United States Patent [19]

Young et al.

[11] **3,710,862**

[45] **Jan. 16, 1973**

[54] **METHOD AND APPARATUS FOR TREATING AND PREPARING WELLS FOR PRODUCTION**

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[73] Assignee: **Otis Engineering Corporation**, Dallas, Tex.

[22] Filed: **June 7, 1971**

[21] Appl. No.: **150,349**

[52] **U.S. Cl.** **166/278**, 166/51, 166/131, 166/205, 166/226

[51] **Int. Cl.**....**E21b 43/04**, E21b 43/10, E21b 43/14

[58] **Field of Search**.....166/126, 278, 131, 133, 143, 166/144, 158, 184, 181, 188, 102, 226, 120, 205, 51, 315, 313, 314

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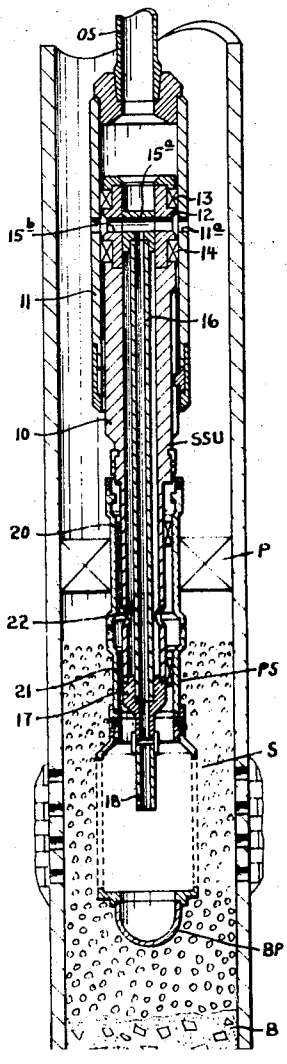
Primary Examiner—Stephen J. Novosad
Attorney—E. Hastings Ackley

[57] **ABSTRACT**

A method and apparatus for setting a packer supporting a screen, treating the well to stimulate production from the formation or for other purposes, gravel packing the well bore around the screen, all without removing the setting string from the well bore, then removing the setting string and installing a producing string in the packer to produce the well; together with apparatus for carrying out the method. In addition, the method and apparatus contemplates successive treatment of a plurality of producing formations one above the other in the well bore without affecting the previously treated and gravel packed formation.

19 Claims, 23 Drawing Figures



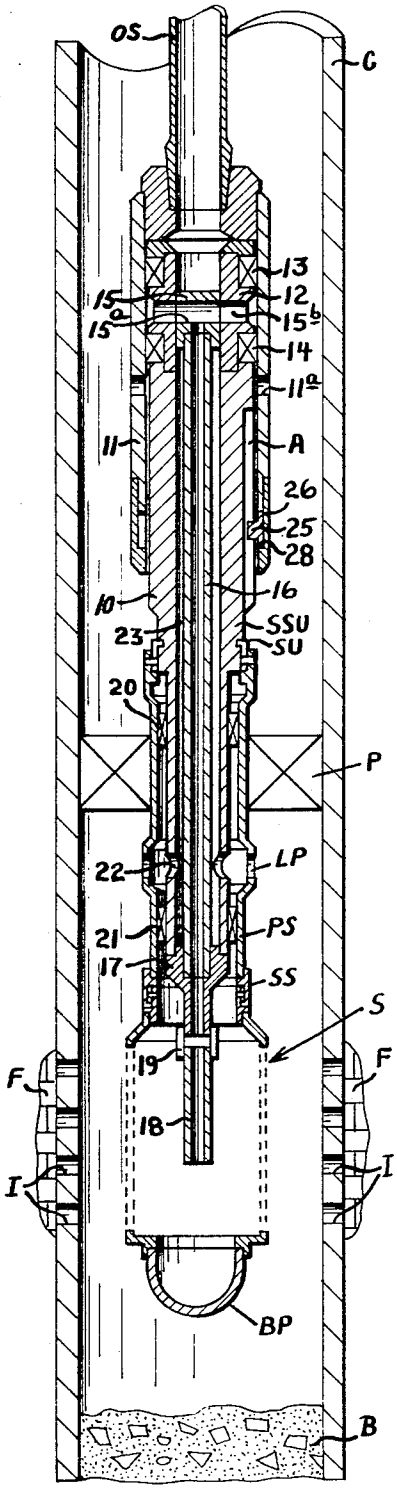


FIG. 1

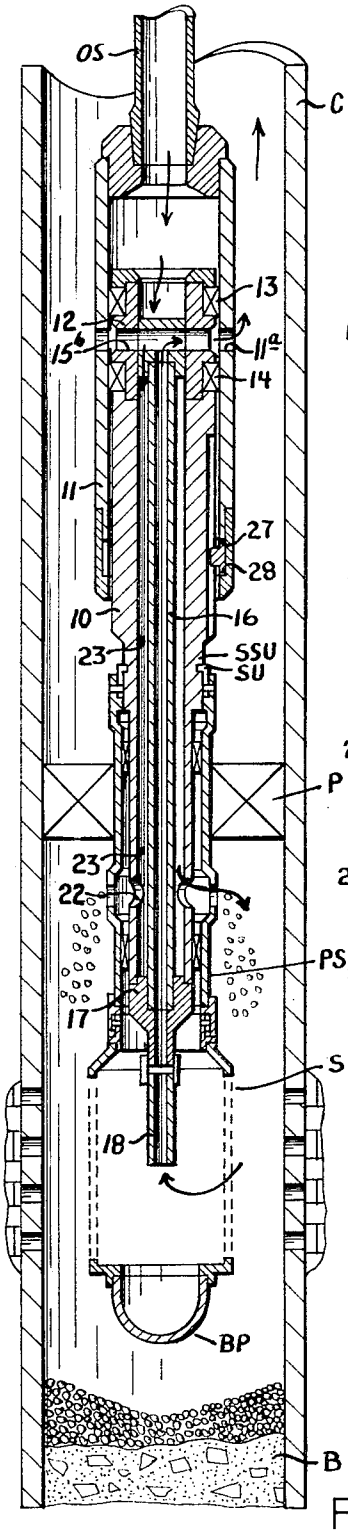


FIG. 2

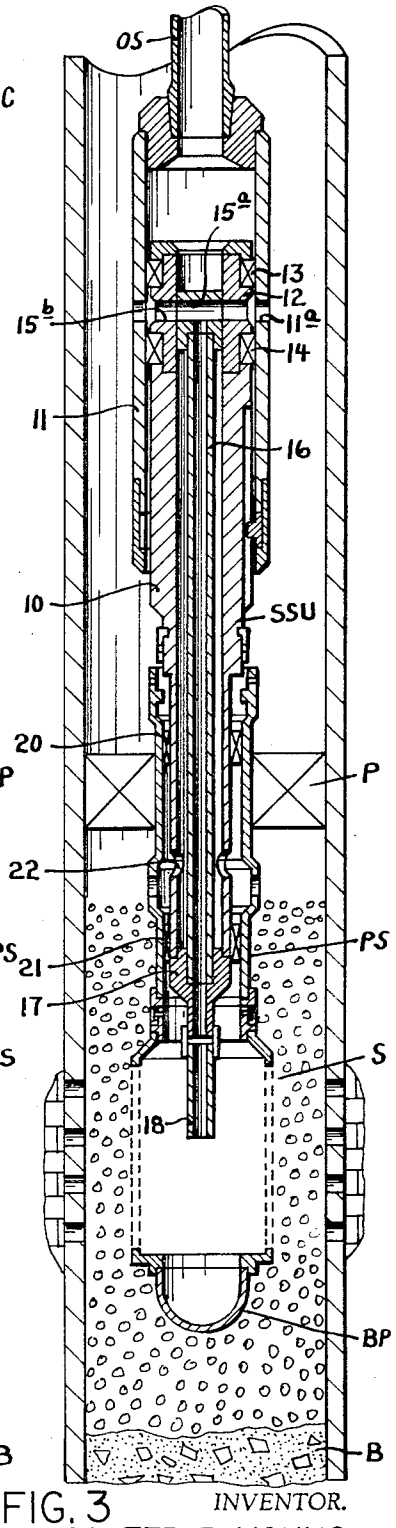


FIG. 3

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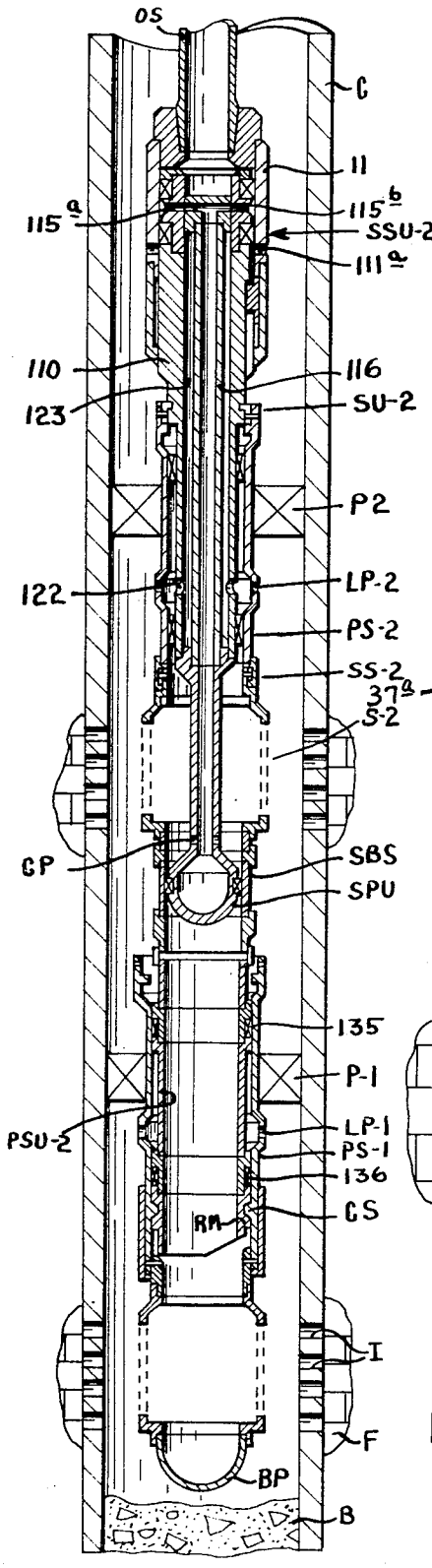

FIG. 11

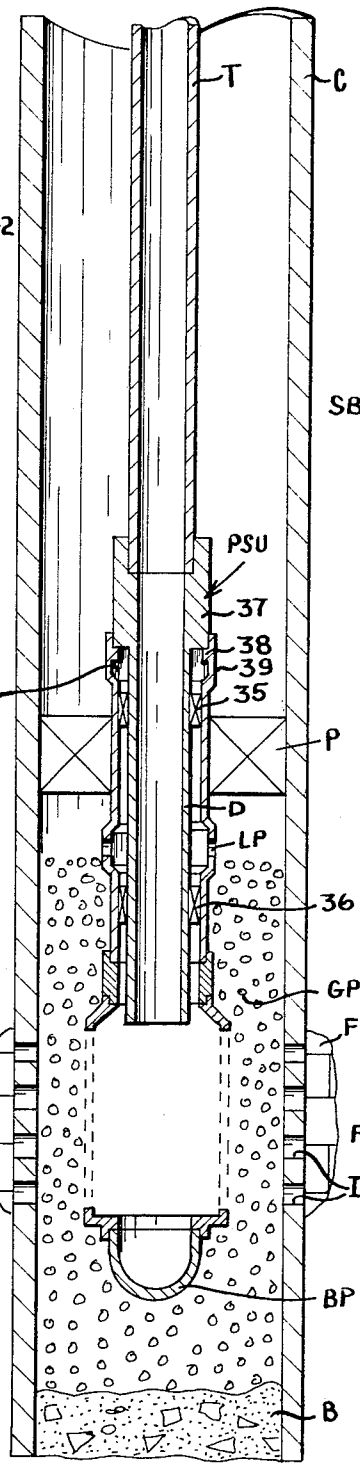

FIG. 4

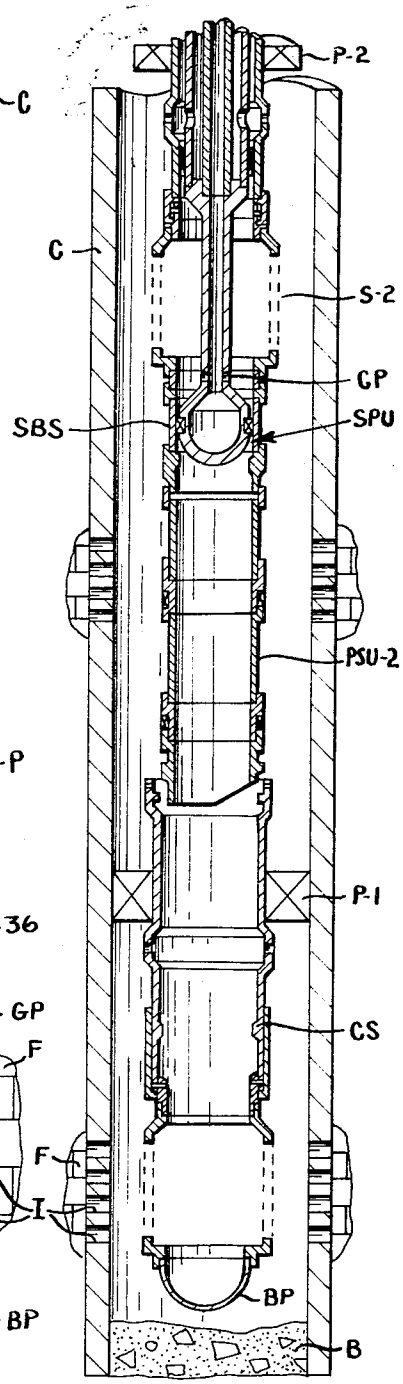

FIG. 10

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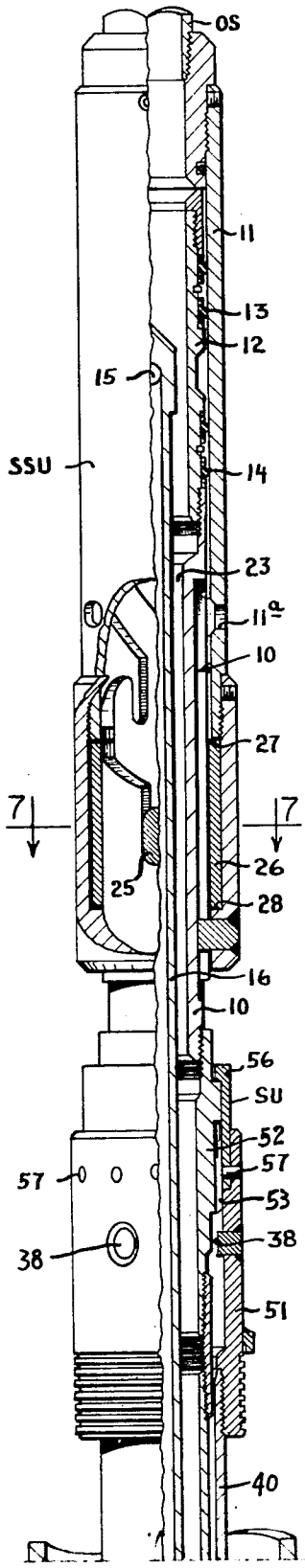

FIG.5A

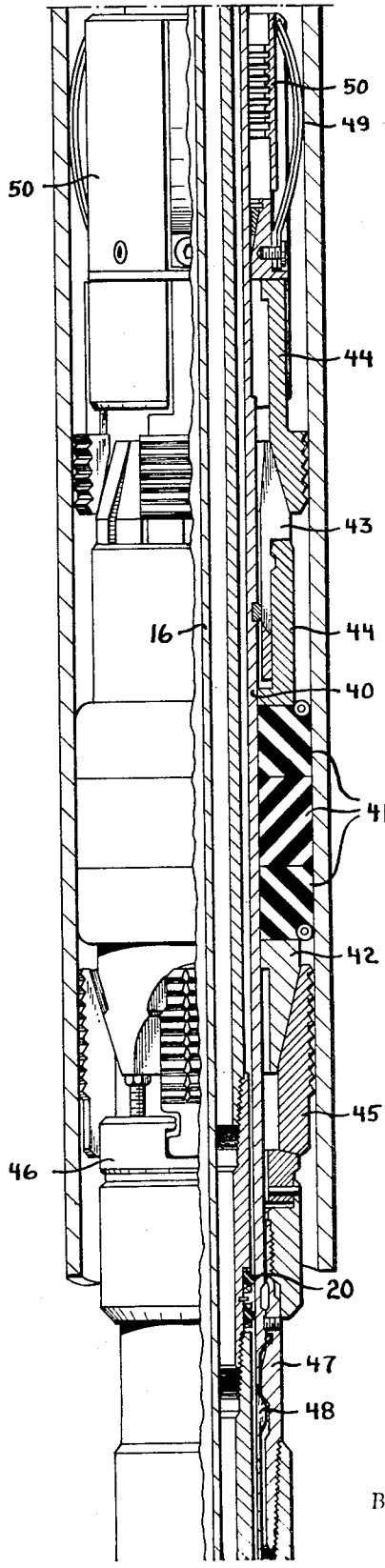

FIG.5B

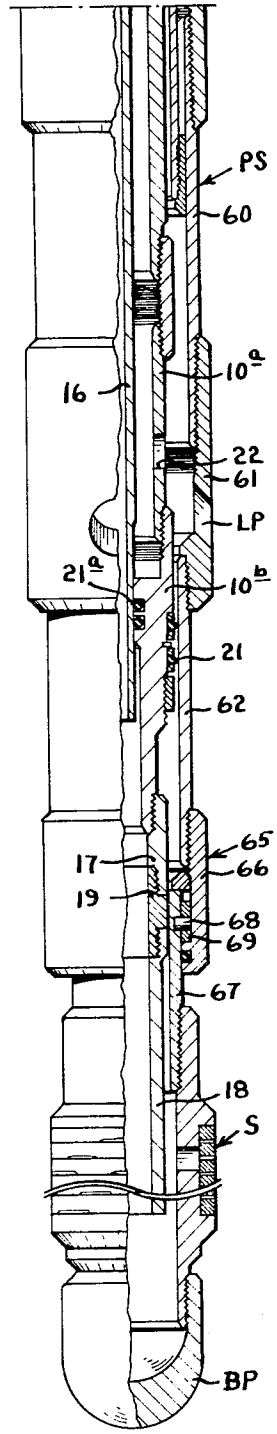

FIG.5C

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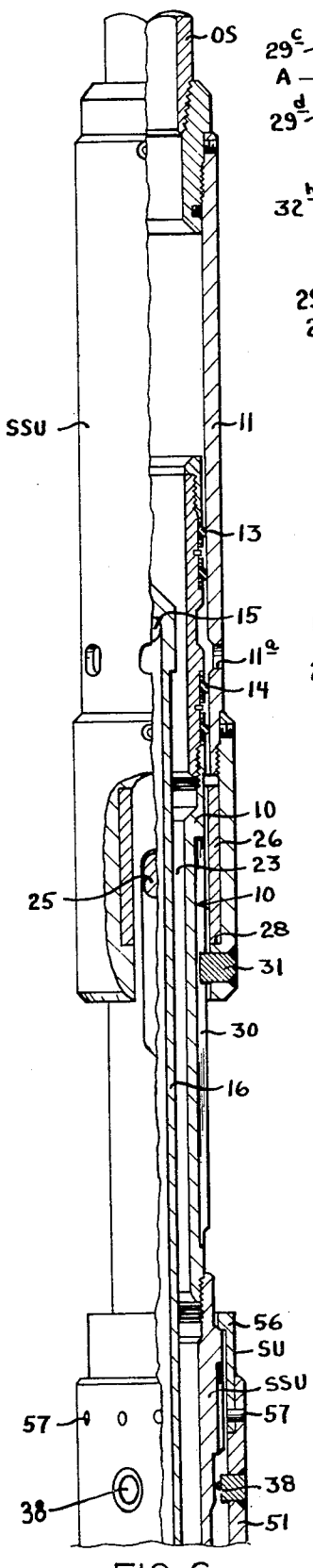

FIG. 6

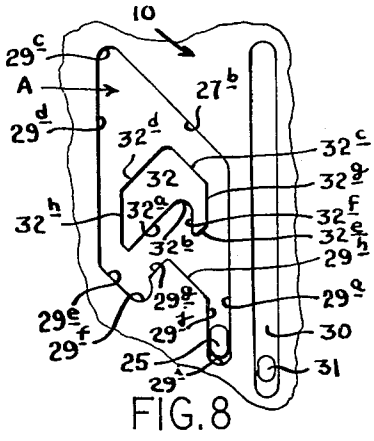

FIG. 8

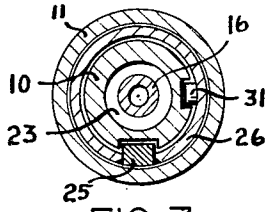

FIG. 7

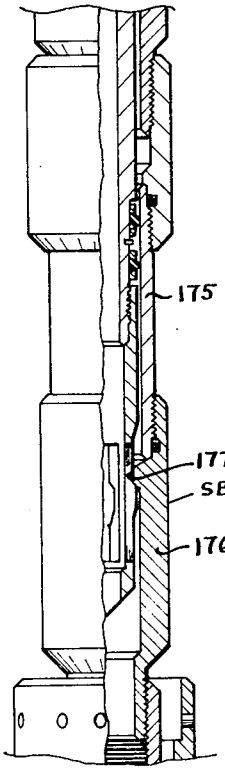

FIG. 16

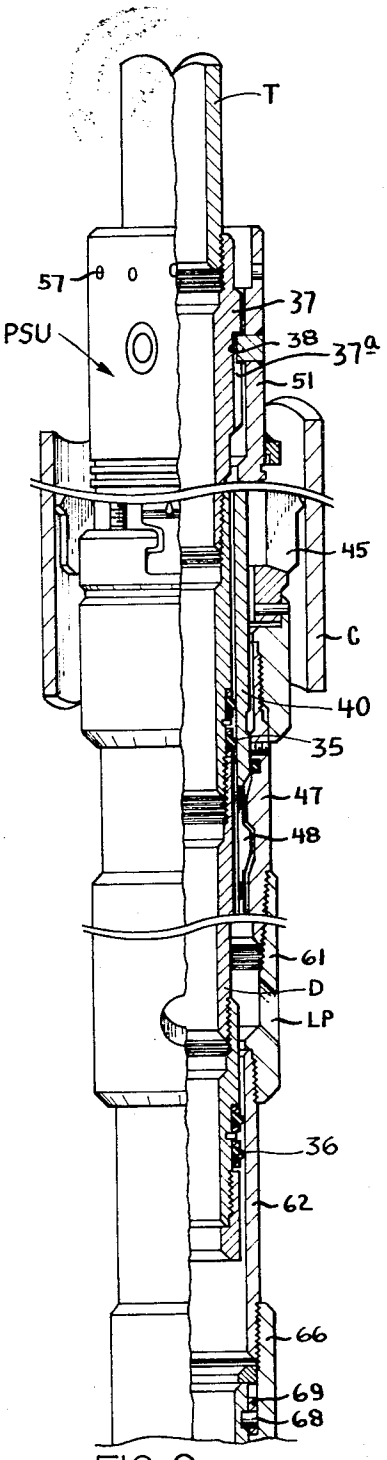

FIG. 9

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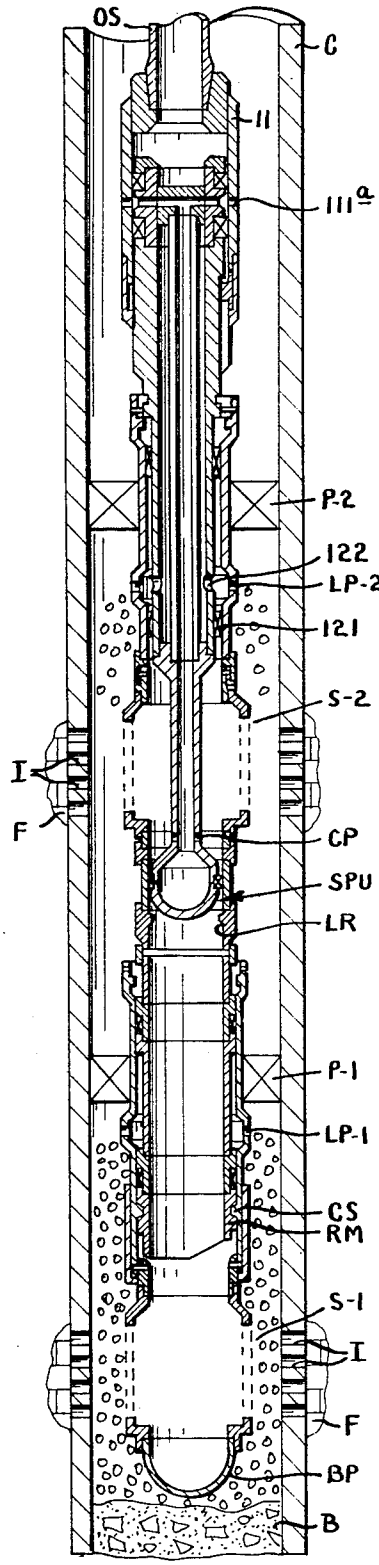

FIG. 12

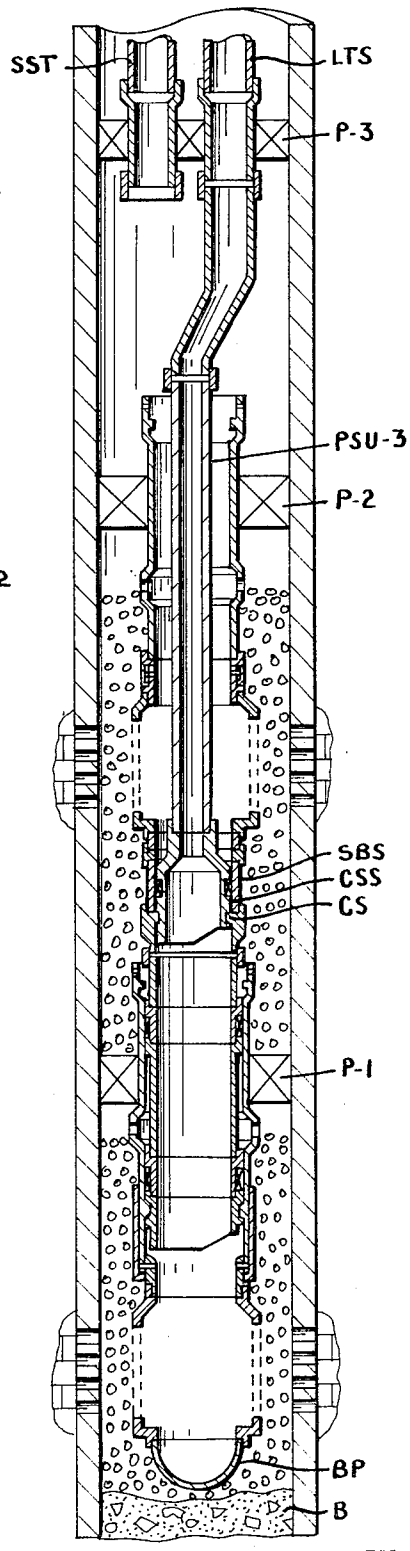

FIG. 14

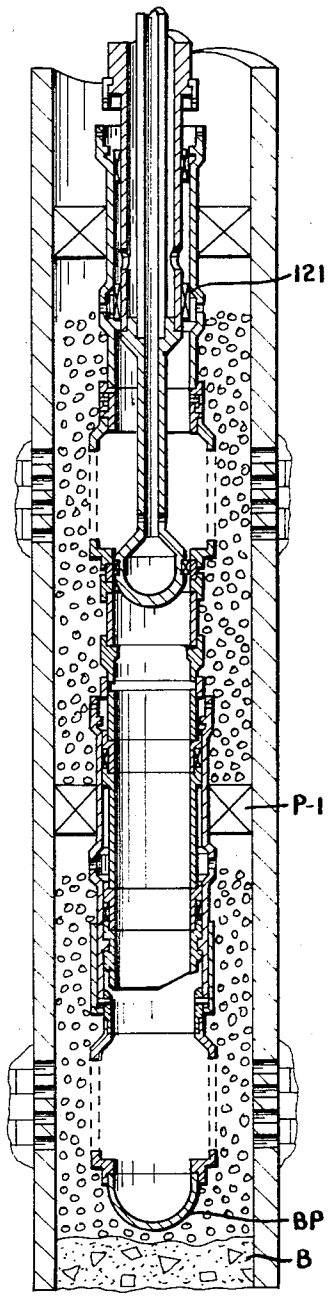

FIG. 13

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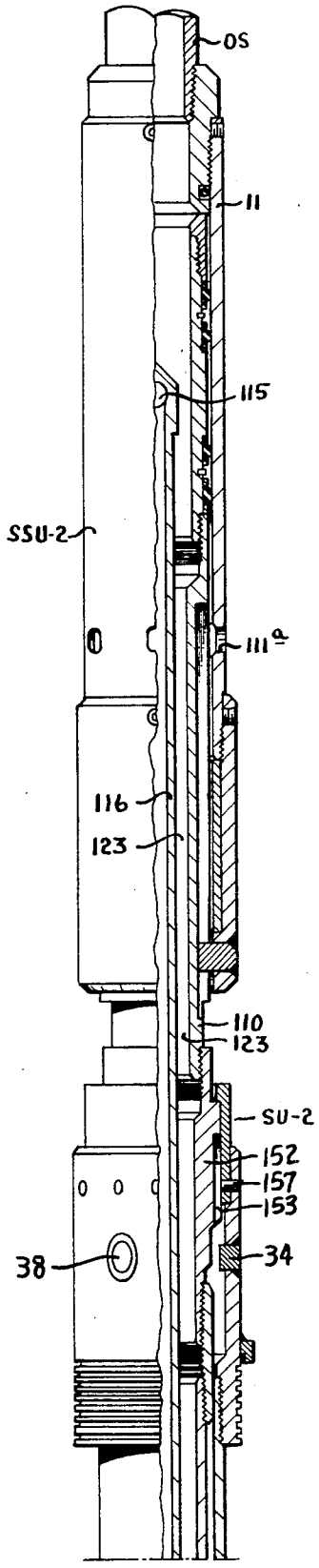

FIG. 15A

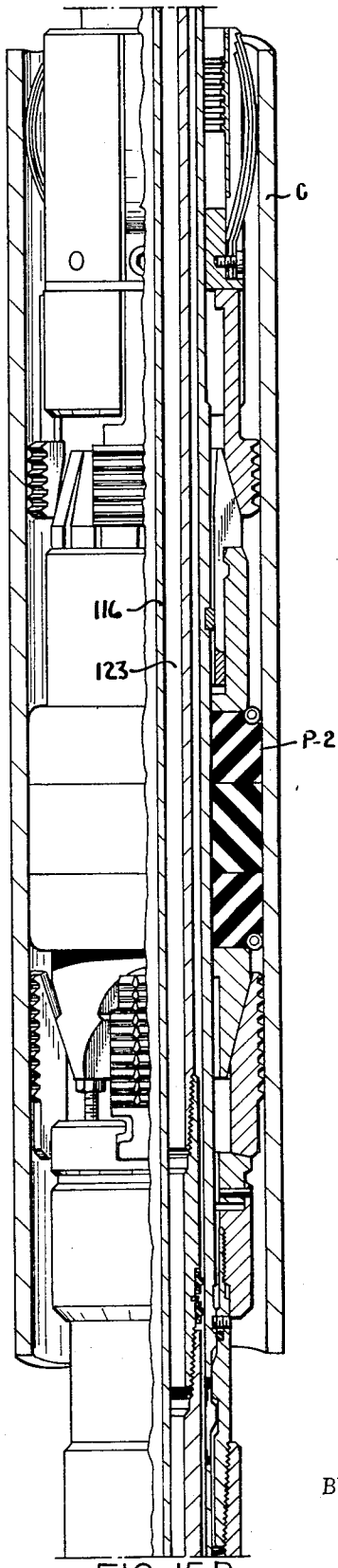

FIG. 15B

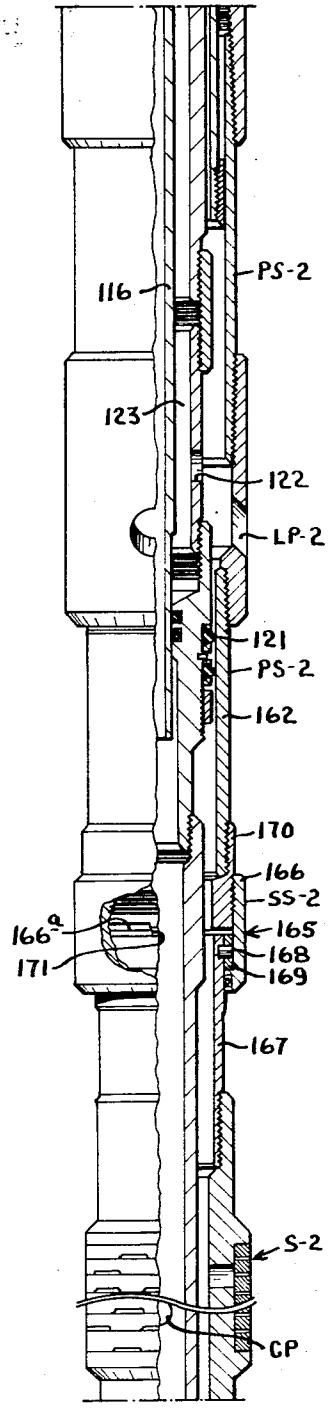

FIG. 15C

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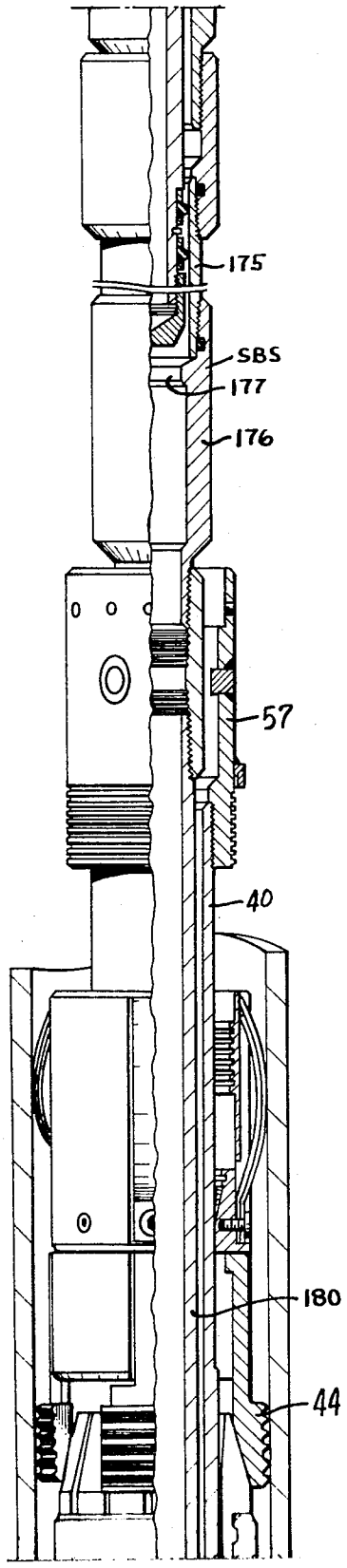

FIG. 15D

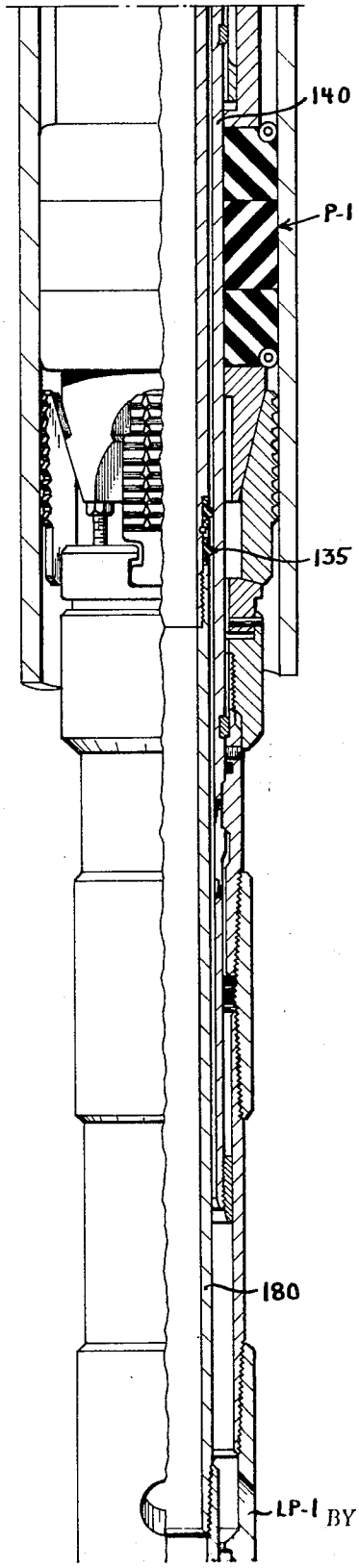

FIG. 15E

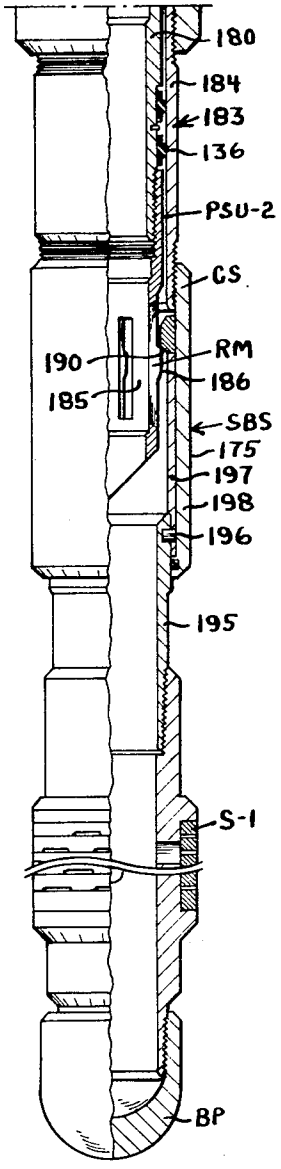

FIG. 15F

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METHOD AND APPARATUS FOR TREATING AND PREPARING WELLS FOR PRODUCTION

This invention relates to new and useful improvements in treating and preparing wells for production.

One object of the invention is to provide apparatus for and methods of installing a well packer and screen, treating the well, gravel packing around the screen and removing the installing string for installation of a producing string.

An important object of the invention is to provide an apparatus and method for installing a packer supporting a screen therebelow, for setting the packer, then treating the producing formation to stimulate flow, to increase productivity, or for other purposes, gravel packing around the screen between the screen and the producing formation or inlets into the well bore, cleaning the well bore, then removing the setting string and setting tool and installing a producing string in the well sealing with the packer for producing from the producing formation.

A particular object of the invention is to provide apparatus for and a method of the character described usable for installing a second packer and screen, treating a second formation above the previously treated formation, gravel packing around the screen above the first packer and then removing the setting tool and string and installing a flow conducting string for producing each of the formations separately.

Still another object of the invention is to provide apparatus of the character set forth wherein after the packer is set, opening and closing the flow paths for directing the flow of fluids and gravel into the well bore is effected by longitudinal movement of the setting string and setting tool, and wherein means is provided for positively indicating that the flow paths are in the desired position.

Still another object of the invention is to provide in apparatus of the character described a setting tool having means for setting a plurality of packers and screens each at a successively higher location in the well in flow communication with the lowest packer and screen, and wherein the operations of treating the well to stimulate production or otherwise, to install the gravel pack around the screens and clean out the well formation are carried out without subjecting to the lower packer or packers to the pressure of the fluids being utilized to treat and gravel pack the screen and formation thereabove.

Still another object of the invention is to provide an improved method for installing packers supporting screens, for treating the producing formation to stimulate production or for other purposes, if desired, for gravel packing around the screen, and for removing the operating tool and string only after all such operations have been performed to permit the producing string to be then installed.

A further important object of the invention is to provide a method of the character described wherein multiple zone wells may be provided with packers, screens and gravel pack, and each of the producing formations may be separately treated, if desired, during a single trip of the installing tool for placing the packer and screen in the well, treating the producing formation

and installing the gravel pack around the screen at each zone, whereby each zone is prepared for production during a single trip of the operating tool and string into the well for preparing the well for production.

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

FIG. 1 is a schematic view of a well installation showing apparatus used in practicing the method of the invention, in position for pressure treating the producing formation;

FIG. 2 is a schematic view similar to FIG. 1, showing the service tool of the apparatus moved to a position to circulate fluids into and out of the producing formation and to install gravel around the screen;

FIG. 3 is a schematic view similar to FIG. 2, showing the gravel inserted around the screen and the service tool being removed from the packer;

FIG. 4 is a schematic view similar to FIG. 3, showing the production seal assembly in place in the packer for producing the well;

FIGS. 5A, 5B and 5C are enlarged views, partly in elevation and partly in section, of the details of construction of the packer and service seal unit used in setting the packer and servicing the well;

FIG. 6 is a fragmentary view of the upper portion of the service seal unit and packer showing the same in position for circulating fluids through the packer and around the screen for gravel packing or treating the well producing formation;

FIG. 7 is a horizontal cross-sectional view, taken on the line 7 — 7 of FIG. 5A;

FIG. 8 is a view showing the operating slots arrangement for controlling opening and closing of the cross-over flow ports of the service seal unit;

FIG. 9 is a fragmentary view of the packer of FIGS. 5A through 5C, showing the production seal unit in place therein for producing the well;

FIG. 10 is a schematic view, similar to FIG. 1, of a dual zone well installation in which a screen and gravel pack arrangement has installed at the lower producing zone, and showing an upper packer and screen for the upper formation being lowered into place by a service seal unit and operating string;

FIG. 11 is a schematic view, similar to FIG. 10, showing the upper packer anchored in place and the service seal unit in position for pressure treating the upper producing formation while sealing off the lower packer and lower producing formation from such pressure;

FIG. 12 is a schematic view, similar to FIG. 11, showing the service seal unit in position for circulating fluid into and out of the upper formation and for inserting gravel around the upper screen above the lower packer;

FIG. 13 is a schematic view, similar to FIG. 12, showing the service seal unit being removed from the well with the packers and gravel pack installation complete;

FIG. 14 is a schematic view of the well installation with the dual zone production seal unit in place for conducting fluids through parallel strings of tubing to the surface past a dual string packer;

FIGS. 15A through 15F are enlarged views, partly in elevation and partly in section, of the details of con-

struction of the lower zone packer and screen, the upper zone packer and screen, and the service seal unit utilized in installing the upper packer and treating the upper formation after the lower packer and screen and gravel pack have been installed; and,

FIG. 16 is a fragmentary view of the seal bore extension between the upper packer and lower packer of the dual installation with a production seal unit in place therein.

In the drawings, FIGS. 1 through 4, is shown a well installation in which a casing C extends downwardly in the well bore to a producing formation F from which fluids flow inwardly through perforations or inlets I in the casing above the usual cement plug B and into the bore of the tubing. In wells in which there is a flow of sand from the producing formation through the perforations into the casing, it is desirable that a screen and gravel pack area be provided at the inlet into the flow conductor of the well. Therefore, as is shown in FIG. 1, a well packer P is installed in the bore of the casing C on the lower end of a service seal unit SSU connected to the lower end of an operating string OS by means of which the packer is set in the usual manner in the casing to seal with the bore wall of the casing. The packer supports a screen S, of the usual well known type, having a plurality of very narrow orifices provided in its wall through which fluids may pass, but which will prevent flow of sand or gravel or the like into the bore of the screen. A bull plug BP is connected in the usual manner to the lower end of the screen for closing the same to direct fluids through the screen. A shear sleeve SS is connected between the screen and the packer P to permit removal of the packer and other well tools above the screen, if desired, by shearing the connection between the screen and the well tools thereabove.

A tubular port sleeve PS is connected to the lower end of the packer P and is provided with a plurality of lateral ports through which fluids may be circulated from the interior to the exterior thereof below the packer and above the screen, as will be hereinafter more fully explained. The packer P may be of any suitable type, but is preferably a retrievable packer of the type shown and described in the patent to Elliston, U.S. Pat. No. 3,398,795, which may be set by manipulation of the tubing, or hydraulically, as desired, and which is retrievable after the period of use has expired.

As shown in FIG. 1, the packer is connected to the lower end of the service seal unit SSU by a shear sleeve unit SU by means of which the packer may be manipulated until it is desired to release the service seal unit from connection therewith and remove it from the well bore above the packer after the same has been set.

The service seal unit includes an elongate tubular body **10** which has a connection at its lower end with the shear unit SU and which extends upwardly into a tubular sleeve **11** in which a cross-over head or cross-flow head **12** is slidable. Sealing units **13** above and **14** below a cross-flow passage member **15** seal between the head and the bore wall of the sleeve **11** to close the cross-flow passages **15a** and **15b** to flow therethrough, when the head is in the position shown in FIG. 1. A longitudinal flow tube **16** is connected to the head and extends downwardly therefrom through the bore of the sleeve **10** to a lower sub **17** to which an elongate extension tube **18** is connected in the usual manner by a coupling **19**. The sleeve **10** has upper and lower external sealing elements **20** and **21** thereon sealing between said sleeve and the bore wall of the packer P and the packer sleeve PS above and below the lateral ports LP in said packer sleeve. Lateral flow ports **22** are formed in the wall of the sleeve **10** in a position to be in communication with the lateral ports LP in the packer sleeve PS, for a purpose which will be hereinafter more fully explained.

Lateral flow ports **11a** are provided in the mid-portion of the sleeve **11** below the cross-flow head **12** at the upper end of the service seal unit SSU to admit fluids into the bore of the sleeve when desired to pass therethrough when the sleeve **11** is in the upper position shown in FIG. **2** for directing fluid from the bore of the screen upwardly through the elongate tube **16** to the cross-flow passages **15*a*** and **15*b*** and outwardly through the lateral ports **11a** to the annular space between the sleeve **11** and the casing C. Fluids pumped downwardly through the operating string OS into the bore of the sleeve **11** above the cross-flow head **12** will move downwardly through the head **12** exteriorly around the cross-flow member **15** and into the annular space between the sleeve **10** and the tube **16** and downwardly therebetween to the lateral ports **22**, then outwardly through said ports between the upper and lower packing seal members **20** and **21** on the sleeve **10** to the lateral ports LP in the packer sleeve PS and outwardly into the bore of the casing below the packer P. The cross-flow member **15** has a cross-flow passage **15a** which communicates with and forms an extension of the lateral openings **15*b*** in the head **12** to provide the isolated separate cross-flow conductor in the head **12** for controlling flow of fluids through the service seal unit above and below the packer.

For controlling positioning of the head **12** and the cross-flow passage member **15** with respect to the lateral ports **11a** of the sleeve **11**, a control slot A is provided in the exterior of the enlarged upper portion of the sleeve **10** and a follower lug **25** projecting inwardly from a rotatable sleeve **26** rides in the control slot A. The engagement of the lug with the upper and lower ends of the slot controls the movement of the sleeve **11** with respect to the tube **10** and the cross-over head **12**, as will be hereinafter more fully explained. As will be seen in FIG. **8**, the control slot A is spaced circumferentially around the sleeve **10** from a longitudinal restraining slot **30** in which a restraining lug **31** is slidable. The lug **31** is secured to the inner wall or bore of the elongate tubular sleeve **11** and rides in the slot **30** to prevent rotation of the sleeve **11** with respect to the body **10** during longitudinal relative movement between the body and the sleeve. The follower lug **25** is carried by the rotatable sleeve **26** confined between opposed shoulders **27** and **28** in the bore of the sleeve **11** and rotatable about the longitudinal axis of the sleeve and the body **10** during a limited arcuate movement determined by the engagement of the follower lug **25** with the lateral surfaces of the control slot A, as will be described.

As shown in FIG. **8**, the control slot has a lower vertical side wall surface **29*a*** which extends upwardly substantially two-thirds of the length of the longitudinal restraining slot **30** and then is inclined upwardly away

along an inclined cam surface **29***b* from the the restraining slot to an upper apex **29***c* which limits upward movement of the lug **25** in the control slot. As the sleeve **11** moves upwardly with respect to the body **10**, the lug **25** will ride up the vertical side wall **29***a* of the lower end portion of the control slot to the inclined cam surface **27***b* extending upwardly and away from the vertical restraining slot **30**, turning the sleeve **26**, until the follower lug engages the uppermost pocket surface **29***c* of the control slot. At this point the sleeve **11** is in its uppermost position with respect to the head **12** and the lateral ports **11***a* therein are in registry with the cross-flow passages **15***a* and **15***b* in the head. Downward movement of the operating string OS will then move the sleeve **11** downwardly and so cause the rotatable sleeve **26**, on which the follower lug is mounted, to ride downwardly along the opposite vertical surface **29***d* of the control slot A to a downwardly and inwardly inclined cam surface **29***e* substantially two-thirds of the length of the vertical restraining slot **30** from the upper end of said slot into an intermediate stop pocket **29***f* which there limits downward movement of the sleeve **11** with respect to the body **10**. In this position, the ports **11***a* are disposed below the lower seals **14** on the head **12** and the cross-flow passages **15***a* and **15***b* are therefore closed against flow therethrough. Above the stop pocket **29***f* is an inward and upward inclined surface **29***g* formed in the outer wall of the slot A for permitting the lug to ride upwardly along a camming surface **32***a* on an internal island camming member **32** disposed in the slot A. The camming surface **32***a* is inclined upwardly and toward the longitudinal restraining slot **30** and terminates in a stop pocket **32***b* which is located substantially medially of the longitudinal restraining slot **30** and at that point limits upward movement of the follower lug **25** and the sleeve **11** with respect to the body **10**. In this position, the ports **11***a* are still held out of fluid communication with the cross-flow passages **15***a* and **15***b* to prevent flow therethrough. It is obvious also, that should fluid pressure acting on the tubing string cause upward movement of the lower end thereof while the ports **11***a* are closed, the engagement of the follower lug **25** in the pocket **32***b* of the island member **32**, just described, will prevent accidental undesired opening of such cross-flow passages to the lateral ports. Downward movement of the sleeve **11** with respect to the body will cause the follower lug **25** to engage a downwardly and inwardly inclined camming surface **29***h* on the outer wall of the control slot A below the pocket **32***b*, which extends downwardly and inwardly toward the straight restraining slot **30** to the lower end of the elongate vertical lower pocket **29***i* of the control slot A which is defined by the outer vertical surface **29***a* and a vertical surface **29***j* spaced from and extending parallel thereto below the inclined camming surface **29***h*.

Thus, it will be seen that the follower lug **25** will move from the pocket **29***i* upwardly along the vertical surface **29***a* to the inclined camming surface **27***b*, then upwardly and away from the straight restraining slot **30** to the apex pocket **29***c* which limits the upward movement of the sleeve **11** with respect to the body and at which point the cross-flow ports are in communication with the lateral ports of the sleeve **11**. Downward movement of the sleeve **11** with respect to the body then causes the follower lug to ride along the vertical surface **29***d* to engage the camming surface **29***e* at the lower end thereof and be directed into the stop pocket **29***f*, which is located below the upwardly inclined camming surface **32***a* of the island cam member **32** located substantially centrally of the cam slot A. Upward movement of the sleeve then causes the follower lug **25** to ride along the cam surface **32***a* to the stop pocket **32***b* in the cam island, which positions the lugs substantially medially of the control slot, at which position the lateral ports **11***a* of the sleeve are spaced from the cross-flow ports **15***a* and **15***b* in the head. After the follower cam has engaged in the pocket **32***b*, downward movement of the sleeve **11** will cause the follower cam to engage the cam surface **29***h* and be directed therealong into the pocket **29***i*, which is the lowermost limit of movement of the follower cam in the control slot A, and in which position the cross-flow ports **15***a* and **15***b* are spaced from and sealed against flow to the lateral ports **11***a* of the sleeve **11**.

The cam island **32** also has a pair of divergent upwardly facing camming surfaces, one the surface **32***a* which follows the incline of the camming surface **29***b*, and the other the surface **32**d which extends downwardly from the upper end of the camming surface **32***c* toward the vertical surface **29***d* of the control slot A. These cam surfaces assure that the cam follower lug **25** moves in the proper direction in the control slot A so that the proper sequence of movement of the follower lug is obtained when the sleeve **11** is reciprocated longitudinally on the body **10**. In addition, an upwardly inclined cammed surface **32***e* is provided at the lower end of the vertical guide surface **32***f* below the pocket **32***b* for directing the follower cam toward the vertical surface **29***a* of the control slot. A vertical follower surface **32***g* is formed on the exterior of the cam island **32** above the cam surface **32***e* and extends upwardly parallel to the outer vertical surface **29***a* of the control slot to the inclined cammed surface **32***c* at the upper end of the cam island. The camming surface **32***d* of the cam island extends downwardly from the apex of the island to a vertical follower surface **32***h* parallel to the vertical surface **29***d* of the control slot A.

Thus, the provision of the cam island and the various straight and inclined surfaces of the control slot A provide for positive control of movement of the cam follower **25** in the control slot and so provide for a proper sequence of events controlling the positioning of cross-flow passages **15***a* and **15***b* in the head **12** with respect to the lateral ports **11***a* of the sleeve **11** to control flow through such cross-flow passages in the head and circulation of fluids through the service seal unit and the packer. Thus, by merely lifting and lowering the operating string, the cross-flow ports may be opened or closed as desired, and by virtue of the fact that the length of movement of the sleeve and the operating string is limited by the engagement of the follower lug **25** with the stop pockets, a positive indication is given to the operator of the position and condition of the cross-flow ports, the seals and the lateral passages and ports of the sleeve and head. This may be positively noted by providing a marker on the exposed upper end of the operating string at the surface by means of which movement of the operating string may be compared to a fixed standard or scale or indicator.

Thus, successive lifting and lowering strokes of the operating string OS will indicate to the operator that the cross-flow passage is open or closed. The greater distance of movement of the operating string as it is lifted to move the follower lug **25** into the apex pocket **29***c* indicating to the operator that the cross-flow passage is in communication with the lateral ports **11***a* and flow may take place therethrough, while a lifting stroke of shorter distance in which the follower lug **25** engages the stop pocket **32***b* indicates that the cross-flow passages **15***a* and **15***b* in the head **12** are sealed off against flow therethrough to the lateral ports **11***a* of the sleeve **11**.

In operation of the apparatus, the service seal unit SSU is connected to the packer P and is suspended from and lowered into the well by means of the operating string OS. When the packer has been lowered to the desired depth in the well, the packer is expanded into locked sealing position in the manner set forth in the patent to Elliston, U.S. Pat. No. 3,398,795, to effect a seal between the packer mandrel and the casing C above the perforations I in the casing communicating with the producing formation.

At this point, with the follower lug **25** in the lower pocket **29***a* of the control slot A on the body **10**, the lateral ports 11a of the sleeve **11** are sealed off from communication with the cross-flow passages **15***a* and **15***b* in the head **12** and fluids pumped downwardly through the operating string OS will move downwardly past the cross-flow member **15** to the annular flow passage **23** between the bore wall of the body **10** and the elongate tube **16** extending axially therethrough. The fluids will be pumped down the annular passage **23** to the lateral ports **22** and outwardly from said ports through the lateral ports LP in the packer sleeve PS into the annular space below the packer to move downwardly in the bore of the casing C to the perforations I and thence outwardly therethrough to the producing formation F for treatment of the formation to stimulate flow therefrom in the usual manner. If desired, this treatment may consist of injection of acid or fracturing material or the like to increase the productivity from the producing formation to the well bore.

After the fracturing or acidizing step has taken place, the fluids may be circulated from the bore of the casing below the packer P by moving the operating string OS upwardly to lift the sleeve **11** until the follower lug **25** rides upwardly in the control slot A to the upper pocket **29***c* at the upper end of said control slot, in which position the cross-flow passages **15***a* and **15***b* in the cross-flow head **12** will be in communication with the lateral ports **11***a* in the sleeve **11**. Flow may then take place upwardly through the extension tube **19** and the axial central tube **16** of the service seal unit to the cross-flow head and outwardly through the cross-flow passages and the lateral ports **11***a* to the annular space between the operating string OS and the casing above the packer P, through which the fluids may return to the surface.

In this manner, acid or other materials injected into the well for treating the formation may be circulated out of the well bore below the packer in the usual manner. Or, if desired, the circulation may be reversed and flow take place downwardly through the annular space inwardly through the cross-flow passages into the bore of the central tube **16**, and downwardly therethrough and through the tubular extension **18**, and outwardly into the base of the screen S to wash the screen and circulate fluids upwardly from the screen to the annular passage **23** and then upwardly and inwardly through the lateral ports LP of the packer sleeve into the annular space **23** between the central tube **16** and the body **10** to the bore of the operating string OS thereabove, through which they may flow to the surface.

After the well has been treated and cleaned as desired, gravel may be pumped downwardly through the operating string OS and through the cross-flow head **12** exteriorly of the cross-flow member **15** into the annular passage **23** between the central tubular member **16** to the lateral ports **22** and outwardly therefrom through the lateral ports LP and the packer sleeve PS into the annular space between the packer sleeve and the casing, and downwardly around the outside of the screen S. The gravel will accumulate above the concrete plug B in the bore of the casing and fill the space below the packer exteriorly of the screen and bull plug until the body of gravel has built up in such space exteriorly of the screen to a point closely adjacent the lateral ports LP in the packer sleeve. When the gravel reaches this elevation in the well, the pressure of the fluids being circulated will rise to indicate that the gravel has reached such level, whereupon, if desired, reverse circulation may be effected to clean the gravel and the screen before performing further operations on the well. After the gravel has been disposed in the bore of the casing around the screen below the packer P, the service seal unit SSU may be disconnected from the packer P by lifting the operating string upwardly, shearing the shear members of the shear unit SU by means of which the service seal unit is connected to the packer.

When the packer has been disconnected, as shown in FIG. 3, the service seal unit may be lifted from the bore of the well casing by means of the operating string OS and the packer left in anchored sealing position in the casing with the screen supported thereby in the casing below the packer and with gravel surrounding the screen filling the area from the plug B upwardly to a level adjacent the lateral ports LP in the packer sleeve PS, whereby fluids entering through the perforations I from the producing formation will flow through the gravel to the screen, and the gravel will trap substantially all of the loose sand and foreign matter entering the bore of the casing through the perforations from the formation and prevent the same from entering the bore of the production string.

After the operating string and service seal unit have been removed, a production string or tubing string T, having a production seal unit PSU connected to its lower end, is lowered into the well through the casing C until the seal assembly D is positioned in the bore of the packer, as shown in FIG. 4, with the upper seal member **35** thereon disposed above the lateral inlet ports LP in the packer sleeve PS and the lower packing unit **36** disposed in the bore of the packer sleeve below such lateral ports LP to seal off the lateral ports and direct flow from the producing formation through the gravel pack GP and the screen S into the bore of the screen

and upwardly through the bore of the seal unit D to the tubing string T thereabove.

A slotted head **37** is provided on the upper end of the production seal unit PSU which engages the connector lugs **38** in the bore of the connecting sleeve **39** at the upper end of the packer in the usual manner. A slot **37a** in the head **37** engages the lugs **38** to limit downward movement of the production seal unit and properly position the seal members **35** and **36** with respect to the lateral ports LP in the packer sleeve. The well is then produced in the usual manner through the gravel packed area and the screen into the tubing and thence to the surface, white flow is prevented from taking place upwardly past the packer in the annular space between the casing and the tubing above the packer.

It will be seen that the packer was run into the well, anchored in place therein; the producing formation was treated to stimulate flow, if desired; the gravel pack was inserted and washed to clean foreign matter therefrom; and the operating string then disconnected from the packer leaving the packer, the screen and the gravel pack in place in the well; all during a single trip of the operating string into the well. After the operating string has been removed, the production string of tubing T having the production seal unit is lowered into the packer for producing the well in the usual manner.

Thus, sand or other foreign matter from the producing formation is prevented from entering the flow conductor or producing tubing string T and is so prevented from damaging any flow controlling devices disposed in the production string for controlling flow from the well, and from cutting or otherwise damaging the flow string or the surface controls or any other equipment in the well. Also, the packer and gravel pack will retain any sand or foreign matter entering the bore of the casing from the producing formation below the packer into the lower portion of the well casing below the packer and so prevent the same from entering the casing above the packer and causing the tubing to bs stuck in place in the well.

The details of construction of the service seal unit and the packer and other associated elements of the system are shown in FIGS. **5A** through **5C**, inclusive. The selective seal unit has already been described and has had numbers applied to it to indicate the elements thereof. The same numbers are applied to the elements of the service seal unit shown in FIG. **5A** through **5C**, and no further numbers will be used nor description made.

The packer P is substantially identical to that shown in the patent to Elliston, U.S. Pat. No. 3,398,795, as hereinbefore explained, and comprises a mandrel **40** having packing rings **41** thereon between lower and upper expander cone members **42** and **43**, respectively. The upper expander cone member is carried in a sleeve **44** which abuts the upper end of the packing rings **41**. Lower slips **45** are supported by a slip carrier **46**, to the lower end of which is connected a collet detent sleeve **47** in which detent collet fingers **48** on the mandrel are engagable to lock the mandrel against upward movement when the packer has been set. In installing the device, the operating string and packer are lowered into the well, and the operating string is then turned while the bow springs **49** hold the internally threaded connector sleeve **50** against rotation to permit the externally threaded connector head **51** at the upper end of the mandrel of the packer to be disconnected from the connector sleeve by rotation of the slotted flange **52** on the service seal unit with the longitudinal slots **53** therein engaged over the internally projecting lugs **38** and the mandrel to be then moved upwardly relative to the sleeve and upwardly relative to the upper slips **44**, to move the expander **43** between the slips to lock the packer against upward movement. Continued upward movement of the mandrel **40** will then move the lower slips **45** upwardly along the lower expander cone **42**, after the packing rings have been fully expanded, and lock the packing rings in the fully expanded position in the well known manner. With the mandrel in the upper position, the packer is held in the anchored position shown in accordance with the teachings of the Elliston patent and as previously described.

The shear unit SU comprises a sleeve **56** connected by shear pins **57** to the upper end of the connector head **51** at the upper end of the mandrel. The packer is preferably set without releasing the shear unit from the upper end of the mandrel. However, should the shear pins **57** be sheared, the provision of conventional releasing J-type connector slot rather than the straight slots **53** in the slotted flange **52** will provide continued releasable connection between the service seal unit and the packer mandrel. The releasable J-slots will also provide for reconnection of the service seal unit to the packer for additional operations, if desired.

To the lower end of the packer mandrel is attached the packer sleeve PS including an elongate tubular member **60** having a ported flow sub **61** connected thereto provided with the lateral flow ports LP. Below the ported flow sub is an extension **62** of the packer sleeve PS, to the lower end of which is connected a swivel shear sub **65** consisting of a bushing **66** in which the upper end of a shear sleeve **67** is telescoped and pinned by shear pins **68** to a connector ring **69** rotatable in the bore of the bushing **66**, so that the sleeve **67** may rotate with respect to the bushing and the packer thereabove may likewise rotate with respect to the screen S therebelow. The bull plug BP is connected by threads to the lower end of the screen in the usual manner.

The body **10** of the service seal unit SSU extends downwardly through the bore of the mandrel, as shown in FIG. **5C**, and has a reduced port sleeve **10*a*** at its lower end provided with lateral flow ports **22**. A seal sub or head **10*b*** is connected to the lower end of the port sleeve **10*a*** and has a lower internal seal unit or seal member **21** on its exterior and an interior seal member **21*a*** sealing between the seal head **10*b*** and the axial or central tube **16** extending downwardly therethrough. The coupling **19** supports the elongate tubular extension **18** which extends downwardly from the lower end of the seal head **10*b*** into the bore of the screen S therebelow, as previously schematically illustrated and described.

It will be seen therefore that the packer, screen and service seal unit illustrated in FIGS. **5A** through **5C**, inclusive, are designed for carrying out the method and function in the manner set forth in the description thereof in the schematic illustrations of FIGS. **1** through **4**. As shown in FIGS. **7** and **8**, the control slot A is offset circumferentially around the body member

10 from the restraining slot 30, and the follower lug 25 is engagable in the control slot while the lug 31 is slidable in the vertical restraining slot 30 spaced from the control slot.

In FIG. 9 is shown the details of construction of the production seal unit PSU engaged in the bore of the packer mandrel and packer sleeve and sealing on opposite sides of the lateral ports LP in the ported flow sub 61 of the packer sleeve PS. The lower seal member or packing 36 of the pack off sub D of the production seal unit PSU seals in the bore of the seal sleeve 62 below the ports LP in the ported sub 61, while the upper seal member or packing 35 seals in the bore of the mandrel 40 above the collet fingers 48, so that all flow from the producing formation is directed upwardly through the mandrel, past any lateral openings below the upper seal member, to the tubing string T thereabove. Likewise, the straight slot 37*a* in the head 37 of the production seal unit engages the lug 38 in the connector member 51 at the upper end of the packer mandrel to position the seals in proper sealing engagement in the bore of the mandrel and in the seal sleeve of the packer sleeve below the ported flow sub. Obviously, the slot 37*a* may be the conventional J-type connector slot, if desired.

Therefore, it will readily be seen that the apparatus is designed to carry out the method and function of the schematically illustrated device.

In FIGS. 10 through 14 is schematically illustrated apparatus and a system for carrying out the method in a multiple zone well. The lower packer and screen for the lower producing zone or formation F1 is installed in the manner already described and the same identical identifying letters and numerals, having a suffix "1", have been applied to the apparatus of such installation. After the packer and screen have been installed; the producing formation treated, if desired; and the gravel pack installed and washed in the manner already described; the operating string for the first packer P-1 is removed from the well casing and an upper zone packer P-2 is lowered into the well casing by means of a service seal unit SSU-2 which is identical in all respects to the service seal unit SSU of FIGS. 1 through 9, but is provided at the lower end of the extension tube 18 with a sealing plug unit SPU for closing the bore of the assembly below the upper screen S-2, for a reason which will be hereinafter made apparent.

The packer P-2 may be identical to the packer P-1, and is installed and set in the same manner. The screen S-2 is connected to the lower end of the packer sleeve PS-2 by means of a shear swivel unit SS-2 which has a clutch connection which will permit rotation of the screen and all associated parts connected therebelow upon downward force being applied to the packer and packer sleeve so that the lower end of the assembly may be readily rotated to introduce the same into the bore of the packer P-1 therebelow.

Below the screen S-2, a seal bore sleeve SBS is connected to provide a sealing surface for the sealing plug unit SPU and for another purpose to be hereinafter more fully set forth. A collet locking recess LR is provided in the bore of the seal bore sleeve and a downward extension in the production seal unit PSU-2 having an upper seal member 135 and a lower seal member 136 secured thereon is designed to be lowered into the bore of the packer P-1 and packer sleeve PS-1 in the same manner as the production seal unit PSU of the form first described. On the lower end of the production seal unit PSU-1 is a collet latch or detent retaining means RM which is adapted to engage an inwardly projecting boss or annular collet stop shoulder CS in the bore of the packer sleeve PS-1 below the lateral ports LP-1 in said sleeve, to restrain the production seal unit PS-2 against displacement from the packer and packer sleeve of the lower assembly.

In use, the upper packer P-2 having the screen attached thereto, with the production seal connecting member PSU-2 attached to the lower end thereof, is lowered through the casing until the lower end of the production seal unit PSU-2 is disposed in the bore of the mandrel of the lower packer P-1. Should it be necessary, the screen and the production seal unit PSU-2 may be rotated by pressing downwardly on the operating string OS and the swivel shear unit SS-2 for causing rotation of the lower end of the assembly to facilitate its entry into the bore of the packer. The assembly is then lowered until the collet retaining means RM is engaged with the collet stop CS to position the seal members 136 and 135 below and above the lateral ports LP-1 of the packer sleeve PS-1. With the tools in this position, the upper packer P-2 is then set in the same manner as was the packer P-1 of the form first described, and the parts are then in the position shown in FIG. 11.

At this point well stimulation or other desired procedures may be carried on to treat the upper formation F-2, as by acidizing or fracturing or other treatment, under pressure, the pressure of the treating fluid being prevented from passing downwardly to the lower formation by the sealing plug unit SPU which closes the bore of the upper packer and screen assembly. The fluids under pressure will pass downwardly through the operating string OS into the bore of the sleeve 111 at the upper end of the body 110 of the service seal unit SSU-2, flow downwardly through the annular space 123 between the central tube 116 and the bore wall of the body 110, then outwardly through the lateral ports 122 and the lateral ports LP-2 in the packer sleeve PS-2 below the packer P-2, and through the perforations into the formation to carry out the desired service operation.

After the well stimulation or other treatment has been completed and it is desired to clean the bore of the well below the packer P-2, the operating string OS is lifted to move the sleeve 111 upwardly to bring the ports 111a of the sleeve into communication with the cross-flow ports 115a and 115b of the head 112 in the manner previously described, whereby fluid under pressure pumped downwardly through the operating string OS will pass downwardly through the annular passage 123 and outwardly through the lateral ports 122 and LP-2 into the annular space below the upper packer P-2, the fluids will then enter the ports lateral ports CP in the lower end of the central tube extension 118 above the sealing plug unit SPU, and flow upwardly through the bore of the axial central tube 116 to the cross-flow passages 115*a* and 115*b* and outwardly therefrom through the lateral ports 111*a* of the sleeve 111 to the annular space above the packer and then upwardly in such annular space to the surface in the

manner already described. Obviously, if desired, the circulation may be reversed, as has been previously explained.

It will be seen that the sealing plug unit SPU will close off flow through the bore of the seal bore sleeve SBS of the upper packer and screen assembly below the upper screen S-2 to prevent any fluids from flowing downwardly to the lower packer and the lower producing formation. All other operations of the method may then be carried out in the same manner as previously described.

The gravel pack may be circulated downwardly through the operating string OS and the annular passage **123** to the lateral ports **122** and through such ports and lateral passages LP-2 of the packer sleeve PS-2 into the annular space above the lower packer P-1 where they will fill the annular space thereabove upwardly past the perforations I-2 in the casing communicating with the upper producing formation F-2, and rise around the screen S-2 to the vicinity of the lateral passages LP-2 of the packer sleeve PS-2 at the lower end of the upper packer P-2, where a rise in the fluid circulating pressure will indicate that the annulus has been filled with gravel to that extent. At this point, reverse circulation for cleaning may be carried out, if desired, to flush out the screen and the gravel to the extent believed proper or necessary.

After the gravel has been installed in the manner described, the operating string OS is lifted to lift the shear sleeve SS-2 at the upper end of the head **151** of the mandrel **140** of the upper packer P-2 to shear the shear members **57** and free the shear sleeve from its connection to the connector head **151**. This permits the service seal unit SSU-2 to be lifted from the well leaving the upper packer P-2 anchored in place with the gravel pack surrounding the screen S-2.

It is believed obvious that, if desired, additional formations above the formation F-2 and above the packer P-2 may be treated in the same manner to isolate the formations below the packer P-2 from any treating operations carried out in the well bore thereabove, should there be more formations above the second producing formation F-2.

If not, then a producing seal unit PSU-3 is connected to the lower end of a long string of tubing LST carried by a dual string packer P-3 and lowered therewith into the well bore until the collet seal sleeve CSS on the lower end of such long string of tubing is positioned in the bore of the collet seal bore extension SBS below the upper screen S-2, with the collet members at the lower end of the body engaged with the detent shoulders in the bore of the seal bore extension member and a seal **170** thereon in sealing engagement with the seal bore extension. The dual string packer P-3 is set in the usual manner to seal off between the long string of tubing LST and the short string of tubing SST connected thereto to separate flow of the zone below the packer P-1 from that of the upper zone between the packers P-1 and P-2. The flow from the lower zone will pass upwardly through the lower packer and the production seal unit PS-2 into the bore of the long tubing string LST and upwardly therethrough to the surface, while the production from the upper zone will pass upwardly through the bore of the screen S-2, the packer sleeve PS-2 and the packer P-2 to the short string SST, and thence to the surface in the usual manner.

From the foregoing it will be seen that the apparatus and method of this invention provides for the installation of packers having screens connected thereto in multiple zone wells, the separate and independent treating and gravel packing of first and lower zone, and then the upper zone or zones, without applying the pressure of the treating fluids or any other pressures used in treating or installing gravel in the upper zone or zones to the zone or zones therebelow which have been previously treated. It will particularly be noted that the operations are carried out in a continuous uninterrupted manner during a single trip of the operating string into the well to install the packer and screen, treat the well producing formation, gravel pack the well around the screen and then clean the well, the gravel pack and screen, if desired, and then install a second packer and screen thereabove in flow communication with the next lower packer, seal off such lower packer and formation, and treat, gravel pack and clean the upper formation without applying fluid pressure during such treating and cleaning to such lower formations during a second trip of the operating string into the well, then removing the operating string for the second trip and installing the producing strings. Thus, only three trips of the operating strings and producing strings are necessary to fully equip and treat and place into service a dual zone well.

The details of construction of the apparatus for carrying out the dual zone method are shown in FIGS. **15A** through **16**, wherein all parts of the service seal unit SSU-2 are identical to the service seal unit SSU previously described and are given the same numbers with the suffix 2 applied to the letter designations and the prefix 1 applied to the numerals. The packer P-2 is identical to the packer P of the form first described and the parts are given the same number with the prefix 1 to the numbers and the suffix 2 to the letters.

The swivel shear unit SS-2 is identical to the swivel shear member SS of the form first described, except that the bushing or sleeve **166** is provided with an upstanding lug **166*a*** which is engagable in a recess **171** in a connector sub **170** to the lower end of which the bushing **166** is attached. Shear pins **168** connect a sleeve **167** to a ring **169** which is rotatable in the base of the bushing **166** of the shear sub **165**. To the lower end of the screen S-2, shown in FIG. **15D**, is attached the seal bore sub extension SBS which consists of a sealing sleeve **175** to the lower end of which is connected to collet receptacle **176** having an inwardly facing annular shoulder **177** therein. The lower end of the collet receptacle is connected to the upper end of the elongate tubular production seal unit PSU-2 which comprises an elongate tubular conductor tube **180** having a lower seal member **183** and collet retainer member RM at its lower end. The collet retainer member RM includes a plurality of resilient collet spring members **185** having detents **186** thereon engagable with the downwardly facing shoulder of a stop ring **190** secured in the upper end of the bore of the swivel shear sub receiver member CS. The seal assembly **183** mounted on the lower end of the tube **180** having the collet retainer member RM seals with the seal bore surface of the sleeve **184** connected to the upper end of the swivel seal bore sub extension SBS. The seal bore sub unit has a sleeve **195** telescoping into its lower end and secured by means of shear pins **196** to

a sleeve **197** confined in the bore of the bushing **198**. Thus, the collet members **185** provide means for positioning the seal units **183**, **121** and **120** properly in the sealing surfaces of the packer P-2 and the seal surface **162** of the port sleeve PS-2. The upper seal **120** on the tube seals with the bore of the mandrel **140** of the upper packer P-2 above the collet members in the lower portion of the mandrel of said upper packer, in the same manner as in the form first described.

The shear pin **196** connecting the sleeve **195** to the sleeve **197** in the bushing **198** of the seal bore sub SBS above the lower screen S-1 permits the lower packer P-1 to be disconnected from the screen S-1 for removal from the well, leaving the screen S-1 in place for later retrieval, if desired. The seal bore sub SBS differs from the shear sub SS of FIG. **5C** in that it is elongated and provides a collet recess below the shoulder of the stop ring **190** at the upper end of the seal bore sub assembly SBS to receive the collet members **185** at the lower end of the production seal unit PSU-2 for positioning the seals **183**, **121** and **120** in proper relationship in the seal sleeve **184** and the ported sleeve PS in the bore of the mandrel **140** of the packer P-2 above the packer mandrel collets **148**.

In FIG. **16**, is shown in fragmentary form, the manner in which the production collet seal sleeve member CSS at the lower end of the production seal unit PSU-3 is positioned in the bore of the seal bore sub SBS and collet receptacle below the upper screen S-2 for directing flow entering the lower packer through the lower screen S-1 upwardly through the production seal unit PSU-3 and the long tubing string LTS thereabove to the surface.

It is readily apparent, therefore, that the service seal unit SSU-2 and the parts affiliated with the screen and packer in FIGS. **15A** through **15F** and **16** are effective to carry out the method of the invention having to do with the installation of packers and screens, with gravel packs therearound, in wells having a plurality of separate zones therein, as was explained in connection with the schematic illustrations of the method, the systems and the apparatus.

The foregoing description of the invention is explanatory only, and changes in the details of the constructions 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 method of treating a well for production which includes: lowering an operating tool string having connected thereto a packer having a screen supported therebelow into the well bore; seating the packer in sealing position in the well bore above a producing formation therein with the screen in communication with the producing formation; opening a flow path for circulation downwardly past the packer and the screen to the producing formation and upwardly past the screen and the packer to the well surface for treating the well formation; introducing gravel through said circulation flow path into the well bore below the packer exteriorly of the screen to fill the annular space between the screen and the well bore to a point above the screen; removing the operating tool string from the well bore; and establishing a production flow course from the packer to the well surface for conducting well fluids entering said flow course from the producing formation through the gravel pack and screen.

2. The method of claim **1** including: opening the circulation path through the packer and screen by longitudinal movement only of the operating string; removing the operating string from the well bore after the gravel pack has been installed; and introducing a production tubing string into the well bore to sealed engagement with the packer to form the production flow course from the packer to the surface.

3. The method of claim **1** including the additional step of introducing treating fluids under pressure into the well producing formation through the packer and screen prior to establishing the circulation path through said packer and screen.

4. The method of claim **1** including: the step of installing a lower well packer in said well bore above a lower producing formation and below an upper producing formation prior to installing the packer having the screen thereon in the well bore; sealing between the lower end of the screen and the lower packer to provide a circulating flow course through the lower packer and the screen and upper packer; seating the upper packer above the upper formation in sealing relation with the well bore above said upper producing formation; and sealing the bore of the lower packer below the screen supported by the upper packer to isolate the power formation from the circulating flow course.

5. The method of claim **1** including: circulating fluids through the operating tool string in a reverse direction to remove excess gravel from the operating tool string after the annular space has been filled to a point above the screen.

6. A method of the character set forth in claim **1** including: circulating treating fluids through the circulation path to remove foreign matter therefrom and through the screen to remove foreign matter therefrom prior to establishing the production flow course from the packer to the well surface.

7. The method of claim **1** including: reconnecting the operating tool string to the packer for reestablishing a flow path past the packer and screen to the producing formation for additional treatment of said formation.

8. The method of claim **7** wherein the step of reconnecting the operating tool string to the packer to reestablish circulation past the packer and screen to the producing formation for treating the same is performed after the production flow course from the packer to the surface has been established and discontinued.

9. A method of treating a well having a plurality of producing formations therein which includes: lowering a first packer and screen into the well bore by means of an operating tool string; seating said first packer above a first lower producing formation and below a second producing formation thereabove; establishing a circulation path through the packer and screen for circulating fluids to said first producing formation and from said first producing formation to the surface; installing gravel in the well bore below the packer exteriorly of the screen through the circulation path to gravel pack the annular space between the packer and the well bore to a point above the screen; disconnecting the operat-

ing tool string from said first packer and screen; removing said operating tool string from the well bore; supporting a second packer and second screen on said operating string and lowering the same into the well bore to seal above said second formation above the first packer with said second screen in communication with said second formation; sealing between said second screen and the first packer to provide a flow course from the first packer through said second screen and said second packer; closing off said flow course below said second screen and above said first packer; establishing a circulation path through said second packer and second screen for circulating fluids from the surface through the operating string to the second formation under pressure while isolating such pressure fluids from said first formation; installing a gravel pack through said circulation path past said second packer and screen into the annular space above said first packer exteriorly of said second screen to fill the annular space between said second screen and the well bore above said first packer to a point above said second screen; disconnecting said operating tool string from said second packer and second screen; removing said operating tool string from the well bore; installing a first flow conductor producing string communicating with the bore of said first packer; and installing a second flow conductor producing string in the well bore communicating with said second formation through the second screen and separated from the first flow conductor producing string.

10. A method of the character set forth in claim **9** including: treating the second well producing formation under pressure to stimulate production therefrom prior to establishing the circulation path past the packer and screen to the producing formation; and cleaning the producing formation of the treating fluids before installing the gravel pack.

11. The method of claim **9** including longitudinally moving said operating tool string only establishing the circulation path through the first packer, and subsequently establishing a circulation path through the second packer and second screen isolated from the first packer and first screen.

12. A method of the character set forth in claim **9** including: reverse circulating treating fluids through the operating tool string connected to the first packer to remove excess gravel from the operating tool string after the annular space between the first screen and the well producing formation has been filled to a point above the screen; isolating the first producing formation from the circulating flow course through the second upper packer and screen; reverse circulating treating fluids through said operating tool string and the annular space above the first packer and exteriorly of the screen thereabove to remove excess gravel from the operating tool string after the annular space exteriorly of the second screen above the first packer has been filled to a point above the upper end of the second screen.

13. Apparatus for treating a well including: a packer having a screen supported therebelow and connected to the packer by a tubular conductor; means providing a lateral flow path to the exterior of the tubular flow conductor between the packer and the screen; and a service seal tool unit for setting the packer and carrying on treating operations in the well therebelow including: means for releasably connecting the service seal unit to the packer; upper seal means sealing between the service seal unit and the packer bore; lower seal means sealing between the service seal unit and the conductor connecting the screen with the packer below the lateral flow course in said conductor; means providing a first flow path through the service seal unit from a lateral opening therein above the lower seal means to the upper end thereof; means providing a second flow path from a point below the lower seal means to the upper portion of the service seal tool unit; cross-flow directing valve means connected in flow communication to the upper end of said second flow path and having a lateral outlet opening; sleeve valve means having a lateral outlet therein movable longitudinally with respect to said cross-flow valve means; means for moving said sleeve valve means longitudinally with respect to said cross-flow direction valve means between a position closing off the lateral outlet opening of said cross-flow directing valve means and a position communicating said lateral flow outlet of said sleeve valve means with the lateral outlet opening of the cross-flow directing valve means for establishing a circulation path through the service seal unit to the exterior thereof.

14. Apparatus of the character set forth in claim **13** including indexing means on said service seal unit and said sleeve valve means co-engageable to limit movement of said sleeve valve means longitudinally of said service seal tool means to indicate the position of the lateral flow outlet of said sleeve valve means with respect to the lateral outlet opening of said cross-flow directing valve means.

15. Apparatus of the character set forth in claim **14** wherein said indexing means comprises means operable by longitudinal movement only of an operating string connected to said sleeve valve means for controlling movement of said sleeve valve means longitudinally; and means for alternately stopping longitudinal movement of said sleeve valve means after a short longitudinal movement at a first position wherein the lateral flow outlet is closed of said cross-flow directing valve means and after a second longitudinal movement of a greater distance at a second position wherein said lateral flow outlet is disposed in communication with the lateral outlet of the sleeve valve means, said means being actuatable by reciprocating movement of the sleeve valve means.

16. Apparatus of the character set forth in claim **13** wherein means is provided on the upper end of said service seal tool unit for connecting the same to an operating string for movement of the service seal unit sleeve valve means longitudinally in the well from the surface of the well with the packer in place in said well.

17. Apparatus of the character set forth in claim **13** wherein the means for releasably connecting the service seal unit to the packer includes: coengageable means on said packer and said service seal unit for releasably reconnecting said service seal unit to said packer.

18. An operating tool for setting a packer and screen in place in a well and establishing a circulation path through the packer and screen in place including: means for connecting said operating tool to said packer

for setting the same in the well; means for establishing a flow path through the packer and screen to the exterior of the screen; means for establishing a circulation path through the packer and the screen downwardly from the surface and upwardly to return to the surface; means for closing off the circulation path; and means for opening the circulation path by longitudinal movement only of an operating string connected to the operating tool.

19. An operating tool of the character set forth in claim 18 wherein said means for connecting said operating tool to said packer includes: means releasably reconnectable with said packer.

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Disclaimer

3,710,862.—*Carter R. Young*, Carrollton, and *Henry J. James*, Dallas, Tex. METHOD AND APPARATUS FOR TREATING AND PREPARING WELLS FOR PRODUCTION. Patent dated Jan. 16, 1973. Disclaimer filed Aug. 25, 1975, by the assignee, *Otis Engineering Corporation.*

Hereby enters this disclaimer to claims 1, 5, 6 and 7 of said patent.

[*Official Gazette November 11, 1975.*]