

Sept. 20, 1971

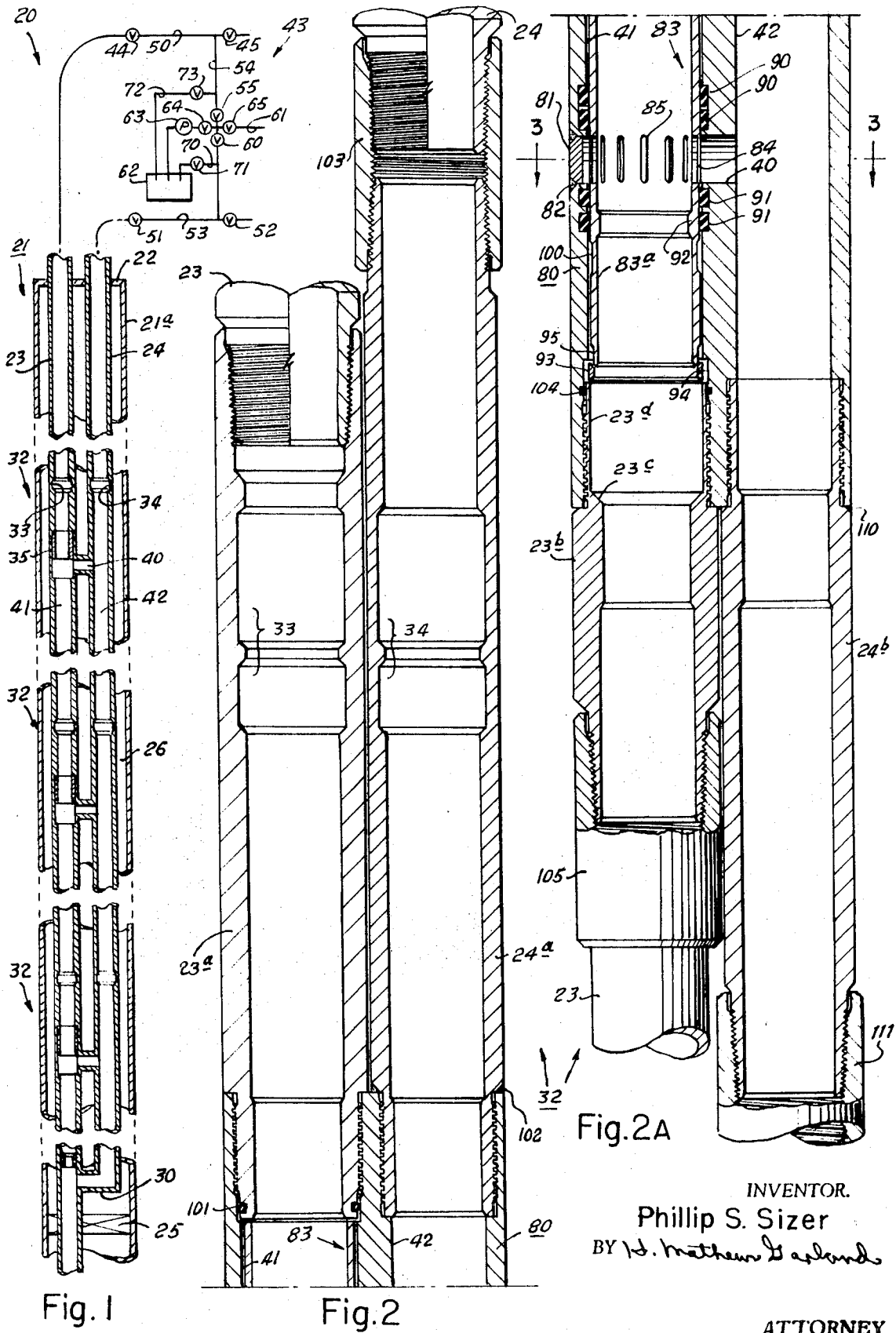
P. S. SIZER

3,606,584

WELL TOOLS

Filed Feb. 19, 1969

3 Sheets-Sheet 1



Sept. 20, 1971

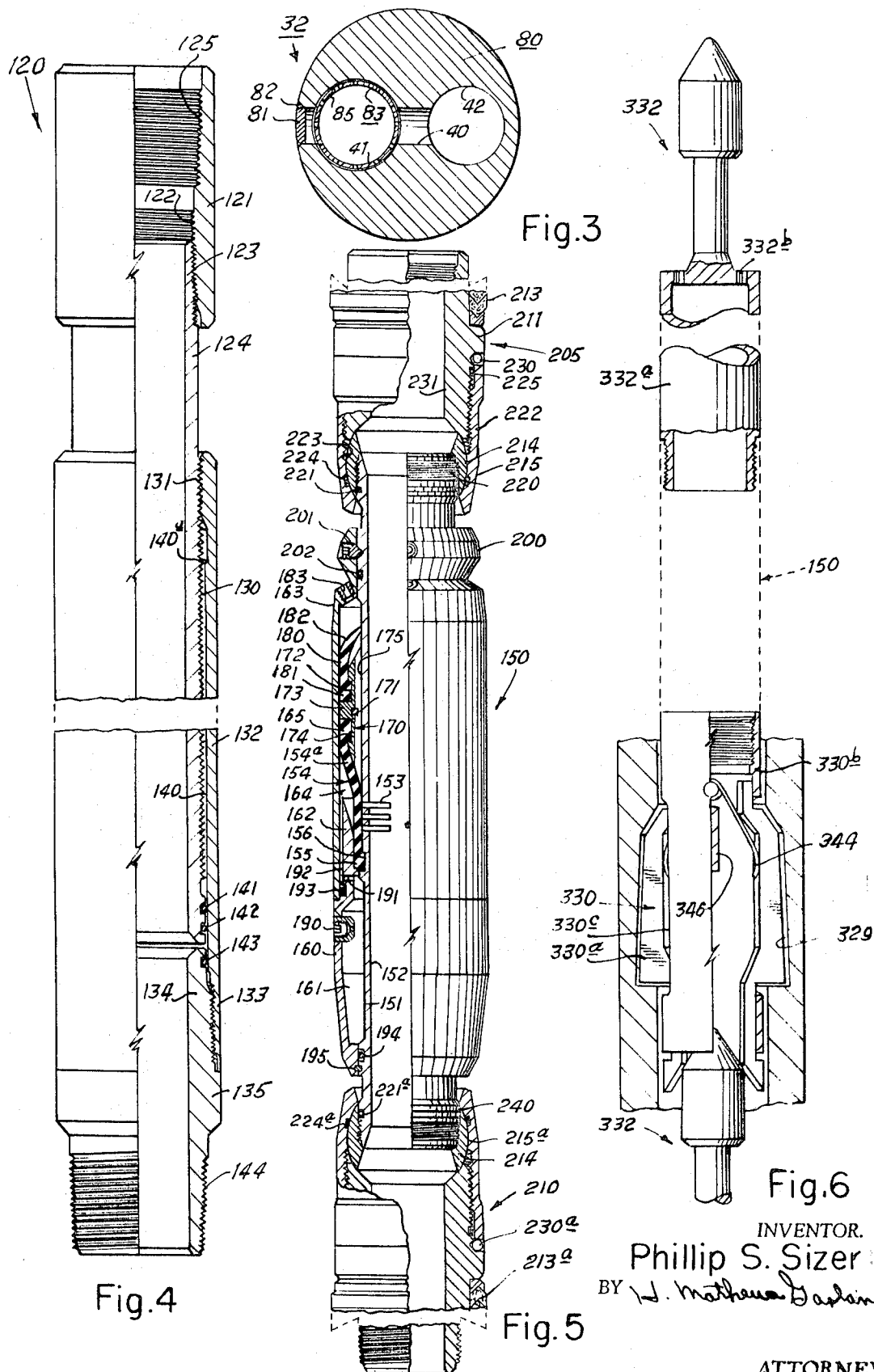
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WELL TOOLS

Filed Feb. 19, 1969

3 Sheets-Sheet 2



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WELL TOOLS

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3 Sheets-Sheet 3

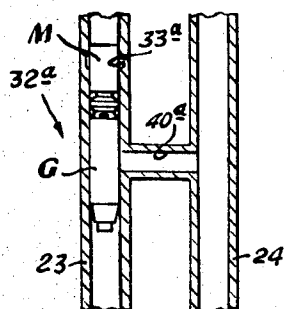


Fig. 7

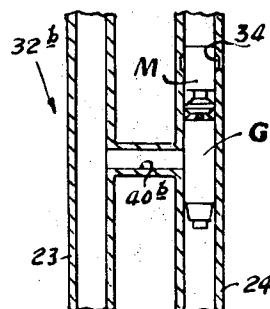


Fig. 8

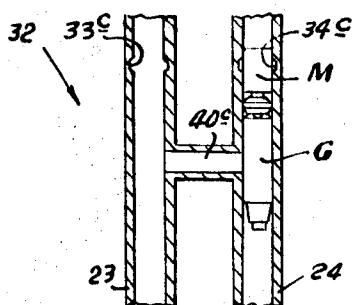


Fig. 9

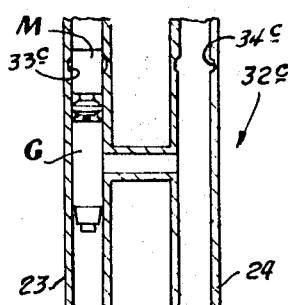


Fig. 10

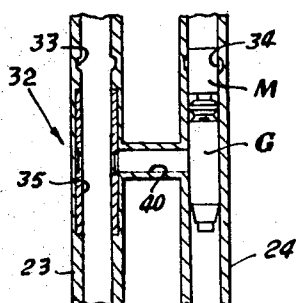


Fig. 11

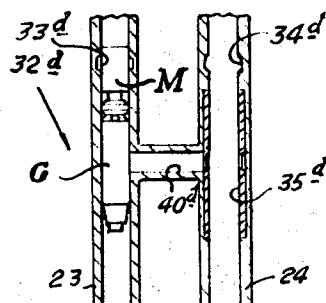


Fig. 12

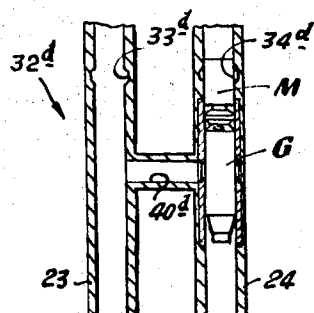


Fig. 13

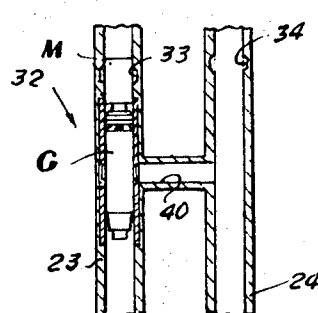


Fig. 14

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WELL TOOLS

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26 Claims

ABSTRACT OF THE DISCLOSURE

A well tool system, particularly adapted to producing wells by gas lift, including spaced parallel tubing strings interconnected by cross-over assemblies for introducing lift gas into a well through one tubing string and production of well fluids through the other tubing string independently of the casing annulus which may remain liquid full during the gas lift procedure.

This invention relates to well tools and more particularly relates to a well tool system especially adapted to production of wells by gas lift procedures.

It is an object of the invention to provide a well tool system for producing well fluids from a well.

It is a particularly important object of the invention to provide a system of well tools for producing wells by gas lift procedures.

It is another important object of the invention to provide a gas lift system for a well wherein the well may remain liquid filled around the well tubing while being produced by gas lift procedures.

It is another object of the invention to provide a gas lift system for a well wherein gas lift valves may be positioned within the main flow stream of injected lift gas to provide maximum protection to the gas lift and sleeve valves from the produced well fluids.

It is another object of the invention to provide a gas lift system wherein gas lift valves may be pumped between a surface installation and operating locations within a well.

It is another object of the invention to provide a well tool system particularly adapted to a gas lift procedure including a pair of well tubing strings for conducting lift gas into a well and removing production fluids from the well.

It is a further object of the invention to provide a gas lift system for wells including spaced parallel tubing strings interconnected by means providing communication between the strings to permit injection of lift gas into the well in one of the strings and the recovery of well fluids in the other of the strings.

It is another object of the invention to provide a new and improved gas lift system including parallel tubing strings interconnected at selected locations along their lengths by H-member cross-over assemblies for supporting gas lift valves and communicating the injection string with the production string through the valves.

It is another object of the invention to provide a gas lift system for wells wherein the injection and production flow passages are defined by interconnected inlet and outlet flow paths through the well which are independent of the annular space in the well around the well tubing strings so that the well may be operated with the annular space in a liquid-filled condition.

It is another object of the invention to provide a gas lift system including a gas lift valve adapted to be disposed in an injection gas lift flow passage for controlling the flow of lift gas from a central flow passage through the gas lift valve to a packed off annular space around the gas lift valve.

It is another object of the invention to provide a gas lift valve having a central injection gas flow passage and

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valve means for controlling flow of the lift gas outwardly to an annulus around the valve.

It is a still further object of the invention to provide a gas lift system utilizing a gas lift valve which is compatible with several known systems for pumping well tools to and from operating locations in a well from a surface installation.

It is still another object of the invention to provide a gas lift system including parallel interconnected tubing strings and a new and improved travel-limiting swivel joint for coupling sections of one of the tubing strings between the cross-over members.

It is still another object of the invention to provide a new and improved travel-limiting swivel joint for coupling pipe sections together.

It is another object of the invention to provide a gas lift system for wells comprising a pair of interconnected parallel tubing strings wherein a gas lift valve is supported at a landing nipple in the production string at the cross-over connection with the injection string and the injection string at such connection has a smooth full-bore opening.

It is another object of the invention to provide a gas lift system of the character described wherein a gas lift valve is supported in the injection string at a cross-over connection and the production string has a smooth full-bore opening at the cross-over connection.

It is another object of the invention to provide a gas lift system of the character described including a cross-over connection providing a landing nipple in both the injection and production strings at the connection and a gas lift valve is supported in the injection string.

It is another object of the invention to provide a gas lift system of the character described including a cross-over connection having landing nipples in both the injection and production strings and a gas lift valve in the production string at the connection.

It is another object of the invention to provide a gas lift system of the character described having a cross-over connection provided with a landing nipple and sliding sleeve valve in the production string at the connection and a landing nipple only in the injection side of the connection with a gas lift valve locked in the landing nipple in the injection side.

It is another object of the invention to provide a gas lift system of the character described including a cross-over connection having a landing nipple in the production string at the connection, a gas lift valve locked in the landing nipple in the production side, and a landing nipple including a sliding sleeve valve at the connection in the injection side.

It is another object of the invention to provide a gas lift system of the character described including a cross-over connection having a landing nipple in the production side at the connection and a landing nipple with a sliding sleeve valve in the gas injection side with a gas lift valve locked within the sleeve valve.

It is another object of the invention to provide a gas lift system of the character described including a cross-over connection having a smooth full bore opening in the gas injection side and a landing nipple with a sliding sleeve valve in the production side including a gas lift valve secured through the sliding sleeve valve.

Additional objects and advantages of the invention will be readily apparent from reading the following description of apparatus constructed in accordance with the invention and by reference to the accompanying drawings thereof wherein:

FIG. 1 is a schematic drawing, partially in section, of a gas lift system for a well embodying the invention;

FIGS. 2 and 2A taken together comprise a detailed longitudinal sectional view of a cross-over assembly for use in the well system of FIG. 1;

FIG. 3 is a sectional view along the line 3—3 of FIG. 2A;

FIG. 4 is a longitudinal view in section and elevation of a travel-limiting swivel joint used in the well system of FIG. 1;

FIG. 5 is a fragmentary, longitudinal view in section and elevation of a gas lift valve and upper and lower seal assemblies for use in a gas lift well system of the type shown in FIG. 1;

FIG. 6 is a fragmentary, longitudinal view in section and elevation of apparatus useful with the gas lift valve of FIG. 5 for pumping a gas lift valve into and out of the well system of FIG. 1 and for locking the valve in operating relationship within one of the tubing strings of the gas lift system;

FIG. 7 is a fragmentary view in section of one arrangement of a cross-over assembly in the system of FIG. 1;

FIG. 8 is a fragmentary view in section of another arrangement of a cross-over assembly in the system of FIG. 1;

FIG. 9 is a fragmentary view in section of another arrangement of a cross-over assembly of the system of FIG. 1;

FIG. 10 is a fragmentary view in section of another arrangement of a cross-over assembly of the system of FIG. 1;

FIG. 11 is a still further arrangement including a sliding sleeve valve of a cross-over assembly in the system of FIG. 1;

FIG. 12 is a fragmentary view in section of another arrangement of a cross-over assembly including a sleeve valve in the system of FIG. 1;

FIG. 13 is a fragmentary view in section of another arrangement of a cross-over assembly including a sleeve valve in the system of FIG. 1; and

FIG. 14 is a fragmentary view in section of a still further arrangement of a cross-over assembly including a sliding sleeve valve in the system of FIG. 1.

Referring to FIG. 1 of the drawings, a well system 20 embodying the invention is particularly adapted to production by gas lift procedures, may be connected with an offshore location, and is well suited to the remote installation and removal of gas lift valves by pumping methods. The well system includes a well 21 having a casing 21a which may extend downwardly through and be perforated at a producing formation, not shown, and is closed at its upper end by a well head 22. A pair of spaced parallel tubing strings 23 and 24 are supported in sealed relationship through the well head, the tubing string 23 extending downwardly through a suitable well packer 25 which seals around the tubing string within the casing above the producing formation. Above the packer the tubing string 24 is connected with the tubing string 23 by a conduit 30. The tubing strings communicate with each other at selected spaced depths within the well through a plurality of spaced H-shaped cross-over assemblies 32. The particular form of cross-over assembly shown schematically in FIG. 1 and illustrated in enlarged detail in FIGS. 2 and 2A has landing nipple recesses 33 and 34 and a sliding sleeve valve 35 which controls communication through a horizontal flow passage 40 connecting spaced vertical flow passages 41 and 42 which communicate with and form portions of the tubing strings 23 and 24, respectively. Each of the cross-over assemblies provides communication between the tubing strings at spaced locations along the lengths of the strings and also support gas lift valves and other desired well tools within the tubing strings. A collar stop 31 is secured in the tubing string 23 above the conduit 30 for use with pump-down tools as discussed in detail hereinafter.

The tubing strings 23 and 24 extend from the well head 22 to a remotely located shore installation 43 at which various control functions for operating the well system are carried out. The tubing string 23 is connected through spaced valves 44 and 45 defining a lubricator tubing sec-

tion 50 for the loading and unloading pumpable well tools. Similarly, the tubing string 24 includes valves 51 and 52 spaced to define a lubricator tubing section 53 in the tubing string 24 at the shore installation. The lubricator sections 50 and 53 communicate through a conduit 54 which connects into the lubricator sections near the valves 45 and 52, respectively, so that liquid may be pumped into the lubricators for displacing well tools from the lubricators through the tubing strings into the well. The conduit 54 is connected through a pair of spaced valves 55 and 60 between which a conduit 61 is connected into the conduit 54. The conduit 61 leads to a reservoir tank 62 through a pump 63 and includes valves 64 and 65 spaced on opposite sides of the conduit 54. A return line 70 including a valve 71 is connected from the tank 62 into the conduit 54 between the valve 60 and the connection of the conduit 54 into the lubricator section 53 of the tubing string 24. Similarly, a line 72 including a valve 73 is connected from the tank 62 into the conduit 54 between the valve 55 and the lubricator section 50 of the tubing string 23. The installation 43 provides facilities for pumping well tools such as gas lift valves to and from the landing nipples in the tubing strings and for directing lift gas into the well through one of the tubing strings while recovering well fluids from the well through the other of the tubing strings. During both the gas lift procedures and the steps of installing and removing well tools the casing annulus 26 within the casing 21a around the tubing strings may remain liquid full.

The preferred connections between the tubing strings 23 and 24 within the well comprise the H-shaped cross-over member 32 shown in detail in FIGS. 2 and 2A. The cross-over assembly includes a central cylindrical body 80 provided with spaced parallel vertical bores defining the flow passages 41 and 42 which communicate through the horizontal flow passage 40. The passage 40 is defined by a horizontal bore drilled in the body 80 from the outside of the body through the passage 41 with the opening formed in the outside wall of the body opening into passage 41 being closed by a plug 81 welded to the body 80 at 82. Flow between the vertical flow passages 41 and 42 in the body through the flow passage 40 is controlled by a sliding sleeve valve 83 which is slightly reduced in external diameter along a central portion 84 provided with a plurality of circumferentially spaced slots 85. Upper seal rings 90 and lower seal rings 91 are disposed in internal annular recesses within the body 80 above and below the bore 40 for sealing around the sleeve valve 83 so that when the valve is moved from the position shown in FIG. 8 downwardly to its lower end position fluid flow may not occur from the passage 40 into the sleeve 83. The sleeve 83 has an internal annular boss 92 for engagement of a sleeve shifting tool, not shown, for moving the sleeve valve between its upper open position and lower closed positions. The sleeve valve is releasably locked at its upper open position by a snap ring 93 disposed in an internal annular recess 94 in the body 80 around the bore 41 and received in an external locking recess 95 defined along the lower end portion of the sleeve 83. An upper external locking recess 100 of the sleeve 83 below the internal boss 92 receives the snap ring 93 when the valve sleeve is at its lower closed position for locking the valve at such position.

An upper tubing string section 23a is threaded into the upper end portion of the bore 41 of the body 80 with the upper end surface of the valve sleeve 83 being engageable with the lower end surface of the tubing section 23a to limit the upward travel of the sleeve valve at the position illustrated in FIGS. 2 and 2A. An O-ring seal 101 is disposed between the lower end portion of the tubing section 23a and the surface defining the bore 41 in the body to prevent leakage from the bore 41 outwardly along the connection between the body and the tubing section 23a. An upwardly extending section of the tubing string 23 is threaded into the upper end of the tubing section 23a,

FIG. 2. Similarly, an upper tubing section 24a is threaded along a lower end portion into the upper end of the bore 42 of the body and welded to the body at 102 to prevent leakage between the body and the tubing section. The locking recesses 33 and 34 as illustrated in FIG. 2 are formed within the upper tubing sections 23a and 24a respectively to provide for locking well tools such as gas lift valves in each side of the cross-over assembly as desired or required by the particular procedure to be carried out by the well system. Upwardly extending to portions of the tubing string 24 and connected by a coupling 103 to the upper end of the tubing section 24a.

A lower tubing section 23b is threaded into the lower end of the bore 41 of the body 80 with the upper end surface of the tubing section 23b supporting the snap ring 93 in its recess 94. An O-ring seal 104 is disposed in a recess of the body around the tubing section 23b and seals between the tubing section and the body at the connection of the tubing section into the body. An internal shoulder 23c limits downward travel of the sleeve valve which telescopes along its lower end portion 83a into the upper bore portion 23d of the section 23b when the sleeve valve is closed.

Downwardly extending portions of the tubing string 23 are connected to the lower tubing section 23b by a coupling 105. A lower tubing section 24b is threaded into the lower end of the bore 42 of the body 80 welded at 110 sealing between the body and the tubing section 24b. Downwardly extending sections of the tubing string 24, not shown in FIG. 2A, are coupled with the tubing section 24b by a coupling 111.

It will be evident in making up the pair of interconnected tubing strings 23 and 24 coupled by the cross-over assemblies 32 that after the cross-over assemblies are connected in one of the tubing strings the conduits comprising the other tubing string cannot be manipulated in the normal manner of a single tubing string thereby requiring special conduit couplings. For example, when running the tubing strings into the well, if the cross-over assemblies are made up in the tubing string 24, the assemblies along with the inter-connecting pipe sections of the tubing string 24 may be screwed together or assembled in the same manner as a single tubing string. However, it will be evident that after the cross-over assemblies are connected in the string 24 the assemblies cannot be rotated to make up the tool string 23. Thus, special coupling apparatus is needed in making-up the pair of tubing strings for connecting the second of the strings to be connected. This function is served by a travel-limiting swivel joint 120 shown in FIG. 4. The swivel joint includes an upper internally threaded coupling 121 secured by lower internal threads 122 on an upper externally threaded end portion 123 of an inner tubular mandrel 124. The coupling 121 has an upper set of internal threads 125 which have the same pitch as external threads 130 formed along a major lower portion of the inner mandrel 124. The threads 130 engage internal upper threads 131 formed within an outer mandrel 32 threaded along a lower end portion 133 on an upper externally threaded portion 134 of a lower coupling or bottom sub 135. Below its threads 131 the mandrel 132 has a smooth internal bore surface 140 which extends substantially the full distance between the upper internal threads 131 and the lower internally threaded end portion 133. O-rings 141 and 142 disposed in external annular recesses along the lower end portion of the mandrel 124 seal around the mandrel with the bore surface 140 at any position of the mandrel 124 within the mandrel 132 so long as the seal rings are below the shoulder 140a. An O-ring 143 is disposed in an external annular recess around the upper end portion of the coupling 135 above its upper external threaded section to seal around the coupling within the mandrel 132. The lower end portion of the coupling 135 has threads 144 for connection of the lower end of the swivel joint with a tubing string section.

The travel-limiting swivel joint 120 provides a conduit

coupling or joint which is adjustable in length over a distance equal to approximately the length of the smooth bore surface 140 of the mandrel 132. The swivel joint as shown in FIG. 4 is adjusted to its minimum length at which the mandrel 124 is telescoped into the mandrel 132 until the lower end of the mandrel is adjacent to the upper end of the lower coupling 135. The swivel joint is extended to its maximum length or any intermediate length by rotation of the mandrel 124 to unthread it from the lower mandrel 132. The mandrel 124 obviously cannot be unthreaded beyond the extended position at which the O-rings 141 and 142 are below the shoulder 140a in the bore of the lower mandrel. The direction of the threads on the inner mandrel upper end portion 123 is opposite to the direction of the threads 125 in the coupling 121 and 130 on the mandrel 124. For example, if the threads on the end portion 123 are left-hand threads, the threads 130 must be right-hand threads so that the coupling 121 may be rotated counterclockwise tending to tighten the coupling on the mandrel 124 while the mandrel 124 is being unthreaded out of the lower outer mandrel 132. With the threads 125 also right-hand threads the upper portion of the upper coupling 121 may be threaded on a tubing section above it, for example, to the lower threaded end portion of the section 23b of the cross-over assembly 32 as the coupling 121 tightens on the mandrel 124 and the mandrel 124 is unthreaded or extended upwardly in the mandrel 132.

The swivel joint 120 is particularly adapted to the preferred arrangement of tubing strings illustrated in FIG. 1 where a plurality of the cross-over assemblies 32 are included in and couple the tubing strings together in the well. In making up and lowering the parallel tubing strings in the well, one of the strings is made up in a conventional manner with the sections of pipe comprising the string being connected together as the strings are lowered into the well. The portion of the tubing string 23 below and extending through the packer 25 is made up by standard procedures and the packer and strings are lowered into the well with the string 23 and the lower end of the string 24 being connected by the horizontal coupling or connector 30. The tubing sections comprising each of the strings 23 and 24 are connected together in a conventional manner as the parallel strings are lowered into the well bore until the lowermost cross-over assembly 32 is connected into the strings. In connecting the cross-over assembly into the tubing strings, the assembly may be first coupled by means of the coupling 111, FIG. 2A, to the upper end of a section of pipe in the tubing string 24 with the cross-over assembly being tightened in the tubing string until its section 23d is aligned with the pipe sections comprising the string 23 below the cross-over assembly. Since the cross-over assembly cannot be rotated to tighten it on both the tubing string 23 and 24, sufficient pipe sections are connected into the tubing string 23 to extend the tubing string upwardly toward the cross-over assembly 32 until the upper end of the tubing string is spaced below the cross-over assembly a distance slightly greater than the minimum length of the swivel joint 120. The travel-limiting swivel joint 120 is then connected by its lower threaded portion 144 into a coupling, not shown, on the upper end of the uppermost pipe section comprising the tubing string 23 below the cross-over assembly. When the lower end portion 144 on the swivel joint is screwed into the coupling at the end of the uppermost pipe section forming the tubing string 23, the coupling 121 at the upper end of the swivel joint is spaced a short distance below the lower threaded end portion of the section 23b of the cross-over assembly. The swivel joint is then extended by turning the coupling 121 to screw the threads 125 of the coupling on the lower threaded end portion of the section 23b of the cross-over assembly. As the coupling 121 is rotated to screw it on to the section 23b, the opposite direction of the threads on the mandrel upper end portion 123 tends to tighten the coupling on

the mandrel and thus unscrew the mandrel 124 from the lower outer mandrel 132 because of the relation of the threads 130 and the threads 131. The mandrel is telescoped or extended upwardly relative to the mandrel 132 until the coupling 121 is tightly connected on the cross-over assembly section 23b.

The identical characteristics of the threads 125 and the threads 130 and 131 effect the exact corresponding movement of the coupling 121 onto the cross-over assembly and of the mandrel 124 relative to the mandrel 132. The seals 141 and 142 maintains a sealed relationship between the mandrel 124 and the mandrel 132 along the smooth inner bore surface 140 of the mandrel 132 as the mandrel 124 is telescoped upwardly in the mandrel 132 to complete the connection of the swivel joint in the tubing string 23. Thus, the travel-limiting joint permits the connection of pipe sections within the tubing strings between the cross-over assemblies. A travel-limiting swivel joint must be used in one of the tubing strings between each pair of cross-over assemblies in order to be able to connect the parallel tubing strings together and run them into the well. Other than in the use of the travel-limiting swivel joints, the various pipe sections, couplings, and other related equipment of the well system 20 and the installation 43 are conventional in structure and installation.

The well system 21 is useful with a variety of types of gas lift valves which may be landed and locked in either of the tubing strings at the cross-over assemblies depending upon the characteristics of the particular valve employed. In one preferred arrangement of the well system the tubing string 23 serves as the production string, the tubing string 24 functions as the gas injection string, and the gas lift valve illustrated in FIG. 5 is used at the cross-over assemblies to provide a system in which the gas lift valves are disposed in the lift gas injection path isolated to a maximum extent from the well fluids in the production string.

The gas lift valve 150 is landed and locked in each of the cross-over assemblies at which gas lift transfer may be desired from the tubing string used for gas injection through the cross-over assembly into the production tubing string. The gas lift valve has a tubular body 151 provided with a full bore opening 152 throughout its length for flow of injection gas through the valve and to allow other well tools to pass through the valve. The body has a plurality of circumferentially extending longitudinally spaced central slots 153 for exit of lift gas from the bore 152 outwardly from the body. Flow of gas from the bore through the slots 153 is controlled by a flexible tubular valve member 154 clamped along a lower thickened end portion 155 between the body and a lower tubular housing 160 secured on the body and defining an annular dome gas chamber 161 between the body and the housing. The housing 160 has an upper reduced portion 162 which telescopes into an upper tubular housing 163 secured in spaced relation around the body 151. The valve 154 is disposed in an annular space 164 between the mandrel and the housing 160. A thickened upper end portion 165 of the valve 154 is clamped against the inner wall of the upper housing member 163 by an annular retainer 170 secured by lock ring 171 along an enlarged longitudinally slotted portion 172 of the body 151. The lock ring 171 is disposed within a flange portion 173 of the retainer below which the retainer has an external annular recess 174 which receives the thickened portion 165 of the valve 154. The lower thickened portion 155 of the valve is clamped in annular recess 156 around the body by the portion 162 of the housing 160. The portion 172 of the mandrel 151 includes vertically extending circumferentially spaced slots 175 for directing lift gas from the valve 154 along the body.

A flexible tubular check valve 180 is clamped along a lower end portion 181 between the housing 163 and the retainer 170 above its flange 173. The check valve 180 has a free upper skirt portion 182 which is movable be-

tween a contracted relaxed position as shown in FIG. 5 to an expanded flared position, not shown, which allows upward flow past the check valve. At the contracted collapsed position shown the valve skirt lies against the upper tapered end surface of the enlarged slotted body portion 172 over the upper ends of the slots 175 to prevent back flow of fluids into the gas lift valve. One or more ports 183 open upwardly and outwardly through a shoulder 163a of the housing 163 for exit of the lift gas from the valve.

The annular space 161 between the housing 163 and the body 151 forms a dome gas chamber for dome gas to bias the central free portion 154a of the valve 154 toward the closed position over the slots 153 in the body. A fitting 190 in the housing 160 provides for injection of dome gas into the annular space 161. A small horizontal passage 191 communicates the reduced upper end portion of the dome gas chamber 161 with a longitudinal slot 192 along the reduced upper end portion 162 of the housing 160 for flow of dome gas from the chamber 161 upwardly into the annular space 164 around the valve 154.

An O-ring seal 193 disposed in an external annular recess at the lower end of the upper reduced end portion 162 of the housing 160 seals between the housing 160 and the internal surface of the lower portion of the upper housing 163. Similarly, an O-ring seal 194 is disposed in an external, annular recess around the body 151 sealing between the body and the lower end portion of the housing 160. The housing 160 is retained on the mandrel by a lock ring 195 disposed in aligned recesses in the body 151 and the housing 160 to lock the housing on the mandrel. The lock ring is inserted through a conventional slot, not shown, opening through the housing at the lock ring recess within the housing.

The upper, outer housing 163 has an enlarged portion 200 above the ports 183 through which a plurality of set screws 201 are threaded into aligned recesses on the body 151 to hold the housing 163 in position on the mandrel. An O-ring seal 202 disposed in an external, annular recess in the body seals between the body and the upper housing 163 below the set screws 201.

When the pressure of the dome gas exceeds the pressure of lift gas within the body bore 152 at the slots 153, the central portion 154a of the valve 154 is pressed over the slots 153 preventing outward flow of lift gas from the the gas lift valve body 151. An O-ring 221 seals within the bore 152 at the slots 153 exceeds the dome gas pressure the central portion of the valve 154 is expanded outwardly releasing lift gas to flow outwardly through the slots 153 and upwardly along the slots 175 around the mandrel within the retainer 170. The lift gas flows upwardly from slots 175 past the check valve 182 exiting from the gas lift valve through the ports 183.

Upper and lower seal assemblies 205 and 210, respectively, are pivotally secured on the gas lift valve for sealing above and below the valve within a flow conductor such as the flow strings 23 or 24 above and below the exit ports 183 so that the lift gas is discharged from the valve into an annular space defined within the flow conductor between the seals of the upper and lower seal assemblies. The upper seal assembly comprises a mandrel 211 having an upper threaded end portion 212 and supporting an annular seal 213 for sealing around the assembly within a flow conductor. A bore 211a of the mandrel communicates with the bore 152 of the gas lift valve. An annular ball member 214 having a spherical outer surface 215 is threaded on the upper end portion 220 of the gas lift valve body 151. An O-ring 21 seals within the ball member 214 around the body. A socket retainer 222 having an internal spherical surface 223 engaging the ball member 214 is threaded on the lower end portion of the mandrel 211 to pivotally retain the seal assembly on the upper end of the gas lift valve. An O-ring 224 seals within the cap retainer with the ball member 214 to prevent leakage along the ball joint. Another O-ring 225 seals between the cap member 222 and the mandrel 211. A ny-

lon ball 230 locks the cap member 222 on the mandrel 211. The ball 230 is installed after first adjusting the cap member on the mandrel to the proper position. A horizontal hole 231 is then drilled through the upper end portion of the cap and into the mandrel at the boundary between the cap and the mandrel. The lower half of the hole is drilled in the cap 222 and the upper half of the hole is in the mandrel 211. The nylon ball 230 is then tightly pressed into the hole to prevent the loosening of the screw connection between the cap 222 and the mandrel 211.

The lower seal assembly 210, pivotally connected on the lower end portion 240 of the mandrel 151, is identical in structure and assembly to the upper seal assembly 205 with the various parts of the lower seal assembly being referred to by the same reference numerals as those used in connection with the upper seal assembly and further identified with the subscript *a*. The structure of the lower seal assembly thus is not further described in detail in view of the above description of the upper seal assembly.

Each gas lift valve is locked in its cross-over assembly 32 by a suitable locking unit which may be one of a number of available locking units depending upon the particular technique to be employed in installing and retrieving the gas lift valves. The well system 20 and the surface installation 43 may be located and arranged so that wireline equipment and techniques may be used for installing and retrieving gas lift valves with commercially available locking mandrels. A suitable locking mandrel for wireline use is the Type X Otis Locking Mandrel illustrated at page 3766 of the 1968-69 Composite Catalog of Oil Field Equipment and Services, published by World Oil, Houston, Tex. In using the Type X Mandrel, the upper packing assembly 205 of the gas lift valve 150 is connected with the lower end of the locking mandrel by a suitable threaded coupling, not shown. The locking dogs of the mandrel are received in either the locking recess 33 of the tubing string 23 or the locking recess 34 of the tubing string 24. Obviously, the longitudinal dimensions and spacing of the various components of the locking mandrel and the gas lift valve are proportioned to position the gas lift valve in alignment with the cross-over assembly flow passage 40 thereby locating the upper and lower seal assemblies 205 and 210, respectively, above and below the cross-over flow passage so that lift gas injected through the valve travels through the passage 40 between the tubing string 24 side of the cross-over assembly and the production tubing string 23 side of the assembly.

If the gas lift valve 150 supported by a suitable locking mandrel is used in the preferred arrangement of the well system 21, with the tubing string 23 serving as the production string and string 24 as the gas lift injection string, a gas lift valve may be locked in the production string 24 at each cross-over assembly 32. The lowest gas lift valve to be installed in the string 24 is run, landed, and locked first with each subsequent valve up the string being individually installed until the last and top valve has been placed in its cross-over assembly. Of course, a complete round trip into and out of the tubing string is necessary for the wireline installation of each of the valves at, least with presently available equipment and techniques. It will be apparent that the profiles of the locking recesses, such as the locking recess 34 in the upper section 24a of the cross-over assembly, are designed compatible with the profile of the locking dogs on the locking mandrel so that the dogs are received in the locking recess for properly securing the gas lift valve by means of the mandrel at the desired position within the tubing string at the cross-over assembly. It is a well known expedient to provide a slightly different locking recess profile at each cross-over assembly with corresponding profiles on the locking mandrels of the gas lift valves so that each valve is lockable at only the cross-over assembly which has a locking recess corre-

sponding with the locking dogs on the mandrel supporting the gas lift valve.

It will be evident that the sliding sleeve valve 35 in each cross-over assembly must be either open or closed depending upon whether or not a gas lift valve is in the other side of the cross-over assembly, and, if present, whether the valve is to be functional in gas lift procedures in the well system. Using wireline procedures for installation of the gas lift valves eliminates the need for a pre-adjustment of the sliding sleeves before valve installation, though they must be open or closed prior to gas lift injection, depending upon which valves are to function. At each cross-over assembly the sleeve 35 is open after a gas lift valve has been landed and locked in the cross-over assembly and gas is to be admitted through the valve to the production string. If the gas lift valve is present but is not to be presently used for gas lift admission, the sleeve valve in the cross-over assembly holding the gas lift valve may be closed. Where a gas lift valve is not required in a particular cross-over assembly the sleeve valve is closed to prevent by-pass of lift gas directly from the injection string 24 into the production string 23. Where the gas lift valves are installed and retrieved by wireline methods, the sleeve valves in the cross-over assemblies likewise may be manipulated by wireline apparatus and procedures. For example, at page 3774 of the Composite Catalog of Oil Field Equipment and Services, supra, a type B Otis Positioning Tool is illustrated which may be used to shift the sleeves 83 between their open and closed positions. Obviously, the profile of the shifting keys of the positioning tool must conform to the internal profile of the sleeve so that the tool keys may engage and properly release from the sleeve for raising and lowering the sleeve in the cross-over assembly.

Another technique and system which may be adapted to installing and removing the gas lift valves 150 in the cross-over assemblies of the well system 21 are illustrated and described in United States Patent 3,334,690 issued to H. U. Garrett, Aug. 8, 1967. The use of the Garrett system and apparatus is one of several available approaches to the installation of gas lift valves by pump-down procedures when wireline techniques are not practical or particularly desired and especially in offshore installations as where the installation 43 is removed from above the well system 21. As previously noted, the installation 43 may be at a shore location while the well system 21 is horizontally removed at a subsea location with its well head 22 at or near the ocean bed surface. FIG. 6 illustrates the Garrett apparatus adapted to gas lift valves 150 so that a plurality of the gas lift valves may be installed in the tubing string 24 in a single operation including one run of the tool string containing the gas lift valves.

Referring to FIG. 6, each gas lift valve 150 is adapted to the Garrett apparatus by fitting it with a locking dog assembly 330 threaded on the lower end of the seal assembly 210 and a fishing head 332 threaded on the upper end of the seal assembly 205. The dog assembly includes a pair of radially expandable and contractable dogs 337a disposed within a tubular housing 330b threaded on the lower end of the lower seal assembly 210. The dogs 337a are biased outwardly by a spring 344 and they expand and contract through windows 330c in the housing 330b. The outer profiles of the dogs are receivable in a locking recess 329 provided in a modified form of the cross-over assembly 32 below the horizontal flow passage 40 on the tubing string 24 side of the assembly for locking the gas lift valve at an operating location in each cross-over assembly. The inner edge surfaces of the locking dogs have profiles which are shaped to secure the dog assembly on the fishing head of a gas lift valve in the tool train immediately below. The fishing head is inserted into the dogs when they are expanded as shown in FIG. 6. When the tool train is inserted into the tubing string the wall of the tubing holds the dogs inwardly locking the fishing head in the dog assembly until a recess 329 is

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reached when one gas lift valve locks at the recess and the fishing head of the next valve is released to allow the tool train to continue. A complete tool train of the gas lift valves 150 with the Garrett apparatus includes the Garrett piston 76 for powering or pumping the tool train through the tubing string. The fishing head body 332a has a plurality of ports 332b to permit fluid flow through the fishing head and the gas lift valve as the gas lift valve is pushed through a tubing string. As the tool train is pumped in the tubing string the dogs 337a are held inwardly by the wall of the tubing until they arrive at a locking recess 329 which permits the dogs to expand with their outer profiles being received within the locking recess to lock the gas lift valve in the tubing at the cross-over assembly so that the valve itself and its upper and lower seal assemblies are properly positioned to direct lift gas through the horizontal flow passage 40 of the cross-over assembly. When the valve dogs expand to lock it at a recess 329, the fishing head of the valve immediately there-below is released by the expansion of the dogs so that the lower valve may continue its downward movement until it arrives at the next locking recess for release and locking at the next cross-over assembly. The profile of the locking dogs and the locking recesses 329 are correlated so that the uppermost valve is released and locked in the uppermost cross-over assembly with the valves then being sequentially released and locked as the tool train moves down the tubing string.

The tool train comprising the plurality of gas lift valves with the Garrett power piston 76 is introduced into the installation 43 at the lubricator section 53 for pumping into the tubing string 24. With the valve 51 closed and the valve 52 open, the tool string is introduced into the open end of the lubricator section of the tubing string. When the string is fully in the lubricator section the valve 52 is closed, the valve 51 is opened, and fluid circulation through the well system 21 is established. The tool train is pumped into the tubing string by a liquid such as water or oil from the reservoir tank 62, the liquid having been previously introduced into the tank through open valves 64 and 65 and the pump 63. The valves 71, 55, and 65 are closed, and the valves 60 and 64 are opened so that the pump 63 draws liquid from the tank 62 discharging it through the open valve 64 and the valve 60 in the conduit 54 into the outward end of the lubricator portion 53 displacing the tool train through the open valve 51 into the tubing string 24. Liquid in the tubing string 24 is displaced at the lower end of the string across through the member 30 into the lower end of the tubing string 23 and upwardly through the tubing string back toward the surface installation 43. The valves 45 and 55 are closed and the valves 44 and 73 are open so that liquid in the tubing string 23 is returned through the lubricator section 50 and the portion of the conduit 54 between the valve 55 and the lubricator section and the conduit 72 back to the reservoir tank 62. Thus, a complete closed fluid circulation path is established from the tank 62 through the tubing string 24 with returns through the tubing string 23 to the tank.

The tool string is displaced downwardly in tubing string 24 with the several gas lift valves in the tool string being released and locked at the cross-over assemblies in accordance with the teachings of the Garrett patent which may be referred to for further details of the manner of operation of the Garrett pump-down system. The sleeve valves 35 in each of the cross-over assemblies may be open or closed during pumping of the tool string downwardly in the tubing string 24. If the sleeve valves are open as the tool train passes each of the cross-over assemblies and releases and locks a gas lift valve, the passage 40 is closed by the valve, and if the displacing liquid pressure is below the opening pressure for the gas lift valve no bypassing occurs. If desired the sleeve valves may be first closed by any suitable means and subsequent to the setting of the gas lift valves the sleeve valves are reopened. Leaving the

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sleeve valve open during the setting procedure would reduce the round trips into the well, however.

With the gas lift valves locked in the cross-over assemblies and the sliding sleeve valves open, the tool pumping equipment of the system is isolated from the remainder of the well system at the surface installation 43 by closure of the valves 60, 71, 55, and 73 preparatory to initiation of gas lift procedures in the well system. With the gas lift valves supported as indicated in the tubing string 24, lift gas from a suitable source, not shown, is forced through the tubing string 24 downwardly through the gas lift valves. In accordance with known procedures and prior to the installation of the gas lift valves, the pressure the valves should be adjusted to open is determined and the dome gas pressure in the chamber 161 of each valve is established at a value which will provide for the opening of the valve 154 at such pressure. Generally, it is preferred that the uppermost valves such as the first and second valves highest in the well initially function with the lower valves being available for future use if and when the liquid level in the well is lowered. The lift gas is forced downwardly in the tubing string 24 into the central bores 152 through the gas lift valves and when the pressure of the lift gas is sufficient to overcome the dome gas pressure in the chamber portion 164 around the valve 154, the central portion of the valve is expanded outwardly uncovering the slots 153 allowing the lift gas to flow upwardly through the slots 175 past the check valve 182 exiting from the valve through the ports 183 into the cross-over assembly bore 42 between the upper and lower lift valve seal assembly 205 and 210. The gas flows laterally through the horizontal flow passage 40 in the cross-over assembly and the ports 85 in the open sleeve valve 83 entering the production tubing bore of the sleeve valve displacing well liquids upwardly in the production tubing string 23 and from the well through the tubing string to the surface installation 43. The well fluids are produced through the tubing string 23 to liquid storage and treatment facilities, such as separators and the like, not shown, downstream from the valve 45. The tubing strings 24 and 23 communicating through the cross-over assemblies thus define a closed circuit flow path or paths within the well for the gas injection and well fluids recovery which are isolated from surrounding spaces in the well such as the annulus 26 within the well casing around the tubing strings. The annulus 26 may thus be maintained liquid filled and if desired, could be filled with cement surrounding the tubing strings. It will be recognized that if it should be desired that the tubing strings be cemented in the well, the well casing 21a could be dispensed with.

Other available gas lift valves may be installed in the well system 21 either by wireline procedures or pump-down procedures depending upon the arrangement of the well system with the installation 43 and the types of gas lift valves to be used. For example, the Otis Type C Gas Lift Valve may be installed in the production tubing string where the other of the strings is to be used for lift gas injection. At page 3850 of the Composite Catalog of Oil Field Equipment and Services, supra, the Type C Gas Lift Valve is illustrated in use in a mandrel having a sliding sleeve valve of the nature of the valve 35 represented diagrammatically in FIG. 1. With the Otis Type C Gas Lift Valve installed in each of the crossover assemblies 32 of the well system 21, the lift gas is injected in the tubing string 24 from which it flows through the passage 40 in each cross-over assembly into the tubing string 23 around the gas lift valve between its upper and lower packing sections. The gas flows inwardly through the gas lift valve in the manner illustrated in the reference with well fluids being produced by the lift gas through the tubing string 23.

Another type gas lift valve which may be utilized in the producing string of the system 21 with gas injection being effected in the other of the parallel interconnected strings is illustrated and described in United States Patent

3,375,847 issued to Norman F. Brown, Apr. 2, 1968. The Brown gas lift valve is flexible and thus readily traverses curves in a tubing string making it especially desirable for offshore operations where it is delivered and retrieved from a land based installation through tubing strings having curved portions such as the tubing strings 23 and 24. As pointed out in the Brown patent, the valve may be installed by either wireline procedures or pump-down procedures as explained therein. Obviously, for the well system 21 to receive the Brown gas lift valves the cross-over assemblies 32 must be provided with locking recesses having proper profiles and properly positioned to accept the locking dogs and selector keys shown in FIG. 2 of the Brown patent. In positioning the Brown gas lift valve in the well system, it will also be noted that the locking assembly of the Brown patent with its upper seal assembly 71 is located above the cross-over passage 40 of the cross-over assembly while the lower packing 184 of the Brown valve is located below the cross-over passage so that lift gas entering from the parallel tubing string will be directed between the upper and lower packing to the admitting ports 153 of the Brown valve. With the particular equipment illustrated in the Brown patent such valves are installed and retrieved individually thus requiring a complete round trip for each valve in the system.

When the gas lift valves used in the well system 21 are of the type which are installed and retrieved by pump-down procedures, it is particularly desirable that the sleeve valves of the cross-over assemblies be movable between their open and closed positions by pump-down sleeve shifting apparatus. One such set of tools is illustrated and described in a United States patent application Ser. No. 709,652, entitled Well Tools, filed by Harry E. Schwegman on the first day of March 1968. The Schwegman sleeve shifting tools are adapted to shift the sleeve valves in either an upward or a downward direction and may be assembled in a single tool train for down-shifting during a downward trip of the train and up-shifting during the return or upward trip of the tool train. Under some circumstances the sleeve shifting tools are included in a tool train with gas lift valves and their latch assemblies for shifting the sleeve valves downwardly closed during the downward trip of the tool train and moving them back upwardly open as the tool train returns to the surface dropping off or releasing and locking a gas lift valve at each cross-over assembly.

Another system of gas lift valves and related equipment for the installation and retrieval of the valves along with the shifting of sleeves at the landing nipples supporting the valves in the tubing strings are illustrated and described in U.S. Pats. 3,419,074 and 3,419,075, both entitled "Well Tools" issued on Dec. 31, 1968, to Norman F. Brown. The valves and other equipment described and claimed in the Brown patents may be used in the production string of the present system 21 with lift gas injection in the parallel tubing string and the lift gas flowing across into the production string through the cross-over assemblies as previously explained. Those forms of the gas lift system of the present invention using the Brown valves and installation and retrieval equipment and techniques are operated during the gas lift phases as previously described.

The several gas lift valves and the equipment and techniques for installation and retrieval of such valves already described in terms of their use in the particular arrangement of the well system 21 shown in FIG. 1 are also applicable to the variations of the well system represented in FIGS. 7 through 14. The variations shown in FIGS. 7 through 14 represents different forms of only the cross-over assemblies of the well system and the location of the gas lift valve.

It will be apparent that FIGS. 11 and 14 correspond with the system 21 as shown in FIG. 1. FIG. 11 schematically shows a gas lift valve G and related supporting and sealing equipment M locked in the tubing string

24 side of the cross-over assembly and the sleeve valve on the tubing string 23 side. FIG. 14 shows the same cross-over assembly arrangement with the gas lift valve, however, supported through the sleeve valve in the tubing string 23 side.

FIG. 7 shows a cross-over assembly 32a having a locking recess 33a on the tubing string 23 side of the assembly and a smooth bore on the tubing string 24 side of the assembly interconnected by the cross-over flow passage 40A. The gas lift valve G including its upper and lower seal assemblies is shown supported from the locking mandrel M in the tubing string 23 side of the cross-over assembly. FIG. 8 shows a cross-over assembly 32b for use in the well system having a smooth bore on the tubing string 23 side of the assembly with a locking recess 34a on the tubing string 24 side of the assembly for the locking mandrel M supporting the gas lift valve G.

The cross-over assembly 32c shown in FIGS. 9 and 10 includes a locking recess in the tubing string 23 side of the assembly and a locking recess 34c in the tubing string 24 side of the assembly. In the system represented in FIG. 9 the gas lift valve G is supported in the tubing string 24 side of the assembly while in FIG. 10 the gas lift valve is supported in the tubing string 23 side of the assembly.

While the embodiments represented in FIGS. 7 through 10 show different gas lift valve locations and different locking recess arrangements at the cross-over assemblies, it will be particularly noted that no sliding sleeve valves are shown in any of the cross-over assembly arrangements. It will be apparent, therefore, that each gas lift system having parallel tubing strings interconnected as shown in FIGS. 7 through 10 will require a gas lift valve at each cross-over assembly for controlling communication between the tubing strings assembly, at least at all depths at which the gas injection into the production string is expected to take place. Below such depths there is no particular objection to free communication between the tubing strings. It will be especially noted that the tubing strings are in continuous communication at their lower ends through the cross member 30 in all forms of the well system represented herein.

Other arrangements of cross-over assemblies for use in the well system are represented in FIGS. 11 through 14 all of which utilize a sliding sleeve valve, with FIGS. 11 and 14 showing the same cross-over assembly 32 as represented in FIG. 1. In FIG. 11 the gas lift valve G is supported in the tubing string 24 side of the assembly while in FIG. 14 it is supported through the sleeve valve in the tubing string 23 side of the assembly. In FIG. 12 the cross-over assembly form 32d has the locking recess 33d on the tubing string 23 side with the sleeve valve 35d and the locking recess 34d on the tubing string 24 side. The gas lift valve G is supported on the tubing string 23 side of the cross-over assembly. FIG. 13 shows the same cross-over assembly arrangement as in FIG. 12 with the gas lift valve, however, supported on the tubing string 24 side of the assembly through the sliding sleeve valve. It will be apparent in the systems shown in FIGS. 11 through 14 that the sliding sleeve may be closed to prevent communication between the tubing strings at those cross-over assemblies where a gas lift valve is not set or where it is desired that the gas lift valve not presently be functional. Obviously, where the gas lift valve is situated through the sleeve, the sleeve is not readily shiftable between open and closed positions so long as the gas lift valve is locked in place in the sleeve. Another requirement for sliding sleeve valves in well systems of the nature described herein is encountered where pump-down procedures are used for gas lift valve installation and retrieval. A sleeve valve is needed at each cross-over assembly to properly direct displacing liquid for pumping the tool along the tubing strings. The sleeves must be closed behind the tool train during installation and ahead of the train during retrieval to prevent by-passing of the liquid between the tubing

strings without pumping the tool train, as already explained.

In all of the variations of the cross-over assembly arrangement shown in FIGS. 7 through 14, the type of gas lift valve used depends upon whether the valve is located in the production or lift gas side of the assembly. If a gas lift valve of the nature of the valve 150 shown in FIG. 5 is used, it is placed in the injection string side, while any of the other valves referred to herein as usable on the production side are placed on the production string side and the well is produced through the gas lift valve. It will be obvious that other arrangements of locking recesses and sleeve valves at cross-over assemblies may be devised. The particular choice of a cross-over assembly arrangement may depend on available equipment, well conditions, and other considerations. Obviously, those forms using sliding sleeve valves and locking recesses on both sides of the cross-over assemblies offer more flexibility in well system arrangement. The form of cross-over assemblies represented in FIGS. 7 and 8 preclude the setting of a gas lift valve in the side of the assembly having the smooth bore except by use of a form of locking mandrel having slips adapted to engage the smooth bore wall creating, of course, problems in properly locating the gas lift valve at the cross-over assembly. However, where it is intended to always locate the gas lift valves in one particular side of the well system, the forms shown in FIGS. 7 and 8 should be quite satisfactory.

It has been stated that a particular advantage of the well system of the invention is the reduction of the paraffin and sand problems, particularly in those forms of the well system where the gas lift valves are supported in the lift gas injection string and especially where the sliding sleeve valves are also located in the lift gas injection string with the gas lift valves supported through them as particularly shown in FIG. 13. While paraffin problems are encountered at relatively shallow depths where the paraffin tends to solidify on the well tools and equipment, sand problems may be encountered at all depths where sand is entrained in the producing well fluids and thus tends to clog well equipment. With the sleeve valves and gas lift valves in the lift gas injection side of the well system, flowing particles of sand which may foul the sleeve valves and hinder their movement are largely limited to the production string side of the system and thus the sleeve valves are provided with maximum protection. Both the sand and paraffin are kept to a maximum extent away from both the sleeve valves and the gas lift valves. The pressure of the lift gas in the injection string side of the system tends to depress the liquid level in the injection string with the injection and tubing strings serving as a "U-tube" so that the liquid level remains substantially lower in the injection string than in the production string. The possibilities of sand getting to the gas lift valves is very much minimized and generally only the upper-most valves are within the paraffin range and they are generally isolated from the liquid by virtue of the depression of the liquid level in the injection gas side. Further advantages inherent in the well system having the gas lift valves in the injection string provide a full bore flow passage throughout the length of the production string thereby substantially reducing the pressure drop in the production fluids as they flow upwardly in the production string so that maximum production is obtained under given well conditions. This is to be distinguished from the normal gas lift system in which each gas lift valve in a production string provides a substantial restriction in the flow passage. Also, the unrestricted flow passage provided throughout the length of the production string permits the pumping of a paraffin scraper or plug type well tool downwardly in the production string to displace paraffin deposits to a depth at which they readily melt and can be produced from the well with the well fluids. Over a period of time, paraffin deposits at the upper levels in the production string often seriously obstruct fluid flow in the

string. A still further advantage of supporting the gas lift valves in the lift gas injection string rather than in the production string is that the valves can be retrieved without encountering paraffin deposits since the valves are inserted and withdrawn from the surface through the tubing string functioning for lift gas injection.

From the foregoing description and the drawings, it will be seen that the present invention provides a well system particularly adapted to production by gas lift wherein lift gas is injected into a well through one tubing string while well fluids are produced in an adjacent interconnected tubing string whereby the lift gas injection and production tubing strings may be cemented in the well, or alternatively, if an annular space exists in the well around the tubing strings it may be maintained in a liquid filled condition. The invention provides maximum flexibility in well equipment arrangement and gas lift valve location within the broad concepts of separate tubing strings for gas lift injection and well fluid production. In particular forms of the well system described and illustrated, the gas lift valves are situated in the tubing string used for lift gas injection thereby providing maximum protection from sand and paraffin conditions to the gas lift valves and also to such other equipment as sliding sleeve valves if present in the lift gas side of the system. Further, a new and novel gas lift valve particularly adapted to use in the lift gas side of the well system with lift gas being injected through a central flow passage in the gas lift valve has been described and illustrated. The gas lift system is compatible with a number of available gas lift valves and equipment and techniques for installation and retrieval of the lift valves. Cross-over assemblies for interconnection of parallel tubing strings in a well have been illustrated particularly for use in gas lift systems embodying the invention. A novel travel-limiting swivel joint has been described and illustrated for connecting tubing strings of a well system employing parallel tubing strings which normally present problems in making up the second of the tubing strings to be connected and run. The travel-limiting swivel joint enables connections to be completed between spaced cross-over assemblies which cannot be rotated during the making-up of the tubing strings. The well system accommodates either wireline or pump-down procedures for gas lift valve installation and removal depending upon the particular arrangement of the well and the surface installation. Either tubing string in the system may be used for lift gas injection while the other string serves for the production of well fluids.

The foregoing description of the invention is explanatory only and changes in the details of the construction illustrated may be made by those skilled in the art within the scope of the appended claims without departing from the spirit of the invention.

What is claimed and desired to be secured by Letters Patent is:

1. A well system comprising: means comprising a first tubing string defining a first flow passage along a well; means comprising a second tubing string defining a second flow passage along said well; said flow passages being disposed in substantially parallel transversely spaced side-by-side relationship isolated from an annular space in said well around said flow passage; means connecting said first and second tubing strings and providing a cross-over passage interconnecting said first and second flow passages; each of said tubing strings being provided with a locking recess for a well tool locking mandrel for locking a well tool in either of said tubing strings at said cross-over passage; one of said tubing strings being provided with a sliding sleeve valve at said cross-over passage movable between open and closed positions for controlling communication between said tubing strings through said cross-over passage; and a gas lift valve located in the tubing string opposite the tubing string in which said sleeve valve is disposed for controlling communication between said first and second flow passages

through said crossover passage responsive to a predetermined fluid pressure in at least one of said first and second flow passages.

2. A well system comprising: means comprising a first tubing string defining a first flow passage along a well; means comprising a second tubing string defining a second flow passage along said well; said flow passages being disposed in substantially parallel transversely spaced side-by-side relationship isolated from an annular space in said well around said passages; means interconnecting said first and second tubing strings providing a cross-over passage within said well interconnecting said first and second flow passages; each of said tubing strings being provided with a locking recess for a well tool locking mandrel for locking a well tool in either of said tubing strings at said cross-over passage; each of said first and said second tubing strings being provided with a sliding sleeve valve movable between open and closed positions for controlling communication between said tubing strings through said cross-over passage; and valve means for controlling communication between said first and second passages through said cross-over passage responsive to a predetermined fluid pressure in at least one of said first and second flow passages.

3. A well system comprising: means comprising a first tubing string defining a first flow passage along a well; means comprising a second tubing string providing a second flow passage along said well; said flow passages being disposed in substantially parallel transversely spaced side-by-side relationship isolated from an annular space in said well around said flow passages; means interconnecting said tubing strings defining a cross-over passage within said well interconnecting said first and second flow passages; each of said tubing strings being provided with a locking recess for a well tool locking mandrel for locking a well tool in either of said tubing strings at said cross-over passage; a gas lift valve supported in the tubing string through which lift gas is injected into said well system and well fluids are produced from said well in the other of said tubing strings by said lift gas admitted through said cross-over passage to said other tubing string by said gas lift valve; said gas lift valve being provided with a central longitudinally extending passage substantially the diameter of the flow passage along the tubing string in which said valve is disposed and extending the full length of the said valve for flow of fluids including lift gas through said gas lift valve and to permit movement of well tools through said gas lift valve, valve means providing for control of outward flow of lift gas from said central passage, and port means for exhaust of said lift gas outwardly from said valve to said cross-over passage to said production string.

4. A well system for producing and servicing a well comprising: a first tubing string supported in said well communicating with a producing formation intersected by said well, a second tubing string supported in said well extending in side-by-side substantially parallel relationship with said first tubing string, said second tubing string being connected into said first string whereby one of said strings may provide an input flow passage and the other of said strings a return flow passage for pumping well tools into and out of each of said tubing strings; one of said tubing strings providing a flow passage for the recovery of well fluids from said well; the other of said tubing strings providing a flow passage for the injection of lift gas into said well; said flow passages in said tubing strings being isolated from an annular space around said tubing strings within said well; a plurality of cross-over connections included in said tubing strings at spaced intervals along the length of said strings, each cross-over connection providing a flow passage interconnecting said tubing strings for conducting lift gas from the tubing string into which lift gas is injected into said well into the tubing string through which well fluids are produced from said well.

5. A well system for producing and servicing a well comprising: a first tubing string supported in said well communicating with a producing formation intersected by said well, a second tubing string supported in said well extending in side-by-side substantially parallel relationship with said first tubing string communicating along a lower portion thereof with said first tubing string, said second tubing string being closable at a location below connections provided between said tubing strings whereby well tools are pumpable into and out of each of said tubing strings by fluid introduced into one of said tubing strings at the surface and returned to the surface through the other of said tubing strings; one of said tubing strings providing a flow passage for the recovery of well fluids from said well; the other of said tubing strings providing a flow passage for the injection of lift gas into said well; said flow passages in said tubing strings being isolated from an annular space around said tubing strings within said well; a plurality of cross-over connections included in said tubing strings at spaced intervals along the length of said strings, each cross-over connection providing a flow passage interconnecting said tubing strings for conducting lift gas from the tubing string into which lift gas is injected into said well into the tubing string through which well fluids are produced from said well.

6. A well system as defined in claim 5 including a surface installation provided with means for selectively pumping into either of said tubing strings in said well while receiving fluid returns from the other of said tubing strings.

7. A well system as defined in claim 6 including means for inserting and withdrawing well tool strings for pumping said well tool strings into and out of either of said tubing strings in said well whereby well tools are installed in and retrieved from said tubing strings from said surface installation.

8. A well system for producing and servicing a well comprising: a first tubing string supported in said well; a second tubing string supported in said well extending in side-by-side substantially parallel relationship with said first tubing string; one of said tubing strings providing a flow passage for the recovery of well fluids from said well; the other of said tubing strings providing a flow passage for the injection of lift gas into said well; said flow passages in said tubing strings being isolated from an annular space around said tubing strings within said well; a plurality of cross-over connections included in said tubing strings at spaced intervals along the length of said strings, each cross-over connection providing a flow passage interconnecting said tubing strings for conducting lift gas from the tubing string into which lift gas is injected into said well into the tubing string through which well fluids are produced from said well; and a lift gas valve installed within one of said tubing strings at selected ones of said cross-over connections for controlling the flow of lift gas between said strings, each said gas lift valve being installed by being pumped through said injection tubing string to and from an operating location at a cross-over connection within said string.

9. A well system for producing and servicing a well comprising: a first tubing string supported in said well; a second tubing string supported in said well extending in side-by-side substantially parallel relationship with said first tubing string; one of said tubing strings providing a flow passage for the recovery of well fluids of said well; the other of said tubing strings providing a flow passage for the injection of lift gas into said well; said flow passages in said tubing strings being isolated from an annular space around said tubing strings within said well; a plurality of cross-over connections included in said tubing strings at spaced intervals along the length of said strings, each said cross-over connection providing a flow passage interconnecting said tubing strings for conducting lift gas from the tubing string into which lift gas is injected into said well into the tubing string through

which well fluids are produced from said well; a gas lift valve installed within the one of said tubing strings used for injection or lift gas into said well at selected ones of said cross-over connections for controlling flow of lift gas between said strings; each of said gas lift valves having a central longitudinal bore communicating with said injection tubing string in which each said gas lift valve is installed and discharge ports for discharging lift gas from said central flow passage into the cross-over connections at which each said valve is supported; and said central bore of each of said gas lift valves being of a diameter and extending throughout the length of each of said valves to permit movement of well tools through each said gas lift valve as said well tools are moved along said tubing string in which said valves are installed.

10. A well system for producing and servicing a well comprising: a first tubing string supported in said well; a second tubing string supported in said well extending in side-by-side substantially parallel relationship with said first tubing string; one of said tubing strings providing a flow passage for the recovery of well fluids from said well; the other of said tubing strings providing a flow passage for the injection of lift gas into said well; said flow passages in said tubing strings being isolated from an annular space around said tubing strings within said well; a plurality of cross-over connections included in said tubing strings at spaced intervals along the length of said strings, each said cross-over connection providing a flow passage interconnecting said tubing strings for conducting lift gas from the tubing string into which lift gas is injected into said well into the tubing string through which well fluids are produced from said well; a gas lift valve installed within the one of said tubing strings used for injection of lift gas into said well at selected ones of said cross-over connections for controlling the flow of lift gas between said strings; each of said gas lift valves including a tubular mandrel provided with a longitudinal flow passage communicating with said tubing string in which said injection gas is introduced into said well and a plurality of ports for flow of lift gas outwardly from said longitudinal flow passage; outer housing means concentrically positioned in spaced relation around said mandrel defining an annular space around said mandrel; means in said annular space dividing said space into a dome gas chamber and an annular flow passage communicating with said ports through said mandrel into said central flow passage, said housing having port means communicating with said annular flow passage for discharging lift gas from said housing; an annular main valve member disposed in said annular flow passage and exposed on one side thereof to dome gas in said dome gas pressure chamber for biasing said valve member inwardly over said ports leading to said central flow passage, said valve member being adapted to be displaced radially outwardly by lift gas pressure transmitted through said mandrel ports for expanding said valve member to release gas from said central flow passage into said annular flow passage for flow through said ports leading from said housing; and an annular check valve member disposed in said annular flow passage between said housing ports and said main valve member to allow lift gas to flow from said mandrel ports to said housing ports and prevent backflow of fluids through said annular flow passage from said housing ports to said mandrel ports.

11. A well system for producing and servicing a well comprising: a first tubing string supported in said well; a second tubing string supported in said well extending in side-by-side substantially parallel relationship with said first tubing string; one of said tubing strings providing a flow passage for the recovery of well fluids from said well; the other of said tubing strings providing a flow passage for the injection of lift gas into said well; said flow passages in said tubing strings being isolated from an annular space around said tubing strings within said well; a plurality of cross-over connections included in said tub-

ing strings at spaced intervals along the length of said strings, each said cross-over connection providing a flow passage interconnecting said tubing strings for conducting lift gas from said tubing string into which lift gas is injected into said well into said tubing string through which well fluids are produced from said well; each of said cross-over connections including a body mandrel provided with spaced longitudinal first and second flow passages and a transverse flow passage communicating said first and second flow passages, said body mandrel being connectible at opposite ends with the conduits comprising said first and second tubing strings whereby flow in one of said tubing strings flows through one of said longitudinal flow passages in said cross-over connection and flow in the other of said tubing strings flows through the other of said longitudinal flow passages of said cross-over connection; each of said cross-over connections including a sliding sleeve having ports therein disposed in a first of said flow passages of said mandrel and movable longitudinally between one position at which said first flow passage communicates with said transverse flow passage and another position at which said first flow passage is isolated from said transverse passage; and a sliding sleeve having ports therein in the other of said flow passages of said body mandrel whereby said longitudinal flow passages of said mandrel may be isolated from each other by either of said sliding sleeves.

12. A well system in accordance with claim **11** including a gas lift valve disposed in one of said sleeves at selected ones of said cross-over connections.

13. A well system for producing and servicing a well comprising: a first tubing string supported in said well; a second tubing string supported in said well extending in side-by-side substantially parallel relationship with said first tubing string; one of said tubing strings providing a flow passage for the recovery of well fluids from said well; the other of said tubing strings providing a flow passage for the injection of lift gas into said well; said flow passages in said tubing strings being isolated from an annular space around said tubing strings within said well; a plurality of cross-over connections included in said tubing string at spaced intervals along the length of said strings, each said cross-over connection providing a flow passage interconnecting said tubing strings for conducting lift gas from the tubing string into which lift gas is injected in said well into the tubing string through which well fluids are produced from said well; each of said cross-over connections comprising a body mandrel provided with spaced longitudinal first and second flow passages and a transverse flow passage communicating said first and second flow passages, said mandrel being connectible at opposite ends with the conduits comprising said first and second tubing string whereby flow in one of said tubing strings flows through one of said longitudinal flow passages in said cross-over connection and flow in the other of said tubing strings flows through the other of said longitudinal flow passages of said cross-over connection; and an extensible swivel joint connected in each tubing string section of one of said tubing strings between adjacent cross-over connections in said well system.

14. A well system as defined in claim **13** wherein said swivel joint comprises telescopically disposed interconnected tubing members adapted to be extended and retracted in sealed relationship for connecting each said tubing string between said cross-over connections.

15. A well system as defined in claim **14** wherein said telescopically related tubular members are interconnected by threads having the same characteristics as threads connecting one end of one of said members into said tubing string section to provide identical travel rates between said members and said end of said joint whereby said members are extended at a rate equal to the rate of threading said end of said joint into said tubing string section.

16. A well system as defined in claim **15** wherein one

of said telescopically related tubular members is threaded over a substantial portion of its length and provided with seal means along an end portion of said member and said other tubular member has a smooth surface over a substantial length thereof engaged by said seal means over substantially the distance travel of said telescopically related members between contracted and extended relative positions of said members for preventing leakage between said members as said members are extended and retracted and at any of the relative positions of said members between the fully extended and fully retracted relationship of said members.

17. A well system for producing and servicing a well comprising: a first tubing string supported in said well; a second tubing string supported in said well extending in side-by-side substantially parallel relationship with said first tubing string; at least one of said tubing strings extending to a producing formation penetrated by said well and being adapted to direct well fluids from said formation through said well to the surface end thereof; the other of said tubing strings providing for injection of lift gas into said well for recovery of well fluids from said well; said first and second tubing strings providing lift gas injection and well production flow passages isolated from the annulus of said well around said tubing strings whereby lift gas is injected into and fluids are produced from said well independently of annulus conditions in said well; a plurality of cross-over assemblies connected in said tubing strings at spaced intervals between the surface end of said well and said producing formation, each of said cross-over connections including a transverse flow passage communicating said gas injection flow and said well production flow passages of said tubing strings; means connected between said tubing strings below the lowermost of said cross-over connections providing a flow passage between said strings to permit said strings to form a closed circuit flow path within said well for pumping well tools to and from said cross-over connections; a valve in said tubing string extending to said producing formation below the interconnection of said tubing strings to allow well fluids to flow upwardly in said tubing string while preventing backflow of well fluids through said tubing string toward said producing formation; and a surface installation connected with said tubing strings for pumping well fluids into either of said tubing strings while receiving well fluid returns from the other of said tubing strings.

18. A well system as defined in claim 17 including a gas lift valve at selected cross-over connections for controlling flow of lift gas between said tubing strings whereby lift gas is injected into said well in one of said tubing strings and well fluids are produced from said well in the other of said tubing strings.

19. A well system for producing and servicing a well comprising: a first tubing string supported in said well; a second tubing string supported in said well extending along said first tubing string; at least one of said tubing strings extending to a producing formation penetrated by said well and adapted to direct well fluids from said formation through said well to the surface end thereof; the other of said tubing strings providing for injection of lift gas into said well for recovery of well fluids from said well; a plurality of cross-over assemblies connected in said tubing strings at spaced intervals between the surface end of said well and said producing formation, each of said cross-over assemblies including a transverse flow passage communicating said tubing strings; a gas lift valve supported in said tubing string providing for injection of lift gas at selected cross-over assemblies for controlling flow of lift gas between said tubing strings whereby lift gas is injected into said well in one of said tubing strings and well fluids are produced from said well in the other of said tubing strings; means connected between said tubing strings below the lowermost of said cross-over assemblies providing a flow passage between said strings to

permit said tubing strings to form a closed circuit flow path within said well for pumping well tools to and from said cross-over assemblies; a valve in said tubing string extending to said producing formation below the interconnection of said tubing strings to allow well fluids to flow upwardly in said tubing string while preventing backflow of well fluids through said tubing string toward said producing formation; and a surface installation connected with said tubing strings for pumping well fluids into either of said tubing strings while receiving well fluids from the other of said tubing strings.

20. A well system for producing and servicing a well comprising: a first tubing string supported in said well; a second tubing string supported in said well extending along said first tubing string; at least one of said tubing strings extending to a producing formation penetrated by said well and being adapted to direct well fluids from said formation through said well to the surface end thereof; the other of said tubing strings providing for injection of lift gas into said well for recovery of well fluids from said well; a plurality of cross-over assemblies connected in said tubing strings at spaced intervals between the surface end of said well and said producing formation, each of said cross-over assemblies including a transverse flow passage communicating said tubing strings; each of said cross-over assemblies including at least one sleeve valve movable between a first position for isolating said tubing strings from each other through said lateral flow passage of said cross-over assemblies and a second position for permitting said tubing string to communicate with each other through said lateral flow passage; a gas lift valve at selected cross-over assemblies for controlling flow of lift gas between said tubing strings whereby lift gas is injected into said well in one of said tubing strings and well fluids are produced from said well in the other of said tubing strings; means connected between said tubing strings below the lowermost of said cross-over assemblies providing a flow passage between said strings to permit said tubing strings to form a closed circuit flow path within said well for pumping well tools to and from said cross-over assemblies; a valve in said tubing string extending to said producing formation below the interconnection of said tubing strings to allow well fluids to flow upwardly in said tubing string while preventing backflow of well fluids through said tubing string toward said producing formation; and a surface installation connected with said tubing strings for pumping well fluids into either of said tubing strings while receiving well fluid returns from the other of said tubing strings.

21. A well system comprising: means comprising a first tubing string providing a first flow passage along a well; means comprising a second tubing string providing a second flow passage along said well; means connecting said tubing strings providing a cross-over passage between the first and second flow passages within said well; each of said tubing strings being provided with a locking recess for a well tool locking mandrel for locking a well tool in either of said tubing strings at said cross over passage; and a sliding sleeve valve provided in each of said tubing strings, said valve being movable between open and closed positions for controlling communication between said tubing strings through said cross-over passage.

22. A well system for servicing a well comprising: a first tubing string supported in said well; a second tubing string supported in said well extending along said first tubing string; one of said tubing strings providing a flow passage for the recovery of well fluids from said well; the other of said tubing strings providing a flow passage for the injection of lift gas into said well; a plurality of cross-over connections included in said tubing strings at spaced intervals along the length of said strings, each providing a flow passage interconnecting said tubing strings for conducting lift gas from the tubing string in which lift gas is injected into said well into the tubing string in which well fluids are produced from said well; a gas lift

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valve installed in said string in which lift gas is injected at selected ones of said cross-over connections for controlling the flow of lift gas between said strings; each of said gas lift valves comprising a tubular mandrel provided with a longitudinal flow passage and a plurality of ports for flow of lift gas outwardly from said longitudinal flow passage, outer housing means concentrically positioned in spaced relationship around said mandrel defining an annular space around said mandrel, means in said annular space dividing said space into a dome gas chamber and an annular flow passage communicating with said ports through said mandrel in said central flow passage, said housing having port means communicating with said annular flow passage for discharging lift gas from said housing, an annular main valve member disposed in said annular flow passage and exposed on one side thereof to dome gas in said dome gas pressure chamber for biasing said valve member inwardly over said ports leading to said central passage, said valve member being adapted to be displaced radially outwardly by lift gas pressure transmitted through said mandrel ports for expanding said valve member to release gas from said central flow passage into said annular flow passage for flow through said passage away from said housing, and an annular check valve member disposed in said annular flow passage between said housing ports and said main valve member to allow lift gas to flow from said mandrel to said housing ports and prevent backflow of fluids through said annular flow passage from said housing ports to said mandrel ports.

23. A well system for producing and servicing a well comprising: a first tubing string supported in said well; a second tubing string supported in said well extending along said first tubing string; one of said tubing strings extending to a producing formation penetrated by said well to direct well fluids from said formation to the surface end of said well; the other of said tubing strings providing for gas lift injection into said well for recovery of well fluid therefrom; cross-over means connected in said tubing strings including a transverse flow passage communicating said tubing strings; means for connecting

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said tubing strings below said cross-over means to permit said tubing strings to form a closed circuit flow path within said well for pumping said well tools to and from said cross-over means; and a surface installation connected with said tubing strings for pumping fluids into either of said tubing strings while receiving return fluids from the said other of said tubing strings.

24. A well system in accordance with claim 23 including gas lift valve means supported at said cross-over means in said tubing string employed for injection of lift gas to said well for controlling the admission of lift gas to said transverse flow passage leading to said tubing string extending to said producing formation.

25. A well system in accordance with claim 23 including gas lift valve means supported at said cross-over means in said tubing string extending to said producing formation for admitting gas from said transverse flow passage into said tubing string extending to said producing formation.

26. A well system in accordance with claim 19 including sleeve valve means in each of said cross-over connections, said sleeve valve means being movable between open and closed positions communicating said tubing strings with each other.

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