

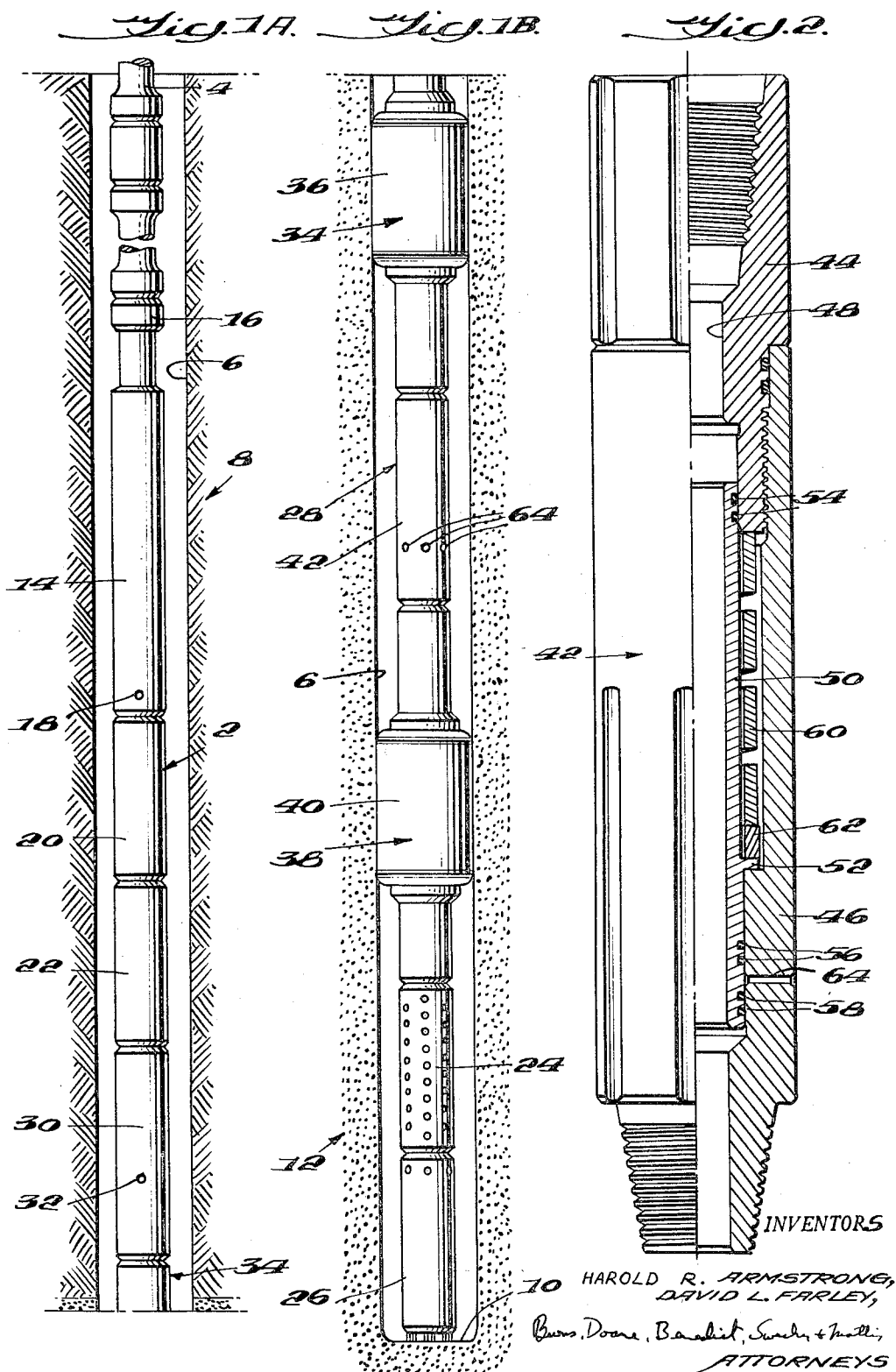
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MULTIPLE PACKER DISTRIBUTION VALVE AND METHOD

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MULTIPLE PACKER DISTRIBUTION VALVE AND METHOD

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ABSTRACT OF THE DISCLOSURE

In drill stem testing of wells, the formation to be tested is sealed from the hydrostatic pressure of fluid in the well. This seal is provided by a pair of expandable packers positioned above the formation. The packers are spaced apart in the tubing string and a port in the sub connecting the packers establishes fluid communication between the interior and exterior of the sub. A valve opens and closes the port in response to fluid pressure acting on the valve element. The valve opens while the string is being run to the depth of the formation in response to the hydrostatic pressure of the well fluid. After the packers have been expanded, the fluid pressure in the annulus below the upper packer drops as fluid bleeds through the port into the interior of the sub. The valve closes when the pressure reaches a certain minimum value. The hydrostatic pressure at the depth of the formation is determined and the valve is adjusted to close at a predetermined lower pressure to establish a pressure differential across the upper packer and pressure differential across the lower packer, so that the hydrostatic load is distributed between the packers.

CROSS REFERENCE TO RELATED APPLICATION

This invention is in some respects an improvement over the invention disclosed and claimed in Olson et al. application, entitled "Pressure Regulating Valve Assembly Between Open Hole Packers and Method," Ser. No. 639,384, filed May 18, 1967, now Patent No. 3,459,264.

BACKGROUND OF THE INVENTION

This invention relates to well apparatus and more particularly to method and apparatus for preventing the leakage of fluid around well packers in open hole drill stem testing.

In drill stem testing, it is common practice to assemble a tester tool and a packer on the lower end of a drill string and to lower the string into the well bore. At the appropriate depth, the packer is expanded to engage the wall of the well bore thereby sealing off the formation below the packer. A valve in the tool then may be operated to obtain a test of pressure and fluid conditions in the isolated formation.

If the formation being tested is at a considerable depth, the pressure differential across the packer due to hydrostatic pressure of the fluid in the bore hole may be sufficiently great to cause leakage around the packer.

The reliability of productivity evaluations based on drill stem testing depends among other factors, on the accuracy of pressure and flow measurements of the isolated formation. If error is introduced through the leakage of pressure fluid around the packer, the values of pressure and flow rate may cause inaccurate production rates and other characteristics of the formation to be estimated.

Attempts have been made to utilize several packers in a string for sealing a formation from drilling mud in the annulus above the formation. For example, Roberts Patent No. 2,959,225, issued Nov. 8, 1960, discloses an air or gas drilling system in which two packers in a tubing string are expanded into sealing relation with the bore

hole. Drilling mud fills the annulus above the packers, while air or gas is pumped down the drilling string to cool the bit and to carry away the cuttings. Roberts further discloses a pressure-proportioning device for equalizing the hydrostatic load across the packers, but the device operates in response to a fixed ratio of pressure above the upper packer to pressure in the space between the packers. The pressure differential across either the upper or lower packer may be so great that leakage will occur around the packers, although the pressure ratio is properly controlled by the device. This problem is particularly significant in deep wells where high hydrostatic pressures are encountered.

Accordingly, it is an object of this invention to provide a method and apparatus for improving the accuracy of drill stem testing of open hole formations.

It is a further object of this invention to provide a method and apparatus eliminating leakage of fluid around a packer due to high hydrostatic pressure on the packer.

Another object of this invention is to provide a method and apparatus for effectively isolating a formation from the hydrostatic pressure of well fluids while conducting formation tests.

SUMMARY OF THE INVENTION

These objects are accomplished in accordance with a preferred embodiment of the invention by providing a pair of packers spaced apart in the drill string. A pressure distribution valve is positioned in the string between the two packers. The distribution valve has a port located between the packers and communicating between the interior and exterior of the string. Fluid flow through the port is controlled by a valve element which is spring biased toward a closed position, but has a fluid reaction surface urging the valve element toward an open position. An anchor positioned in the string below the lower packer allows fluid to flow into the interior of the string. A central passage in the string provides fluid communication between the anchor and the distribution valve.

While the string is being run in the bore hole, hydrostatic pressure of the fluid in the bore hole communicates through the anchor to the interior of the string where the hydrostatic pressure acts on the reaction surface of the distribution valve. The spring in the distribution valve allows the valve element to open the port when the hydrostatic pressure at the depth of the valve is at a selected value below the hydrostatic pressure at the depth where the packers are to be set. When the packers reach the depth of the formation, the packers are expanded into engagement with the wall of the open bore hole. The interior of the string is then isolated from the pressure of the well fluid above the upper packer. The distribution valve remains open to bleed fluid from the space between the upper and lower packers while the packers are being expanded and until the pressure reaches the selected value. The valve then closes, isolating the space between the upper and lower packers, and as a result, the pressure differential across the upper packer and across the lower packer is sufficiently low to avoid leakage around the packers into the test zone.

DESCRIPTION OF THE DRAWINGS

This preferred embodiment is illustrated in the accompanying drawings, in which:

FIG. 1A is a schematic view in elevation of the upper portion of a test string made up in accordance with this invention and run in a bore hole;

FIG. 1B is a schematic view of the lower portion of the test string as in FIG. 1A; and

FIG. 2 is a cross sectional view of a pressure relief valve.

DESCRIPTION OF PREFERRED EMBODIMENT

Formation testing techniques have been developed to determine the potential productivity of a subsurface formation. A tubing string or drill string is positioned in a bore hole that is drilled into the formation that is to be tested. A packer on the string isolates the formation from hydrostatic pressure of drilling mud in the annulus and fluid from the formation is allowed to flow into the drill string under simulated production conditions. The test is conducted for a short period of time, and while the fluid is flowing from the formation into the drill string, the pressure of the formation fluid and the flow rate in the drill string are measured. From these measurements, the potential productivity of the formation may be calculated.

In FIGS. 1A and 1B, information testing apparatus H is secured in a conventional manner to the lower end of a drill string 4. A bore hole 6 extends through an overlying formation 8, and the lower end of the apparatus 2 is positioned at the bottom 10 of the bore hole. The formation 12 at the bottom of the bore hole is the formation that is to be tested.

The formation testing apparatus includes a tester tool 14 which is secured to the string 4 by a conventional coupling 16. The purpose of the tester tool is to control the flow of fluid from an isolated formation while the test is being conducted. The tester valve is usually operated by axial and rotational movement of the drill string. Examples of well tester tools which may be employed for the tool 14 are those disclosed in Schwegman Patent No. 2,740,479, and Chisholm Patent No. 3,105,553.

Below the tester 14, conventional well tools, such as Bourdon tube pressure recorder 20 for measuring the pressure on the outside of the tool, a jar 22, and, at the bottom of the hole 6, a flush joint anchor 24 may be included in the string. Below the anchor 24 is a Bourdon tube pressure recorder 26.

The jar 22 is a conventional well tool for applying a sharp axial blow to the string to break loose a tool, such as a packer, that may have become stuck in the well bore. The anchor 24 is merely a thick wall pipe having a plurality of small perforations through which well fluid flows to the interior of the string. The pressure recorders 20 and 26 are conventional devices utilizing a Bourdon tube with a stylus attached to the movable end of the tube to record on a moving chart the local pressure as a function of time.

The apparatus 2, which includes the tester tool 14, the jar 22, the pressure recorders 20 and 26, and the anchor 24 are merely illustrative of tools used in a typical testing string. The invention is concerned with establishing a seal which isolates the formation being tested from the hydrostatic pressure in a well bore while the test is being conducted. Thus, various testing tools and conventional auxiliary tools may be assembled in a testing string in combination with the improved packer assembly of this invention.

The packer assembly 28 of this invention is positioned in the string between the hydraulic jar 22 and the anchor 24. The packer assembly 28 separates the formation 12 at the bottom of the bore hole 6 from the annulus surrounding the tubing string above the packer assembly 28. In conventional practice, the bore hole is filled with drilling mud in order to contain the formation fluid within the formation and to prevent the rapid release of pressure that might be encountered in drilling. Often the drilling mud is weighted with additives and if the testing is carried out at substantial depths, the hydrostatic pressure of the drilling mud may be extremely high. The packer assembly 28 serves to isolate the formation 12 that is to be tested from this hydrostatic pressure.

Usually a tester tool has associated with it a bypass valve to equalize pressure across the packers before they are collapsed after completion of the test. The ports 18 correspond to the bypass ports 64 of Chisholm, No.

3,105,553, for example. A safety joint 30 is shown schematically in FIG. 1A. This tool permits the drill pipe and testing tools to be detached from the packer and anchor in the event that one or both become stuck in the well. The safety joint 30 consists of two parts which are unscrewed by a series of rotational and vertical movements of the drill pipe. This tool also has a bypass valve indicated at 32 which acts as an auxiliary to the bypass in the tester tool 14.

An upper packer 34 includes expanding shoe assemblies and a resilient expandable packer ring 36. The assembly 28 also includes a lower packer 38 similar to the packer 34 and including a resilient expandable packer ring 40. Secured between these packers is a pressure distribution valve 42.

The packers 34 and 38 should be retrievable and may be of any conventional construction that would not interfere with the operation of the tester 14, but preferably, the packers are of the compression type as disclosed in Morrisett Patent No. 2,808,889.

The distribution valve 42 includes a top adapter 44 and a bottom adapter 46. The adapters 44 and 46 have internal and external threaded portions, respectively, for being rigidly secured to the adjacent packers 34 and 38. The adapters 44 and 46 have a continuous central passage 48 which extends from one end of the valve to the other. A mandrel 50 is mounted in the central passage 48 and is movable longitudinally relative to the adapters 44 and 46. The mandrel 50 has an external flange 52. The external diameter of the mandrel 50 above the flange 52 is less than the external diameter of the mandrel below the flange 52, as viewed in FIG. 2. A pair of O-ring seals 54 at the upper end of the mandrel 50 prevent the leakage of fluid between the mandrel and the upper adapter 44. O-ring seals 56 and 58 are also provided at the lower end of the mandrel 50.

Since the exposed cross sectional area at the lower end of the mandrel 50 is larger than the cross sectional area at the upper end of the mandrel 50, fluid pressure in the passage 48 tends to urge the mandrel 50 upwardly. Movement of the mandrel, however, is resisted by a coil spring 60 in the space between the mandrel and the lower adapter 46. A spacer ring 62 is inserted between the lower end of the spring 60 and the flange 52. Preferably, the coil spring 60 has a linear spring rate, so that the spring force increases in proportion to the axial compression of the spring. The spacer ring 62 imposes an initial compression of the spring, thereby increasing the spring biasing force on the mandrel which must be overcome by the pressure differential acting on the mandrel to move the flange 52 upwardly off its seat. The amount of precompression of the spring 60 may be varied by replacing the spacer ring 62 with another spacer ring having a different axial length, or the ring may be entirely removed to allow the lower end of the spring 60 to engage the flange 52.

The lower adapter 46 has a plurality of radial ports 64. When the mandrel 50 is at its lowermost position, as shown in FIG. 2, the ports 64 are sealed from the interior passage 48 by the O-rings 56 and 58. When the mandrel 50 is displaced upwardly, relative to the lower adapter 46, a sufficient distance for the seal rings 58 to be positioned above the ports 64, then the interior passage 48 is in communication with the exterior of the valve 42 through the ports 64.

Due to the difference in cross sectional area of the lower end of the mandrel 50 relative to the upper end of the mandrel 50, fluid pressure in the passage 48 tends to move the mandrel 50 upwardly in opposition to the force of the spring 60. By selecting appropriate springs 60 or spacer rings 62, the valve 42 can be arranged to open the port 64 at the desired fluid pressure in the passage 48 and to close the valve again when the pressure drops below a selected pressure. Although the valve 42, shown in FIG. 2, is preferred, other valves which oper-

ate to allow communication through the valve body when the pressure at the valve 42 exceeds a predetermined value may be used.

In operation, the string is made up as in FIG. 1A and FIG. 1B, with the packers 34 and 38 in a collapsed condition. The string is lowered into the bore hole on the drill pipe with the tester valve in the tool 14 closed to prevent entry of well fluid into the drill pipe. The bypass ports 18 and 32 are open to allow circulation of fluid from the anchor 24 to the tester tool 14. When the string reaches the bottom of the bore hole 6, the packers 34 and 38 are expanded in accordance with conventional practice into sealing relation with the adjacent wall of the bore hole 6.

Since the bore hole is filled with drilling mud, the hydrostatic pressure of the mud gradually increases as the string is being lowered in the bore hole. This pressure is applied to the mandrel 50 through the anchor 24. The mandrel 50 in the valve 42 opens the ports 64 when the hydrostatic pressure of the drilling mud acting on the mandrel exceeds a predetermined value. The value selected for opening the ports 64 is preferably below the measured or calculated hydrostatic pressure of the drilling mud at the bottom of the bore hole. Therefore, in lowering the drill string to the bottom of the bore hole, the fluid pressure in the passage 48 causes the mandrel 50 to be displaced upwardly when the depth of the tool is sufficient to impose the required hydrostatic pressure on the mandrel. The ports 64 remain open, while the packers 34 and 38 are being expanded, so that the fluid pressures in the annulus above the upper packer 34, between the packers, and below the lower packer 38, are all approximately the same, allowing for differences due to hydrostatic head.

When the packers have been expanded, the bypass valve in the safety joint 30 and the bypass port 18 in the tester are closed and the tester valve is opened. The formation 12 below the lower packer 38 is relieved of the hydrostatic pressure of the well fluid, and is exposed through the open tester valve to the atmospheric pressure in the empty drill pipe. As soon as the tester valve opens, the pressure in the passage 48 of the distribution valve 42 is reduced and fluid from the annulus flows through the ports 64 into the passage 48. This flow continues to reduce the pressure in the annulus until such time as the pressure in the passage 48 has been reduced to the pressure at which the mandrel 50 is displaced by the spring 60 to the closed position.

The pressure below the lower packer 38 continues to be reduced while the tester valve is open, since well fluid flows through the anchor 24 and upwardly through the passage 48 and into the drill pipe above the tester 14. At this time, the upper packer 34 is exposed from above to the hydrostatic pressure of the well fluid and the lower side of the upper packer is exposed to the intermediate pressure established by the distribution valve 42. The lower packer 38 is exposed to the intermediate pressure on its upper side and to a lower pressure on its lower side, depending upon the pressure of fluids in the formation 12. Thus, the pressure differential across the upper packer is substantially less than the total differential across the entire packer assembly 28.

At the end of the test, the tester valve is closed and the pressure is equalized across the packers by opening the ports 32 and 18. The packers 34 and 38 are then collapsed and the drill string may be raised from the bore hole.

The distribution valve 42 not only establishes a predetermined differential of pressure across the upper and lower packers, but also overcomes the danger of fracturing the formation or destroying the upper packer seal by hydraulic pressure of fluid trapped between the packers 34 and 38 while they are being expanded. For example, if the upper packer 34 was expanded first to seal against the bore hole wall, rapid expansion of the lower packer 38 may produce pressure surges which would destroy the upper packer seal. The ports 64 in the sub between the

packers, relieve any excessive increases in pressure in this zone. By distributing the pressure across two or more packers, the pressure differential across each packer is substantially reduced, so that there is less tendency for the well fluid to communicate through a vertically fractured formation into the bottom of the well bore where it would flow into the test string.

The operation of the method and apparatus of this invention have been verified by field tests with a pressure recorder inserted in the string between the upper and lower packers to record the pressure in the annulus. During the field test, the pressure recorder indicated that while the packers were expanding, the pressure in the annular space between the packers exceeded the hydrostatic pressure. This increase in pressure was due to the inflation or expansion of the packers. An excessive rise in pressure can fracture or destroy the upper packer seal.

As an example, if a test is being taken in a bore hole having a depth of 20,000 ft. with drilling mud having a density of 10.5 lbs. per gallon, the hydrostatic mud pressure at the bottom of the hole would be approximately 10,900 p.s.i. It is anticipated that the maximum pressure in the formation 12 at the bottom of the hole is 5000 p.s.i. A water cushion of 8000 ft. is run inside the test string creating a back pressure of 3400 p.s.i. The packers 34 and 38 are positioned in the string as shown in FIGS. 1A and 1B, with the distribution valve 42 adjusted to open at a pressure in the passage 48 of 7000 p.s.i. As the string is being lowered in the bore hole, the valve 42 opens at a depth corresponding to a hydrostatic pressure of approximately 7000 p.s.i. The valve remains open while the packers are being expanded. After the bypass ports have been closed, and the tester valve 16 has been opened, the pressure in the annular space between the packers drops from 10,900 p.s.i. to approximately 7000 p.s.i. At this pressure, the mandrel 50 closes the ports 64, trapping fluid in the annular space between the packers at a pressure of approximately 7000 p.s.i. Consequently, there is a differential of about 3900 p.s.i. across the upper packer 34 and between 2000 p.s.i. and 3600 p.s.i. across the lower packer 38. The differential pressure across each packer is considerably less than the 5900 p.s.i. differential that would exist if a single packer were used.

While this invention has been illustrated and described in a preferred embodiment, it is recognized that variations and changes may be made therein without departing from the invention as set forth in the claims.

We claim:

1. In a drill string of the type having means for establishing a temporary seal in the annulus between said string and the wall of a bore hole in which the drill string is run, said seal extending around the periphery of said drill string to prevent flow vertically through the annulus, said seal comprising:

an upper packer ring and a lower packer ring on said drill string, means for selectively expanding said packer rings radially relative to said string, said string including tubing having a central passage extending continuously from a point above said seal to a point below said seal and remaining in continuous communication with said annulus below said seal, said tubing having a port communicating between said central passage and said annulus, said port being between said upper and lower packer rings,

a valve element in said tubing and movable to open and close said port, said valve element having a pair of opposed fluid reaction surfaces of different areas, the larger reaction surface urging said valve element from said closed position toward said open position in response to fluid pressure in said tubing acting on said surface, both of said reaction surfaces being positioned in said tubing central passage, and spring means biasing said valve element toward said closed position, whereby said valve element is opened when the hydrostatic pressure on said fluid reaction sur-

face exceeds a predetermined minimum pressure to relieve fluid pressure in the annulus between said packer rings through said port while said packer rings are being expanded and until a predetermined pressure differential is established across said upper packer.

2. Apparatus according to claim 1 wherein the biasing force of said spring means is adjustable.

3. Apparatus according to claim 1 wherein said drill string includes conduit means therein extending between said central passage and the top of said string, and tester valve means for selectively controlling fluid flow between said conduit means and said central passage, whereby opening said tester valve means after said packer rings are expanded isolates the central passage from hydrostatic pressure in the annulus above said upper packer.

4. Apparatus according to claim 1 wherein said fluid reaction surface is sealed from exposure to fluid in said port when said valve is in said closed position.

5. Well apparatus for establishing a temporary seal in a bore hole above a formation that is to be tested comprising tubing having a central passage therethrough, an upper expandable packer, a lower expandable packer, said passage communicating with the exterior of said tubing below said lower packer, said tubing having a port between said packers extending through the wall of said tubing and communicating with said central passage, valve means including a valve element movable to open and close said port, said valve element having a fluid reaction surface in position for moving said element to said open position in response to fluid pressure acting on said reaction surface, said reaction surface being exposed to fluid in said passage and sealed from exposure to fluid in said port when said valve element is in said closed position, and means for biasing said valve element toward said closed position, whereby fluid pressure bleeds through said port until the pressure in the interior of the tubing is reduced below a predetermined minimum pressure, thereby establishing an intermediate pressure in the annular space between said packers independently of the hydrostatic pressure above said upper packer.

6. Well apparatus according to claim 5 wherein said valve element is mounted in said central passage and said valve element is movable axially without obstructing flow through said central passage.

7. Well apparatus according to claim 5 wherein said valve element is in the form of a hollow mandrel, said mandrel being mounted coaxially in said tubing for limited longitudinal movement relative to said tubing, said port being positioned intermediate the limits of said longitudinal movement, whereby said mandrel is movable in response to fluid in said tubing.

8. Well apparatus according to claim 7 including shoulder means on said mandrel, said biasing means including a coil spring aligned with said shoulder means, and a spacer ring between said shoulder means and said spring, whereby opening of said port can be adjusted by varying the length of said ring.

9. The method of establishing in an open bore hole a predetermined pressure differential across the upper packer of a pair of packers in a tubing string comprising: determining the hydrostatic pressure in the bore hole at the depth of a selected formation, running said tubing string down said bore hole, said tubing string including a pressure distribution valve controlling fluid flow between the exterior of said tubing string between said upper packer and the lower packer and the interior of said tubing string, opening said valve in response to a selected fluid pressure within said tubing string at a predetermined differential below the hydrostatic pressure at said selected formation, expanding said packers into sealing relation with the wall of said bore hole above said formation,

reducing the fluid pressure in said tubing string adja-

cent said valve, closing said valve in response to fluid pressure in said tubing string below said selected pressure, and maintaining said valve closed while the fluid pressure in said tubing string adjacent said valve remains below said selected pressure, whereby the pressure differential across each of said packers is less than the total pressure differential across both packers.

10. The method according to claim 9 wherein said valve closing occurs in response to absolute pressure in the annulus between said expanded packers.

11. The method according to claim 9 wherein said tubing string interior is in fluid communication with said selected formation, and wherein said pressure reducing includes opening said tubing string interior to atmospheric pressure after expanding said packers, whereby predetermined pressure differentials are established across the upper and lower packers.

12. A method of establishing a temporary seal while testing a formation in a bore hole containing fluid comprising:

running a tubing string in the hole with a pair of expandable packers spaced apart axially in said string, positioning said pair of packers above said formation, said string including a valve communicating between the exterior and interior of said string between said packers,

opening said valve in response to hydrostatic pressure above a predetermined pressure in said bore hole adjacent said valve, said predetermined pressure being intermediate the hydrostatic pressure in said bore hole at said formation and fluid pressure in said formation, expanding said packers in sealing relation with said bore hole above said formation, reducing the fluid pressure in the interior of the string,

closing said valve in response to said reduction of fluid pressure below said predetermined pressure, maintaining said valve closed while pressure in said tubing string adjacent said valve remains below said predetermined pressure, and conducting productivity tests on said formation, whereby said valve establishes an intermediate pressure in the annular space between the upper and lower packers.

13. The method according to claim 12 wherein said valve closing occurs at a predetermined pressure differential with respect to the hydrostatic pressure directly above said upper packer.

14. The method according to claim 13 including determining said formation fluid pressure and said hydrostatic fluid pressure in said bore hole, said predetermined pressure being at a selected pressure differential between said formation pressure and said hydrostatic pressure, whereby predetermined pressure differentials are achieved across said upper packer and said lower packer which said tests are being conducted.

15. A valve assembly for controlling flow between the exterior and the interior of tubing in a well comprising:

a tubular body having means at opposite ends thereof for connection of said body in a tubing string, said body having a central bore extending throughout its length, said body having a substantially radial port extending through the wall and communicating between said bore and the exterior of said body,

a sleeve in said bore, said sleeve being movable longitudinally of said body and having a pair of opposed fluid reaction surfaces exposed continuously to fluid pressure in said bore, said surfaces having different surface areas,

said sleeve being movable axially of said body in one direction for closing said port, and in the opposite direction for uncovering said port, the larger reaction surface being in position to urge said sleeve axially to uncover said port, said sleeve having an outwardly projecting flange thereon, said flange

having opposite faces, said body having a pair of shoulders on opposite sides of said flange faces, and

spring means and an individual spacer ring interposed between one of said shoulders and one of said faces, said spring means yieldably urging said sleeve axially in said one direction toward a position closing said port, the other of said body shoulders being positioned to be engaged by the other of said flange faces when the sleeve is in said port closing position, whereby fluid pressure in said bore greater than a predetermined value overcomes the force of said spring means to displace said sleeve longitudinally, thereby uncovering said port and whereby the length of said spacer ring provides adjustment of the closing force of said spring means.

16. The valve assembly according to claim 15, wherein said body has a recess in said bore, said sleeve extending over said recess and said sleeve flange being received in said recess, said spring means and said spacer being positioned in said recess, said port being spaced longitudinally from said body recess, whereby said sleeve and said spacer are confined in said recess by said sleeve.

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