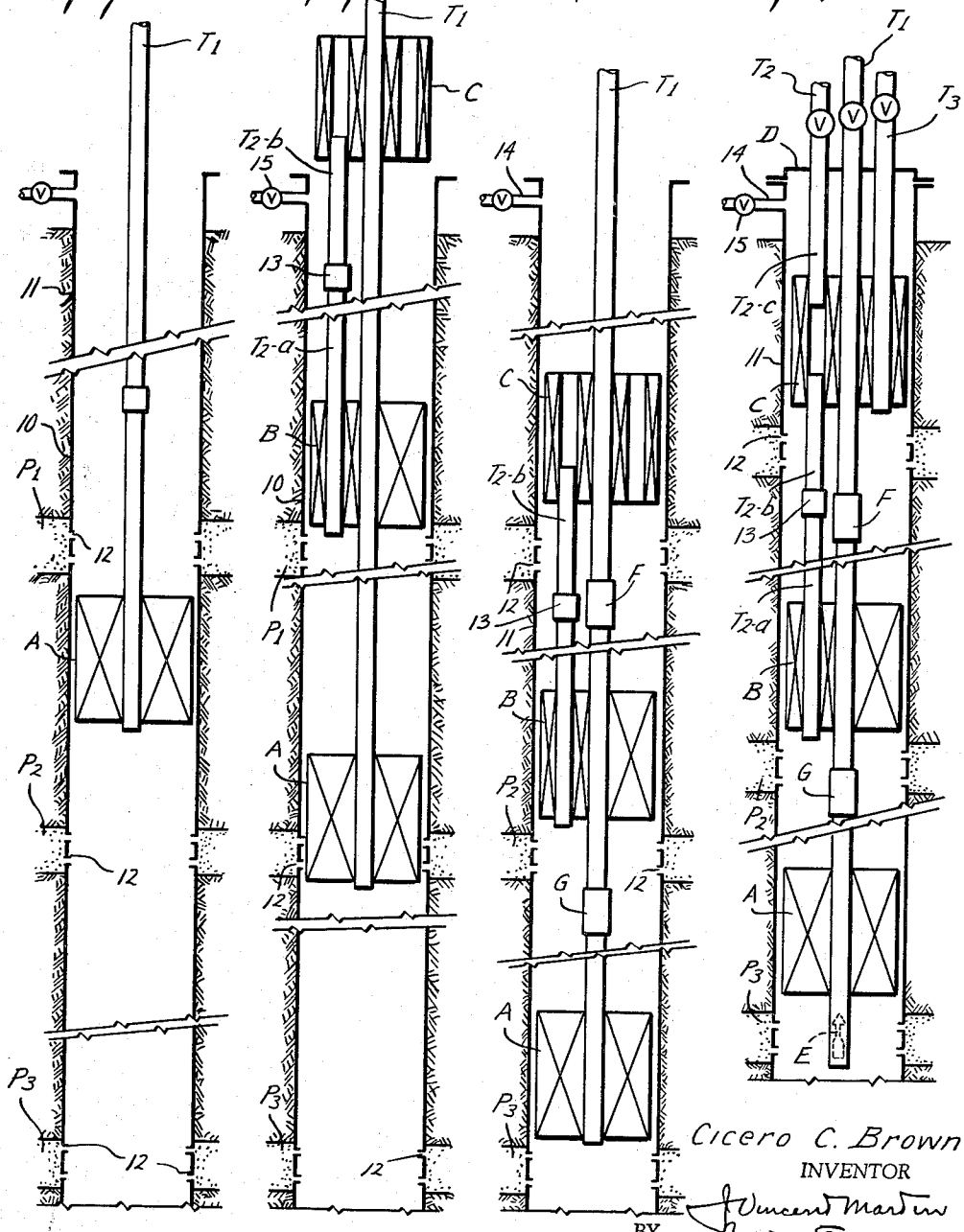
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METHODS OF AND APPARATUS FOR COMPLETING MULTIPLE ZONE WELLS

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Fig. 1 Fig. 2 Fig. 3 Fig. 4



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Fig. 5A

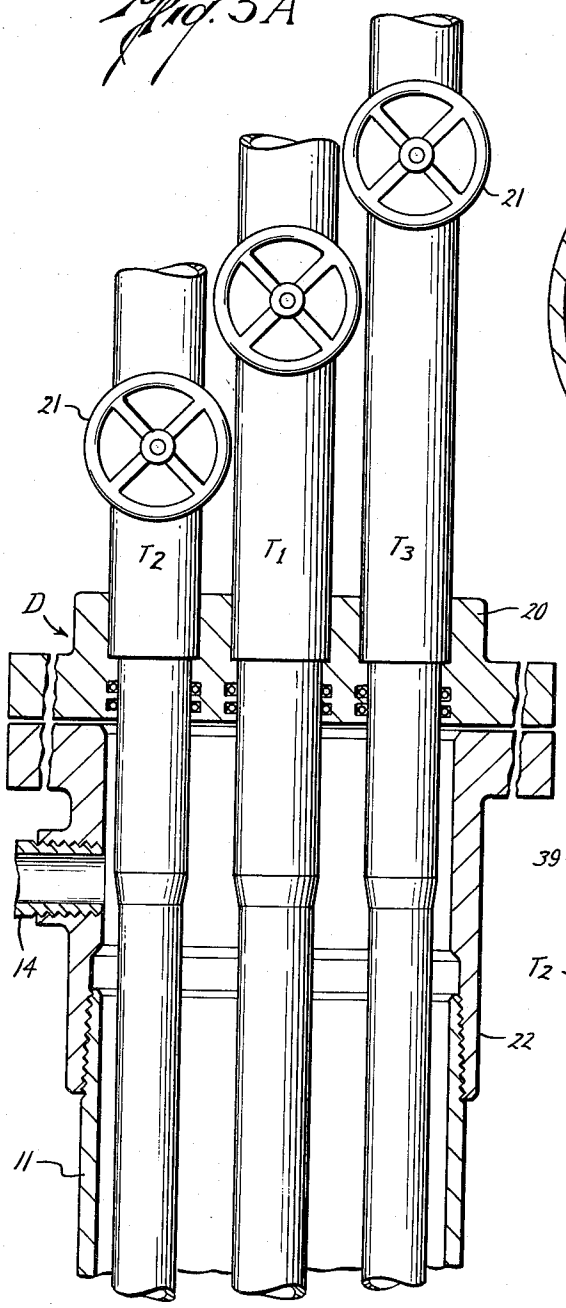


Fig. 6

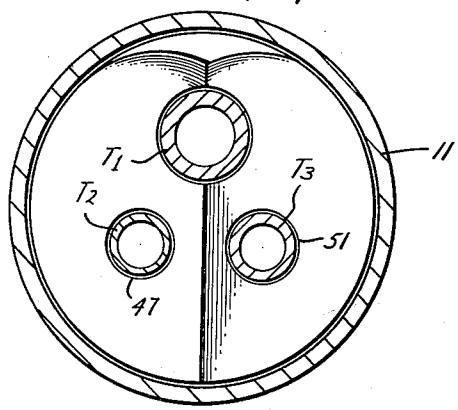
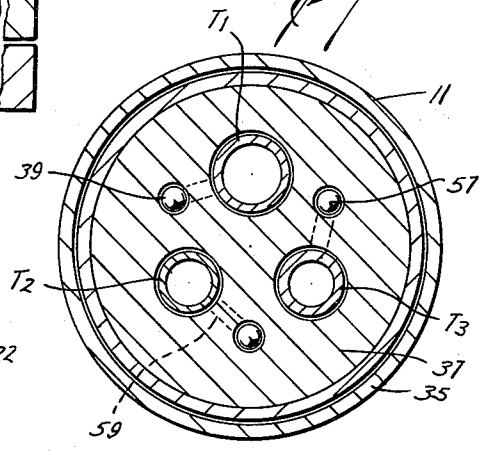


Fig. 7



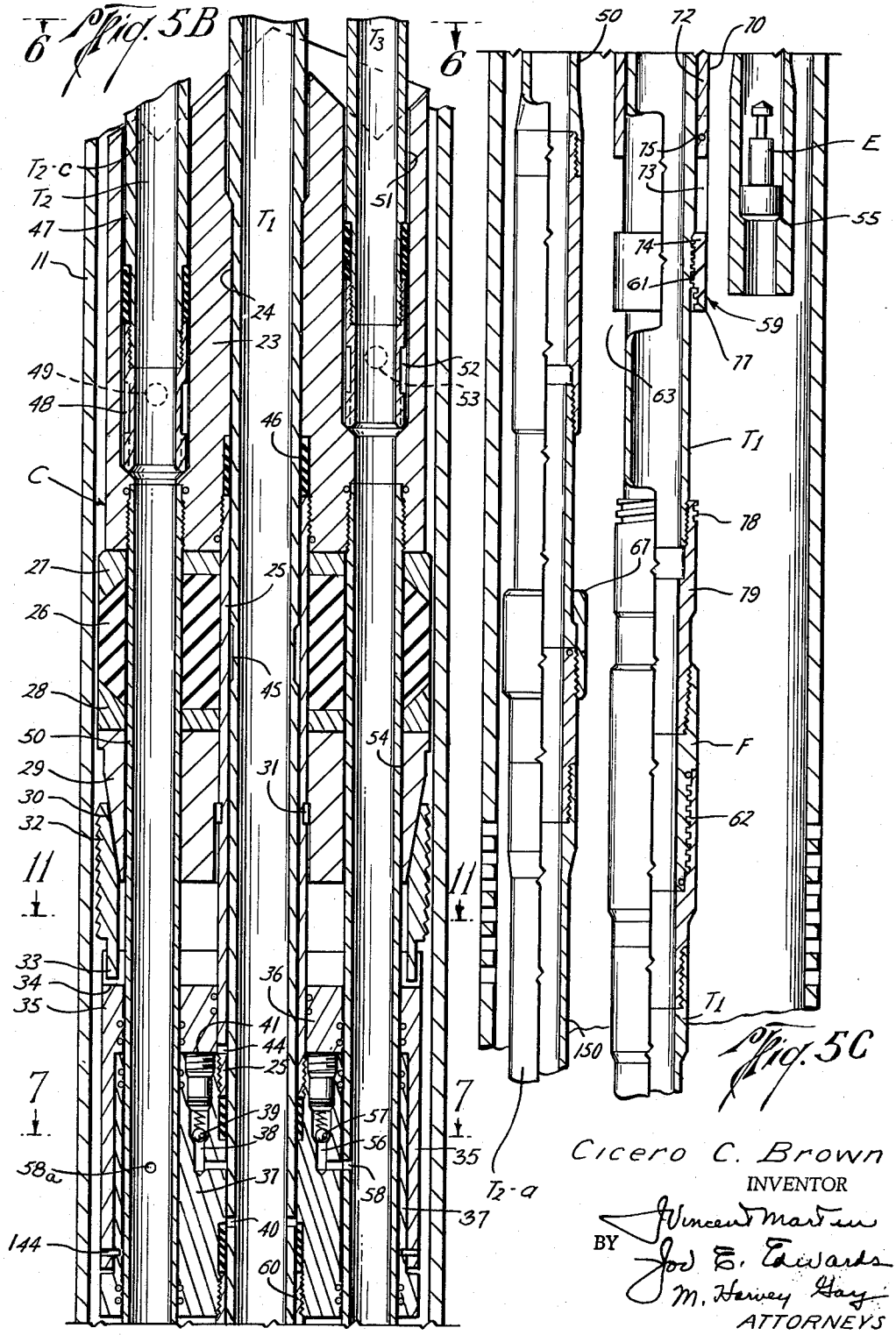
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METHODS OF AND APPARATUS FOR COMPLETING MULTIPLE ZONE WELLS

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Fig. 5D

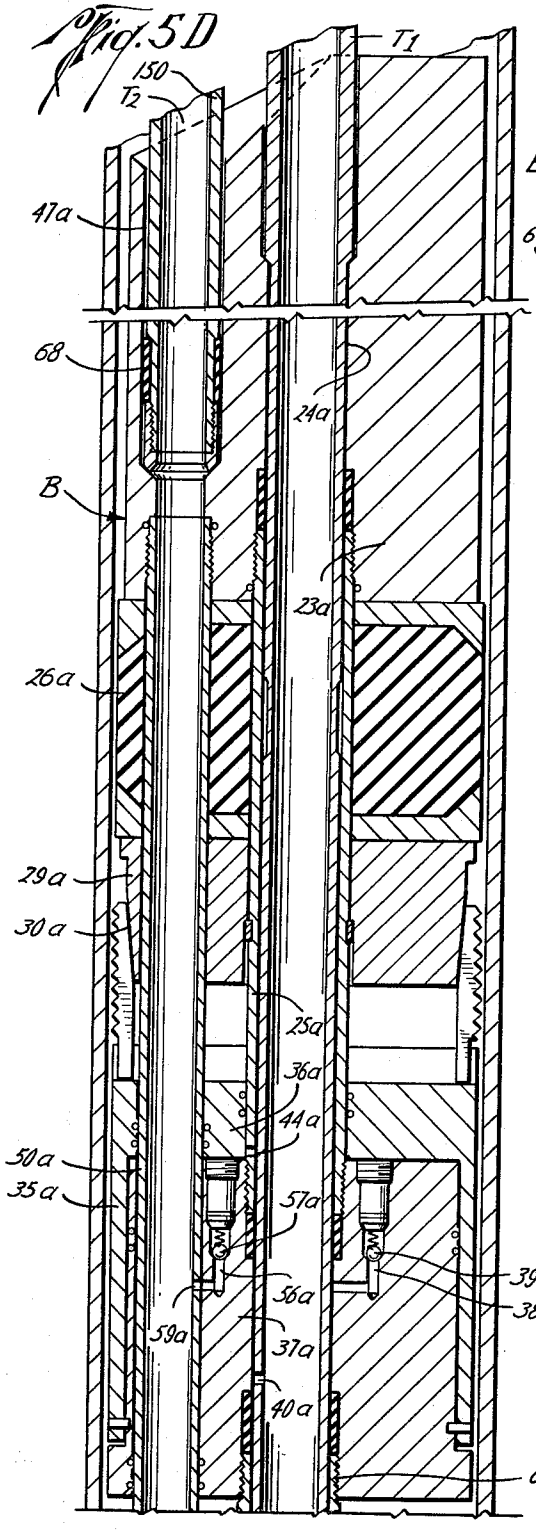
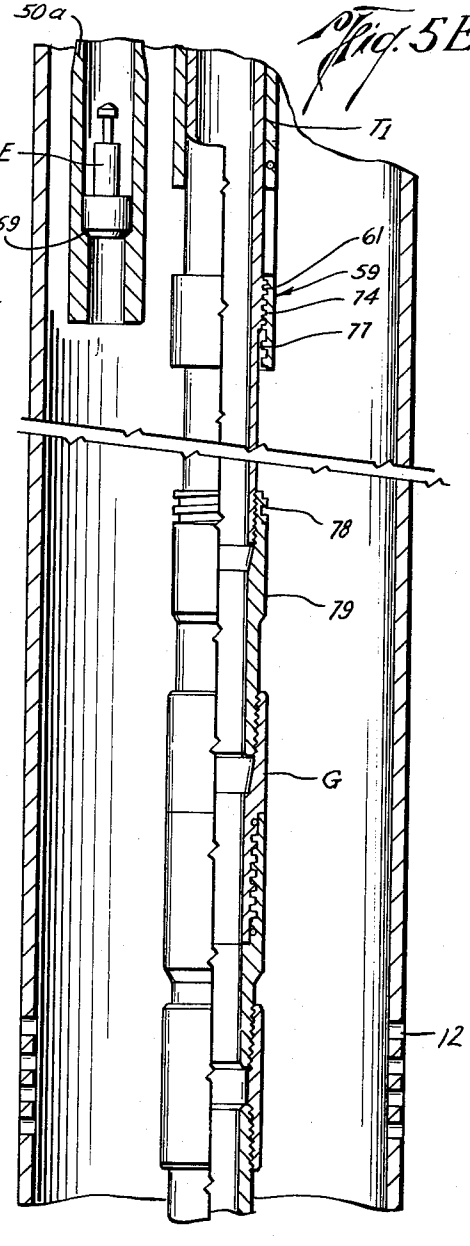


Fig. 5E



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Fig. 5F

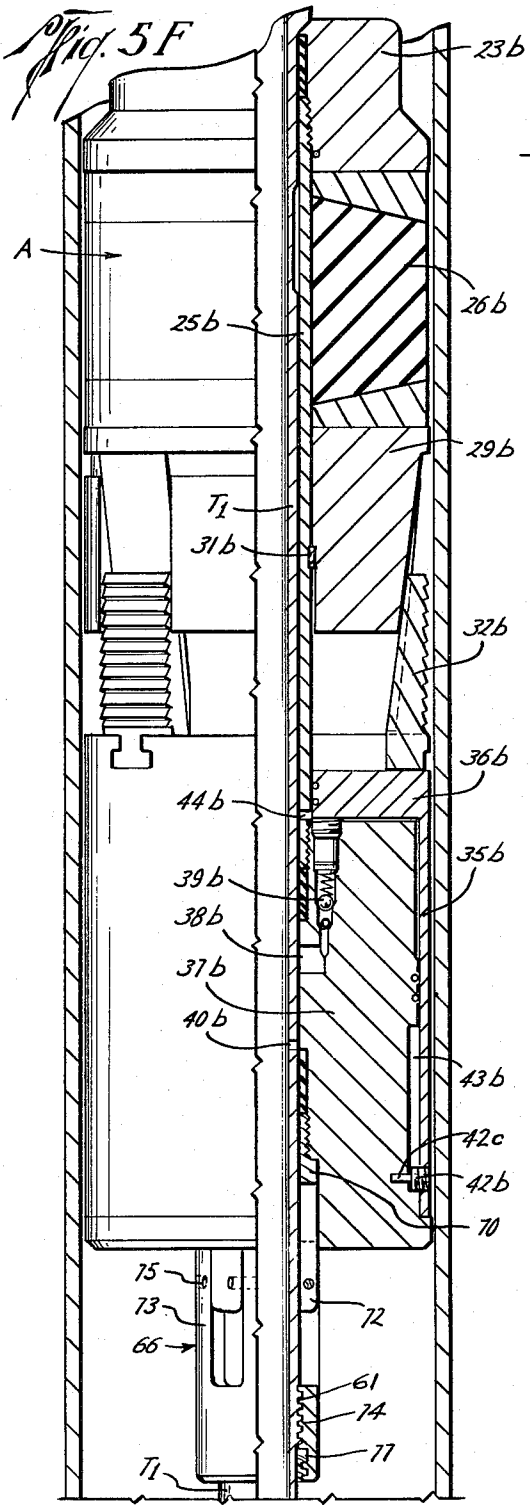
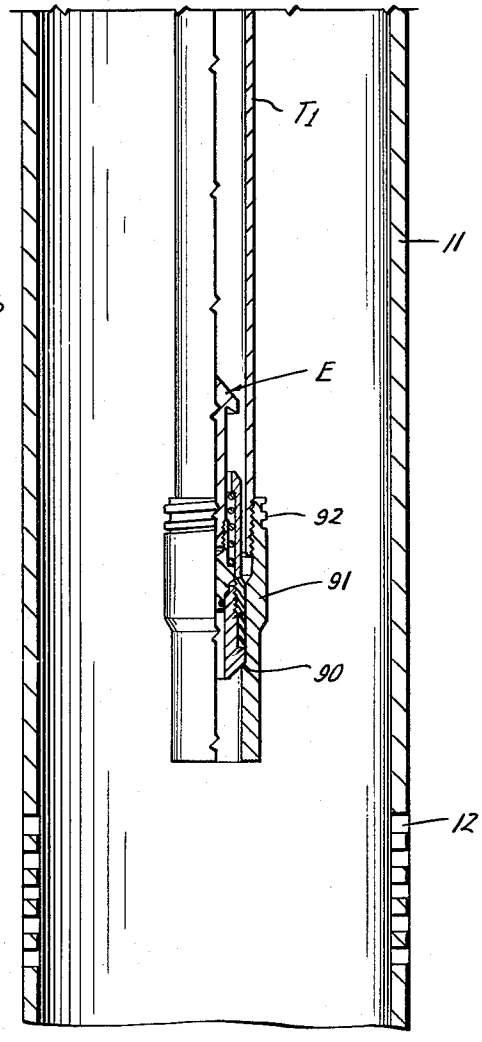


Fig. 5G



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Fig. 8

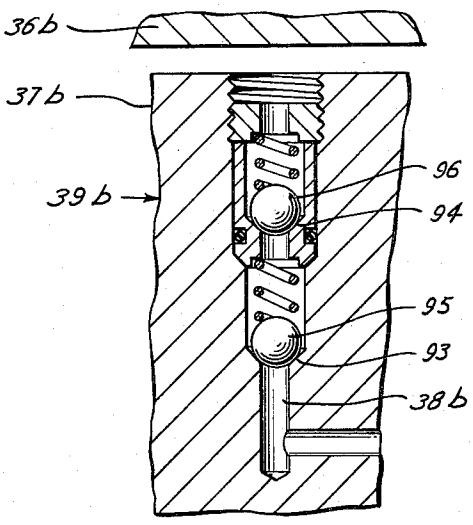


Fig. 9

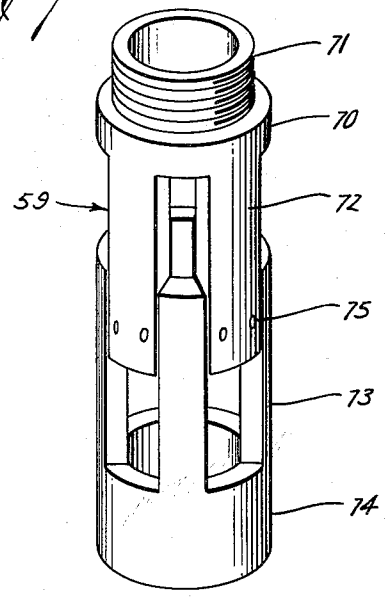


Fig. 10

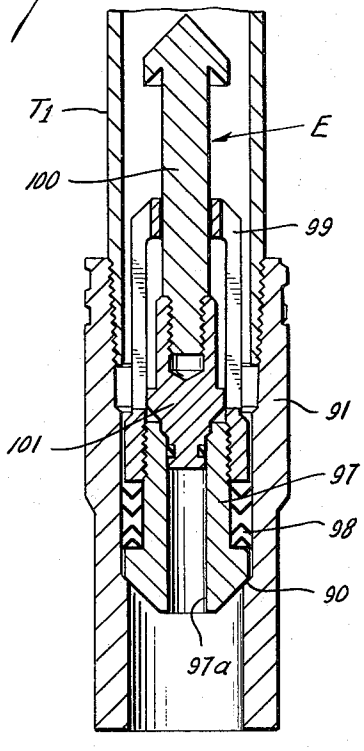
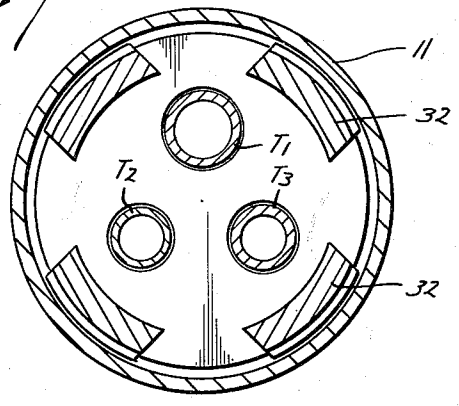


Fig. 11



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3,098,524

METHODS OF AND APPARATUS FOR COMPLETING MULTIPLE ZONE WELLS

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Filed Apr. 16, 1958, Ser. No. 728,967
15 Claims. (Cl. 166—48)

This invention relates to new and useful improvements in methods of and apparatus for completing multiple zone wells.

The invention disclosed herein is an improvement on the method and apparatus illustrated in my co-pending application, Serial No. 659,197, filed April 26, 1957, now Patent No. 2,991,833.

It is one object of this invention to provide an improved method and apparatus for completing multiple zone wells, wherein a plurality of well tubing strings may be landed in final position in the well head equipment prior to the setting of the well packers which seal off between said formations and also wherein the well packers are hydraulically-actuated and are of the type in which the packing element thereof is moved into sealing position by the application of an endwise force to said element.

An important object is to provide an improved well apparatus including a plurality of hydraulically-actuated packers mounted upon a first production string, together with additional production strings extending to and through certain of the packers to conduct well fluids from the various production zones which are separated by the packers, said packers being settable by pressure applied thereto from one or more of the production strings and being releasable by manipulation of the first production string, whereby unsetting and removal of all packers may be accomplished solely by means of said first production string.

Another object of the invention is to provide an improved method of lowering a plurality of well packers and production strings into a well bore wherein a first production string, a portion of the second string and a trio of well packers are lowered simultaneously into position into the well bore, after which the remaining portion of the second string and a third production string are lowered and connected with the uppermost packer to establish the desired communication with the various producing formations.

Still another object of the invention is to provide an improved well apparatus having hydraulically-actuated packers for sealing off between production zones, which zones communicate with their respective production tubing strings; the apparatus including means whereby the packers may be selectively set and properly tested by the application of pressure through the various strings, thereby assuring that proper sealing has been accomplished before the well is finally put on production.

Still another object is to provide an apparatus of the character described in which each packer, after being set, is maintained in set position without the necessity of holding pressure within the respective production strings, release of the pressure acting to maintain the packers in set position being effected by manipulation of only one of the production strings.

A further object is to provide a well apparatus of the character described in which safety joint connections are properly positioned between the spaced packers so that in the event that the packers can not be removed in a normal manner by the manipulation of one of the production strings, a disconnection may be made thereby permitting subsequent removal of the packers by any other well-known means.

A particular object of the invention is to provide a well apparatus of the character described, wherein the packing element of each well packer is deformed into a set position by an endwise compressive force and also wherein each packer is so arranged that the force applied to the packing element to set the same is not transmitted to the production string on which the element is mounted, whereby stretching of said string during setting of the packer is avoided.

The construction designed to carry out the invention will be hereinafter described, together with other features thereof.

The invention will be more readily understood from a reading of the following specification and by reference to the accompanying drawings forming a part thereof, wherein an example of the invention is shown, and wherein:

FIGURE 1 is a schematic view illustrating the lowermost packer being moved downwardly within the well bore;

FIGURE 2 is a schematic view showing the intermediate and upper packers mounted on the first tubing string and also showing a portion of the second tubing string connecting the intermediate and upper packers and illustrating continued lowering of the apparatus within the well bore;

FIGURE 3 is a view similar to FIGURES 1 and 2 with the three packers in substantially final elevation within the well bore;

FIGURE 4 is a similar view showing the remaining portion of the second tubing string and the third tubing string in position and also schematically illustrating all three strings in final landed position in the control head equipment;

FIGURE 5A is a view partly in section and partly in elevation of the upper end of the well bore showing the three tubing strings landed in final position in the control head equipment; for the sake of clarity, the three production strings are shown as arranged in transverse alignment although in actual practice said strings will be disposed at various radial points with respect to the axial center of the well bore;

FIGURE 5B is a continuation of FIGURE 5A showing the structural details of the upper packer;

FIGURE 5C is a continuation of FIGURE 5B showing the details of the connections between the upper packer and the intermediate packer;

FIGURE 5D is a continuation of FIGURE 5C showing the structural details of the intermediate packer;

FIGURE 5E is a continuation of FIGURE 5D illustrating the connection between the intermediate packer and the lower packer;

FIGURE 5F is a continuation of FIGURE 5E showing the structural details of the lower packer;

FIGURE 5G is a continuation of FIGURE 5F showing the lower extension of the first tubing string;

FIGURE 6 is a horizontal cross-sectional view taken on the line 6—6 of FIGURE 5B;

FIGURE 7 is a horizontal cross-sectional view taken on the line 7—7 of FIGURE 5B;

FIGURE 8 is an enlarged cross-sectional view of the check valve assembly;

FIGURE 9 is an isometric view of the clutch element which connects each piston of the packer assembly with the tubing string;

FIGURE 10 is an enlarged sectional view of the retrievable closure plug which may be employed to close flow through the tubing strings, and

FIGURE 11 is a horizontal cross-sectional view taken on the line 11—11 of FIGURE 5B.

In the drawings (FIGURES 1 to 4), the numeral 10

designates a well bore having the usual well casing extending therethrough. The well bore is illustrated as traversing an upper producing formation or zone P1, a second or intermediate producing formation or zone P2, and a third or lower producing formation or zone P3. The casing is formed with the usual perforations 12 opposite each producing zone whereby the well fluids from that zone may enter the bore of the casing.

In order to produce the well fluids from each zone or formation independently of the other zones or formations, it is necessary to seal or pack off each zone from the others and to establish communication between each isolated zone and its respective production string or well tubing. FIGURE 4 illustrates a lower packer A positioned between the lower and intermediate zones, a second packer B located between the intermediate and the upper zones, and a third packer C located above the upper zone. A first production or tubing string T1 extends from the surface through all three packers, A, B and C, and as will hereinafter appear, communicates with the lowermost zone or formation P3 to conduct the well fluids from this formation to the surface. A second production or tubing string T2 extends from the area below the intermediate packer B, then upwardly through the upper packer C and to the surface. A third production or tubing string T3 extends from the area below the upper packer C and upwardly to the surface. As will be explained, all three tubing strings, T1, T2 and T3, having the packers connected and sealing therewith in the manner hereinafter described, are landed in the control head equipment schematically illustrated in FIGURE 4 and designated by the letter D. As shown in FIGURE 4, final landing of the strings in the control head equipment is made prior to the time that the packers A, B and C are moved into a set or sealing position within the wall of the well casing. Thus, after landing of the three strings, it is possible to circulate through any one or all of the strings and a free circulation around all packers may be accomplished. Thereafter, by means of hydraulic pressure, the packers A, B and C may be moved into sealing or set position, such pressure being applied through the bore or bores of the tubing strings. When the packers move into sealing or set position, they function to isolate the producing formations from each other and at that time the lowermost formation or zone P3 is produced through the first tubing string T1 and the fluids from the intermediate formation or zone P2 are produced through the tubing string T2 and the fluids from the upper formation or zone P1 flow to the surface through tubing string T3.

The present invention involves a novel method of lowering and finally setting the packers as well as an improved method of removing said packers when such removal becomes necessary and FIGURES 1 to 4 illustrate the manner in which said packers and strings are positioned within the well bore. Referring to FIGURE 1, the lower packer A is connected to or mounted upon the lower portion of the first string T1 and is lowered within the well by means of said tubing string a predetermined distance and lowering is halted when the packer B is to be connected. The distance between packers A and B is in accordance with the location and extent of the producing zones P3 and P2. Packer B is then connected to or mounted upon the first tubing string T1, this being accomplished at the well surface and lowering is then continued. Thereafter, a tubular conductor or section T2–*a* of the second tubing string (FIGURE 2) is run into the well and connected to packer B. Packer C is then mounted upon or connected to the first tubing string T1 in the manner illustrated in FIGURE 2, and at this time another section T2–*b* of the second tubing string T2 is connected in place. The section T2–*b* has its upper end coupled to the lower end of packer C with its lower end secured to a union coupling 13, which may be just beneath the upper packer. The union is employed to make the connection between sections T2–*a* and T2–*b* so that, in effect, the packers B and C are connected together, not only by the first tubing string T1, but also by the coupled sections T2–*a* and T2–*b* of the second tubing string T2, which coupled sections form a tubular conductor extending between packers B and C.

Thereafter, this portion of the assembly is lowered as shown in FIGURE 3 and lowering is continued until the packers A, B and C are located at their proper elevations with respect to the producing formations or zones P1, P2 and P3, At this time the packers are not set and are not in sealing engagement with the well casing 11.

Thereafter, the upper section T2–*c* of the second tubing string T2 is lowered within the well bore and is coupled to the upper packer C and, as will be explained, such coupling establishes communication with the tubular conductors formed by the sections T2–*a* and T2–*b* of the string T2. Following this the third tubing string T3 is run into the well independently of the other strings and is coupled or connected to the uppermost packer C. All three strings, T1, T2 and T3, are then landed in the control equipment in their final position and the well is then completely under control. However, at this point the packers A, B and C are not in sealing engagement with the well casing. This position of the parts of the apparatus is illustrated in FIGURE 4.

It will be evident that at this time a circulation may be effected downwardly through the first tubing string T1 and such circulation will pass upwardly around the lowermost packer A and may return upwardly through tubing T2; or a portion of the return may be through the third tubing string T3 since the circulation may pass around the outside of the unset packer B. The control head equipment D includes the usual outlet 14 from the casing, which is controlled by valve 15 and, if desired, this valve may be opened so that circulation may be downwardly through one or more of the tubing strings T1, T2 or T3 with returns being conducted from the casing through outlet 14. Similarly, if desired, circulation can be in a reverse direction. It is, therefore, possible to carry out any desired washing or circulating step with all tubings in place, finally landed in the control head and prior to the time that any of the packers are set.

As will be explained, the packers are constructed to be set by hydraulic pressure which is applied through one or more of the tubing strings. By dropping a closure plug, generally indicated at E in FIGURE 4, within the first tubing string T1 a pressure may be built up within the tubing string and, as will be explained, such pressure may be utilized to set all three of the packers A, B and C. If the plug E is dropped into the second tubing string T2, pressuring up in tubing T2 may function to set the intermediate packer B and the upper packer C. If it is desired to set only the upper packer C, the plug E may be dropped within tubing T3 and pressure applied through this tubing will set the uppermost packer. The apparatus is thus extremely versatile and the particular packer or packers which are set and the order in which they are set is subject to the particular well conditions. The arrangement also makes it possible to set the packer and then test the same to be certain that it is in sealing engagement with the well casing.

For example, plug E may be lowered in tubing T3 and pressure applied to set the upper packer C. Then by circulating downwardly through tubing T1 and upwardly around packers A and B with return through tubing T2, it is possible to test to be sure that the packer C has been properly set. This circulation may also accomplish a washing operation which clears the bore below the second packer of mud and washes the face of the producing formations. If the plug E is removed from the tubing T3 after the upper packer C is set, then downward circulation through tubing T3 and return through tubing T1 accomplishes a washing of that portion of the well bore below the upper packer C. Thereafter, packer B

may be set by dropping a plug through the second tubing string T2. A pressure test from above packer B may be made by circulating downwardly through tubing T3 and a test below said packer may be effected by circulating downwardly through the first tubing string T1. Thereafter, the lower packer A may be set, and by proper application of pressure through tubing T2 or tubing T1, this packer may be tested for sealing efficiency.

After all of the packers are set, the plugs E are, of course, removed and flow from each producing formation is conducted to the surface through its respective tubing string.

As will be explained, release and unsetting of the packers and removal thereof may be effected by a manipulation of the first tubing string T1. This is one of the features of the invention since all three packers may be released simultaneously and removed from the well bore by the single production string. In such case the upper section T2–C of the second production string T2 and the third production string T3 are first removed after which the first string T1 is manipulated and removed. If, for some reason, simultaneous release and removal of all three packers can not be effected by the first string, the apparatus is so arranged in the well that the upper packer may first be released and then by means of a safety joint F below said first packer, a disconnection of the upper packer and upper section of the first tubing from the remainder of said first string and the lower packers may be accomplished. Thereafter, a suitable overshot or similar tool may be engaged with that portion of string T1 still remaining in the well to remove the intermediate packer B and the lowermost packer A. If both of these packers will not release on the same operation, another safety joint G is provided between packers B and A so that another section of string T1 and packer B may be independently removed. Thereafter the final section B of string T1 with the lower packer may be removed.

Although the particular construction of the individual packers is subject to variation, insofar as the method of running, completing, setting of the packers and subsequently removing said packers is concerned, it is preferred to employ hydraulically-actuated well packers, each of which have an elastic packing element which is deformable into sealing position by endwise compression or force. This type of packer is distinguished from the so-called "balloon type" wherein pressure is applied to the interior of the element. The drawings illustrate the preferred type of well packers.

FIGURES 5A to 5G illlustrate the complete apparatus from control head equipment D to the lower end of the well bore and it is noted that the three tubing strings are shown as in transverse alignment; however, in actual practice the strings would not be in such alignment and are shown in this manner for illustrative purposes only. Actually, the three strings are spaced at various radial positions with respect to the axis of the well bore as shown in FIGURE 7.

Referring to FIGURE 5A, this figure illustrates the three tubing strings T1, T2 and T3 suspended from a tubing head 20 which forms part of the control head equipment D. Each tubing string has a suitable control valve 21 connected therein whereby flow through each string may be controlled. The valved outlet 14 is mounted in the body portion 22 of the tubing head. The tubing head is, of course, supported on the upper end of the well casing 11.

The first tubing string T1 extends downwardly through all three packers C, B and A and the other two strings T2 and T3 have connection with the uppermost packer C as is illustrated in FIGURE 5B. The packer C includes a main body 23 having an axial bore 24 extending completely therethrough and the first tubing string T1 extends entirely through this bore. A tubular mandrel or pipe section 25 has its upper end connected to the lower end of the bore 24 and extends downwardly therefrom, the bore of the mandrel 25 forming a continuation of the bore 24. Surrounding the mandrel 25 and disposed below the body 23 is an elastic packing element 26 having confining rings 27 and 28 engaged with its upper and lower ends. Below the elastic packing element and also mounted on the mandrel 25 is a slip expander cone 29 having an outer tapered surface 30. The cone 29 is normally supported on a ring or shoulder 31 secured to the exterior of the mandrel 25.

Adapted to co-act with the expander cone 29 are a plurality of gripping slips 32 which are mounted for radial movement in an outward direction when the cone and slips are moved with respect to each other. The lower end of each slip is formed with a T-shaped lug 33 engaged in a complementary recess 34 formed in the upper end of a cylinder member 35. The cylinder member surrounds the lower portion of the tubular section or mandrel 25 and has a head 36 at its upper end. The cylinder encircles a piston body 37 which, in turn, is attached to the lower end of the tubular mandrel 25. An angular fluid passage 38 having a back-check valve 39 is formed in the piston and the lower end of the passage communicates with the space between the tubing T1 and the bore of the piston 37. The tubing T1 is provided with a radial port 40 and when fluid pressure is applied to the interior of the tubing T1, such pressure may pass the check valve 39 and may enter the space indicated at 41 between the upper end of the piston and the lower surface of the head 36 of the cylinder upwardly with respect to the piston and with respect to the tubular mandrel 25 as well as the parts carried by such mandrel.

The cylinder is slidable axially on the piston 37 and a shear pin 144 normally connects the cylinder to the piston until a predetermined pressure is applied between the piston and the cylinder.

The slips, piston and cylinder are normally in the position shown in FIGURE 5B, but when pressure is applied beneath the head 36 of the cylinder, the pin 144 is sheared and the piston is moved upwardly. Since the slips 32 are connected with the cylinder and since the expander cone is carried by the support 25, which is stationary at this time, the slips are moved upwardly into gripping engagement with the wall of the casing. As soon as the slips engage, further upward movement of the cylinder is halted and the pressure within the space between head 36 of the cylinder and the piston will react in a downward direction against the piston. When this occurs, the piston 37 will be moved downwardly relative to the cylinder, slips and expander cone and through the tubular support will apply downward force to the upper body 23. Such downward force will apply a downward pressure upon the upper end of the elastic packing element 26 and will effect a distortion of said elastic packing element into sealing engagement with the wall of the well casing. Due to the back-check valve, the pressure will be trapped between the piston and the head 36 of the cylinder and will retain the packing element and slips in set position even though pressure within the tubing string T1 is relieved.

In order to release the pressure so that the packing element and slips may be released, the tubing T1 is rotated, as will be explained, and is moved upwardly with respect to the various parts of the packer C assembly. Such upward movement will locate the port or opening 40 in the tubing T1 opposite a relief port 44 which extends through the tubular support 25 opposite the upper end of piston 37. Registration of ports 40 and 44 will allow the pressure, which is trapped between the piston and the head 36 of the cylinder, to be relieved through the interior of the tubing string T1 so that the slips may be returned to their original position with respect to the expander cone and applied pressure to the packing element 26 will be relieved. At the same time that port 40 is moved into registration with port 44 a reduced portion 45 on the exterior of tubing T1 will span the packing

member 46 which normally seals off around the tubing T1 to allow a bypass of fluid around this packing so that pressures across the unit may be equalized. The registration of ports 40 and 44, together with the co-action of the reduced portion 45 with the packing member 46, provide a release means for effecting a release of the set packing element 26 and the gripping slips 32 to thereby release the packer C from set position.

In addition to the bore 24, which is provided in the upper body 23 of the upper packer C, said body is formed with a second bore 47 which receives the lower end of the section T2–*c* of the second tubing string. The lower end of this section of the second string is formed with a J-slot coupling 48 which co-acts with a connecting pin 49 formed within the bore 47. Thus, the upper section T2–*c* of the second tubing string is detachably or releasably connected with the upper packer C.

A continuation of bore 47 entirely through the packer C is provided by a tubular pipe section 50 which extends through aligned openings in the elastic packing element 26, the expander 29, head 36 of cylinder 35 and the piston 37.

The upper body 23 of the packer C is also formed with a third bore 51 which is adapted to receive the lower end of the third tubing string T3. This third tubing string has its lower portion formed with a J-slot coupling 52 engageable with a connecting pin 53 so that the third tubing string may be releasably attached to the upper packer. The bore 51 is preferably of a different diameter or size than the bore 47 and the tubings T2 and T3 are of different diameters so that when each of these strings is run independently and adapted to be attached in its respective bore, the proper tubing will set within the proper bore. The bore 51 of the upper body 23 is continued by means of an elongate pipe section 54 which extends downwardly through aligned passages provided in the elastic packing element 26, expander 29, cylinder head 36 and piston 37; obviously, this pipe section forms a continuation of the tubing string T3 and, as shown in FIGURE 5C, this section terminates just below the upper packer C. Within the lower portion of the pipe section or conductor 54 is an annular seat 55 which is adapted to receive one of the removable plugs E when it is desired to pressure up within the third tubing string T3.

As previously described, the upper packer C may be set by applying fluid pressure from the interior of the first tubing string T1. However, it might be desirable to actuate the packer by fluid pressure from within the tubing T3 and for this purpose an angular passage 56 (FIGURE 5B) is provided. The passage is similar in construction to passage 38 and has a back-check valve 57 mounted therein. The passage communicates with an opening or port 58 formed in the tubular conductor or pipe 54. A similar passage (not shown) is formed in the piston 37 and has its lower end communicating with a port 58*a* provided in the tubular conductor 50 which forms a part of the second tubing string T2. With this arrangement it is obvious that the packing element 26 and slips of the upper packer may be set by pressuring up through any one of the three tubing strings. Release of pressure, however, and unsetting of the packing element and slips of said packer is accomplished only by manipulating the first string T1.

After extending through the upper packer C, the first tubing string T1 extends downwardly below the upper packer and is connected thereto by a special clutch coupling 59 formed on a tubular extension 60 which extension is secured to the piston 37 of the packer assembly.

The coupling 59 is of special construction and is provided, not only for the purpose of coupling the packer C to the string T1, but also for the purpose of permitting the endwise compressive force to be applied to the packing element 26 without transmitting the downward movement of the packing element, piston and mandrel 25, as caused by such compressive force, to the string T1; with such arrangement, the hydraulic pressure which imparts the downward movement to the piston 37 and mandrel 25 and upper body 23 will not result in stretching the tubing. Also, the co-operating parts of the coupling may function as a jar, as will be explained.

The coupling 59 is illustrated in detail in FIGURE 9 and includes an upper body section 70 having a threaded pin 71 which connects to the tubular extension 60 depending from the piston 37. The body has finger portions 72 which telescope upstanding fingers 73 of a lower section 74. The fingers are normally in the position shown in FIGURE 9 and are extended with respect to each other, being held so by shear pins 75. The bore of the lower section 74 has the internal threads 61 which couple to the tubing T1 and below said threads are additional coarse coupling threads 77 which subsequently co-act with coarse coupling threads 78 of a coupling 79, the latter being also carried by tubing T1.

In the operation of the special coupling 59 the initial application of pressure to the area between the piston 37 and the cylinder head 36 will result in an upward movement of the cylinder to set the slips 30. Then the reactive force is in a down direction which would tend to move the piston 37 downwardly as above explained. This results in shearing the pins 75 of coupling 59 and, thereafter, the piston 37 may move downwardly the length of movement between fingers 72 and 73. Since the fingers 72 are also, in fact, connected with the piston and the fingers 73 are connected with the tubing T1, the piston may undergo a downward movement sufficient to set the elastic packing element 26 without imparting the same movement to the tubing string T1. In this manner any stretch in the tubing, which might be caused by pressure application, is eliminated.

Below the coupling 79 is the safety joint F, said joint including threads 62 which have the same lead as the threads 61 of the coupling 59.

When it is desired to release the packing element and slips of the packer C, it is necessary to raise the tubing T1 with respect to the packer. The threads 61 of coupling 59 are left-hand threads and by rotating the tubing T1 to the right, the threads 61 are disconnected thereby permitting the tubing T1 to be raised with respect to the packer to place the ports 40 in registration with release ports 44. After the pressure between the piston and cylinder is relieved, it is desirable to reconnect the tubing T1 to the packer assembly and to accomplish this, the threads 78 of the coupling 79 are engaged with the threads 77 of the coupling 59. The distance between coupling 59 and coupling 79 is such that sufficient upward movement of the tubing T1 may be accomplished to effect release of pressure and, thereafter, tubing T1 is reconnected through said threads 77 and 78 to the upper packer C whereby the tubing T1 may be utilized to withdraw the packer from the well bore.

In the event it is necessary, the ends of the fingers 72 and 73 may be engaged with each other and then by taking tension on the tubing and thereafter rotating said tubing, an upward jarring blow will be delivered to the extension 60 and mandrel 25 to assist in releasing the packer.

As will hereinafter appear, the manipulation of tubing T1 may also effect a release of the intermediate packer B and the lowermost packer A. However, if the two lower packers do not release for one reason or another, the continued rotation of tubing T1 will break out the threads of the safety joint F and the upper packer may be withdrawn from the well bore separately from the other packers.

The first tubing string T1 continues downwardly through the second packer as is illustrated in FIGURE 5D. The construction of the intermediate packer B is substantially the same as that of the upper packer C except that it is provided with one bore 24*a* for the reception of tubing T1 and a second bore 47*a* for the reception of the second tubing string T2. Since tubing string T3 terminates just be-

low the upper packer, it is not necessary to provide a third bore through the packer B.

Since the construction of the intermediate packer is substantially the same as the upper packer, it is not believed necessary to describe the same in detail. However, briefly, the intermediate packer includes an upper body 23*a*, a packing element 26*a*, an expander cone 29*a*, slips 30*a*, a cylinder 35*a* having a head 36*a* and a piston 37*a*. The piston has an extension 60*a* projecting downwardly therefrom and the special clutch coupling 59 connects the tubing T1 with the packer B.

The piston 37*a* is formed with an angular port 38*a* having a back-check valve 39*a*. The angular port is adapted to communicate through an opening or port 40*a* provided in the tubing T1 with the bore of the tubing whereby pressure within the tubing T1 may be introduced into the area between the piston 37*a* and the cylinder head 36*a*. A release of pressure from this area may be effected when the tubing T1 is lifted and the port 40*a* is registered with a release port 44*a* provided in the tubular support or mandrel 25*a* of the packer B.

To permit pressuring up through the second tubing string, a tubular conduit 50*a* extending through the packer assembly B and forming a continuation of the second tubing string T2 is formed with a port 59*a*. This port is adapted to register with a second angular passage 56*a* having a check valve 57*a* therein.

The packers C and B are not only connected by reason of the first tubing string T1 but are also connected by the tubular conductor formed by the sections T2–*a* and T2–*b* (FIGURE 5C). As previously explained, the sections T2–*a* and T2–*b* are joined together through a union 13, such union being necessary in order that the tubular conductor formed by the sections may be made up at the same time that the tubing T1 is connected to the packers B and C. As has been noted, it is desirable to lower packers B and C by means of the first tubing string T1 and it is also desirable that the sections T2–*a* and T2–*b* of the second tubing string be in place between these two packers. The provision of the union 13 makes it possible to connect the pipe or conductor 50, which is part of the string T2 and which is actually the section T2–*b*, to another conductor 150 which actually forms the lower portion of section T2–*a*. The conductor 150 fits within the bore 47*a* of the intermediate packer B and has its lower end sealed off by suitable packing 68. It might be noted that the pipe 150 does not have a J-slot connection but is merely a sliding fit within bore 47*a*, so that it may be run into position and removed separately from the first tubing string.

The tubular pipe or conductor 50*a*, which forms a continuation of tubing T2, terminates just below the packer B and is provided with an internal valve seat 69 (FIGURE 5E) which is adapted to receive one of the removable plugs E which is dropped into position when it is desired to pressure up the tubing T2. Of course, when the plug is not in place, the lower end of tubing T2 is in communication with the area below the intermediate packer B.

The second packer B operates in substantially the same manner as the upper packer C as has been described and when pressure is applied between the piston 37*a* and the cylinder head 36*a*, slips 30*a* are first moved up into gripping position and then the reacting force moves the piston 37*a* downwardly to apply a downward force through the tubular support 25*a* to the upper end of the elastic packing element 26*a*. This effects a setting of the packing element and slips of the packer B. The provision of the special coupling 59 permits setting of the packing element of the packer B without applying a downward stretch to the strings T1 and T2.

As noted, the tubing T2 terminates below the intermediate packer B but tubing T1 extends downwardly through the lowermost packer A. In releasing the intermediate packer B, tubing T1 is rotated to the right and disconnects the left-hand threads 61 of coupling 59. This permits upward movement of the tubing T1 to locate the pressure port 40*a* in alignment with the release port 44*a* of packer B thereby relieving the pressure from between the piston 37*a* and the cylinder head 36*a*. Thereafter, the tubing T1 may be reconnected with the packer B through the threads 77 of coupling 59, which threads engage the threads 78 of coupling 79. A safety joint G is connected below coupling 79 and if packers B and A can not be released at the same time, this safety joint may be broken out to allow removal of packer B separately from the lower packer A.

The first tubing string T1 extends downwardly and through the lower packer A (FIGURE 5F) and supports said lower packer. The lower packer A is illustrated in FIGURE 5F and generally follows the construction of packers B and C heretofore described. As shown in FIGURE 5F, packer A includes an upper body or header 23*b*, which has a tubular pipe section or mandrel 25*b* extending downwardly therefrom. An elastic packing element 26*b* surrounds the mandrel section 25*b* and below said packing element is an expander cone 29*b*, which is suitably supported on a shoulder or ring 31*b*. Gripping slips 32*b* have their lower ends connected to the upper end of the cylinder head 36*b* of a cylinder 35*b*.

A piston 37*b* has connection with the lower end of the tubular section or mandrel 25*b*. The cylinder is nonrotatably connected to the piston by means of an index pin 42*b* which rides in a slot 43*b* in the exterior of the piston. A shear pin 42*c* formed on the inner end of the index pin normally connects the cylinder in a lowered position relative to the piston.

The tubing T1 extends entirely through the packer A, passing downwardly through the tubular section or mandrel 25*b* and projecting from the lower end of piston 37*b*. The special clutch coupling 59, illustrated in FIGURE 9, has its lower porton 74 threaded onto the extending end of the tubing string T1. The upper section 70 of the special coupling 59 has its fingers 72 interengaged with the fingers 73 of the lower section and the shear pins 75 connect the parts in the position shown in FIGURE 5F.

Pressure may be applied to the area between the piston 37*b* and the head 36*b* of the cylinder 35*b* through an angular passage 38*b* having a check valve 39*b* disposed therein. A port 40*b* is provided in the tubing T1 and when a plug E is dropped into the lower end of the tubing T1, as shown in FIGURE 5G, to seat upon a shoulder 90 within special coupling 91, pressure within the tubing T1 is directed through port 40*b* past the check valve and into the area between piston and cylinder head.

The packing element and slips of packer A is set in the same manner as the other packers, that is initial pressure between the piston and cylinder head, shears pin 42*c* allowing upward movement of the cylinder and results in setting of the slips 32*b*; upon setting of the slips, the reaction force of the pressure urges the piston 37*b* downwardly to shear the pins 75 in the special coupling 59. Thereafter, piston 37*b* and tubular section or mandrel 25*b* move downwardly to apply a force on the upper end of the elastic packing element 26*b*. This downward movement of the piston is permitted without aplying any downward stretch to the tubing string T1.

In order to release the packer A, the tubing string is lifted upwardly until the coupling 91 at the lower end thereof has its threads 92 engaged with the internal threads 77 of the special coupling 59, after which the tubing string T is again reconnected with the lower packer A to permit removal thereof from the well bore.

The particular construction of the check valves 39, 39*a* and 39*b* and the check valves 57 and 57*a* is subject to variation; however, a preferred form of check valve arrangement is illustrated in FIGURE 8 which shows the check valve 39*b* in the lower packer. The angular passage 38*b* is provided with a lower annular seat 93 and an

upper annular seat 94. A spring pressed ball 95 engages the lower seat and a spring pressed ball 96 engages the upper seat. Both valves open to permit entry of pressure fluid into the area between piston 37*b* and the head 36*b* of the cylinder but function to prevent any reverse flow through the passage. By providing two ball valves, it is assured that the pressure will be properly retained within the area between piston and cylinder head since if one valve leaks, the other will hold.

Any suitable type of removable plug E may be employed and, as a matter of fact, a ball valve could be dropped in lieu of the plug E to close the lower ends of the three strings of tubing T1, T2 and T3. By providing a plug, it is possible to retrieve the same and to remove it by a wire line operation and one form of plug is shown in FIGURE 10. This figure illustrates the coupling 91 at the lower end of string T1 and, as mentioned, this coupling includes an annular seat 90. The plug E includes a main body 97 having sealing rings 98. The body is provided with a cage 99 which is telescoped by a fishing neck 100. The lower end of the fishing neck carries an inner valve 101 which has a portion sealing with the bore 97*a* of the body 97.

It will be obvious that the plug, when in position as shown in FIGURE 10, will close the bore of the tubing string T1 against downward flow therethrough. When a suitable retrieving tool is engaged with the enlarged head of the fishing neck 100, the inner valve 101 is unseated to equalize pressures across the plug and continued upward movement will remove the plug from its seat.

The use of the apparatus and the particular method of completing multiple zone wells is illustrated in FIGURES 1 to 4. As previously mentioned, the first tubing string T1 has the lower packer A mounted thereon and is lowered as shown in FIGURE 1. Properly spaced on tubing T1 is packer B and after packer B is mounted, the section T2–*a* of the second tubing string T2 is placed in position. Thereafter, the uppermost packer C is connected to the first tubing string T1 and at this time the second section T2–*b* of the second string T2 is coupled in position by the union 13. This arrangement is illustrated in FIGURE 2. The three packers are then lowered by means of the first string T1 with the tubular conductor formed by sections T2–*a* and T2–*b* extending between packers B and C and being lowered along with said packers.

After the packers are properly located, the upper section T2–*c* is independently run into the well and its lower end is coupled by means of the J-slot connection 48—49 (FIGURE 5B) to the upper packer seat. Finally the third string T3 is run into the well and is coupled to the upper packer through J-slot connection 52—53. The hanger 20 of the control head D is then positioned and all three production or tubing strings are properly supported therefrom after which the hanger is bolted in place in the usual manner on the tubing head 22. Since the tubing strings have the control valves 21 therein and since the outlet 14 of the tubing head is provided with a control valve, the well is completely under control.

When all of the production or tubing strings are in finally landed position in the control head equipment, none of the packers A, B or C are in set position and it is now possible to circulate or perform any washing or other operation within the well while said well is under complete control. Thereafter, the packers may be selectively set in any desired order and without causing a stretching of the production strings. If a plug E or closure is dropped into tubing T1 and this tubing is pressured up, all three packers may be set simultaneously by the same pressure. On the other hand, if it is desired to set the uppermost packer first, this may be done by pressuring up through the string T3. After setting of the upper packer, pressure testing to assure that it is properly set may be carried out, this being accomplished by circulating downwardly through the first tubing string T1 and then upwardly around the unset lower packers. Or, as explained, a washing operation may be carried out to clean the well bore of mud and to wash the face of the formations. By dropping the plug into the second tubing string T2, the intermediate packer B and the uppermost packer C can be set simultaneously and by proper circulation and pressure buildup through the tubings T1 and T3, the sealing efficiency of these packers can be tested. The apparatus is extremely versatile and permits the carrying out of any desired operations and the setting of the packers in any desired order, followed by proper testing to assure that they are in set position.

In releasing the packers, it is only necessary to rotate and raise the first tubing string T1 since this will relieve the trapped pressure from between the operating pistons and cylinders of said packers. Thereafter, strings T3 and T2 may be uncoupled and independently removed, after which all packers may be removed by withdrawal of the string T1.

The provision of the safety joints F and G between the packers assures that if initial rotation of the first string T1 will not effect a release of all connections between the string T1 and the respective packers, it is possible to first break out the safety joint F between packers B and C and to remove the upper packer C. Such removal would, of course, remove the lower sections T2–*a* and T2–*b* of string T2 since this string merely has a slip joint connection with packer B. Thereafter, a suitable fishing tool or overshot may be engaged with the string T1 at the upper safety joint and through manipulation both packers A and B may be removed. If packer A is not disconnected from the string T1 at this time, the second or lowermost safety joint may be uncoupled so that packer B can be withdrawn separately. Subsequently packer A may be removed independently.

The use of the hydraulically set packers, which are positively actuated by the pressure between piston and cylinder head, assures that positive setting of the packers is obtained upon the application of pressure through one of the tubing strings. As noted, each packer is of the type in which the packing element is deformed by endwise compressive force and the construction is such that stretching of the strings is avoided when the packing element is moved to set position. Since the pressure is trapped in the area between the piston and cylinder, the packers can not be released until the pressure acting upon the packers is released. Release of all packers is accomplished by manipulation of only the first production string T1, whereby control is maintained through the single string.

Although three packers are shown as separating three separate formations, the apparatus lends itself to the use of any number of packers and in actual practice as many as five packers separating five producing zones in a single well have been employed. Of course, in such instance two additional strings of tubing must be provided to conduct independent flow from each zone to the surface. Of importance from a practical standpoint is the fact that all production strings may be landed in final position in the control head equipment prior to the time that the packers are set whereby various washing or other operations may be carried out; the packers, being hydraulically set, may thereafter be moved into sealing position without disturbing the production strings.

The foregoing disclosure and description of the invention is illustrative and explanatory thereof and various changes in the size, shapes and materials, as well as in the details of the illustrated construction, may be made within the scope of the appended claims without departing from the spirit of the invention.

I claim:

1. The method of completing a multiple zone well which includes, connecting a lower hydraulically-actuated well packer to the lower end of a first production string and lowering said packer and string a predetermined dis-

tance within the well bore, the lower end of said first production string communicating with the area below the lower packer, then connecting a hydraulically-actuated intermediate well packer to said first production string and continuing the lowering of said first string and packers, lowering a tubular conductor into the well and connecting the lower end thereof to the intermediate packer to extend upwardly therefrom, the lower end of said conductor communicating with the area between the lower and intermediate packers, thereafter connecting an upper hydraulically-actuated packer to said first production string and also coupling the upper packer to said tubular conductor, then further lowering the first production string, packers and conductor to locate said packers in final position within the well bore, then running the upper portion of a second production string and releasably connecting it to the upper packer to communicate with the tubular conductor, said upper portion of the second string and the tubular conductor forming the complete second production string, running a third production string and releasably connecting it with the upper packer to communicate with the area between the upper and intermediate packers, landing all production strings in final position in the well bore, and thereafter setting all hydraulically-actuated well packers by applying a pressure thereto from the bores of the production strings.

2. The method as set forth in claim 1, together with the additional steps of maintaining the actuating pressure against the well packers to maintain the same in set position even though the pressures in the bores of the production strings are reduced, and subsequently manipulating the first production string to relieve the hydraulic pressure applied to the well packers to effect a simultaneous release and unsetting of all packers.

3. The method of completing a multiple zone well which includes, connecting a lower hydraulically-actuated well packer to the lower end of a first production string and lowering said packer and string a predetermined distance within the well bore, then connecting a hydraulically-actuated intermediate well packer to said first production string and continuing lowering of the string and packers, lowering a tubular conductor into the well and connecting the lower end of a tubular conductor to the intermediate packer to extend upwardly therefrom, thereafter connecting an upper hydraulically-actuated packer to said first production string and coupling said upper packer to said conductor, then further lowering the first production string, packers and conductor to locate said packers in final position within the well bore, then running the upper portion of a second production string and releasably connecting it to the upper packer to communicate with the tubular conductor so that said upper portion and said tubular conductor forms the complete second production string, running a third production string and releasably connecting it with the upper packer, landing all production strings in final position in the well bore, setting the upper packer by conducting pressure from the third production string to said packer, performing a washing operation within the well bore below the upper set packer to wash the well bore, and thereafter setting the intermediate and lower packers by conducting pressure from the first production string to said packers.

4. A well completion apparatus including, a first production string, a lower well packer, releasable means releasably connecting the lower well packer to said production string, an upper well packer spaced upwardly from the lower well packer, means releasably connecting the upper packer to said production string, the lower end of said first production string communicating with the area below the lower packer, a second production string extending through the upper packer and having its lower end communicating with the area between the packers, each packer including hydraulically-actuated means for setting the packer, means for directing fluid pressure from the first production string to the hydraulically-actuated means of the lower packer to actuate the same whereby said lower packer may be set by pressure conducted thereto from the first production string, means for directing fluid pressure from the second production string to the hydraulically-actuated means of the upper packer to actuate the same whereby the upper packer may be set independently of the lower packer, means in each packer maintaining pressure within the hydraulically-actuated means to maintain the packers in set position, the releasable means connecting the first production string and the well packers being releasable by a manipulation of the first production string whereby said first production string is moved relative to said packers, and valve means on said first production string operated by such movement of said production string to release the pressure acting upon the hydraulically-actuated means of said packers to effect an unsetting of said packers.

5. A well completion apparatus as set forth in claim 4, together with means for reconnecting the well packers to said first production string after said packers have been unset, whereby the packers may be removed from the well bore by means of said first production string.

6. A well completion apparatus including, a first production string, a lower well packer, releasable means releasably connecting the lower well packer to said production string, an upper well packer spaced upwardly from the lower well packer, releasable means releasably connecting the upper well packer to said production string, the lower end of said first production string communicating with the area below the lower packer, a second production string extending through the upper packer and having its lower end communicating with the area between the packers, each packer including hydraulically-actuated packer-setting means for setting the packer, means for directing fluid pressure from the first production string to the hydraulically-actuated packer setting means of both packers to actuate said packers whereby both packers may be set by pressure conducted thereto from the first production string, means within each well packer for trapping the pressure which has been applied to the hydraulically-actuated packer-setting means thereof to maintain the packer in set position without the necessity of maintaining pressure in the production strings, the releasable means between the first production string and the well packers being releasable by a manipulation of said first production string whereby the first production string is moved relative to the set packers and valve means on the production string operated by such movement of said production string to release the trapped pressure acting upon the packer-setting means of the packers to effect unsetting of said packers.

7. A well completion apparatus as set forth in claim 6, together with means for reconnecting the well packers to said first production string after said packers have been unset, whereby the packers may be removed from the well bore by means of said first production string.

8. The method of completing a multiple zone well as set forth in claim 1, together with the step of conducting pressure from the first production string to all three of the hydraulically-actuated packers to set said packers.

9. The method of completing a multiple zone well as set forth in claim 1 together with the steps of conducting pressure from the third production string to the hydraulically-actuated upper packer to set the same, and conducting pressure from the first production string to the hydraulically-actuated intermediate and lower packers to set the same.

10. The method of completing a multiple zone well as set forth in claim 1, together with the steps of conducting pressure from the second production string to the upper and intermediate packers to set the same, and conducting pressure from the first production string to the lower packer to set the same.

11. A well completion apparatus including, a first production string lowered into a well bore which traverses

at least two producing zones, a pair of well packers mounted upon and releasably connected to said string and adapted to seal off the producing zones when moved to a set position, said first production string having its lower end communicating with the area below the lower packer, means releasably connecting said well packers to said first production string, a second production string extending from the surface of the well and through the upper packer with the lower end of said second production string communicating with the area between the packers, the well packers being in a retracted non-sealing position during lowering thereof to the desired elevation within the well bore, hydraulically-actuated means in each packer for moving each packer to a set or sealing position, means for conducting fluid pressure from at least one of said production strings to said hydraulically-actuated means to actuate the same and set the packers, normally closed valve means associated with the hydraulically-actuated means of each packer for trapping the actuating fluid pressure within said hydraulically-actuated means to maintain each packer in set position, said valve means being opened by a manipulation of said first production string when the first production string is moved relative to the packers to release the trapped fluid pressure and thereby release the packers from set position.

12. A well completion apparatus including, a first production string lowered into a well bore which traverses at least two producing zones, a pair of well packers mounted upon and releasably connected to said string and adapted to seal off the producing zones when moved to a set position, means releasably connecting said well packers to said first production string, each packer including an elastic packing element which is deformable by application of an endwise force thereto and also including hydraulically-actuated means for applying such endwise force to said packing element, said first production string extending through both packers and having its lower end in communication with the area below the lower packer, a second production string extending from the surface and through the upper packer with the lower end of said second production string communicating with the area between the packers, said packers being in a retracted non-sealing position during lowering thereof to the desired elevation within the well bore, means for conducting fluid pressure from at least one of said production strings to said hydraulically-actuated means to actuate the same and set the packers, normally closed valve means associated with said hydraulically-actuated means of each packer for trapping the actuating fluid pressure within said hydraulically-actuated means to maintain each packer in set position, said valve means being opened by a manipulation of said first production string when the first production string is moved relative to the packers to release the trapped fluid pressure and thereby release the packers from set position.

13. A well completion apparatus including, a first production string, a lower well packer mounted on and releasably connected to said string, an intermediate well packer mounted on and releasably connected to said string, an upper well packer mounted on and releasably connected to said string, means releasably connecting said well packers to said first production string, a tubular conductor extending through and between the upper packer and the intermediate packer and having its lower end communicating with the area between the intermediate and lower packers, the first production string having its lower end communicating with the area below the lower packer, said first production string, well packers and connecting tubular conductor being lowerable in the hole as a unitary assembly with the packer in a retracted position, an upper section of a second production string extending upwardly from the upper packer and having its lower portion releasably connected to the upper packer and having its lower end communicating with the tubular conductor, said section of the second string and the tubular conductor forming the complete second production string, a third production string having releasable connection with the upper packer, means communicating the lower end of the third production string with the area between the upper and intermediate packers, control head equipment at the surface of the well, means for landing all three production strings in final position in said control head equipment while the well packers are still in unset position, each well packer including hydraulically-actuated packer-setting means for setting said packer, and means conducting fluid pressure from a production string to the hydraulically-actuated packer-setting means of each packer to actuate the same and effect setting of the packers after the control head equipment is in place on the well head.

14. A well completion apparatus as set forth in claim 13, together with normally closed valve means associated with the hydraulically-actuated means of each packer for trapping the actuating fluid pressure within the hydraulically-actuated means to maintain each packer in set position, the first production string being moved relative to the packers to open said valve means and release the trapped pressure and thereby simultaneously release the packers from set position.

15. A well completion apparatus as set forth in claim 13, together with a safety joint connection in the first production string and located between the lower and intermediate packers, and a second safety joint connection in said first production string and located between the intermediate and upper packers.

References Cited in the file of this patent

UNITED STATES PATENTS

381,013	Hoadley	Apr. 10, 1888
1,523,286	Railsback	Jan. 13, 1925
1,861,332	Waitz	May 31, 1932
2,121,002	Baker	June 21, 1938
2,791,277	Ilfrey et al.	May 7, 1957
2,903,066	Brown	Sept. 8, 1959