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 PRESSURE REGULATING VALVE ASSEMBLY BETWEEN
 OPEN HOLE PACKERS AND METHOD
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3,459,264

Fig. 1.

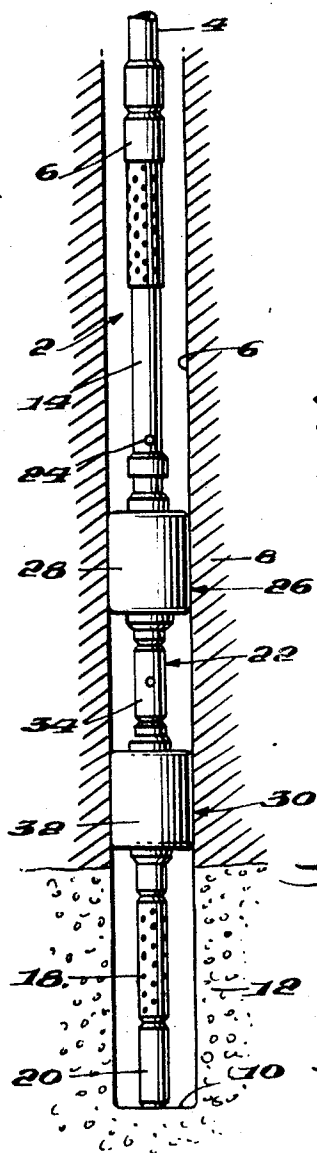


Fig. 3.

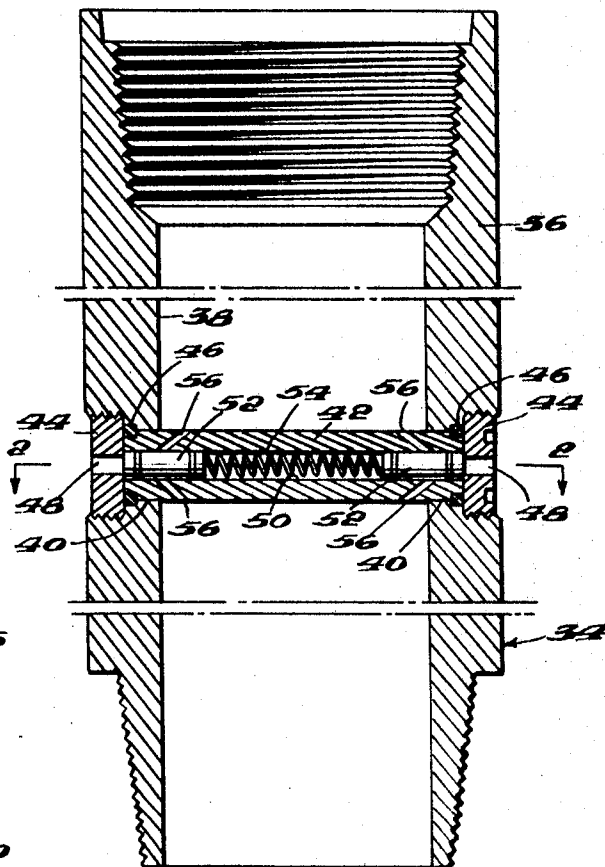
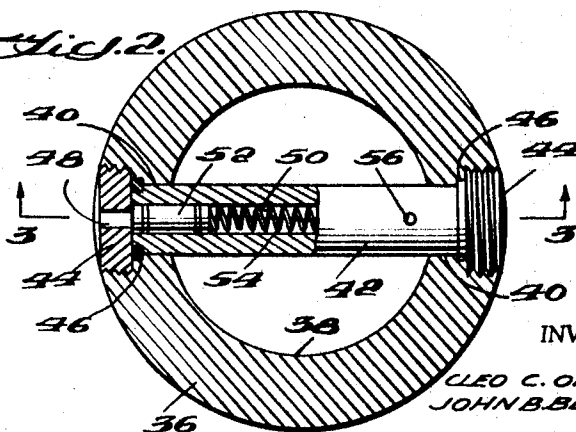


Fig. 2.



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PRESSURE REGULATING VALVE ASSEMBLY BETWEEN OPEN HOLE PACKERS AND METHOD

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15 Claims

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 a pressure differential across the lower packer, so that the hydrostatic load is distributed between the packers.

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 flow 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

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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 if 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. The reaction surface is exposed to fluid pressure on the exterior of the string. 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 acts on the reaction surface of the distribution valve urging the valve element toward an open position. 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. 1 is a schematic view in elevation of a test string made up in accordance with this invention and run in a bore hole;

FIG. 2 is a cross sectional view of the distribution valve along the line 2—2 in FIG. 1; and

FIG. 3 is a cross sectional view of the distribution valve along the line 3—3 in FIG. 2.

Description of preferred embodiment

Formation testing techniques have been developed to determine the potential productivity of a subsurface for-

mation. 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 FIG. 1, formation testing apparatus 2 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 in the tool 14 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 a flush joint anchor 18 and a Bourdon tube pressure recorder 20 may be included in the string. The anchor 18 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 recorder 20 is a conventional device 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 anchor 18 and the pressure recorder 20 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 22 of this invention is positioned in the string between the tester tool 14 and the anchor 18. The packer assembly 22 separates the formation 12 at the bottom of the bore hole 6 from the annulus surrounding the tubing string above the packer assembly 22. 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 22 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 port 24 at the lower end of the tester tool 14 corresponds to the bypass ports 34 of Schwegman, No. 2,740,479, or ports 64 of Chisholm, No. 3,105,553, for example.

An upper packer 26 includes expanding shoe assemblies and a resilient expandable packer ring 28. The assembly 22 also includes a lower packer 30 similar to the packer 26 and including a resilient expandable packer ring 32. Secured between these packers is a pressure distribution valve 34.

The packers 26 and 30 should be retrievable and may be of any conventional construction that would not inter-

fere with the operation of the tester tool 14, but preferably, the packers are of the compression type, as described in Morrisett et al. Patent No. 2,808,889.

The distribution valve 34 includes a conventional tubing sub 36 which is threaded at opposite ends for being rigidly secured to the adjacent packers 26 and 30. The sub 36 has a continuous central passage 38 which extends from one end of the valve to the other. The sub 36 has openings 40 formed in the wall on diametrically opposite sides of the sub. The opposite ends of a cylindrical valve case 42 are received in the openings 40. The case 42 is held in place in the sub 36 by threaded caps 44 which are secured in each opening 40. A seal ring 46 between the cap 44 and the case 42 seals against leakage of fluid through the openings 40 around the case 42.

Each cap 44 has a central port 48. The ports 48 are aligned with a cylindrical passage 50 which extends throughout the length of the case 42. A valve element or piston 52 is mounted for sliding movement in the passage 50 at each end of the case 42. Seal rings on the pistons 52 prevent leakage of fluid around the outside of the pistons. A spring 54 is mounted in the passage 50, and the opposite ends of the spring 54 engage the pistons 52 to urge the pistons outwardly into engagement with the caps 44.

There are a plurality of passages 56 in the case 42 which communicate between the exterior of the case and the central passage 50. The pistons 52 are sufficiently long to close the passages 56 when the pistons engage the caps 44, thereby cutting off the flow of fluid between the central passage 38 in the sub 36 and the port 48 at the exterior of the sub 36.

As shown in FIGS. 2 and 3, the valve pistons 52 have a fluid reaction surface which is exposed at all times to the pressure of fluid on the outside of the sub 36, since this pressure is communicated to the piston reaction surface by the port 48. When the pistons are in the position shown in FIGS. 2 and 3, the fluid pressure on the interior of the sub 36 does not cause displacement of the pistons because this pressure is isolated from either end of the piston by the seal rings on the exterior of the pistons. The spring 54 is preferably calibrated to impose a biasing force on the pistons 52 which is sufficient to prevent displacement of the pistons until a predetermined pressure is applied to the exposed end of each piston. Thus, the valve can be adjusted to open at a selected value to establish fluid communication through the port 48 and the passages 56.

In operation, the string is made up as in FIG. 1, with the packers 26 and 30 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 port 24 is open to allow circulation of fluid from the anchor 18 to the tester tool 14. When the string reaches the bottom of the bore hole 6, the packers 26 and 30 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 pistons 52 through the ports 48. The pistons are displaced sufficiently to open the ports 56 when the hydrostatic pressure of the drilling mud acting on the pistons exceeds a predetermined value. The value selected for opening the ports 56 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 valve 34 opens before the string reaches the bottom 10 of the bore hole. The ports 56 remain open, while the packers 28 and 32 are being expanded, so that the fluid pressure in the annulus above the upper packer 26, between the packers, and below the lower packer 30, are all approximately the same, allowing for differences due to hydrostatic head,

When the packers have been expanded, the bypass port 24 in the tester tool is closed and the tester valve is opened. The formation 12 below the lower packer 30 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 38 of the distribution valve 34 is reduced and fluid from the annulus flows through the ports 48 and 56 into the passage 38. This flow continues to reduce the pressure in the annulus until such time as the pressure in the annulus has been reduced to the pressure at which the pistons 52 are displaced by the spring 54 to the closed position.

The pressure below the lower packer 30 continues to be reduced while the tester valve is open, since well fluid flows through the anchor 18 and upwardly through the passage 38 and into the drill pipe above the tester 14. At this time, the upper packer 26 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 34. The lower packer 30 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 26 and 30. By selecting a spring 54 of a certain spring rate, the valve can be adjusted to open at a predetermined pressure differential above the pressure of fluid in the formation 12 and a predetermined pressure differential below the hydrostatic pressure in the annulus above the upper packer. This permits substantially equal pressure differentials to be maintained across each packer.

At the end of the test, the tester valve is closed and the pressure is equalized across the packers by opening the port 24. The packers 26 and 30 are then collapsed and the drill string may be raised from the bore hole.

The distribution valve 34 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 26 and 30 while they are being expanded. For example, if the upper packer 26 was expanded first to seal against the bore hole wall, rapid expansion of the lower packer 30 may produce pressure surges which would destroy the upper packer seal. The ports 56 in the sub 36 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 leak around the packers 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 expansion of the packers. An excessive rise in pressure can fracture or destroy the upper packer seal, unless the pressure is relieved.

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 26 and 30 are positioned in the string as shown in FIG. 1, with the distribution valve 34 adjusted to open at a pressure

on the exterior of the sub 36 of 7000 p.s.i. As the string is being lowered in the bore hole, the valve 34 opens at a depth corresponding to a hydrostatic pressure of approximately 7000 p.s.i. The valve passages 56 remain open while the packers are being expanded. After the bypass port 24 has been closed, and the tester valve 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., as fluid bleeds through the passage 56 into the central passage 38. At this pressure, the pistons 52 close the passages 56, 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 26 and between 2000 p.s.i. and 3600 p.s.i. across the lower packer 30. 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. A method for improving the seal in the bore hole annulus surrounding a tubing string above a formation that is to be tested comprising:

positioning said tubing string in said bore hole with a pair of packers spaced vertically on said string, expanding said packers into engagement with the wall of said bore hole, thereby isolating the portion of the annulus between the packers from the annulus above and below the packers,

creating a predetermined pressure differential across the upper one of said packers and a predetermined pressure differential across the lower one of said packers, said created pressure differentials each being substantially less than the sum of the differentials across both of said packers, said pressure differential creating step including reducing the fluid pressure in said isolated annulus portion below a selected pressure, whereby the seal established by said packers resists leakage around the seal when large pressure differentials are applied across the seal.

2. The method according to claim 1 wherein said pressure reducing step includes bleeding fluid from said isolated annulus portion to a zone of lower pressure.

3. The method according to claim 1 including maintaining said isolated annulus portion below said selected pressure.

4. The method according to claim 1 including determining the hydrostatic pressure of fluid in the bore hole at the depth at said formation.

5. The method according to claim 2 including reducing the fluid pressure in said tubing string to a pressure substantially below said annulus pressure above said upper packer, said fluid being bled into said tubing string from said isolated annulus portion.

6. A method of establishing in an open bore hole a predetermined pressure differential across the upper packer of a pair of packers on 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 thereof,

opening said valve in response to a selected fluid pressure at a predetermined differential below the hydrostatic pressure at the depth of 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 adjacent said valve, closing said valve when the fluid pressure in the space between said packers at the ex-

terior of said tubing string falls below said selected pressure, and maintaining said valve closed while the fluid pressure in said space 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.

7. The method according to claim 6 wherein said valve closing occurs in response to absolute fluid pressure in the annulus between said expanded packers.

8. The method according to claim 6 wherein said tubing string interior is in fluid communication with said selected formation, and wherein said pressure reducing includes reducing the pressure in said tubing string interior to a pressure below said selected fluid pressure, whereby predetermined pressure differentials are established across the upper and lower packers.

9. 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 on said string, positioning said pair of packers above said formation, said string including a valve communicating between the interior and exterior 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 the 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 a reduction of fluid pressure in the annular space between said packers 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.

10. The method according to claim 9 including opening said valve after said packers are expanded whenever the pressure in said bore hole adjacent said valve exceeds said predetermined pressure, whereby said predetermined pressure is maintained in the annulus between the packers.

11. Well apparatus for establishing a seal in a bore hole above a formation that is to be tested comprising: tubing means, an upper expandable packer and a lower expandable packer on said tubing means, said tubing means including a passage extending from the exterior of said tubing means between said packers to the interior of said tubing means, valve means in said tubing means for controlling the flow through said passage, said valve means including a valve element, said valve element having a fluid reaction surface in position for displacing said valve element in one direction in response to fluid pressure to allow fluid flow through said passage, spring means biasing said valve element in a direction opposite to said one direction to block fluid flow through said passage,

said spring means and said fluid reaction surface cooperating to displace said valve element in said opposite direction in response to fluid pressure greater than the hydrostatic pressure on the exterior of said tubing means at the depth at which the packers are to be set,

whereby the valve element opens said passage while the tubing means is being lowered in the bore hole when the predetermined pressure is greater than the hydrostatic pressure at the depth where the packers are to be set.

12. The well apparatus according to claim 11 wherein said interior of said tubing means is in fluid communication with the exterior of said tubing means below said lower packer independently of said passage.

13. The well apparatus according to claim 11 wherein said predetermined pressure value is adjustable by varying the force of said spring means.

14. The well apparatus according to claim 11 including case means in said tubing means, said case means including a cylinder, said valve element being in the form of a piston having said reaction surface at one end thereof, said piston being mounted in said cylinder for axial movement relative thereto, said passage including a port communicating between the exterior of said tubing means and said piston end, said case means including a conduit communicating with said cylinder adjacent said port, said piston being movable in said one direction to provide fluid communication between said port and said conduit and in said opposite direction to block fluid communication between said port and said conduit.

15. The well apparatus according to claim 11 wherein said tubing means includes openings on opposite sides thereof, a valve case extending through said tubing means and being supported in said openings, said case having a central cylindrical passage, said valve element being in the form of a piston mounted for reciprocating movement in said case passage, said fluid reaction surface being at one end of said piston, whereby said piston allows fluid to flow into said tubing means in response to a predetermined pressure acting on said piston end.

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