Aug. 28, 1962 N. K. ANDREW ETAL 3,051,245

WELL TOOLS FOR SUBSURFACE FLOW CONTROL

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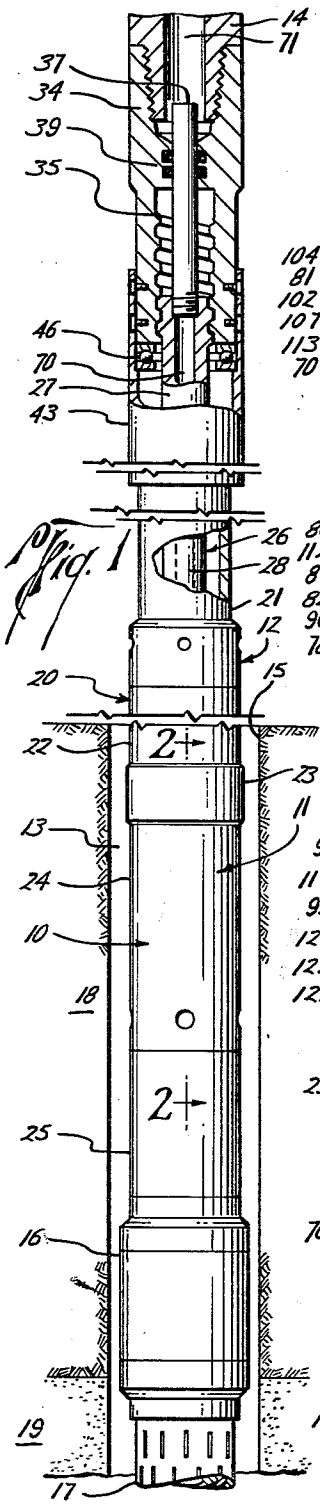


Fig. 1

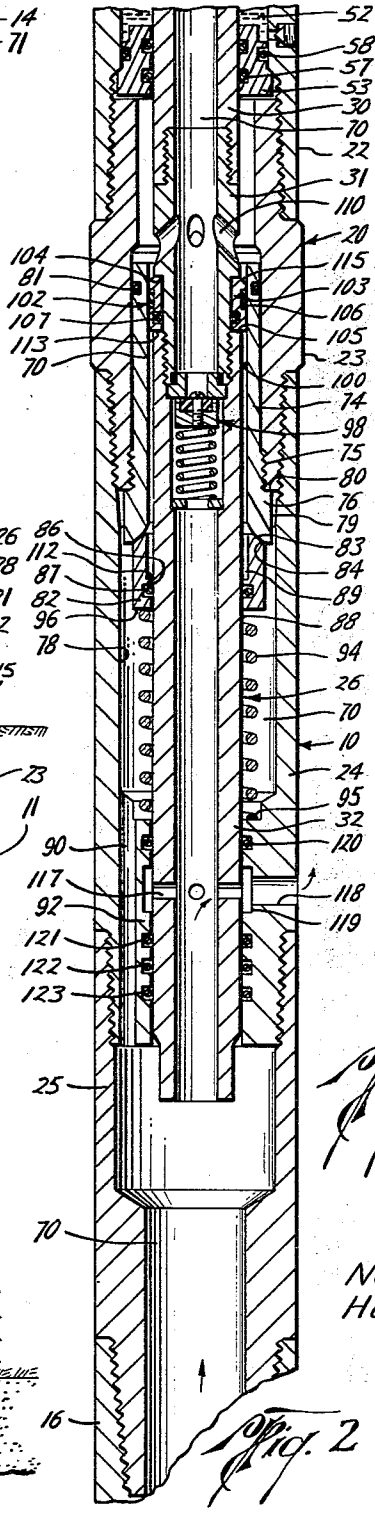


Fig. 2

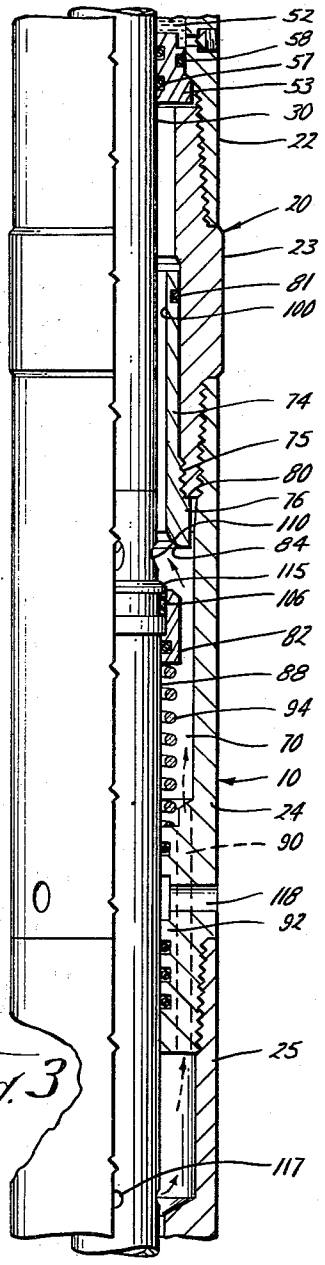


Fig. 3

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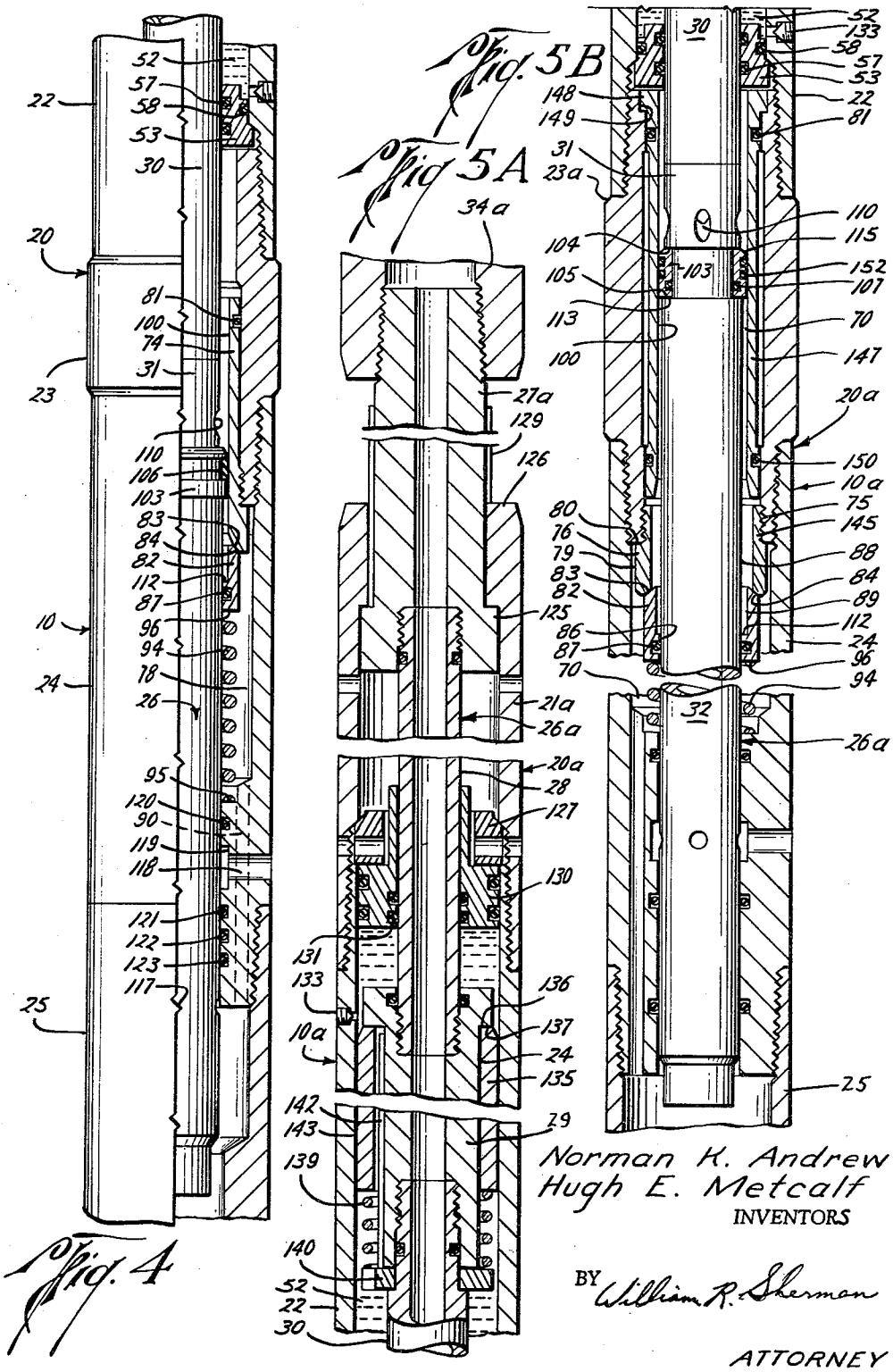
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Fig. 6

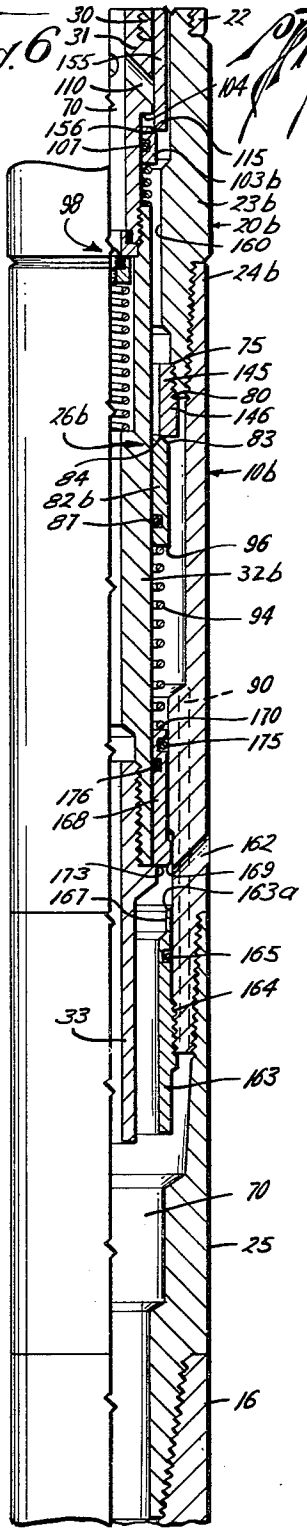


Fig. 7

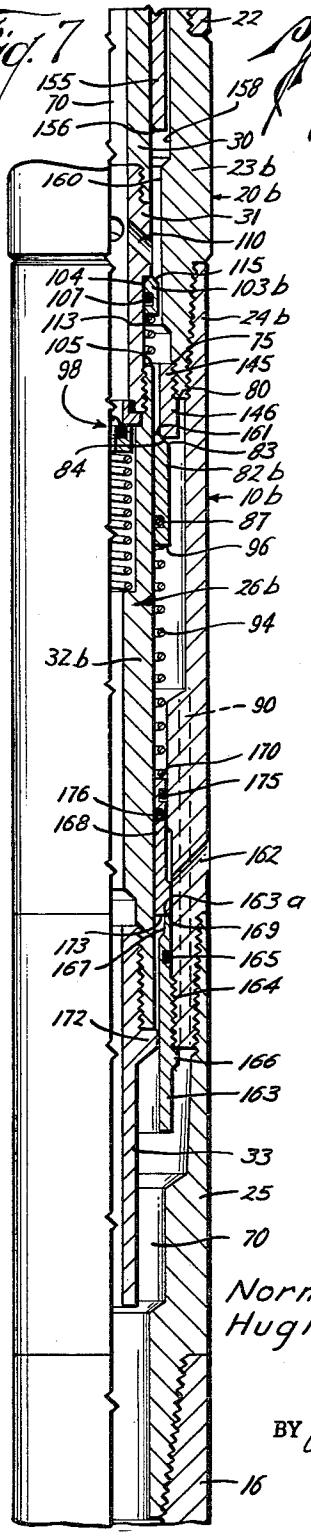
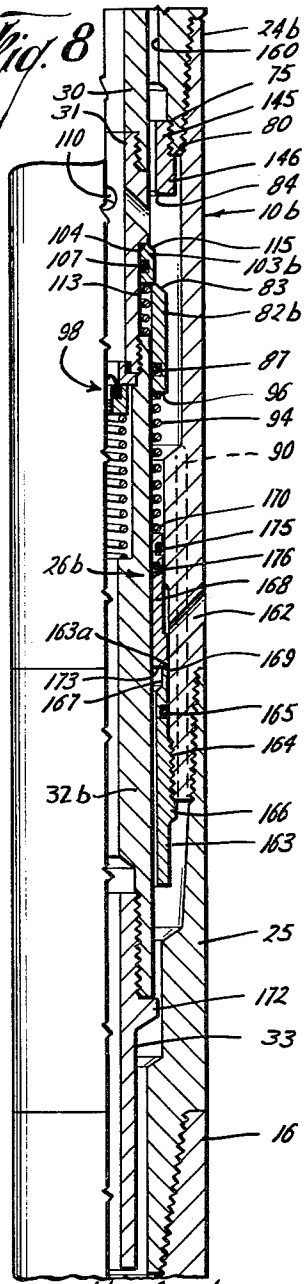


Fig. 8



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WELL TOOLS FOR SUBSURFACE FLOW CONTROL

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Filed Aug. 19, 1958, Ser. No. 755,932
15 Claims. (Cl. 166—226)

This invention relates to well tools and, more particularly, to tools for connection with well pipe to provide subsurface control of fluid flow such as may be required in formation testing.

Formation testing tools employed to admit and retain fluid samples have evolved over a period of years from a type utilizing a heavy spring to keep the test ports closed to a type having an hydraulically delaped opening. Representative of the spring-type are the formation testing tools of Johnston Patents Nos. 1,790,424 and 2,073,107, while tools of the hydraulic type are disclosed in Deters et al. Patent No. 2,703,696 and Moosman Patent No. 2,737,246. Tools of the spring-type enjoyed a widespread use characterized by efficient and economical operation and only in recent years have been replaced by the highly versatile and reliable hydraulic testing tools.

In a typical assembly of a spring-type testing tool, such as that disclosed in Patent No. 2,073,107, it was common practice to include a so-called trip valve spaced above the testing tool. Should the test ports for any reason open prematurely during descent, as when a constriction or bridge in the well was encountered, such trip valve ensured that well fluid would not enter the drill string thereabove. With the introduction of the hydraulic-type testing tool, the hydraulically delayed opening of the test ports prevented premature entry of fluid and removed the need for a trip valve. The transition from spring-type to hydraulic-type tools was also accompanied by a change from a poppet valve with a metal-to-metal seal to a sliding valve with a resilient seal.

Despite the many advantages in the hydraulic testing tools which have thus evolved, there has remained in the field a desire to return to the operating economy and positive action characterizing the spring-type tool.

It is therefore, an object of the present invention to provide an improved formation testing tool adapted for positive and economical operation.

It is also an object of the present invention to provide an improved well tool which is characterized by a highly reliable seal in the closed position.

Another object of the present invention is to provide a well tool which incorporates a valve having a positive opening characteristic with a minimum likelihood of premature opening.

A further object of the present invention is to provide a new and improved well tool having substantially an optimum suitability for admitting and retaining samples of formation fluid in the testing of well formations under widely varying and adverse conditions.

Yet another object of the present invention is to provide a well tool which may readily be operated and maintained by field personnel.

These and other objects of the invention are obtained by providing an annular valve disposed between a tubular housing and a mandrel slidably received in the housing. Such valve includes a seat formed within the bore of the housing and an annular valve head movable with respect to both the housing and the mandrel and displaced relative to the valve seat after a predetermined stroke of the mandrel. More particularly, the annular valve head is slidably disposed along a flow channel defined by the mandrel and the housing for opening and closing movement in the manner of a poppet valve. When hydrostatic pressure is overcome in the initial opening of the annular valve, a detectible impulse is obtained at the surface. A secondary valve is incorporated in the tool for a more reliable seal upon reclosing of the tool.

In one embodiment of the invention, a sliding seal is maintained along the channel between the mandrel and the housing to provide a secondary valve which remains closed prior to the accomplishment of the predetermined stroke by which the mandrel opens the annular valve. When the annular valve head is displaced from its closed position by stroking of the mandrel, the sliding seal is received protectively by the valve head to avoid its erosion by fluid passing through the annular valve. A one-piece liner section cooperates with the sliding seal and the valve head to provide sealing surfaces which may readily be replaced. In another embodiment, a two-piece liner section is employed.

In yet another embodiment, two annular valve heads are spaced along the flow channel to provide sequentially opened metal-to-metal or poppet valves. In addition, a third annular valve head may be employed to open and close equalizing ports with stroking of the mandrel relative to the housing.

Additional objects and advantages of the invention will become apparent from the following detailed description of representative embodiments thereof, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a view in elevation of a well tool in accordance with the present invention assembled in a string of pipe arranged for formation testing;

FIG. 2 is a detailed vertical section of valve portions of the well tool taken along the lines 2—2 of FIG. 1;

FIG. 3 is a view similar to FIG. 2 showing the well tool in open opsition for receiving a formation fluid sample;

FIG. 4 is a view similar to FIG. 2 showing the well tool in its intermediate closed or "shut-in" position for obtaining a "shut-in" pressure test;

FIGS. 5A and 5B are detailed vertical sections of a modified well tool in closed position showing, respectively, the hydraulic delay and valve portions of the well tool; and

FIGS. 6, 7 and 8 are detailed vertical sections of modified valve portions of the well tool of FIGS. 5A and 5B, showing the same in closed, intermediate and open positions.

In FIG. 1 is shown a well tool 10 exemplifying the principles of the present invention and including a valve portion 11 at its lower end which is described in detail hereafter in connection with FIGS. 2–4. At its upper end end is a control portion 12 which may of the type shown and described in copending application Serial No. 495,247 filed by Benjamin P. Nutter on March 18, 1955, now Patent No. 2,901,001, for "Hydraulic Tester and Shut-In Pressure Tool."

The well tool 10 is arranged to be dependently secured to a string 14 of drill pipe or tubing for lowering through a borehole 15 to a desired depth. The borehole 15 may be cased or uncased and, when uncased as illustrated, such depth is generally selected to provide a good seat for a packer 16 dependently secured to the well tool 10 and supported off the bottom of the borehole by anchor means, such as perforated anchor pipe 17. For example, the anchor pipe 17 may be of such length as to position the packer 16 against the wall of a hard formation 18 just above a permeable formation 19 which is to be tested for fluid production. The anchor pipe 17 may provide a housing for one or more pressure recorders (not shown) which may be of the type described in M. A. Garrison Patent No. 2,816,440.

Referring to FIGS. 1 and 2, the well tool 10 in accord-

ance with the present invention includes a multi-section tubular housing **20** made up of sections **21**, **22**, **23**, **24** and **25** threadedly connected together in end-to-end fluid-tight alignment. Slidably but nonrotatably received within the housing **20** for movement between an extended and retracted position is a tubular mandrel **26** which may likewise be of sectional construction including sections **27**, **28**, **30**, **31** and **32**, threadedly connected together in end-to-end fluid-tight alignment. Such nonrotation may result from the interfitting of splines (not shown) carried by the housing section **21** and the mandrel section **28**, for example.

The mandrel **26** is connected in fluid-tight relation to the pipe string **14** above by means of a top tubular sub **34** having a standard threaded connection with the string **14** and a threaded driving connection **35** with the upper mandrel section **27**. The drive connection may, for example, be provided by an Acme thread such that rotation of the top sub **34** by rotation of the pipe string **14** (conventionally to the right) draws the mandrel section **27** upwardly into the top sub. At the same time, the threaded driving connection **35** serves to transmit longitudinal movement of the top sub **34** to the mandrel **26**. In order that a longitudinal fluid channel **70** provided by the bore of the mandrel **26** may be continued upwardly in sealed relation past the drive connection **35** into flow course **71** defined by the bore of the pipe string **14**, a wash pipe **37** has a fluid-tight threaded connection with the upper mandrel section **27** and extends upwardly through an internal shoulder **39** in the top sub **34** in sealed sliding relation thereto.

As thus far described, the control portion **12** of the well tool provides for downward stroking of the mandrel **26** relative to the housing **20** by a downward movement of the pipe string **14** transmitted through top sub **34** and threaded drive connection **35**. Downward travel of the mandrel is limited by engagement of the lower end of top sub **34** with the upper end of housing section **21** and a thrust bearing **46** may be positioned therebetween to facilitate rotation of the top sub **34** relative to the housing section **21** under load conditions. When the top sub **34** is rotated by the pipe string **14**, the mandrel **26** is displaced upwardly by threading of the mandrel section **27** into the top sub **34**. This upward displacement may, for example, be approximately half the previously described downstroke. Upon upward movement of the pipe string **14** and top sub **34** relative to the housing **20**, the mandrel **26** is returned to its original upper position, the limit of its travel being determined by the interengagement of mandrel section **27** and housing section **21**, for example. Thus, the mandrel may be placed at first, second and third positions (as shown in FIGS. 2, 3 and 4, respectively) by the remote manipulations of the pipe string **14**, or as described in more detail in the aforementioned application Serial No. 495,247. As further taught in that application, the top sub **34** may dependently support a sleeve **43** which serves to co-rotatively secure the top sub to the housing section **21** in the first or upper position of the mandrel while permitting rotation of the top sub relative to the housing section for movement of the mandrel between its second (or lower) and third (or intermediate) positions.

To retard downward movement of the mandrel relative to the housing, housing section **22** incorporates an annular hydraulic fluid chamber **52** (FIG. 2) through which the mandrel **26** extends. A variety of arrangements may be employed for retarding the stroke of the mandrel through this hydraulic fluid chamber, exemplary arrangements being described in the aforementioned application Serial No. 495,247 and hereafter in conjunction with FIG. 5A. While the downstroke of the mandrel is thus retarded for a time-delayed travel, provision is made for an unrestricted upstroke.

Turning now to a detailed consideration of valve portion **11** of the well tool, reference is made to FIG. 2. The annular chamber **52** is shown to be sealed off at its bottom end by means of an annular O-ring retainer **53** including O-rings **57** affording a sliding seal with the mandrel section **30** and O-ring **58** sealed with the housing, the retainer **53** being secured with respect to the housing **20**. A liner section **74** extends upwardly into the housing section **23** and is secured to the same by means of a thread connection **75**. An enlarged portion **76** of the liner section **74** extends below the housing section **23** into an enlarged bore **78** defined by the housing section **24**. For easy maintenance, the enlarged portion **76** of the liner section affords an external surface **79** which is exposed to receive a wrench when housing section **24** is unthreaded from housing section **23** so that the thread connection **75** may readily be made or broken. The enlarged portion **79** also defines an upwardly directed shoulder **80** which abuts against the lower end face of housing section **23** for transmission of compression loads. To prevent leakage of fluid externally of the liner section **74** past the shoulder **80** and thread connection **75**, an O-ring **81** may be received in an external groove formed in the liner section **74** to seal with the bore of housing section **23**.

Within the enlarged bore **78** defined by the housing section **24** is an annular valve head **82** having a valve surface **83** at its upper end confronting a valve seat **84** formed on the lower end face of the liner section **74**. The valve head **82** and seat **84** together define an annular valve serving to control the flow of fluid through the flow channel **70** defined by the mandrel and housing and extending lengthwise through the entire well tool. Since the well fluid or connate fluid which is admitted through the flow channel **70** into the pipe string **14** is often of an abrasive character and frequently flows at high velocity, the liner section **74** and the valve head **82** and valve seat **84** are preferably constructed of a tough, erosion resistant material such as a suitable steel to provide a metal-to-metal seal. The sealing action is enhanced by the configuration of the valve seat **84** tending to center the sealing face **83** of the valve head **82** in conforming, fitted relation. Also, the configuration follows the line of fluid flow. Thus, the valve seat **84** is preferably formed with a conical taper opening downwardly and having an inclination with respect to the axis of the well tool such as 45° and lying within the angular range of greater than a sticking taper (on the order of 7°) but less than a flat 90°, the valve head face **83** having a complemenary taper.

To provide for ample flow of fluid externally past the valve head **82** when it is displaced downwardly to an open position, the exterior diameter of the valve head is substantially less than the interior diameter of the enlarged housing bore **78**. By providing the valve head **82** with a bore **86** sized to slidably receive the lower section **32** of the mandrel and by retaining the O-ring **87** within an internal groove relieved from the bore **86** for a sliding seal with the uniform exterior of the mandrel section **32**, leakage of fluid between the mandrel and valve head **82** is precluded. The valve head **82** is further provided with a counter bore **89** opening upwardly for a purpose to be explained hereafter.

When submerged in well fluid, the valve head **82** is arranged to be maintained in its sealed or closed position by hydrostatic pressure. Thus in the assembly of the well tool **10** in a well string for purposes of formation testing, for example, as illustrated in FIG. 1, well fluid is admitted through the perforation of anchor pipe **17** and flows upwardly through the packer **16** into the bottom section of the well tool housing. The lengthwise flow channel **70** through the well tool extends upwardly from the bore of the bottom housing section **25**, through a longitudinal bypass passage **90** formed in a reduced bore portion **92** of housing section **24** and into the enlarged bore **78** of the housing section **24**. The upward hydrostatic force applied against the valve head **82** is then

proportional to the product of the hydrostatic pressure at the given depth and the annular area, the inner diameter of which corresponds with the outer diameter of the mandrel section 32 inwardly of the O-ring 87 and the outer diameter of which corresponds with the effective diameter of the seal between the valve head face 83 and the valve seat 84. For a pressure of, say, 10,000 p.s.i. the valve head 82 may be designed to experience a seating force in its closed position on the order of 6,000 pounds.

However, since the well tool is generally introduced into a well in a dry condition, it is desirable that the valve head 82 be retained in its upper, closed position against the force of gravity by a biasing force in addition to the frictional force developed by the O-ring 87. Such biasing force is conveniently developed by a coil spring 94 developing a force in compression of, say, 100 lbs. or higher. While the lower end of the coil spring 94 may be supported with respect to the mandrel, preferably it bears against an upwardly facing annular shoulder 95 formed at the junction of the enlarged bore 78 and the reduced bore section 92, the upper end of the coil spring 94 bearing against the downwardly directed confronting shoulder 96 defined by the lower face of the valve head 82. The mandrel section 32 thus extends through not only the valve head 82 but also the coil spring 94 to support the same in alignment.

To prevent an upward flow of fluid through the bore of the mandrel section 32 which would bypass the annular valve 82—83—84, there is retained at the threaded connection between mandrel sections 31 and 32 a downwardly opening check valve 98 which may be opened by fluids pumped downwardly through the pipe string 14 under pressure for emergency purposes but is otherwise closed to retain any fluids standing in the bore of the mandrel thereabove. Reference may be had to the aforementioned application Serial No. 495,247 for a more detailed description of this check valve 98. The flow course 70 extending lengthwise through the well tool thus serves exclusively for the upward flow of fluids through the well tool and into the pipe string 14.

Above the valve head 82 the flow course 70 is defined by the annular region between the uniform bore 100 of the liner section 74 and the external surface 88 of the mandrel section 32. In the closed position of the well tool illustrated in FIG. 2, the flow course 70 is sealed off not only by the valve head 82 but also by a sliding seal 102 effected between the mandrel and the liner bore 100 and defining a secondary valve. This seal 102 is provided by a seal ring 103 carried on the mandrel section 31 and longitudinally retained between a downwardly facing annular shoulder 104 of the mandrel section 31 and the confronting upper end 105 of the mandrel section 32.

The seal ring 103 carries an annular packing element 106 which may be in the form of one or more O-rings but, as illustrated, is preferably formed as a band of rubber or other resilient material bonded or otherwise securely retained in an annular groove circumscribing the seal ring 103. To prevent a leakage of fluid between the seal ring 103 and the underlying surface of the mandrel section 31, the seal ring 103 may have an annular groove relieved from its bore to receive an O-ring 107 in sealing contact with the mandrel section.

Thus, the valve head 82 and the seal ring 103 serve to close off the flow course 70 by seals of substantially different character, both of which are effective in the closed position of the tool. While the valve head 82 (primary valve) provides the initial seal against fluid pressure applied upwardly through the tool (as occurs, for example, when well tool 10 is being lowered through the well fluid 13), the seal ring 103 (secondary valve) provides the initial seal against pressure acting downwardly through the tool arising, for example, from the column of recovered fluids retained in the mandrel and pipe string above the seal ring 103 as the well tool is withdrawn.

To complete the flow course 70 through the well tool when the valve head 82 and the seal ring 103 are displaced to their open position, the mandrel section 31 is provided with a plurality of ports 110 opening laterally from the bore of the mandrel section to its exterior. Such ports 110 may be directed outwardly and downwardly at an inclination with respect to the axis of the tool, the angle of 45° being exemplary, in order to minimize the eroding effect of fluids flowing often at high velocities through the tool into the well string. Since the ports 110 are in the section 31 of the mandrel which, in operation remains substantially free of stress and since the ports are not required to pass through any packing, they may be as large in diameter as desired, for example, on the order of one-half the diameter of the mandrel bore and four of them may be employed at right angles to one another.

As may best be seen in FIG. 3, downward stroking of the mandrel relative to the housing brings the seal ring 103 past the valve seat 84 into the counter bore 89 of the valve head 82. Thus, the counter bore 89 is sized with a diameter at least as great as the diameter of the liner bore 100 so as to accommodate the sealing element 106 in the radial direction. The depth of the counter bore 89 to its upwardly directed annular shoulder 112 corresponds with the longitudinal dimension of the seal ring 103 measured between its downwardly directed annular shoulder 113 (which extends outwardly beyond the profile of the mandrel section 32) and a point above the sealing element 106. To minimize erosive wear, the upper exterior edge of the seal ring 103 may have a chamfer 115 so as to be sloped in the direction of the test ports 110 and of the valve surfaces 83, 84 defining the direction of flow.

In the manner disclosed in the aforementioned Moosman Patent No. 2,737,246 issued March 6, 1956, for "Hydraulic Valve Device," the well tool of the present invention may incorporate equalizing ports 117 in the lower section 32 of the mandrel which, in one position of the mandrel relative to the housing, are in register with lateral ports 118 extending through the wall of the reduced bore portion 92 for the housing section 24. To facilitate such registry, the portion 92 of the housing section 24 may have an annular recess 119 relieved from its bore at the inner end of the port 118 and extending above and below it a distance short of the annular packing provided by an upper O-ring 120 and lower spaced O-rings 121—123, these O-rings being received in corresponding grooves relieved from the reduced bore of the housing section 24. The O-rings 120—123 are thus arranged to effect an annular seal between the mandrel section 32 and the housing section 24 above and below the recess 119 and to seal off the port 118 when the equalizing port 117 of the mandrel is stroked below the O-ring 121.

In an exemplary operation of the well tool 10 as shown in FIGS. 1–4, the assembled tool is made up in dependent relation to the string of pipe 14 by threadedly connecting the top sub 34 of the tool to a stand of the pipe. The lower housing section 25 is threadedly connected with the packer 16, and the anchor pipe is connected below the packer. When properly made up, each thread joint is fluid tight whereby a continuous flow course is provided upwardly from the perforations of the anchor pipe 17 interiorly through the packer 16, through the flow channel 70 of the well tool 10 and thence upwardly through the pipe string 14 as indicated at 71 (FIG. 1).

While the string is being lowered into a well, this flow course is closed off by the closure of the valve head 82 upon the valve seat 83 and the further seal effected by the seal ring 103 with respect to the liner bore 100. However, well fluid may flow upwardly through the anchor pipe perforations and the interior of the packer 16 and outwardly through the equalizing ports 117

and side ports **118** to accommodate a rapid descent of the pipe string despite a relatively close fit between the periphery of the packer **16** and the borehole wall. During the descent of the tool into the well, the registry of ports **117** and **118** is maintained by the engagement between the mandrel section **28** and the housing section **21** which limits further extension of the mandrel upwardly with respect to the housing. The tendency of the mandrel to move in the direction of such extension relative to the housing is promoted not only by the force of gravity acting downwardly on the housing and the packer and anchor suspended therebeneath but also, if desired, by the hydrostatic unbalance arising from the difference in the sealed outside diameters of the mandrel sections **30** and **32**. Thus, by making the mandrel section **32** of a larger diameter at the O-ring **87** than is the mandrel section **30** at the O-rings **57**, a net annular area of the housing is effectively exposed to hydrostatic pressure acting downwardly to maintain the housing downwardly displaced to its limit position with respect to the mandrel.

When the anchor pipe **17** engages the bottom of the well, a portion of the weight of the string of pipe may be set upon packer **16** tending to expand the same into sealed engagement with the surrounding formation **18**. As the packer is set, formation **19** opposite the anchor pipe **17** is placed in isolated communication through the perforations of the anchor pipe with the flow course extending upwardly through the string. Simultaneously with setting of the packer **16**, the weight of pipe applied to the mandrel **26** via top sub **34** causes the mandrel to stroke downwardly with respect to the housing toward its retracted position. The rate of stroking is, however, retarded by the hydraulic delaying mechanism within the housing section **22**. In dependence upon the desired adjustment of such delaying mechanism, a period of, say, one to several minutes may elapse as the mandrel moves from its closed position illustrated in FIG. 2 to its open position illustrated in FIG. 3.

Such delay allows the well tool **10** to be "spudded" or forced by intermittent application of weight through bridges or constrictions encountered as it is lowered into the borehole without risk of premature opening of the valve head **82**. It may be observed that the floating support of the valve head whereby it is free for relative longitudinal movement with respect to both the housing and the mandrel allows the valve head to remain in its closed position despite sudden movements or shocks of the mandrel **26** in the downward direction. For example, when a bridge or constriction in the borehole is suddenly encountered or when the pipe string being lowered into the borehole is suddenly braked, the consequent "jugging" or shock displacement of the mandrel relative to the housing does not result in opening of the valve head **82**. The mass of the valve head **82** is sufficiently slight with respect to the forces tending to hold it in its closed position that inertial forces imposed upon the valve head **82** will not open it.

With downward stroking of the mandrel relative to the housing, equalizing ports **117** will first be closed by displacement below the O-ring **121**. Then, after the elapse of the desired period prior to opening of the tool to a recovery of test fluid, shoulder **113** of seal ring **103** engages shoulder **112** of valve head **82** with the sealing element **106** protectively received in the counter bore **89**. When the mandrel has been stroked downwardly to this point, then, only the seal effected between the valve head **82** and seat **83** is effective to exclude well fluid from flowing upwardly into the test ports **110** and the well string thereabove.

While the coil spring **94** tends to resist opening of the valve head **82** by further downward stroking of the seal ring **103** with the mandrel, its force may be of a moderate amount compared with the hydrostatic force arising from pressure unbalance across the valve head, as previously described. In such instance, a very considerable force measured in the thousands of pounds arises as the seal ring shoulder **113** strikes the valve head shoulder **112** to resist further downward movement of the mandrel. Even with a so-called water cushion comprising a column of water deliberately introduced in the pipe string **14** and standing above the valve head **82**, there will remain a substantial hydrostatic pressure difference across the valve head **82** sufficient to impose a strong resisting force at the moment of opening the valve head. This suddenly arising force, in any event, creates a shock wave which travels upwardly the length of the pipe string so as to be detectible by an operator at the surface to provide an indication of opening of the well tool for flow of fluid into the pipe string. In addition to this significant feature, the hydrostatic unbalance across the valve head **82** also promotes a fluid tight seal across the valve seat **84**. Furthermore, a generous annular area for flow exists when valve head **82** is just off seat **84** whereby erosion at the instant of opening or closing is minimized. It is noteworthy that these advantages are secured while the hydraulic delaying mechanism is still effective to ensure against premature opening.

When the mandrel **26** has completed its downward stroke relative to the housing **20**, as determined by endwise engagement between the top sub **34** and the housing section **21** via bearing **46**, the valve head will be in the position shown in FIG. 3 with the test ports **110** fully exposed to accommodate flow of fluids through the longitudinal passage **70** defined by the mandrel and housing.

After a sufficient time has elapsed with the valve head **82** in its open position as illustrated in FIG. 3 to obtain the desired test of the isolated formation, the valve head **82** may be returned to its closed position by an upstroking of the mandrel **26** relative to the housing either to the position shown in FIG. 4 or to the position shown in FIG. 2 depending upon whether or not a so-called "shut-in" pressure test is desired. If such a test is not desired, the valve head **82** may be closed as shown in FIG. 2 simply by picking up weight on the pipe string **14** to stroke the mandrel upwardly with respect to the housing. The construction of the hydraulic delaying mechanism permits such upstroke to be of unrestricted speed so that the well tool may quickly be closed whenever desired. When a shut-in pressure test is desired, on the other hand, the pipe string **14** is rotated, usually to the right, to draw the mandrel **26** upwardly relatively to housing **20** by the operation of thread connection **35** between the top sub **34** and the upper mandrel section **27**. As the pipe string is rotated, first the valve head **82** seals with respect to the valve seat **84** and then seal ring **103** moves upwardly out of the counter bore **89** and into the bore **100** of the liner **74** to seal therewith stopping at the intermediate position illustrated in FIG. 4.

As seen in FIG. 4, rotation of the pipe string **14** strokes the mandrel upwardly a distance less than that required to bring the equalizing ports **117** into registry with the side ports **118**. Hence, upward flow of fluid into the well tool and through either the test ports **110** or the equalizing ports **117** is completely shut off and, consequently, the pressure of such fluid will gradually increase from the flowing pressure toward a static pressure corresponding with the pressure of connate fluid in the isolated formation. Such pressure buildup may be recorded by the pressure recorder (not shown) contained within the anchor pipe **17**. After completion of the shut-in pressure test, the pipe string **14** may be picked up to move the mandrel to its fully extended position corresponding to that shown in FIG. 2.

When the well tool **10** is retrieved at the surface, the valve head **82**, seal ring **103**, liner **74** and test ports **110** may conveniently be inspected and interior parts of the tool washed by breaking the threaded connections between housing sections **23**, **24** and **25** and between the

mandrel sections 30, 31 and 32. Such disassembly of the tool leaves the O-ring retainer 53 in place and the hydraulic delaying mechanism undisturbed. The liner 74 may be unthreaded from the housing section 23, if desired, and if the valve seat 84 or the bore 100 of the liner have suffered any damage by erosion or the like, such liner may conveniently be replaced at a minimum expense.

While the well tool 10 has been described in conjunction with the test of a formation 19 at the bottom of an uncased borehole, it will be evident that the well tool may be used for other types of testing such as the testing of selected formations at an intermediate depth in the hole, formation testing and water shut-off tests in cased holes, the placing of wells on production for extended periods of time, and acidizing of formations in open hole. Further, the well tool 10 illustrated in FIGS. 1–4 is subject to various modifications including, for example, the modifications shown in FIGS. 5A and 5B.

Referring now to FIGS. 5A and 5B, there is shown a modified well tool 10*a* comprising a multi-section tubular housing 20*a* including sections 21*a*, 22, 23*a*, 24 and 25 and telescopically received therein, a tubular mandrel 26*a* including sections 27*a*, 28, 29, 30, 31 and 32. These housing and mandrel sections correspond generally with the housing and mandrel sections of similar numerical designations shown in FIGS. 1–4 and are similarly assembled with endwise fluid-tight threaded connections. The upper end of the upper mandrel section 27*a* has a fluid-tight threaded connection with a top sub 34*a* which, in turn, provides a thread box for making a threaded connection with pipe string 14 or the like, while the lower end of bottom housing section 25 is adapted for threaded connection with packer 16.

The mandrel section 27*a* has an enlarged lower end portion 125 received in the bore of housing section 21*a* for supporting engagement with reduced upper end portion 126 of the housing section 21*a* in the extended position of the mandrel with respect to the housing, while upper face of portion 126 supports the top sub 34*a* in the retracted position of the mandrel. To prevent co-rotation between the mandrel and housing, a longitudinal spline connection 129 may be provided between housing section 21*a* and mandrel section 27*a*.

Within the housing section 22 is an hydraulic delaying mechanism which serves the purpose of retarding downward stroking of the mandrel relative to the housing while permitting a rapid upstroke. To provide such mechanism, there is defined between the housing section 22 and the mandrel the annular oil chamber 52 sealed at its upper and lower ends by O-ring retainers 130 and 53, respectively. The retainer 130 has interior grooves receiving O-rings 131 to provide a sliding seal with respect to mandrel section 28. By making the outer diameter of mandrel sections 28 and 30 the same, the volume of oil chamber 52 remains constant with stroking of the mandrel. Threaded plugs 133 provide closures for access ports at the upper and lower ends of chamber 52 through which a suitable incompressible fluid, such as a high temperature, high pressure oil, may be introduced.

To retard the movement of the mandrel downwardly through the oil chamber 52, mandrel section 29 slidably carries a sleeve valve 135 having an upper annular flat end surface 136 for sealing with a flat annular valve seat 137 as a downwardly directed shoulder on the mandrel section 29. A coil spring 139 may encircle the mandrel section 29 and be supported by a washer 140 retained at the junction of sections 29 and 30 to act upwardly upon the sleeve valve 135, maintaining it sealed with the valve seat 137 despite the downward force of gravity. Defined between the mandrel section 29 and the surrounding sleeve valve 135 is a longitudinal passage 142 extending interiorly through the sleeve valve. During the downstroke, this interior passage 142 is closed by the sealed engagement between the sleeve valve 135 and the seat 137 so that the transfer of fluid in the chamber 52 from the lower side to the upper side of the sleeve valve is accommodated only by a restricted annular passage 143 defined between the exterior surface of sleeve valve 135 and the bore of housing section 22. This passage 143 may, for example, have a radial dimension on the order of a few thousandths of an inch. During upstroke of the mandrel, of course, the sleeve valve 135 leaves the valve seat 137 to permit flow through the interior passage 142.

Referring particularly to FIG. 5B now, the intermediate housing section 23*a* is seen to have an interior threaded connection at its lower end with a valve collar 145. In similarity to the liner 74 of FIG. 2, the collar 145 has an enlarged portion 76 seated on the lower end of housing section 23*a* and extending downwardly to provide the valve seat 84 for sealing with valve head 82. A liner 147 separate from the valve collar 145 is secured within the bore of housing section 23*a* by reception of an enlarged upper end portion 148 of the liner in an upwardly opening counter bore 149 provided at the upper end of housing section 23*a*. As may be seen, the O-ring retainer 53 prevents upward displacement of liner 147 while O-rings 81 and 150 received in external annular recesses at the upper and lower ends of liner 147 seal the exterior of the liner with respect to the bore of housing section 23*a*.

As a further modification with respect to the embodiment shown in FIGS. 1–4, the seal ring 103 is seen in FIG. 5B to carry O-rings 152 in spaced annular grooves formed in the exterior of the seal ring, in lieu of the sealing element 106. While O-rings carried externally of a mandrel below the test ports are usually subject to a washing out of their grooves by inrushing fluid, it will be appreciated that the O-rings 152 are safely lodged within counter bore 89 of valve head 82 prior to opening of the valve head whereby the O-rings 152 may be retained for successive operations.

In other respects the modified well tool 10*a* of FIGS. 5A and 5B may be similar to the well tool 10 described in conjunction with FIGS. 1–4 and its operation will be understood from that described in conjunction with the well tool 10 except that provision is not made for obtaining a shut-in pressure test by operation of the well tool 10*a* itself.

In a further embodiment illustrated in FIGS. 6, 7 and 8, the sliding seal afforded by the seal ring 103 is replaced by a poppet-type annular valve and, similarly, a poppet-type annular valve may be substituted for the sliding seal valve which controls the equalizing ports.

More particularly, there is shown in FIG. 6 the valve portion of a modified well tool 10*b*, which may be substituted either for the valve portion of well tool 10 shown in FIG. 2 or for the valve portion of well tool 10*a* shown in FIG. 5B. The housing 20*b* of the modified valve portion is again made up of threadedly connected sections, namely, sections 22, 23*b*, 24*b* and 25. Likewise, the modified mandrel 26*b* is made up of threadedly connected sections 30, 31, 32*b* and a new lower section 33. As before, the mandrel is slidably but nonrotatively received in the housing for limited longitudinal movement between extended and retracted positions and, if desired, an intermediate, "shut-in" pressure position.

The principal valve controlling the longitudinal flow passage 70 is of the poppet-type similar to valve 76—82 of FIG. 5B and comprises a modified valve head 82*b* slidably received on the mandrel section 32*b*. The modification of valve head 82*b* resides in elimination of the counter bore 89, rendered unnecessary by elimination of the O-rings 152 from the modified valve ring or head 103*b*.

A secondary valve controlling longitudinal flow through the fluid passage 70 is provided by the valve head 103*b* in cooperation with liner section 155 and particularly its downwardly and outwardly tapered surface providing a valve seat 156. In the closed position shown in FIG. 6

valve seat **156** engages valve surface **115** of the annular head **103***b* with a complementary taper. Liner section **155** may be retained at its upper end and sealed with respect to the housing in the same manner as liner section **147** of FIG. 5*b* but is of shorter length, supported in spaced relationship within an enlarged upper bore portion **158** of housing section **23***b*. The bore of liner section **155** is sized to receive the mandrel sections **30** and **31** in closely fitted, sliding relation, the valve seat **156** carried by the liner section being spaced only a short distance below the downwardly facing shoulder **104** of mandrel section **31** in the extended position of the mandrel.

In order that the valve head **103***b* may remain in its closed upper position until the mandrel has been stroked a predetermined short distance downwardly, the upper face of the valve head is spaced this short distance below the shoulder **104** of mandrel section **31**, thereby to remain on the valve seat **156** until travel of the mandrel section **31** through the valve head brings the shoulder **104** into engagement with the upper face of the valve ring. Conveniently, a bias spring **159** may encircle the reduced diameter portion of the mandrel section **31** so as to act in compression between the upper face **105** of mandrel section **32***b* and the lower face **113** of valve ring **103***b*. The spring is thus effective to hold the valve ring **103***b* on the valve seat **156** until downward stroking of the mandrel overcomes the spring bias and any hydrostatic pressure acting upwardly upon the valve ring. With further downward stroking of the mandrel, the valve ring **103***b* travels with spaced clearance through the reduced bore portion **160** of the housing section **23***b* and similarly through the bore of collar **146** into engagement with the upper face **161** of the valve head **82***b*. The surfaces **113** and **161** are then in engagement, as seen in FIG. 8, whereby the test ports **110** may be opened to longitudinal flow through passage **70**.

While the arrangement of equalizing ports shown in FIG. 2 may be employed in the modified well tool **10***b*, the poppet-type equalizing valve shown in FIG. 6 may instead be used with this type of valve. Equalizing ports **162** are preferably inclined upwardly and outwardly at an angle of say 45 degrees through the wall of housing section **24***b*, offset from longitudinal bypass passages **90**. To provide for closure of the equalizing ports **162**, the housing section **24***b* receives in its lower end a liner section **163** threadedly connected at **164** and sealed by O-ring **165**. The liner section **163** extends in downwardly and inwardly spaced relation from the enlarged bore of housing section **25** to leave an annular passage in communication with bypass passages **90** and at its upper end the liner section **163** provides a valve seat **163***a*. An external flange **166** of the liner section **163** engages the lower end of housing section **24***b* to position the valve seat **163***a* immediately below the inner end of equalizing ports **162**, the upper end of liner section **163** having a counter bore **167** below valve seat **163***a* to accommodate unrestricted flow of fluid through the ports **162**.

A valve head **168** is slidably carried by the mandrel section **32***b* at its lower end for cooperation with the valve seat **163***a* to provide a poppet-type valve for controlling the equalizing ports. Thus, the valve head **168** is provided with a valve surface **169** on its enlarged lower end, having an upward and outward taper conforming with the complementary taper of the valve seat **163***a* and preferably corresponding with the inclination of the ports **162**. To bias the valve head **168** toward its closed position in a manner similar to the biasing of valve head **82***b*, the same coil spring **94** may be employed. As seen in FIG. 7, for example, the coil spring **94** acts in compression between the lower face **96** of valve head **82***b* and upper face **170** of valve head **168** when both the valve heads are in their closed position, and the spring contracts when either valve head is in its open position. To overcome the bias of spring **94** in the open position of valve head **168** and to provide for opening of the valve head from its closed position upon upward stroking of the mandrel, lowermost mandrel section **33** has an external flange **172** which extends outwardly beyond the profile of mandrel section **32***b* to engage lower face **173** of valve head **168** after a predetermined upward travel from the lowermost position of the mandrel (FIG. 8 to FIG. 7). To prevent leakage around the valve head **168** when it is in its closed position, and also in its open position, O-ring **175** carried in an external groove of the valve head seals with the reduced bore of housing section **24***b* and O-ring **176** carried in an internal groove of the valve head seals with the outer periphery of mandrel section **32***b*.

In a typical operation of the modified well tool **10***b* of FIGS. 6, 7 and 8, the tool is lowered into a well with both the main valve **82***b*—**84** and the secondary valve **103***b*—**156** closed to the longitudinal flow of fluid through passage **70**, as seen in FIG. 6. With setting of the packer by weight exerted through the test string, the mandrel **26***b* is stroked downwardly at a rate controlled by the hydraulic delaying mechanism. After, say, a quarter inch of downward travel, the valve head **103***b* of the secondary valve is moved off valve seat **156**. Thereafter, the valve head **103***b* moves downwardly with a mandrel.

Upon a further downward travel of, say, three-quarters of an inch, the valve head **168** for the equalizing valve is carried by the bias of spring **94** into closing engagement with the valve seat **163***a*. Thereupon, further flow of well fluid through the equalizing ports **162** is cut off and the valve head **168** remains stationary with respect to the housing. Yet a further downward stroking of the mandrel for a distance, say, of 5½ inches brings the lower shoulder **113** of secondary valve head **103***b* into engagement with the upper face **161** of main valve head **82***b* to lift the main valve head **82***b* off valve seat **84**. As in the previously described embodiments, this opening of the main valve during the hydraulically retarded downward stroking of the mandrel creates a shock force with overcoming of the hydrostatic pressure of the valve head such that an operator at the surface may derive a tangible or audible indication of the opening of the testing tool for flow of formation fluid into the test string thereabove.

If desired, the mandrel may be returned from the open position illustrated in FIG. 8 to an intermediate position shown in FIG. 7 by an actuating mechanism such as that shown in FIG. 1. In this case, the main valve head **82***b* engages valve seat **84** again to close off the longitudinal flow passage **70**, while the equalizing valve remains closed so that pressure may be built up below the testing tool. With further upward stroking of the mandrel, the equalizing valve head **168** first moves to its open position and then the secondary valve head **103***b* moves to its closed position, thus assuring retention of the recovered sample of formation fluids in the test string above the testing tool. Since the secondary valve closes after the primary valve has already closed, its sealing its reliably accomplished without risk of fluid cutting or erosion.

It will be evident that the foregoing embodiments of the invention are subject to various changes and modification including, for example, use of the last described equalizing valve in lieu of equalizing valves shown in FIG. 2 or FIG. 5*b*. Also, the hydraulic delaying mechanism may be positioned at the lower end of the tool and other equalizing valve arrangements may be devised in lieu of those herein described. If desired the mandrel section **32** may be blanked off, in lieu of the emergency circulating valve **98**, particularly in the embodiment of FIG. 6 where primary and secondary valves **82***b* and **103***b* will accommodate flow of fluid downwardly under pump pressure applied at the surface.

The valve ring **103***b* of FIG. 6 may, if desired, have a sealing element like ring **103** arranged to provide a similar sliding seal which is protectively received in a

counter bore (not shown) of valve head 82*b*. In addition to, or in lieu of the hydraulic delaying mechanism, the testing tool may be maintained in its closed position by a heavy bias spring acting with respect to the mandrel and housing.

Accordingly, the invention is not to be limited to the embodiments illustrated and described but is of a scope defined in the appended claims.

We claim:

1. A well tool comprising a tubular housing having an annular valve seat along its bore, an annular valve head in said bore movable between a closed and an open position with respect to said valve seat, means normally biasing said valve head toward its closed position, a tubular mandrel extending into said bore and slidably through said valve head for limited longitudinal movement with respect to said housing, said mandrel having a lateral flow port spaced therealong for movement past said valve seat which port is opened by movement of said valve head to its open position to place the interior of said mandrel on one side of said valve head in communication with the exterior of said mandrel on the other side of said valve head, and a member carried by said mandrel and projecting outwardly therefrom for engaging said valve head to move it with said mandrel, said member being spaced from said valve head prior to engagement and arranged for moving said valve head with said mandrel to its open position as said flow port is moved past said valve seat.

2. A well tool comprising a tubular housing having an annular valve seat along its bore, an annular valve head in said bore movable between a closed and an open position with respect to said valve seat, means normally biasing said valve head toward its closed position, a tubular mandrel extending into said bore and slidably through said valve head, means for limiting longitudinal movement of said mandrel with respect to said housing, means providing a sliding seal between said mandrel and said valve head in at least the closed position of said valve head, said mandrel and said housing together defining a flow channel exterior to said valve head and lengthwise through said tool which is opened and closed by said valve head and valve seat, annular means arranged between said mandrel and said housing to provide a seal therebetween and along said flow channel only when it is closed by said valve head and valve seat, and means carried by said mandrel for moving said valve head after a predetermined displacement of said mandrel relative to said valve head to control flow through said channel.

3. A well tool comprising a tubular housing having an annular valve seat along its bore, an annular valve head in said bore movable between a closed and an open position with respect to said valve seat, said valve head and said valve seat having confronting surfaces which are in abutting engagement in the closed position of said valve head, means normally biasing said valve head toward its closed position, a tubular mandrel extending into said bore slidably through said valve head and having a lateral flow port communicating through said mandrel with only one end thereof, means for limiting longitudinal movement of said mandrel with respect to said housing, said mandrel and said housing together defining a flow channel through said tool which extends through said port and is opened and closed by said valve head and valve seat in their opened and closed position respectively, and means carried by said mandrel for moving said valve head to its open position when said mandrel is displaced to position said port opposite the opening between said valve head and valve seat, thereby permitting flow through said channel.

4. A well tool comprising a tubular housing having an annular valve seat along its bore, an annular valve head in said bore movable between a closed and an open position with respect to said valve seat, a tubular mandrel extending into said bore slidably through said valve head and having a lateral flow port spaced longitudinally of said valve head, means for limiting longitudinal movement of said mandrel with respect to said housing, said mandrel and said housing together defining a flow channel through said tool which extends through said port and is opened and closed by said valve head and valve seat, means acting between said valve head and said housing for biasing said valve head toward its closed position, and means carried by said mandrel for moving said valve head to its open position when said port is displaced opposite the opening between said valve head and valve seat to permit flow through said channel.

5. A well tool comprising a tubular housing having a reduced bore section and an enlarged bore section and an annular valve seat therebetween, an annular valve head in said enlarged bore section movable between a closed and an open position with respect to said valve seat, means normally biasing said valve head toward its closed position, a tubular mandrel extending slidably into said bore sections through said valve head, means retaining said mandrel in said bore sections for limited longitudinal movement with respect to said housing, said mandrel having a lateral flow port, means providing a sliding seal between said mandrel and said reduced bore section cooperating with said valve head to close said port only when said valve head is in its closed position with respect to said valve seat, and means carried by said mandrel for moving said valve head to its open position after a predetermined displacement of said port from said reduced bore section to a position adjacent said valve seat.

6. A well tool comprising a tubular housing having an annular valve seat along its bore, an annular valve head in said bore movable between a closed and an open position with respect to said valve seat, means normally biasing said valve head toward its closed position, a mandrel extending into said bore and through said valve head for limited longitudinal movement with respect to said housing, means adapted to provide a fluid tight connection between said mandrel and a string of pipe, said mandrel and said housing together defining a flow channel through said tool for communication with the interior of said pipe, which channel is opened and closed by movement of said valve head, means providing a sliding annular seal along said channel between said mandrel and said housing bore only for a predetermined displacement of said mandrel while said valve head is in its closed position, and means carried by said mandrel for moving said valve head to its open position after said predetermined displacement of said mandrel relative to said housing and said valve head to open said channel of fluid flow.

7. A well tool comprising a tubular housing having an annular valve seat along its bore, an annular valve head in said bore movable between a closed and an open position with respect to said valve seat, means normally biasing said valve head toward its closed position, a mandrel extending slidably into said bore and through said valve head for limited longitudinal movement with respect to said housing, said mandrel and said housing together defining a flow channel through said tool which is opened and closed by movement of said valve head, means providing a sliding annular seal between said mandrel and said housing bore only in the closed position of said valve head to seal off said channel, and means carried by said mandrel for moving said valve head to its open position after a predetermined displacement of said mandrel relative to said valve head to open said channel to fluid flow therethrough, said valve head being arranged to protect said seal means from erosion by said fluid flow in its open position.

8. A well tool comprising a tubular housing including an exterior section defining an enlarged bore and a liner section removably secured within said exterior section adjacent said enlarged bore, said liner section having a uniform bore of reduced diameter terminating in a shoulder shaped to define a valve seat confronting said enlarged

bore, a tubular mandrel received in said housing for limited movement between an extended and a retracted position, a seal ring carried by said mandrel providing an annular seal with said liner bore in the extended position of said mandrel, an annular valve head slidably carried on said mandrel in sealed relation thereto for movement within said enlarged bore between a closed and an open position with respect to said valve seat and normally biased toward its closed position, said valve head being engageable by said seal ring as said mandrel is moved toward its retracted position for displacement to said open position, said seal ring being displaced from said reduced bore into said enlarged bore as said mandrel is moved toward its retracted position, and means normally biasing said valve head toward its closed position.

9. A well tool comprising a tubular housing having a first bore section and a second bore section of larger diameter subjacent thereto and in communication with the lower end of said well tool, and a downwardly-facing annular valve seat at the junction of said sections, an annular valve head received in said enlarged bore section for movement between an open and a closed position with respect to said valve seat and having a conical valve surface confronting said valve seat for sealing engagement therewith in the closed position of said valve head, a tubular mandrel extending through said first bore section and into said second bore section and arranged at its upper end for fluid tight connection with a string of pipe to continue the flow course therethrough, said valve head being slidably fitted about said mandrel in sealed relation thereto and inwardly spaced from said second bore section to permit longitudinal fluid flow therepast, means for biasing said valve head toward its closed position, said mandrel having an enlarged portion and an annular seal means carried thereby for providing a sliding seal with said first bore section only in the closed position of said valve head, said enlarged mandrel portion being engageable with said valve head upon downward movement of said mandrel to displace said valve head to its open position, said valve head having a counter bore opening upwardly to receive said enlarged portion and said seal means while in its closed position and extending upwardly about said seal means in its open position, said mandrel having a port opening above said seal means and in communication with the upper end of said mandrel which port is open through said second bore section to the lower end of said well tool when said mandrel is moved downwardly to displace said valve head from its closed position, means providing an annular seal between said mandrel and said housing above said port, means for blocking fluid flow upwardly through said mandrel to said port and means for retarding downward movement of said mandrel relative to said housing prior to opening of said valve head, said valve head having its lower face exposed for application of hydrostatic well pressure whereby overcoming said hydrostatic pressure upon opening said valve head transmits a shock upwardly through said well tool.

10. A well tool comprising a tubular housing having at least two annular valve seats spaced along its bore, for each of said valve seats an annular valve head in said bore movable between a closed and an open position with respect to such valve seat, a mandrel extending into said bore and through said valve heads, means resiliently biasing said valve heads toward their closed position, means for limiting longitudinal movement of said mandrel with respect to said housing between an extended and a retracted position, said mandrel and said housing together defining a flow channel lengthwise through said tool which is closed when one of said valve heads is in its closed position, and means carried by said mandrel for moving one of said valve heads to its open position after a predetermined displacement of said mandrel relative to said housing and for moving another of said valve heads to its open position after a further such displacement of said mandrel to permit flow through said channel.

11. A well tool comprising a tubular housing having at least two annular valve seats of different diameter along its bore, for each of said valve seats an annular valve head in said bore movable between a closed and an open position with respect to such valve seat, a mandrel extending into said bore and through said valve heads for limited longitudinal movement with respect to said housing, means resiliently biasing said valve heads toward their closed position, said mandrel and said housing together defining a flow channel lengthwise through said tool which is closed when one of said valve heads is in its closed position, and means carried by said mandrel for moving one of said valve heads to its open position after a predetermined displacement of said mandrel relative to said housing and for moving another of said valve heads to its open position after a further such displacement of said mandrel to permit flow through said channel.

12. A well tool comprising a tubular housing having two annular valve seats of different diameter along its bore, for each of said valve seats an annular valve head in said bore movable between a closed and an open position with respect to such valve seat, a mandrel extending into said bore and through said valve heads for limited longitudinal movement with respect to said housing, means resiliently biasing said valve heads toward their closed position, means providing a sliding seal between said mandrel and said valve heads, said mandrel and said housing together defining a flow channel lengthwise through said tool which is closed by said valve heads when said mandrel is in its extended position, the valve head corresponding to said smaller diameter valve seat being sized to pass through the larger diameter valve seat, and means carried by said mandrel for moving the smaller diameter valve head to its open position after a predetermined displacement of said mandrel relative to said housing and for moving said smaller diameter valve head through the larger diameter valve seat and thereupon moving the larger diameter valve head to its open position by a further displacement of said mandrel to permit flow through said channel.

13. A well tool comprising a tubular housing having two annular valve seats of different diameter along its bore, a large diameter annular valve head for the large diameter valve seat and a small diameter annular valve head for the small diameter valve seat, a tubular mandrel extending into said bore and through said valve heads and interengaged with said housing for limited longitudinal movement between an extended and a retracted position, said valve heads being slidable along said mandrel in sealed relation thereto and movable between a closed and an open position with respect to the corresponding valve seat, said mandrel and said housing together defining a flow channel lengthwise through said tool which is closed by said valve heads when said mandrel is in its extended position, means resiliently biasing said valve heads toward their closed position, and means carried by said mandrel for moving said smaller diameter valve head to its open position after a predetermined displacement of said mandrel relative to said housing toward its retracted position, said smaller diameter valve head being sized to pass through the larger diameter valve seat for engaging with and moving said larger diameter valve head to its open position upon a further such displacement of said mandrel to permit flow through said channel.

14. A well tool comprising a tubular housing having smaller and larger diameter valve seats spaced along its bore, for each of said valve seats an annular valve head of corresponding diameter in said bore movable between a closed and an open position with respect to said valve seat, a tubular mandrel extending into said bore slidably through said valve heads and having a lateral flow port spaced outwardly of said valve heads, means for limiting longitudinal movement of said mandrel with respect to said housing between an extended and a retracted position, said mandrel and said housing together defining a

flow channel through said tool which extends outwardly past said valve heads through said port and outwardly through said mandrel, said flow channel being closed by said valve heads when said mandrel is in its extended position, means for biasing each of said valve heads toward its closed position, said mandrel having a smaller diameter portion terminating in an outer shoulder and spaced inwardly of said port slidable in sealed relation through said smaller diameter valve head for a predetermined displacement of said mandrel from its extended position, said smaller diameter valve head being engageable by said shoulder for movement with said mandrel after said predetermined displacement for passing through the larger diameter valve seat upon a further displacement to engage said large diameter valve head and move the same to its open position as said mandrel moves to its retracted position, and means for retarding movement of said mandrel from its extended to its retracted position.

15. A well tool comprising a tubular housing having at least two annular valve seats along its bore, for each of said valve seats an annular valve head in said bore movable between a closed and an open position with respect to said valve seat, a tubular mandrel extending into said bore slidably through said valve heads and having a lateral flow port spaced longitudinally of one of said valve heads, means for limiting longitudinal movement of said mandrel with respect to said housing, said mandrel and said housing together defining a flow channel through said tool which extends through said port and is opened and closed by said one valve head and the corresponding valve seat, said housing having a lateral port intermediate said two valve seats for fluid communication with one end of said well tool controlled by another of said valve heads and the corresponding valve seat, means acting between said one and another valve heads for biasing the same toward their closed positions, and means carried by said mandrel for moving said another valve head to its closed position upon a predetermined displacement of said mandrel relative to said housing and for moving said one valve head to its open position upon the further such displacement of said mandrel whereby said housing port is first closed and then said mandrel port is opened to fluid flow as said mandrel is displaced in one direction.

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