly 150 also includes a radially outwardly extending ledge 153 which is adapted to selectively engage an inwardly extending ledge 157 on a sliding valve member 156. Bow-type collet spring assembly 150 is sized so as to be deflectable to pass beneath radially inwardly extending surface 159 of housing extension 161, and also to radially expand so as to engage ledge 157 of sliding valve member 156, upon upward longitudinal movement of sleeve portion 146 of crossover mandrel 132.

Sliding valve member 156 is located immediately beneath radial apertures 130 and 134. Sliding valve member 156 is adapted to selectively be moveable upwardly so as to isolate radial aperture 134 through use of seals 158 and 160. At the upward extent of sleeve 156 is a radially outwardly extending collet assembly 162 which extends generally circumferentially around sleeve 156. Threadably engaged at 164 with housing member 136 is a collet receiving assembly 166. Collet receiving assembly 166 includes a radially inwardly extending shoulder 168

adapted to receive and engage collet assembly 162 on sleeve 156 to retain sleeve 156 in an upward position, when engaged.

Referring now to Figure 4, therein is depicted an exemplary embodiment of a differential pressure operated reversing valve 40. Differential pressure reversing valve 40 includes a coupling mandrel 170 coupled to housing 34 inside gravel pack screen 32. Coupling mandrel 170 is threadably coupled at 172 to a lower housing 174. Lower housing 174 includes a radial aperture 176. Coupling mandrel 170 also includes a plurality of radial apertures 178 which are preferably longitudinally offset from radial apertures 176. Communication between apertures 176 and 178 is initially precluded by a closure sleeve 180 which sealingly engages seals 182 and 184 on housing 170 and seal 186 on lower housing assembly 174. Closure sleeve 180 is urged against an upwardly limiting shoulder 188 on coupling mandrel 170 by an extension spring 190. As will be appreciated from the disclosed apparatus, a pressure in the annulus applied through port 176 will act on closure sleeve 180 against the force of spring 190. When such pressure becomes sufficiently high, sleeve 180 will be moved downwardly, beneath seal 182, and valve 40 will thereby allow fluid communication between radial apertures 176 and 178, and therefore fluid communication between the annulus, through gravel pack screen 32, and interior bore 192 within valve 40.

As depicted in Figure 4, in one exemplary embodiment, coupled beneath differential pressure operated circulating valve 40 is tell-tale screen assembly 44. Tell-tale screen assembly 44 includes a housing 200 having a plurality of radial apertures 202 therein. A conventional gravel pack tell-tale screen 204 surrounds housing 200 at least proximate apertures 202. A selectively moveable

valve sleeve 206 is secured such as by shear pins 208 to housing 200 whereby sleeve 206 sealingly isolates apertures 202. Sleeve 206 includes a ball receiving seat 210 adapted to receive a conventional sealing ball, as is known to the industry.

Referring now to Figure 5, therein is disclosed an exemplary embodiment of crossover sleeve 36. Crossover sleeve 36 may be a design such as the Sliding Side-Door Circulation Valve manufactured and offered by Otis Engineering Corporation. Crossover sleeve 36 includes a housing assembly 251 which, as depicted in Figure 5 will be within a portion of primary gravel pack screen 32. Housing assembly 251 has a plurality of radial ports 243 extending therethrough. A movable inner mandrel 245 is situated within housing 251. Mandrel 245 engages seal assemblies 253a and 253b on opposite sides of radial ports 243. Mandrel 245 thus, in a first position, precludes fluid flow between the tool interior bore 192 and the annulus through radial ports 243. Proximate the lower end of mandrel 245 are a plurality of circumferentially arranged collet fingers, indicated generally at 252. Collet fingers 252 include radially outwardly extending detent ledges 254 adapted to engage recesses in housing assembly 251. Housing assembly 251 preferably includes at least two sets of detent grooves 256, 258. As depicted in Figure 5, when detent ledge 254 engages upward detent groove 256, inner mandrel 245 is maintained in a first, upward position precluding fluid flow as described above. Inner mandrel 245 also includes a plurality of tool-engaging mechanisms, such as an upward lip 259 and lower inwardly extending flanges 260 which are adapted to engage shifting tools, in a manner well known to the art. Such shifting tools may be used to move mandrel 245 from the first position as depicted in Figure 5 to a second position, wherein detent ledges 254 will engage lower

detent groove 258. In this position, a plurality of circumferentially arranged apertures 262 will be longitudinally aligned with radial ports 243, and a flow path will be established between the annulus surrounding crossover sleeve 36 (through primary gravel pack screen 32), and tool interior bore 192. Interior bore 192 is, of course, only one portion of the bore through perforating/gravel pack assembly 10.

Operation of the exemplary embodiment of a perforating gravel pack apparatus 10 of Figures 1-5 is as follows. Perforating/gravel pack apparatus 10 will be lowered in the wellbore until perforating gun 18 is adjacent zone of interest 20. Retrievable packer 46 will then be seated to isolate a lower portion of the wellbore 50 (beneath packer 46), from an upper portion of the wellbore 51. At this time, there will be an open path through the interior of the tubing string and through perforating/gravel pack assembly 10. Accordingly, any desired conventional means for actuating perforating gun 18 may be utilized. For example, firing head 52 associated with perforating gun 18 may be either mechanically actuated, such as through use of a drop bar, or may be actuated by fluid pressure which will be communicated through tubing string 22 and either through the interior of tubing string 22 to firing head 52, or out into lower annulus 50, where firing head 52 is responsive to annulus pressure. After perforating, perforating gun 18 and firing head 52 will preferably be dropped into the bottom of wellbore 12. this may be done by any conventional means, such as, for example, an automatic gun release firing head.

Once the zone of interest 20 has been perforated (as depicted in Figure 1B), the well will be allowed to flow as desired, such as to clean perforations, and the well

will be killed. A sealing ball (shown in phantom lines in Figure 4) may be dropped in the tubing string and allowed to rest on seating surface 210 of movable valve sleeve 206 (see Figure 4). When a predetermined pressure, for example 1,000 psi. (6895 KN/m^2) is reached, shear pins 208 will shear and movable sleeve 206 will shift downwardly. Sleeve 206 may be allowed to be "blown" out of the lower end of perforating/gravel pack apparatus, through the opening provided after dropping of perforating gun 18. Movement of movable sleeve 206 opens apertures 202 behind tell-tale screen 204, allowing fluid communication between the annulus and the interior bore 192 of perforating/gravel pack apparatus 10. Retrievable packer 46 will be unset, and perforating/gravel pack assembly 10 will be lowered within wellbore 12 until primary gravel pack screen 32 is adjacent zone of interest 20 (as depicted in Figure 1C). Retrievable packer 46 will then be reset at this depth.

After this flow path is established, packer 26 may be set. The setting of packer 26 defines an upper wellbore annulus 51 above packer 26 and a lower wellbore 52 annulus below packer 26. Packer 26 will preferably be set by dropping "dart" assembly 220 through tubing string 22. Dart assembly 220 is depicted in dashed, "shadow", representation in Figure 2E, in the position in which the relative components will be when dart assembly 220 is initially placed into position in closing sleeve 120 on perforating and gravel packs assembly 24.

For purposes of this description, dart assembly 220 will be described in relation to Figure 3. Dart assembly 220 includes an outer housing member 222. Housing assembly member 222 includes a generally conical or "bullet-shaped" lower end 224. Proximate its upper end, housing 220 includes a radially enlarged upset portion 228 and an outwardly extending seating portion 230. Seating

portion 230 is preferably placed at an upwardly extending angle, as depicted in Figure 3. Dart housing assembly 222 includes a plurality of seals thereon. A first pair of seals 232, 234 is adapted to sealing engage an upward recess 236 in closing sleeve 120. A lower seal 238 is adapted to engage a lower portion within the bore of closing sleeve 120. Dart housing assembly 222 includes a plurality of lower ports 242 which communicate with an internal chamber 244 in dart housing assembly 222. Chamber 244 includes a lower portion 244a and an upward, radially enlarged portion 244b. These portions are separated from one another by a transition area 246 forming a ball seat. A check ball 248 is included within dart housing assembly 222, and acts as a check valve within dart assembly 220, allowing fluid to flow upwardly from smaller portion 244a of chamber 244 to radially enlarged portion 244b, but not in the opposite direction. A plurality of radial apertures, indicated generally at 250, provide fluid communication between radially enlarged chamber portion 244b to the exterior of dart assembly 220. As can be seen in Figures 2E and 3, when dart assembly 220 is seated within closing sleeve 120, radial ports 250 will be longitudinally aligned with ports 121 in closing sleeve 120. Dart assembly 220, which will be seated by dropping it down the tubing string, the portion 228 will facilitate dart assembly 220 being retrieved from the well on wireline or slickline. As used herein, the term wireline is considered to embrace cable having electrical conductors, generically referred to as "wireline," and also cable without electrical conductors, such as is commonly referred to as "slickline."

When dart 220 is received within closing sleeve 120, fluid flow downwardly through interior bore 192 of the tool string will again be precluded, by seals 232, 234 on

dart assembly 220. Accordingly, pressure may be applied through the interior of tubing string 22, to act upon actuation piston 80 through port 88, and to thereby set packer 26 in the manner described in U.S. Patent Nos. 4,832,129 and 4,834,175, mentioned previously. Once packer 26 has been set, the pressure in the tubing string may be elevated to a second threshold level to shift closing sleeve 120. In one particularly preferred embodiment, tubing pressure will be elevated to approximately 2,800 psi. (19306 KN/m^2) to accomplish this shift. Once this threshold pressure is achieved, shear pins 122 will shear, and sleeve 120 will move downwardly with respect to inner mandrel 164 until stop block assembly 138 rests adjacent inwardly projecting ledge 144, as depicted in Figure 3. This movement of sleeve 120 will open ports 128, 130 and 134 to the fluid annulus. The alignment of those ports thus establishes the gravel pack slurry path from the interior of tubing string 22 to the annulus.

Once the dart is in position (fig. 3), fluid flow will exit out of the tubing through ports 128,130 and 134 and be returned through the annular return path 192 (fig. 5). Fluid flow is received through port 202 in the tell-tale assembly (fig. 4) upward into aperture 242 in dart assembly 220, past check valve 247 and out through apertures 250 and through apertures 121 in closing sleeve 120 as depicted in fig. 2E. The fluid flow will be communicated with the upward annulus by raising tubing string 22 and attached service tool assembly 66 to a point where crossover port 65 is elevated above top of the packer mandrel.

At this time seals previously in packer mandrel 64 above crossover port 65 are above the packer mandrel allowing return fluid up the casing annulus. The screen/casing annulus adjacent to zone of interest 20 may then be gravel packed in a conventional manner by flowing the slurry down through the tubing string into the annulus through apertures 128,130 and 134 allowing carrier fluid to return through ports 202 in tell-tale or production screen (whichever is used) until screen out occurs.

As will also be apparent, differential pressure operated circulating valve 40 will be responsive to an increase of pressure in the well annulus (communicating with valve 40 through port 176), relative to the pressure of the return carrier fluid within interior bore 192. When this pressure overcomes the resistance of spring 190, closing sleeve 186 will move downwardly, providing a return flow path through valve 40. Additionally, a return flow path will be provided for fluid within screen 32 by sleeve valve 36. As noted previously, sleeve valve 36 is a wireline-shiftable valve to provide a return flow for fluid through primary gravel pack screen 32. Sleeve valve 36 may be opened prior to the commencing of introduction of the gravel pack slurry, but most preferably will be opened during the actual gravel pack operation, as fluid flow is eventually occluded through tell-tale screen assembly 44.

Once the gravel pack has been completed, tubing string 22 will be raised again, approximately 4-6 feet (1.22-1.83m), to allow reversing out of the interior of tubing string in a conventional manner. This elevation of tubing string will raise radial port 130 generally above tube guide extension 74, and will allow conventional reverse circulation to displace remaining carrier fluid from the interior of tubing string 22. Additionally, this upward movement of tubing string 22 will raise bow-type collet string assembly 150 (see Figures 2E and 7). Upward movement of crossover mandrel 132, and therefore of bow-type collet assembly 150 will cause collet assembly 150 to deflect to pass beneath inwardly extending surface 159 of housing extension 161, but to radially expand upon passing such

surface such that radially outwardly extending ledge 153 will engage shoulder 157 of sliding valve member 156. Continued upward movement of crossover mandrel 132 will move sliding valve member 156 upwardly until radially outwardly extending collet assembly 162 engages radially inwardly extending shoulder 168 of collet receiving assembly 166. Further upward movement of sliding valve member 156 is precluded by stop assembly 171. Thus, once sliding valve 156 has been moved to an upper, closed position, preventing fluid flow through radial port 134 (as depicted in Figure 7), further upward movement of sliding valve member 156 will be precluded.

Once the reverse circulation is complete, tubing string 22 will then again be lowered, returning port 130 to a sealed engagement within tube guide extension 74. Downward movement of crossover mandrel 132, and thereby of bow-type collet assembly 150 will not affect the position of sliding valve member 156 as radially outwardly extending ledge 153 is free to pass downwardly from sliding valve member 156, and as sleeve valve 156 is retained by collet assembly 162 and collet receiving assembly 166 as described earlier herein. At such time, the tubing string may then be appropriately spaced out, and the wellhead may be connected to the tubing string in a conventional manner. At such time, dart assembly 220 may be removed from packer/crossover assembly 24. Dart assembly 220 may preferably be removed by engaging head 252 thereof with a conventional wireline-conveyed retrieving tool and pulling dart assembly 220 upwardly out of packer/crossover assembly 24.

If for some reason, such as a pressure differential, it is difficult to pull dart assembly 220 from the well through such use of a wireline and retrieving tool, pressure may be applied to the interior of tubing string

22 to establish a pressure differential in favor of the tubing string above dart assembly 220. Once such pressure differential exceeds the shear value of shear pins 142, dart assembly 220 along with closing sleeve 120 may be "blown out" of interior bore 192 of perforating/gravel pack apparatus 10, through the opening left by the dropping of perforating gun 18 and firing head 52. At this time, an open flow path is established from interior bore 192 into tubing string 22 which is suitable to serve as a production flow path for fluid from zone of interest 20 through the gravel pack annulus and gravel pack screen 32. The well may thus be placed on production. Accordingly, the well has been perforated, gravel packed, and placed on production with only a single trip of the tool string into the wellbore.

Referring now to Figure 9, therein is depicted an alternative embodiment of a sliding sleeve valve 260 suitable for use in place of ball type sliding sleeve valve 44 as described with respect to Figures 1 and 4. Sliding sleeve valve 260 includes an upper sub 262 which is threadably coupled at 264 to lower sub 266. Lower sub 266 is threadably coupled at 268 to an adjacent sub or pup joint 270. Lower sub 266 includes a radially extending aperture 272 which is, in a first state of valve 260, selectively occluded by sliding sleeve 274. Lower sub 266 includes a sealing member 276, such as a conventional O-ring which engages the exterior surface of lower skirt 288 of sliding sleeve 274. Similarly, sliding sleeve 274 includes a recess 278 containing a sealing member 280, again such as a conventional O-ring. Sealing member 280 sealingly engages an inner extension surface 282 of lower sub 266.

Between aperture 272 and sealing member 276 in lower sub 266, lower sub 266 includes a radially inwardly

extending upset 284. Sliding sleeve 274 is complimentarily configured such that it has a radially inwardly extending ledge 286 extending to the dimension of lower skirt 288 which engages sealing member 276. Sliding sleeve 274 also includes a radially outwardly extending upset 290 which engages a sealing surface 292 within upper sub 262.

In operation, the configuration of sliding sleeve 274 provides a piston area established by the difference in dimension of the inner surface of upper extension 282 of lower sub 266, adjacent sealing member 280, and the dimension of lower skirt 288 of sliding sleeve 274, adjacent sealing member 276. Annulus pressure within aperture 272 will act upon this piston area. Once the pressure in the well annulus becomes sufficient to exert a force on the piston area which overcomes the shear value of shear pin 275, sliding sleeve 274 will move upwardly, until radially outwardly extending upset 290 engages a stop shoulder 294 within upper sub 262.

Sliding sleeve valve 260 also preferably includes a locking mechanism to retain sliding sleeve 274 in its upper, opened position, once the valve has been actuated. In the depicted preferred embodiment, this locking mechanism includes a split ring, such as a radially expansible C-ring 296 housed within a recess 298 in radially outwardly extending flange 290. As sliding sleeve 274 moves upwardly, locking ring 296 will be brought adjacent a radial locking recess 300 in upper sub 262. Split ring 296 will then expand, engaging recess 300, and presenting further movement of sliding sleeve 274.

Referring now to Figures 10A-B, therein is depicted a slightly modified multi-position running tool, indicated

generally at 310, adapted to be utilized with a modified closure assembly, indicated generally at 312. Because modified multi-position running tool 310 and closure assembly 312 have components which are identical to multi-position running tool 60 of Figure 2 and dart assembly 220 of Figure 3, similar structures will be assigned the same numbers as applied to such previously described components. The combination of multi-position running tool 310 and closure assembly 312 is particularly well suited for some applications involving the use of a perforating assembly in combination with the packer and gravel packing assemblies. In certain such perforating operations, the possibility may exist that detonation of the perforating gun could be transmitted within the tubing string and, could cause premature setting of the packer. Multi-position running tool 310 includes a closure sleeve 314. Closure sleeve 314 houses a pair of seals 316, 318 which, when closure sleeve 314 is in a first position straddle and therefore isolate port 88 in tool mandrel 66 from the interior bore thereof. Sleeve 314 is retained in this first position by a shear pin 320 which engages tool mandrel 66 and sleeve 314. A tapered transition to the inner diameter of sleeve 314 is formed by end sleeve 322, which is threadably coupled at 324 to top sub 326. Closure sleeve 314 includes an inwardly extending shoulder 328 adapted to engage an upper skirt 330, which is coupled by means of a shear pin 332 to dart 334.

Dart 334 may be of essentially the same configuration as described and depicted relative to dart 220 of Figure 3. Dart 334, as depicted, differs from dart 220 primarily in that it includes chevron-type seals 336, 338 rather than O-ring seals on its exterior surface.

Multi-position service tool 310 also includes an additional interior sleeve 340 extending within tool

mandrel 66. Interior sleeve 340 extends down to inwardly extending upset 342.

The operation of multi-position service tool 310 and closure assembly 312 during a perforating/gravel packing operation is as follows. Prior to insertion of closure assembly 312, the perforating gun will be actuated as described with respect to the embodiment of Figures 1-3. During such time, any fluid pressure generated by the perforating operation within the tubing string will be isolated from port 88 and annulus 72 by closure sleeve 314. Accordingly, there should be no risk of inadvertent setting of the packer through pressure generated by the perforating operation.

Subsequently, closure assembly 312 (dart 334 having skirt 330 attached thereto), will be placed in the well and allowed to seat in the position depicted in Figure 10A wherein sleeve 330 seats against shoulder 328 of closure sleeve 314. Pressure within the tubing string will then be evaluated to a first threshold level, for example, 500 psi (3448 KN/m^2), causing shearing of shear pin 320 and a downward shift of closure sleeve 314 until the lower extent of closure 314 hits the upper surface 344 of inner sleeve 340. Further movement of closure sleeve 314 will thereby be prevented.

Referring now also to Figure 11, the pressure within the tubing string may then be further elevated, for example, to 1,000 psi (6895 KN/m^2) to cause the shearing of shear pin 332, thereby separating dart assembly 334 from skirt 330. Skirt 330 will remain adjacent shifted closure sleeve 314, and dart assembly 334 will be allowed to move downwardly within multi-position running tool 310 until it seats as depicted in Figure 3 relative to the preceding embodiment. The pressure within the tubing string may then be further

elevated, for example, another 1,000 psi to 2,000 psi (6895 to 13790 KN/m^2) to cause setting of packer 26 in the manner previously described.

Many modifications and variations may be made in the techniques and structures described and illustrated herein without departing from the spirit and scope of the present invention. For example, designs may be envisioned where a downhole valve, manipulable either through wireline or fluid pressure, could be implemented to selectively close the interior bore of the tool string and to provide the crossover paths described herein. Additionally, many other types of closure mechanisms placed from the surface, other than the dart assembly described herein may be envisioned for establishing all or part of such crossover paths. Accordingly, it should be readily understood that the embodiments described and illustrated herein are illustrative only.

CLAIMS:

1. A gravel pack assembly for use in a tool string for gravel packing an annular area of a wellbore surrounding at least a portion of said tool string in said wellbore, said assembly adapted to be placed in said wellbore by being suspended from a tubing string; comprising: a packer assembly; a crossover assembly, said crossover assembly being selectively operable from a first state in which fluid communication is precluded between an interior bore of said crossover assembly and said annulus, and a second state wherein a first flow path is established communicating an upper interior portion of said crossover assembly with said annulus, and further being selectively manipulable to establish a second flow path from a lower interior portion of said crossover assembly to a wellbore annulus above said packer; a gravel pack screen disposed around a portion of said gravel pack assembly; a selectively operable valve member operable to allow fluid communication from the annulus in said wellbore exterior to said screen to a lower interior portion of said crossover assembly; and an operating mechanism selectively engageable with said crossover assembly to occlude fluid flow through said interior bore of said crossover assembly, at least in a first direction, and to operate said crossover assembly between said first and second states.

2. An assembly according to claim 1, wherein said operating mechanism comprises a probe assembly selectively insertable into said crossover assembly after said crossover assembly has been placed in said wellbore.

3. An apparatus according to claim 1 or 2, wherein said crossover assembly is manipulable between said first and second states in response to hydraulic pressure applied in said tubing string.

4. A method for gravel packing a wellbore using the assembly of claim 1, and for producing fluids from said wellbore on a single trip of said tool string into said wellbore, said method comprising the steps of: lowering said tool string into said well, said crossover assembly having an open bore therethrough selectively closing said open interior bore of said crossover assembly to set said packer at a first level of pressure in said tubing string; establishing a second pressure level in said tubing string, said second pressure level operating said crossover assembly to establish said first flow path; selectively operating said crossover tool to establish said second flow path; introducing a gravel slurry through said tubing string to said crossover assembly and thereby gravel packing said annulus surrounding said tool string; re-establishing said open bore through said crossover assembly without removing said crossover assembly from said wellbore; and producing fluids from said wellbore through said gravel packed annulus and through said crossover assembly.

5. A method according to claim 4, wherein said step of selectively closing said open bore of said crossover assembly is accomplished, at least in part, by placing a probe member in said tool string after said tool string is disposed in said wellbore.

6. A method according to claim 4 or 5, wherein said tool string further comprises a perforating assembly, and wherein said method further comprises the step of perforating said wellbore.

7. A method in accordance with claim 4, 5 or 6, wherein said step of selectively operating said crossover tool to establish said second flow path comprises the step of longitudinally moving a portion of said crossover tool.

8. A method in accordance with any one of claims 4 to 7, wherein said step of re-establishing said open bore through said crossover assembly is accomplished by disengaging a movable member from association with said crossover assembly.

9. An apparatus for using a tool string for perforating a formation penetrated by a wellbore and for gravel packing an annulus surrounding said tool string in said wellbore, said apparatus suspended from a tubing string, comprising: a first packer assembly; a crossover assembly selectively operable to provide a flow path from the interior of said tubing string at a location above said first packer assembly to the wellbore annulus below said first packer assembly, and selectively operable to provide a second flow path from the interior of said tool string below said first packer assembly to the annulus in said wellbore above said first packer assembly, said crossover assembly having an open bore therein; a perforating assembly selectively operable to perforate said formation, the said perforating assembly being operable in response optionally to either mechanical impact or fluid pressure; and an operating mechanism associatable with said crossover assembly for selectively closing said open bore and for selectively operating said crossover tool to establish, at least in part, said first and second flow paths.

10. An apparatus according to claim 9, wherein said operating mechanism comprises an assembly adapted to be placed in said crossover assembly after said crossover assembly is placed in said wellbore.

11. An apparatus according to claim 10, wherein said operating mechanism cooperatively engages a movable member in said crossover assembly to preclude downward flow of fluid through the interior of said crossover assembly at a first degree of pressure within said tubing string.

12. An apparatus according to claim 11, wherein said movable member of said crossover assembly is movable in response to a second level of pressure in said tubing string; wherein said movement will establish said first flow path.

13. An apparatus according to any one of claims 9 to 12, wherein said perforating assembly comprises a second packer assembly.

14. A method for perforating and gravel packing a wellbore using the apparatus of claim 9, and for producing fluids from said wellbore on a single trip of said tool string into said wellbore, said method comprising the steps of: lowering said tool string into said well; actuating said perforating assembly to perforate said formation; selectively closing said open interior bore of said crossover assembly to set said packer at a first level of pressure in said tubing string; establishing a second pressure level in said tubing string, said second pressure level operating said crossover assembly to establish said first flow path; selectively operating said crossover tool to establish said second flow path; introducing a gravel slurry through said tubing string to said crossover assembly and thereby gravel packing said annulus surrounding said tool string; re-establishing said open bore through said crossover assembly without removing said crossover assembly from said wellbore; and producing fluids from said wellbore through said gravel packed annulus and through said crossover assembly.

15. A method according to claim 14, wherein said step of selectively closing said open bore of said crossover assembly is accomplished, at least in part, by placing a probe member in said tool string after said tool string is disposed in said wellbore.

16. A method according to claim 14 or 15, wherein said perforating assembly comprises a packer, and wherein said method further comprises the steps of: setting said perforating assembly packer prior to said step of actuating said perforating assembly; and unsetting said perforating assembly packer subsequent to said step of actuating said perforating assembly.

17. An apparatus in accordance with claim 9, constructed and arranged for use and operation substantially as described herein with reference to the accompanying drawings.

18. A method of gravel packing using the assembly of claim 1, substantially as described herein.

19. A gravel pack assembly in accordance with claim 1 substantially as described herein.