

June 6, 1967

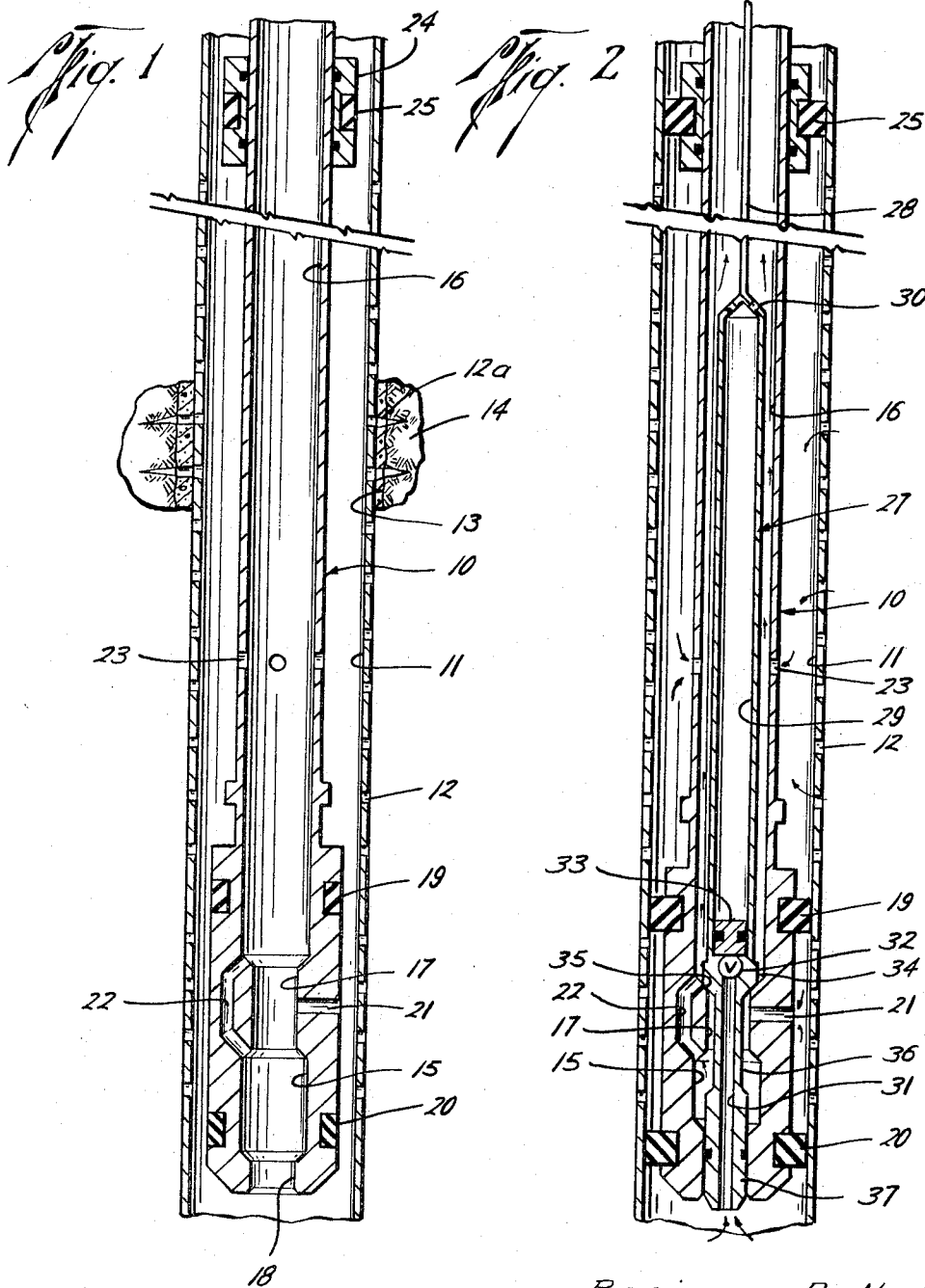
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3,323,360

METHODS AND APPARATUS FOR ANALYZING WELL PRODUCTION

Filed Aug. 13, 1963

5 Sheets-Sheet 1



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METHODS AND APPARATUS FOR ANALYZING WELL PRODUCTION

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Fig. 3

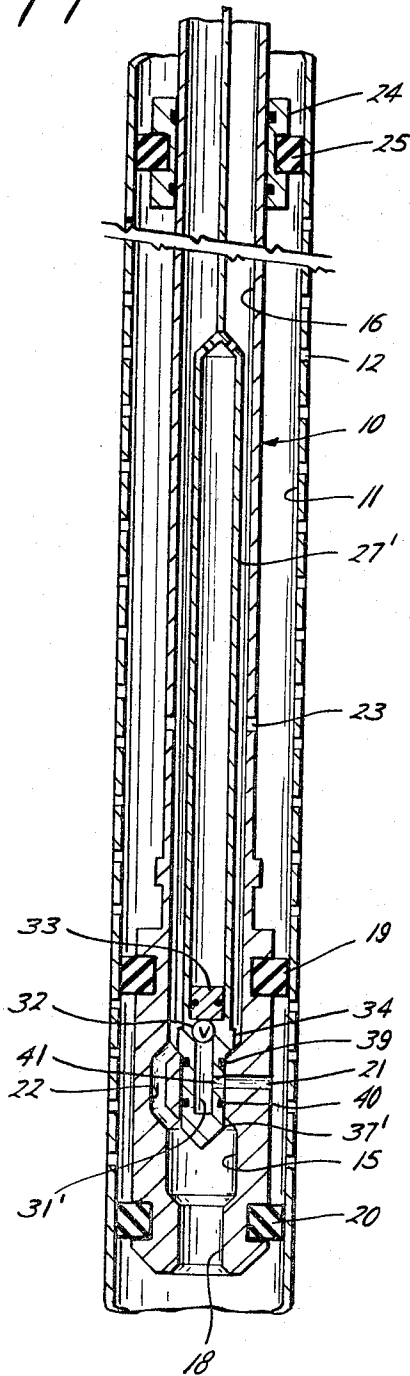
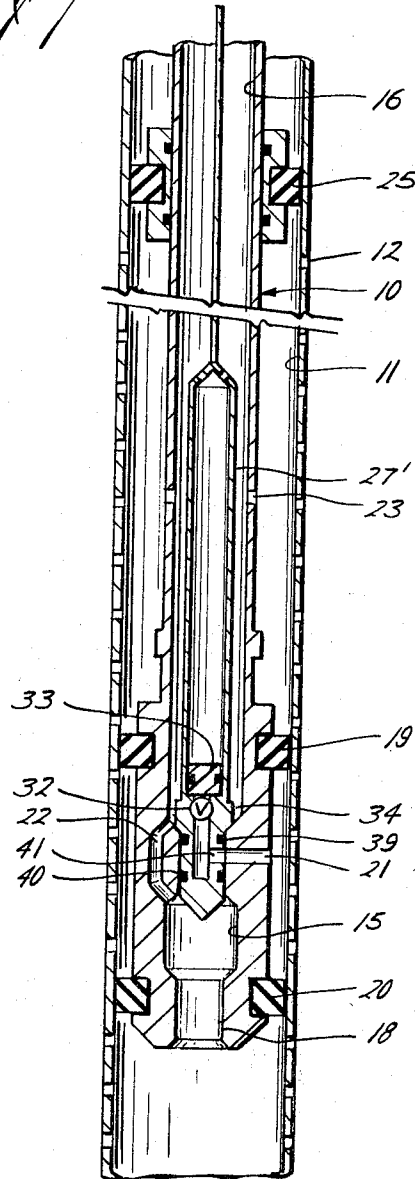


Fig. 4



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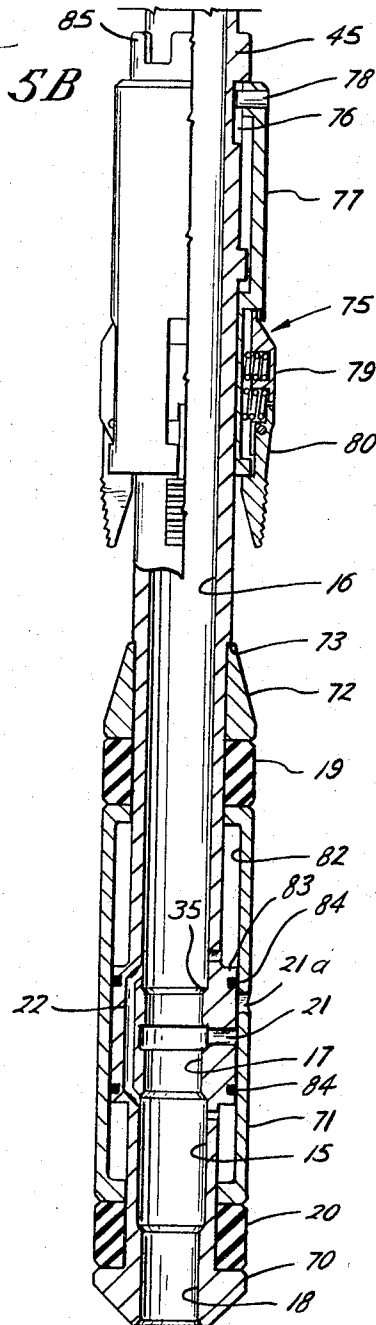
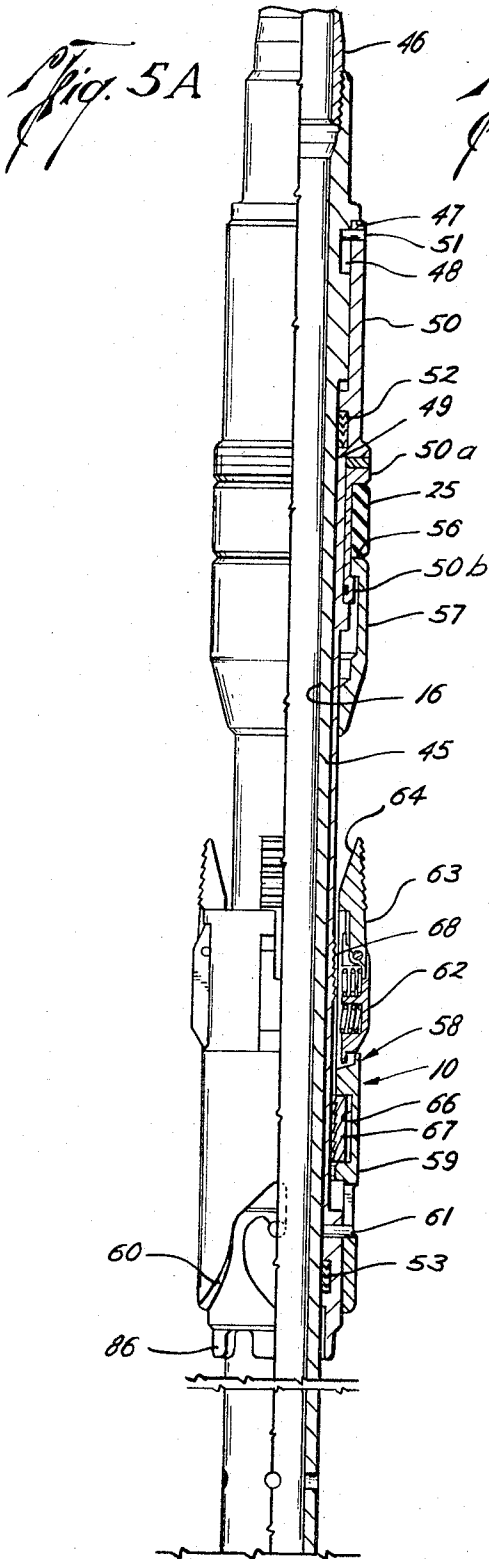
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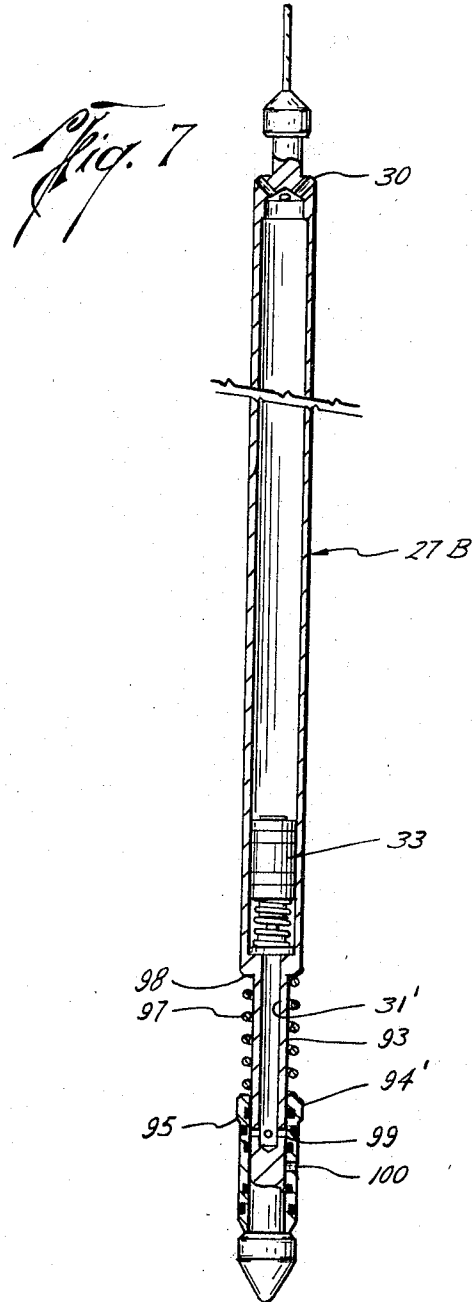
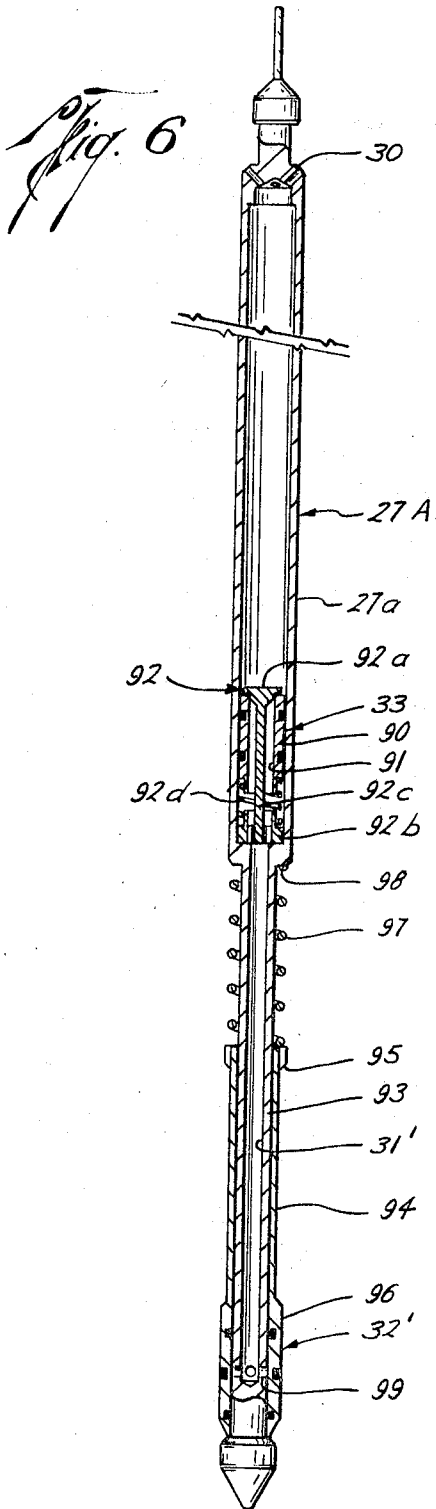
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METHODS AND APPARATUS FOR ANALYZING WELL PRODUCTION

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5 Sheets-Sheet 4



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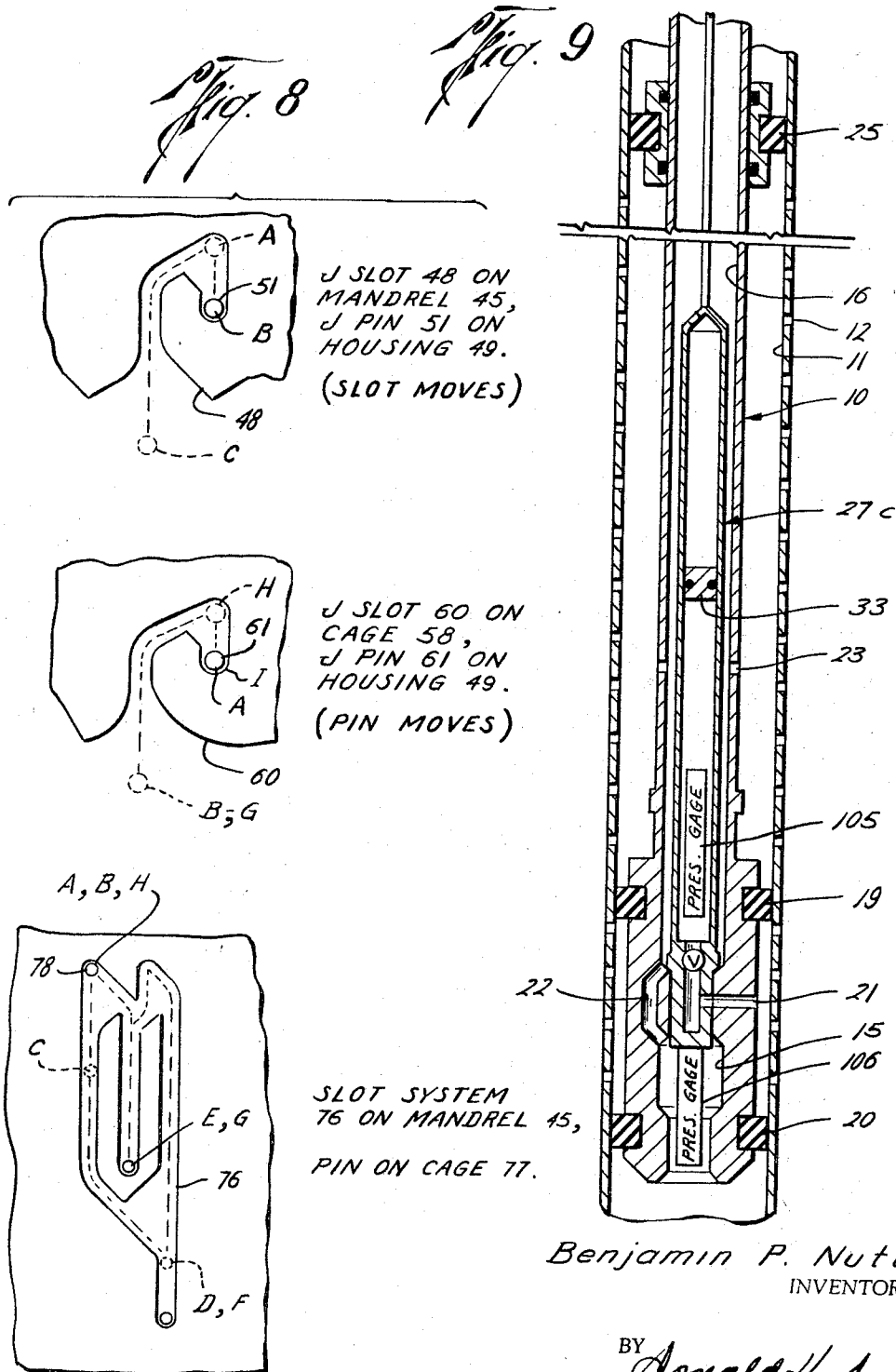
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METHODS AND APPARATUS FOR ANALYZING WELL PRODUCTION

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5 Sheets-Sheet 1



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METHODS AND APPARATUS FOR ANALYZING WELL PRODUCTION

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Filed Aug. 13, 1963, Ser. No. 301,752
24 Claims. (Cl. 73—155)

This invention relates to methods and apparatus for analyzing production from an oil well. More particularly, the methods and apparatus of the present invention are useful in wells which are incapable of flowing in production quantities without the use of in-place pumps or other artificial fluid-lifting equipment.

Usually it is necessary to extend a casing through a well bore to prevent the cave-in of unconsolidated earth formations. The casing is normally cemented to the wall of the borehole to prevent undesired fluids, such as water, in other formations from leaking into the production zones. After being cemented in place, the casing is then perforated along those portions adjacent to producing formations so that the production fluids may enter the casing and be recovered. Occasionally, earth formations will be consolidated and it is not necessary to case the entire well. In this event, production fluids enter the well bore directly from the earth formations.

Although only oil and gas are desired, it is common experience that produced fluids will include quantities of water which reduce the effective oil and gas output of a well. Water may enter the well either from formations within the production zone or from remote formations if the cementing happens to be defective. Most of these problems can be cured, however, by common remedial procedures but the nature of the problems must first be determined or defined.

Where the formation fluids do not flow in any appreciable quantities and require production by secondary recovery techniques, it will be readily grasped that determination of problems in the production zone is not easy.

The present invention concerns apparatus and methods for profiling the fluid flow characteristics of a well requiring artificial fluid-lifting where the well is capable of producing through the wall surfaces into a well bore over a given interval. The method includes the steps of: lowering a tubing string to a zone for testing, packing-off the tubing string in the well bore above the test zone, artificially producing flow from the isolated zone into the tubing string, isolating the flow from the wall surfaces of the well bore into at least two portions, sequentially trapping the individual fluid portions and recovering the trapped fluid portions for analysis. In a further application of the present method, pressure measurements are taken to analyze other conditions of the well.

Apparatus in accordance with the present invention includes a device connected to the end of a tubing string for packing-off the tubing string above a producing zone of a well bore. The device has means for diverting the entire fluid flow into the interior of the tubing string. A retrievable sampling apparatus is arranged for positioning in the device and, when so positioned, obtains a sample of fluids flowing from a given section of the producing zone while the remaining portion of the fluid is directed into the tubing string. Means are also provided for obtaining pressure measurements of both portions of the fluid flow.

Accordingly, it is an object of the present invention to provide new and improved methods and apparatus for determining fluid flow characteristics of a well requiring artificial fluid-lifting.

Still another object of the present invention is to provide new and improved methods and apparatus for

testing the production capabilities of a well requiring artificial fluid-lifting.

Another object of the present invention is to provide new and improved methods and apparatus for sampling a part of a fluid flow from a well which requires fluid-lifting equipment.

The novel features of the present invention are set forth with particularity in the appended claims. The present invention, both as to its organization and manner of operation together with further objects and advantages thereof, may best be understood by way of illustration and example of certain embodiments when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a view in cross-section schematically illustrating apparatus in a casing traversing earth formations;

FIG. 2 is a view similar to FIG. 1 but showing the apparatus of FIG. 1 in an operative position and a first wireline device disposed within the apparatus;

FIG. 3 is a view similar to FIG. 2 showing the apparatus of FIG. 1 in an operative position and a second wireline device disposed within the apparatus;

FIG. 4 is a view similar to FIG. 3 but showing the apparatus of FIG. 1 in a second operative position;

FIGS. 5A and 5B together illustrate in partial cross-section a first embodiment of apparatus used in the present invention;

FIG. 6 illustrates in cross-section a first wireline device; FIG. 7 illustrates in cross-section a second wireline device;

FIG. 8 illustrates parts of the apparatus in FIGS. 5A and 5B in plan view for explanation purposes; and

FIG. 9 illustrates another form of the present invention.

Referring now to FIG. 1, a tubular apparatus or tool 10 is positioned in a casing 11 by means of a tubing string (not shown) extending above the tool. The casing 11 has perforations 12 extending along its length coextensive with the production zone of the earth formations. Borehole 13 (shown in partial view) traverses earth formations 14 and casing 11 is cemented to the borehole by a column of cement. A perforation 12a, typical of those made by conventional perforating device, extends between the earth formations and the interior of the casing.

The tool 10 is tubular and is coupled to the lower end of a tubing string, with the bore 16 of the tool being generally the same size as the bore of the tubing string. At the lower end of the tool, the bore 16 is interrupted by a bore section 17 of reduced diameter followed by an enlarged bore section 15, and the terminal end of the tool has a bore section 18 of reduced diameter. On the exterior of the tool and disposed above and below bore section 17 are spaced packers 19, 20 which straddle a flow port 21 extending between the bore section 17 and the exterior of the tool. A bypass passageway 22 extending longitudinally of the tool connects the bore section 15 to bore 16 to permit fluid flow therebetween in the event bore section 17 is closed off.

The tool 10 is provided with one or more lateral ports 23 disposed intermediate of its length and a portion of the tool has an annular body 24 with packing element 25 slidable relative to the main portion of the tool. Thus, when packing elements 19, 20 and 25 sealingly engage with the casing, fluid can flow into bore 16 and on into the tubing string in the following ways:

- (a) From below the tool via bores 18, 15, 17 (and bypass 22) and 16;
- (b) From between the sealing elements 19, 20 via port 21, bore 17 and bore 16;
- (c) From between sealing elements 19 and 25, via ports 23 and bore 16.

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It is also important to note that packer 25, when expanded, closes the annulus between the tool 10 and casing 11 (or the borehole wall if the well is uncased) so that all of the flow paths described are directed into the bore 16 of the tool. It will also be appreciated that flow is from the *entire interval* of perforations 12 extending below the packer 25.

Referring now to FIG. 2, the packers 19, 20 and 25 are shown in an expanded position with a retrievable sampling tool 27 (lowered by means of an attached wire-line 28) positioned within the bores 15, 16 and 17 of tool 10. Sampling tool 27 has an elongated cylindrical chamber 29 which is ported at its upper end 30 and open at its lower end by a bore 31 extending longitudinally downwardly to the lower extremity of the sampling tool. A one-way check valve 32 permitting only upward flow is disposed in bore 31. A floating piston 33 is provided in chamber 29, the piston initially being disposed at the lower end of the chamber adjacent to the upper end of bore 31. Sampling tool 27 has an enlarged portion 34 near its lower end which engages a shoulder 35 in the tool. Below the enlarged portion 34 is a section 36 reduced in diameter to provide an annular space within the bore section 17 of tool 10. Below the reduced section 36 is a section 37 sized for sealing reception into the terminal bore section 18 of tool 10. The lowermost section 37 is provided with an O-ring sealing means (not numbered).

In the position shown, bore 31 of sampling tool 10 is open to the casing below packer 20 so that any fluid below packer 20 will enter bore 31. Fluid entering bore 31 is collected in the lower portion of sampling chamber 29 which is formed between floating piston 33 and check valve 32. The upper portion of chamber 29 lying above piston 33 is filled with fluid, for example a light-weight fluid such as kerosene, which escapes out of the ports at the upper end 30 as fluid fills the lower portion of the sampling chamber.

During the time a fluid sample is being taken, formation fluids between packers 19, 20 can enter tool 10 through port 21 and pass into bores 15 and 17, bypass 22 and the annulus formed between the sampling tool 27 and bore 16. Fluids between packer elements 19 and 25 can also enter tool 10 through ports 23 and pass into the bore 16. It will be appreciated that fluids can flow from the *entire interval* below packer 25, and that fluids flowing into the casing *above* packer 20 are maintained separate from those fluids flowing into the casing *below* packer 20, with the latter fluids being trapped between piston 33 and valve 32. Thus, sampling tool 27 may be retrieved for analysis of the trapped fluid sample.

Before proceeding further, a brief discussion of the usual nature of fluid flow from formations into a well is in order. In a well requiring artificial production, if the artificial motivating means is stopped, there generally is sufficient formation or reservoir pressure to build up a fluid column within the well and above the production zone to a static level where hydrostatic pressure from the fluid column equals the pressure in the earth formations. The fluid flow to build up a static fluid column may be either

- (a) Slow, so that a considerable period of time is required for the fluid column to rise to its static level; or
- (b) Rather rapid, so that the fluid column rises to its static level in a short period of time.

Considering first the case (a) above: the tool 10 is positioned in the well adjacent the production zone and the packer elements actuated to seal with the casing at spaced locations. Next, a swab unit (not shown) is lowered into the tubing and fluid is bailed from above tool 10 to reduce the fluid column well below the level of tool 10. Immediately following this, sampling tool 27 is lowered into place within tool 10. Because of the reduced level of the fluid column, the fluid will naturally flow to

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build up the fluid column and it is during this fluid build up that the trapped fluid sample is obtained. If an increased flow rate is desired, the tubing string may be swabbed while obtaining the fluid sample.

In case (b), as in case (a), tool 10 is positioned in the casing and the packer elements set. However, sampling tool 27 is first positioned in the tool 10 and wire-line 28 disconnected from the sampling tool and removed. A swabbing unit is then inserted into the tubing to pump the fluids upward while the sampling tool is in position with the resultant trapping of a fluid sample therein.

Following a first sampling operation of fluid flow from below packer 20, sampling tool 27 is quickly removed and replaced with a second sampling tool 27'. Sampling tool 27', as illustrated in FIG. 3, is similar to tool 27 but has a modified nose piece 37' below the enlarged portion 34 which has O-ring sealing elements 39, 40 straddling a port 41 to a blind bore 31' in nose piece 37'. Thus, with sampling tool 27', fluid from below packer element 20 enters bore 18 of tool 10 and travels via bypass 22 to bore 16 and on into the tubing string. Fluid intermediate of packers 19 and 20 enters port 21 of tool 10 and into port 41 of sampling tool 27 to pass via bore 31' on into the sample chamber formed between piston 33 and valve 32. Fluid intermediate of packers 19, 25 enters tool 10 via port 23 and on into bore 16. Hence, it will be appreciated that with sampling tool 27', a second portion of the flow is also recovered for analysis.

Following this operation and the recovery of sampling tool 27', the lower two packers 19, 20 can then be released and tool 10 can be elevated independently of packer 25 to another section of the casing, as shown in FIG. 4, and the flow testing of this section accomplished with subsequent runs of sampling tool 27' as above described. The operation is continued in this manner for the entire production zone. Thus recovery of discrete flow samples for individual sections of the entire production zone are obtained.

Also, if desired, the lower bore 18 can be closed to fluid flow by making the nose piece 37' longer so as to extend into the bore section 18. Suitable O-rings can be provided for sealing purposes.

Referring now to FIGS. 5A and 5B, an exemplary embodiment of apparatus of the present invention is illustrated. Tool 10 has a longitudinally-extending tubular mandrel body 45 with bore sections 15-18 as described heretofore. The upper end of the mandrel is arranged for threaded coupling to a string of tubing 46.

The upper end of the mandrel also has a downwardly-facing shoulder portion 47 adjoining a downwardly-facing J-slot 48 formed in an enlarged outer surface of the mandrel (see FIG. 8). The J-slot 48 has an offset locking recess and is arranged open to the outer surface 49 of the mandrel. A tubular, upper housing 50 is slidably received on the upper end of the mandrel and has an inwardly-extending J-pin 51 for register with J-slot 48 of the mandrel. In a normally-locked position of pin 51 in J-slot 48 while the apparatus is going in the well bore, housing 50 can abut shoulder portion 47 of the mandrel. When housing 50 is unlocked from the mandrel, the mandrel may be moved relative to the housing. The J-slot is arranged to be unlocked when the mandrel is lowered, torqued in a counterclockwise direction and then picked up. The internal bore of upper housing 50 is provided with upper and lower sealing elements 52, 53 providing a fluid-tight seal between the housing and mandrel.

The upper housing 50 has rotatably mounted thereon, a bearing sleeve 50a and an annular, elastomer packing element 25 on sleeve 50a. A packer-expander element 57 is slidably received on the upper housing and sleeve 50a. Sleeve 50a has a flange portion 50b for limiting downward movement of expander 57 relative to sleeve 50a.

Spaced longitudinally from expander element 57 on upper housing 50 is a slip cage assembly 58 which has a tubular cage 59 with a downwardly-facing J-slot 60. A J-

pin 61 is mounted on the lower end of the housing registering with J-slot 60 of the housing. In the normally-locked position of pin 61 in J-slot 60, cage 59 is held against movement relative to the housing. When pin 61 is unlocked from slot 60, the housing may be moved relative to the cage. Cage 59 carries radially-spaced drag-blocks 62 which are spring-biased outwardly for frictional engagement with the wall of a casing or an uncased well bore. Slip elements 63 are pivotally connected to the drag-blocks and have inclined surfaces 64 which cooperate with expander 57 to move the slip elements into engagement with a casing wall.

The cage 58 also has an internal annular recess 66 which receives resiliently inwardly-biased, internally-threaded segments 67 disposed about the circumference of the housing. The housing has on its outer surface, a threaded portion 68 which is adapted, upon a relative movement between slip cage 59 and the housing to be received by threaded segment 67 and prevent the housing from moving upwardly relative to the cage. The threaded connection is, however, releasable upon right-hand rotation of the housing relative to cage 59.

From the apparatus thus far described, it will be appreciated that mandrel 45 is releasably connected to housing 50 and that housing 50 is releasably connected to cage assembly 58. If the tubing string and mandrel 45 are lifted upwardly, torqued clockwise and then lowered, housing 50 will become freed or "unjayed" from the cage assembly permitting the housing and mandrel to be moved downwardly until slip-expander 57 engages with slip elements 64. Further downward movement of the housing and mandrel compresses packing element 25 into sealing engagement with the casing wall. In this position, the threaded, resiliently-biased segments 67 engage with threaded portion 68 on the housing to hold the housing and cage assembly in fixed position relative to one another while yet permitting mandrel 45 to be moved relative to the housing. Mandrel 45 in unjayed relative to the upper housing by lowering the mandrel, rotating counterclockwise and then picking up.

The mandrel 45, at its lower end, is provided with spaced, annular, elastomer packing elements 19 and 20. The lower packing element 20 is shouldered between a flange 70 on the mandrel and a tubular spacer housing 71 slidably mounted on the mandrel. The upper packing element 19 is shouldered between tubular spacer housing 71 and an expander 72 slidably mounted on the mandrel. In the relaxed position of the packer elements, expander 72 abuts a downwardly-facing shoulder 73 on the mandrel.

Spaced upwardly from expander 72 is a slip cage assembly 75. The mandrel has a slot system 76 in its outer surface (FIG. 8) and slidably received over this part of the mandrel is a tubular cage 77 with an inwardly-extending pin 78 registering with the slot system 76. The cage 77 also has resiliently-mounted drag-blocks 79 and pivotally-mounted slips 80. The slot system 76 is arranged so that when the mandrel 45 is lifted, lowered, and then lifted again, the mandrel can be moved relative to the cage a sufficient distance to set slips 80 and packers 19, 20. It will be appreciated that upward movement of the mandrel relative to the lower slip assembly 79 will cause expander 72 to place slips 80 into engagement with the casing followed by expansion of the uppermost packer 19 and the subsequent expansion of the lower packing element 20.

Within the confines of tubular spacer housing 71 (which forms an annular space 82 between its inner wall and the outer mandrel wall), mandrel 45 is provided with an enlarged diameter portion 83. The enlarged diameter portion 83 has a flow port 21 straddled by O-ring seals 84, the flow port 21 opening into the bore section 17 of the mandrel which is smaller in diameter than its general bore 16. The spacer housing 71 also has a flow port 21a intermediate its length which flow port is arranged to register with flow port 21 when the packer

elements are expanded. The enlarged portion 83 of the mandrel is also provided with a bypass passageway 22 extending between bores 15 and 16 above and below the smaller bore 17.

Just above the slot system 76 on mandrel 45 (FIG. 5B) are upwardly-facing clutch fingers 85. Housing 50 at its lowermost end has downwardly-facing clutch fingers 86. When clutch fingers 85, 86 are interengaged, the housing can be rotated relative to cage assembly 58 to release the threaded interconnection 67, 68 so that packer 25 can be released from the casing.

For obtaining a fluid test, the wireline fluid sampler 27 is passed through the tubing string by means of a wireline or, if so desired, it can be dropped through the tubing.

As shown in FIG. 6, a more refined sampler tool 27A is illustrated and includes an elongated, cylindrically-shaped sample-receiving housing 27a ported at its upper end 30 and having at its lower end, a valve 32'. The floating piston 33, which is initially in the lowermost portion of the housing, is disposed within the sample-receiving housing 27a.

The piston 33 is unique in that it provides for fluid bypass in either direction. Piston 33 has a first tubular valve part 90 slidably and sealingly received within housing 27a. A second valve part 92 has spaced-apart valve elements 92a, 92b connected to one another by a valve stem 92c. The valve stem 92c passes through bore 91 of part 90 and is longer than part 90. A spring 92d between parts 90 and 92 holds valve element 92a sealed relative to bore 91. Spring 92d is strong enough to retain valve element 92 sealed relative to bore 91 under pressure so that parts 90, 92 combined form piston 33 which moves upwardly forcing any liquid thereabove out of the ports in the upper end of housing 27a. The piston 33 will continue to move upwardly until part 90 engages the end wall of the housing 27a. A counter bore in the end wall of housing 27a permits pressure below piston 33 to overcome the force of spring 92d and displace element 92a from its sealed position so that fluid can bypass the piston in an upward direction.

In the position shown for the piston 33, if the pressure above the piston exceeds the pressure below, the part 90 will be shifted downwardly to permit fluid to bypass the piston through ports in the valve element 92b. The lower tubular extension 93 of the sampling unit receives a slidably-mounted sleeve housing 94. The sleeve housing has longitudinally-grooved flange portions 95 engageable with shoulder 35 on the mandrel and a lower sealing portion 96 with inner and outer O-rings for sealing engagement with bore 18 in the mandrel. The sleeve housing 94 is biased outwardly by a spring 97 extending between a shoulder 98 on housing 27a and flange 95 to normally retain sleeve housing 94 in a position where the O-ring seals close off a port 99 in the tubular extension 93. Engagement of flange 95 with shoulder portion 35 in the mandrel permits displacement of sleeve housing 94 relative to tubular extension 93 to disposed port 99 in a position below the lower end of the mandrel so that fluid from below the lower packer element 20 can flow into bore 31' of the tubular extension 93.

In FIG. 7, a sampling tool 27B is disclosed which is similar to sampling tool 27A of FIG. 6 except that the tubular extension 93' and sleeve housing 94' are shortened and the sleeve housing 94' has ports 100. The arrangement is such that when flange 95 engages shoulder 35 in the mandrel 45, ports 100 are placed into fluid communication with port 21 of the mandrel. Upon relative movement between housing 94' and extension 93', bore 31' is placed into fluid communication with ports 99, 100.

The operation of the apparatus of FIGS. 5A and 5B is as follows: The apparatus of FIGS. 5A and 5B is lowered into the well with the various parts in the position illustrated. Once located in position where the upper packer 25 is above the perforated section of the casing,

the following operations can be performed with the apparatus of FIGS. 5A-5B. For convenience in illustration, the various J-slots and pin positions are keyed by letters to the following description.

A. Go into a position where test desired and packer 25 is above uppermost perforation.

B. Pick up mandrel, turn clockwise and set down; housing 49 unlocked from cage assembly 58 (see FIG. 8), upper packer 25 set; packer 25 locked in set condition by segments 67 and threaded portion 68.

C. Turn mandrel counterclockwise and pick up; mandrel 45 unlocked from housing 49 (see FIG. 8).

D. Push down mandrel to index pin 78 in slot system 76 and pick up; packers 19 and 20 set.

E. Push down mandrel to index pin 78 in slot system 76 and pick up; packers 19 and 20 unset.

F. Push down mandrel to index pin 78 in slot system 76 and pick up; packers 19 and 20 set.

G. Push down mandrel to index pin 78 in slot system 76 and pick up; packers 19 and 20 unset.

H. Rotate mandrel clockwise unthreading segments 67 from threaded portion 68 and pick up; packer 25 unset; rotation can be accomplished by bringing clutch fingers 85 and 86 into mesh or rejoying mandrel 46 to J-slot 48 where housing 49 can be rotated relative to cage 58.

In the foregoing description of the J-slot arrangement of FIGS. 5A and 5B, it should be appreciated that slot system 76 is relatively long so that the up and down mandrel motions to operate J-slots 48 and 60 do not bring the lower slip cage 79 into engagement with expanders 72. When slip cage 79 is to be brought into operative engagement with expanders 72, the pick up is a long stroke and a relative rotation occurs between cage 79 and mandrel 45. This rotation may be facilitated, if desired, by a swivel connection between the friction blocks of cage assembly 79 and the portion of cage 77 carrying the pin 78. Slot system 76, as illustrated, provides a continuous transfer function when a sufficient longitudinal stroke is provided. For the position E, slot system 76 has a groove terminating so that cage 79 and expanders 72 are in a spaced-apart position.

To perform operations in accord with the present invention with the apparatus of FIGS. 5-7, packer 25 is set above the uppermost perforation and packers 19 and 20 are set as described in operations A-D above.

Next the sampling tool 27A is lowered into the mandrel 49 and flange 95 of tool 27A engages shoulder 25 of mandrel 49. The weight of the tool 27A permits the tubular extension 93 to move relative to sleeve housing 94 placing ports 99 in an open position below the end of packer 20.

At this time, if the well column has been previously bailed out, part of the fluid return will enter ports 99 displacing piston 33 upwardly. Should the piston reach the upper limit of the housing 27a, the fluid can bypass through valve piston 33 into the tubing string.

If the well has a relatively fast rate of fill-up, tool 27 is positioned in mandrel 49 before the test is begun. After positioning tool 27B in mandrel 45, the wireline is disconnected from the sampling tool 27 and removed. Fluid can then be induced to flow by a swabbing operation which pumps the fluid upwardly. Alternatively to a swabbing operation, a fluid drive or gas lift operation could be used to move the fluid.

After retrieving sampling tool 27A, its contents can be analyzed to provide a determination of the fluids flowing from below packer 20. Following the first test, sampling tool 27B is placed in the mandrel 49 and a fluid sample from the casing perforations intermediate packers 19 and 20 can be trapped in a manner similar to that described with respect to tool 27A.

To test the next section of the perforated interval, only the packers 19, 20 are unseated (operation E above) and raised a suitable distance for testing of the next interval. Once again the packers 19 and 20 are seated in the

casing (operation F). Sampling tool 27B is used to recover a fluid sample as described heretofore.

Each interval is successively tested in a like manner and, ultimately, the clutch fingers 85 and 86 are engaged so that rotation can release the upper packer 25 from seating engagement with the casing. To unseat packer 25, mandrel 49 is raised and expander 57 is disengaged from slips 64. The device can be retrieved in this position. It should be appreciated that the upper packer 25 also can be released by resetting the apparatus to its initial position of operation.

It will be appreciated that once the packer 25 is set, well fluids in the annulus between the casing and tubing are isolated from the testing zone for the entire operation. Thus, the sampling operations may quickly be accomplished without emptying the well bore of fluid each time the sampling section is moved. Of course, the tool may be repositioned at various levels for sequential testing of formation intervals.

Referring now to FIG. 9, a further refinement of apparatus used in the present invention is illustrated wherein a sampling tool 27C is provided with conventional pressure recorders 105, 106. One of the pressure recorders 105 is disposed in the sampling chamber between piston 33 and bore 31, while the other recorder 106 is connected to the lower end of the tubular extension. Tool 27C has a closed end so that the space between the piston and closed end may be at atmospheric or a low pressure. It will be appreciated that sampling tools 27, 27', 27A can be similarly equipped with pressure recorders or closed ends.

The pressure recorders 105, 106, of course, measure pressures of the parts of the fluid flow and from the independent pressure measurements over given time intervals, the pressure potential of the isolated zone can be determined. Furthermore, the presence of channeling either between the casing and the formation or within the formation itself (through a fracture or the like) can be determined.

The advantages of the present invention are manifold. For example, the testing produces results which are both qualitative and quantitative. The qualitative results are obtained from the retrieved fluid sample which can be analyzed for its precise fluid content. Quantitative results are obtained by retrieving a sample before the sample chamber is completely filled while measuring the time required to obtain the sample. This gives an indication of the rate of fluid flow. If desired, a timing device can be attached to the sampling tool to indicate the time of fill-up for the sample chamber.

From the pressure measurements, it can be determined if the cement column has channeled. For example, if there is no pressure buildup within the sample chamber, it can be deduced that the flow is bypassing the particular section being then tested. The pressure measurement may also indicate the existence of communication between production zones such as occurs when a higher-pressure production zone is thieved by lower-pressure production zone.

While particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. A method of determining fluid flow characteristics of an interval of earth formations comprising the steps of: packing off a well bore at a first location above the uppermost portion of the interval of formations to be tested, and thereafter sequentially packing off spaced short sections of the well bore to produce isolated sections along said interval while maintaining said first location packed off, and for each subsequent and sequential isolation of

a respective short section, artificially producing a fluid flow from the earth formations from said entire interval, lowering sampling tools into the well bore to points adjacent to said short sections, trapping flow samples in said sampling tools including samples of fluids flowing into said well bore at said isolated short sections, and retrieving such flow samples to the earth's surface for analysis to compile a composite of information regarding the flow characteristics of the earth formations along said interval.

2. Apparatus for testing a well comprising: a tubular mandrel member, a housing sleeve member telescopically mounted on said mandrel member, first releasable interconnecting means for holding said members in a substantially fixed position relative to one another and operable for releasing said sleeve member from said mandrel member to permit longitudinal positioning of said mandrel member relative to said sleeve member, packer means including a packer element received by said sleeve member; cage means on said sleeve member including friction wall-engaging means and anchor means selectively operable for engaging the well bore and cooperating with said packer means for expansion of said packer element, second releasable interconnecting means for selectively holding said cage means and sleeve member in a substantially fixed position relative to one another and operable for releasing said cage and sleeve member relative to one another, said anchor means and packer element being movable to set positions upon relative movement between said sleeve member and cage means; and locking means cooperable between said sleeve member and cage means for releasably locking said anchor means and packer element in said set positions.

3. The apparatus of claim 2 wherein said locking means includes complementary latching portions on said sleeve member and cage means releasable, when engaged, by rotation.

4. The apparatus of claim 2 wherein said second releasable interconnecting means includes pin and slot means interconnecting said sleeve member and cage means releasable by longitudinal manipulation of said sleeve member relative to said cage means.

5. The apparatus of claim 4 wherein said first releasable interconnecting means includes pin and slot means interconnecting said sleeve member and mandrel member.

6. The apparatus of claim 2 wherein said packer means includes means for rotatably supporting said packer element on said sleeve member.

7. Apparatus for use in testing a well comprising: a sleeve member; a mandrel slidably disposed within said sleeve member and adapted for longitudinal positioning relative to said sleeve member; first control means cooperable between said mandrel and said sleeve member for selectively preventing and permitting sliding movement of said mandrel and said sleeve member relative to one another; seal means between said sleeve member and said mandrel to prevent fluid leakage therebetween; cage means slidably disposed on said sleeve member, said cage means including wall-engaging friction drag means to retard movement of said cage means; second control means cooperable between said sleeve member and said cage means for selectively preventing and permitting sliding movement of said sleeve member and cage means relative to one another; normally retracted anchor means shiftable upon relative movement between said sleeve member and cage means to extend positions for anchoring a well conduit; normally retracted packing means disposed about said sleeve member and movable upon relative movement between said sleeve member and cage means to expanded positions for packing off the annulus between said sleeve member and a surrounding well conduit wall; and releasable locking means for locking said anchor means and packing means in respective extended and expanded positions, said locking means being releasable by relative rotation between said sleeve member and cage means.

8. The apparatus recited in claim 7 further including

means on said mandrel engageable with said sleeve member for rotating said sleeve member relative to said cage means to release said locking means.

9. Apparatus for testing a well comprising: at least three longitudinally-spaced packer means for packing off a well bore; telescopically-mounted pipe members, one of said members supporting one of said packer means, the other of said members supporting the remaining packer means; means on each of said members for setting said packer means in a well, means for selectively coupling said members relative to one another so that when said one packer means on said one member is set in a well, the remaining packer means may be selectively positioned longitudinally with said other member relative to said one packer on said one member, said apparatus having means defining ports intermediate of said packer means providing fluid communication between the exterior and interior of said apparatus.

10. Apparatus for testing a well comprising: at least three longitudinally-spaced packer means for packing off a well bore each having packer elements; telescopically-mounted flow pipe members, one of said members supporting one of said packers, the other of said members supporting the remaining packers; means on each of said members for setting said packer means in a well, said setting means including a friction cage assembly as well as slips and expander means cooperative upon relative movement between a packer element and the cage assembly for bringing said slips into engagement with a well bore permitting expansion of a packer element, means for selectively coupling said members relative to one another so that when said one packer on said one member is set in a well the remaining packers may be selectively positioned longitudinally with said other member relative to said one packer on said one member, said apparatus having means defining ports intermediate of said packer means providing fluid communication between the exterior and interior of said apparatus.

11. Apparatus for testing a well comprising: a tubular mandrel member, an upper, tubular housing sleeve member slidably received on said tubular mandrel, means releasably interconnecting said upper sleeve and mandrel members including first slot and pin means, first expander means slidably received on said sleeve member, a first packer element received between an abutment on said sleeve member and said first expander element, a first cage assembly slidably received on said sleeve member and including wall-engaging friction means and slip elements arranged for cooperation with said expander means, means releasably interconnecting said sleeve member and first cage assembly including second slot and pin means, said mandrel member at its lower end having a second packer element and a third packer element disposed on opposite ends of a lower housing sleeve member slidably received on the mandrel member, said second and third packer elements and lower housing member being disposed between an abutment on said mandrel member and second expander means, said second expander means being slidably received on said mandrel member, a second cage assembly slidably received on said mandrel member and including wall-engaging friction means and slip elements arranged for cooperation with said second expander means, and means releasably interconnecting said mandrel member and second cage assembly including third slot and pin means, said mandrel member having ports intermediate of said packer elements providing fluid communication between the exterior and interior of said mandrel member.

12. The apparatus of claim 11 wherein said releasable interconnecting means between said sleeve member and first cage assembly further includes complementary threaded portions on said sleeve member and first cage assembly engageable after expansion of said first packer element and releasable by rotation.

13. The apparatus of claim 11 wherein said ports

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providing fluid communication between the exterior and interior of said mandrel member include ports in said lower housing sleeve member and the lower end of said mandrel member.

14. The apparatus of claim 11 wherein said first slot and pin means include a J-slot opening downwardly, said second slot and pin means include a J-slot opening downwardly, and said third slot and pin means include a slot arranged for continuously indexing of said pin between upper, lower and intermediate positions in response to relative longitudinal movement.

15. The apparatus of claim 11 wherein said mandrel member has means in its interior for seating a sampling tool, and further including a retrievable flow sampling tool including a housing having a chamber in communication with upper and lower ports, said upper port being open to the exterior of the tool, said lower port being in a lower portion of said housing, a movable piston in said chamber, valve means for said lower port including a valve sleeve slidably received on the lower portion of said housing, resilient means to normally position said valve sleeve in one position on said lower portion, seal means between said valve sleeve and lower portion for closing said lower port from fluid flow in said one position, said valve sleeve having cooperating means engageable with said seating means for shifting said valve sleeve to open said lower port to fluid flow, and seal means on the exterior of said valve sleeve for sealing said valve sleeve relative to said mandrel member below said lower port.

16. The apparatus of claim 11 wherein said mandrel member has means in its interior for seating a sampling tool, and further including a retrievable flow sampling tool including a housing having a chamber in communication with upper and lower ports, said upper port being open to the exterior of the tool, said lower port being in a lower portion of said housing, a movable piston in said chamber, valve means for said lower port including a valve sleeve slidably received on the lower portion of said housing, said valve sleeve having ports, resilient means to normally position said valve sleeve in one position on said lower portion, seal means between said valve sleeve and lower portion for closing said lower port and valve sleeve ports from fluid communication in said one position, said valve sleeve having cooperating means engageable with said seating means for shifting said valve sleeve to place said lower port and sleeve ports in fluid communication, and seal means on the exterior of said valve sleeve above and below said valve sleeve ports for sealing said valve sleeve above and below said mandrel member ports.

17. The apparatus of claim 11 wherein said mandrel member has means in its interior for seating a sampling tool, and further including a retrievable flow sampling tool including a housing having a chamber in communication with upper and lower ports, said upper port being open to the exterior of the tool, said lower port being in a lower portion of said housing, a movable piston in said chamber, valve means for said lower port including a valve sleeve slidably received on the lower portion of said housing, resilient means to normally position said valve sleeve in one position on said lower portion, seal means between said valve sleeve and lower portion for closing said lower port from fluid flow in said one position, said valve sleeve having cooperating means engageable with said seating means for shifting said valve sleeve to open said lower port to fluid flow, and seal means on the exterior of said valve sleeve for sealing said valve sleeve relative to said mandrel member below said lower port, said piston including a tubular sleeve member sealingly and slidably received within said chamber, said tubular sleeve having one end thereof forming a valve seat, a valve member received in said tubular sleeve and having one end thereof formed for valve cooperation with said valve seat for closing the opening through said tubular sleeve, said valve member

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having a valve stem extending through said tubular sleeve and having its remaining end formed for providing a bypass in said chamber for fluid flow, means resiliently biasing said remaining end and sleeve away from one another thereby normally positioning said one end of said valve member on said valve seat and closing the opening through said tubular sleeve, said chamber at one end having means for engaging said tubular sleeve only for permitting said one end of said valve member to be displaced relative to said valve seat against the force of said biasing means, said chamber at its other end having means for engaging said remaining end of said valve member for permitting said tubular sleeve to be displaced relative to said one end of said valve member against the force of said biasing means.

18. The apparatus of claim 11 wherein said mandrel member has means in its interior for seating a sampling tool, and further including a retrievable flow sampling tool including a housing having a chamber in communication with upper and lower ports, said upper port being open to the exterior of the tool, said lower port being in a lower portion of said housing, a movable piston in said chamber, valve means for said lower port including a valve sleeve slidably received on the lower portion of said housing, said valve sleeve having ports, resilient means to normally position said valve sleeve in one position on said lower portion, seal means between said valve sleeve and lower portion for closing said lower port and valve sleeve ports from fluid communication in said one position, said valve sleeve having cooperating means engageable with said seating means for shifting said valve sleeve to place said lower port and sleeve ports in fluid communication, and seal means on the exterior of said valve sleeve above and below said valve sleeve ports for sealing said valve sleeve above and below said mandrel member ports, said piston including a tubular sleeve member sealingly and slidably received within said chamber, said tubular sleeve having one end thereof forming a valve seat, a valve member received in said tubular sleeve and having one end thereof formed for valve cooperation with said valve seat for closing the opening through said tubular sleeve, said valve member having a valve stem extending through said tubular sleeve and having its remaining end formed for providing a bypass in said chamber for fluid flow, means resiliently biasing said remaining end and sleeve away from one another thereby normally positioning said one end of said valve member on said valve seat and closing the opening through said tubular sleeve, said chamber at one end having means for engaging said tubular sleeve only for permitting said one end of said valve member to be displaced relative to said valve seat against the force of said biasing means, said chamber at its other end having means for engaging said remaining end of said valve member for permitting said tubular sleeve to be displaced relative to said one end of said valve member against the force of said biasing means.

19. A retrievable flow sampling tool for use with a well tool in a well bore comprising: a housing having a chamber in communication with upper and lower ports, said upper port being open to the exterior of the tool, said lower port being in a lower portion of said housing, a movable piston in said chamber, valve means for said lower port including a valve sleeve slidably received on the lower portion of said housing, resilient means to normally position said valve sleeve in one position of said lower portion, seal means between said valve sleeve and lower portion for closing said lower port from fluid flow in said one position, said valve sleeve being shiftable to open said lower port to fluid flow, and seal means on the exterior of said valve sleeve for sealing within a bore of a well tool, said piston including a tubular sleeve member sealingly and slidably received within said chamber, said tubular sleeve having one end thereof forming a valve seat, a valve member received in said tubular sleeve and having one end thereof formed for valve cooperation with said

valve seat for closing the opening through said tubular sleeve, said valve member having a valve stem extending through said tubular sleeve and having its remaining end formed for providing a bypass in said chamber for fluid flow, means resiliently biasing said remaining end and sleeve away from one another normally positioning said one end of said valve member on said valve seat and closing the opening through said tubular sleeve, said chamber at one end having means for engaging said tubular sleeve only for permitting said one end of said valve member to be displaced relative to said valve seat against the force of said biasing means, said chamber at its other end having means for engaging said remaining end of said valve member for permitting said tubular sleeve to be displaced relative to said one end of said valve member against the force of said biasing means.

20. A retrievable flow sampling tool for use with a well tool in a well bore comprising: a housing having a chamber in communication with upper and lower ports, said upper port being open to the exterior of the tool, said lower port being in a lower portion of said housing, a movable piston in said chamber, valve means for said lower port including a valve sleeve slidably received on the lower portion of said housing, said valve sleeve having ports, resilient means to normally position said valve sleeve in one position on said lower portion, seal means between said valve sleeve and lower portion for closing said lower port and valve sleeve ports from fluid communication in said one position, said valve sleeve being shiftable to open said lower port to fluid flow, and seal means on the exterior of said valve sleeve above and below said valve sleeve ports for sealing within a bore of a well tool, said piston including a tubular sleeve member sealingly and slidably received within said chamber, said tubular sleeve having one end thereof forming a valve seat, a valve member received in said tubular sleeve and having one end thereof formed for valve cooperation with said valve seat for closing the opening through said tubular sleeve, said valve member having a valve stem extending through said tubular sleeve and having its remaining end formed for providing a bypass in said chamber for fluid flow, means resiliently biasing said remaining end and sleeve away from one another thereby normally positioning said one end of said valve member on said valve seat and closing the opening through said tubular sleeve, said chamber at one end having means for engaging said tubular sleeve only for permitting said one end of said valve member to be displaced relative to said valve seat against the force of said biasing means, said chamber at its other end having means for engaging said remaining end of said valve member for permitting said tubular sleeve to be displaced relative to said one end of said valve member against the force of said biasing means.

21. A retrievable flow sampling tool for use with a well tool in a well bore comprising: a housing having a chamber in communication with upper and lower ports, said upper port being open to the exterior of the tool, said lower port being in a lower portion of said housing, a movable piston in said chamber, valve means for said lower port including a valve sleeve slidably received on the lower portion of said housing, resilient means to normally position said valve sleeve in one position on said lower portion, seal means between said valve sleeve and lower portion for closing said lower port from fluid flow in said one position, said valve sleeve being shiftable to open said lower port to fluid flow, and seal means on the exterior of said valve sleeve for sealing within a bore of a well tool.

22. A retrievable flow sampling tool for use with a well tool in a well bore comprising: a housing having a chamber in communication with upper and lower ports, said upper port being open to the exterior of the tool, said lower port being in a lower portion of said housing, a movable piston in said chamber, valve means for said lower port including a valve sleeve slidably received on the lower portion of said housing, said valve sleeve having ports, resilient means to normally position said valve sleeve in one position on said lower portion, seal means between said valve sleeve and lower portion for closing said lower port and valve sleeve ports from fluid communication in said one position, said valve sleeve being shiftable to open said lower port to fluid flow, and seal means on the exterior of said valve sleeve above and below said valve sleeve ports for sealing within a bore of a well tool.

23. In a well tool, a housing having a chamber with upper and lower ports, a movable piston in said chamber, said piston including a tubular sleeve member sealingly and slidably received within said chamber, said tubular sleeve having one end thereof forming a valve seat, a valve member received in said tubular sleeve and having one end thereof formed for cooperation with said valve seat for closing the opening through said tubular sleeve, said valve member having a valve stem extending through said tubular sleeve and having means in its end portion for providing a bypass in said chamber for fluid flow, means resiliently biasing said remaining end and sleeve away from one another thereby normally positioning said one end of said valve member on said valve seat and closing the opening through said tubular sleeve.

24. In a well tool, a housing having a chamber with upper and lower ports, a movable piston in said chamber, said piston including a tubular sleeve member sealingly and slidably received within said chamber, said tubular sleeve having one end thereof forming a valve seat, a valve member received in said tubular sleeve and having one end thereof formed for valve cooperation with said valve seat for closing the opening through said tubular sleeve, said valve member having a valve stem extending through said tubular sleeve and having means in its end portion for providing a bypass in said chamber for fluid flow, means resiliently biasing said remaining end and sleeve away from one another thereby normally positioning said one end of said valve member on said valve seat and closing the opening through said tubular sleeve, said chamber at one end having means for engaging said tubular sleeve only for permitting said one end of said valve member to be displaced relative to said valve seat against the force of said biasing means, said chamber at its other end having means for engaging said remaining end of said valve member only for permitting said tubular sleeve to be displaced relative to said one end of said valve member against the force of said biasing means.

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