APPARATUS FOR THE SELECTIVE INJECTION OF FLUIDS INTO GEOLOGICAL FORMATIONS

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This invention relates to repressuring and flooding of subterranean oil formations and is more concerned with method and apparatus for permitting selective injection of fluid into formations of low permeability.

In the flooding and repressuring of subterranean oil formations, it is common practice to seal off the formations of high permeability in order that the water, gas or other fluid injected into the well bore will be forced into the formation of low permeability. In order to accomplish selective sealing, mechanical packers have been used as well as chemical sealing agents. In accordance with our invention, we use a collapsible or inflatable packer controlled by mechanism above the earth's surface for sealing off the formations of high permeability and permitting the fluid to be injected into the formations of low permeability.

One of the objects of our invention is to provide a method for selectively repressuring or flooding subterranean oil formations.

Another object of the invention is to provide apparatus for selectively sealing off different formations along an earth bore.

Still another object of the invention is to provide apparatus for control at the earth's surface of the differential pressure on a collapsible or expandable packer in an earth bore.

Still another object of the invention is to provide method and apparatus for controlling the volume and pressure of fluid injected into a well bore.

A still further object of the invention is to provide method and apparatus which will permit acidizing of selected strata along a well bore.

Other objects of the invention will become apparent from the following description and the accompanying drawing, of which

Figure 1 is a diagrammatic view of the differential pressure control mechanism for controlling the pressure on the collapsible packer element shown in Figure 2.

Figure 2 is a vertical cross-sectional view of a well bore in which has been inserted a packer in accordance with our invention:

Figure 3 is a slightly different arrangement for injecting fluid into the earth bore and packer; and Figure 4 is still another modification of apparatus for injecting fluid into the formation and the packer.

Referring to the drawing, the numeral 1 indicates the inlet of a pipe line 2 to which water, hydrocarbon gas or other fluid is charged by means of a pump or compressor not shown. The pressure in line 3 is controlled by valve 5 which may be hand-operated or which may be automatically controlled to maintain a constant pressure on the downstream side thereof and provide against increase of pressure caused by plugging of the walls of the well bore. A pressure gauge 7 and a meter 8 are placed in the line on the downstream side of valve 5 in line 3, and a check valve 9 is also placed on the downstream side of valve 9 in the line in order to prevent back-flow of fluid through the line in the event of failure of the pressure source at inlet 1.

A pipe 11 of smaller diameter than line 3 is connected to the latter on the upstream side of valve 9. A valve 13 is placed in line 11 in order to permit the line to be shut off. Differential pressure regulator 15 is placed in line 11 on the downstream side of valve 13. The pressure regulator 10 is adapted to open upwardly. The pressure regulator 15 comprises a closure element 17 adapted to be sealed on seat 8. The closure element 17 is connected to a stem 20. A diaphragm (not shown) located in the housing 21 is connected to a rod 23. A compression coil spring 25 is held in place under desired compression between seat 27 on the upper end of stem 20, and the seat 28. Seat 28 is adapted to be adjusted upwardly or downwardly by means of the adjusting screw 29 mounted in a threaded opening in yoke 30. A line 31 connects line 3 on the downstream side of valve 13 to the space below the diaphragm in the housing 21. A line 33 connects the line 11 on the downstream side of the regulator 15 to the space above the diaphragm in the housing 21. A check valve 35 is placed in line 11 between valve 13 and pressure regulator 15. The pressure gauge 7 is placed in line 11 on the downstream side of regulator 15.

A line 39 connects the line 11 on the downstream side of pressure regulator 15 with line 3 on the downstream side of valve 9. A pressure regulator 41 is placed in line 39. The pressure regulator 41 is adapted to open when the closure element 43 is forced downwardly or as shown in the drawing when forced to the left. Closure element 43 is connected to a stem 45. A diaphragm (not shown) is contained in the housing 41. The diaphragm is connected to a rod 49. A compression coil spring 51 is held under desired compression between seat 52 and
seat 55 mounted on the end of stem 45. The compression of the spring is adjusted by adjusting screw 56 mounted in threaded yoke 57. A line 58 connects the space below or to the left of the diaphragm in housing 47 to the line 39 and the line 3. A line 59 connects the space above or to the right of the diaphragm in housing 47 to line 35 to a point between the line 11 and the pressure regulator 41. Line 35 is connected at a point beyond check valve 9 to tubing head 61 (Figure 2) on well casing 63. Line 11 is connected at a point beyond pressure gauge 37 to the upper end of well tubing 65.

Referring more particularly to Figure 2, there is illustrated a subterranean formation surrounding an earth bore showing two strata 67 of high permeability and low oil content spaced between three strata 69 of low permeability and high oil content. The well casing 63 is sunk to the top of highest formation 69 of low permeability and high oil content. Well tubing 65, which is of smaller diameter than the casing is disposed within the borehole. The tubing 65 has fastened to its outer wall at points opposite the subterranean formations of high permeability fluid impermeable and/or collapsible envelopes 71 which may suitably be made of rubber, tightly woven and treated cloth or other expandable and/or collapsible material which is substantially impervious to gas and liquid. The lower end of the tubing 65 extends below the lower end of the packer and has perforations 65 below the lowest packer in order to permit fluid to pass therefrom into formation. The envelopes 71 are substantially of the same length as, or of slightly greater length than, the depth of the high permeability formation which the envelope or sleeve is intended to seal. The ends of the envelope or sleeve 71 are fastened by rings or collars 73 to the outside of the tubing 65 in such manner as to prevent leakage of fluid therefrom and to prevent the envelopes from moving along the tubing. The thickness of the sleeve or envelope 71 should be such as not to require too much pressure to expand the envelope against the wall of the earth bore. We have found that a flexible, rubber envelope having a wall thickness of approximately one inch to one inch is satisfactory.

A circular disk 75 with an opening large enough to accommodate a small pipe 77 is placed in the tubing 65 at a point above the topmost envelope or sleeve 71. The pipe 77, the closed upper end of which extends above the disk 75 and which is perforated adjacent its upper end as shown at 79, extends through the disk 75 to a point within the lowermost sleeve or envelope 71. The pipe 77 is provided with outlets 81 extending through tubing 65 into the space between the tubing 65 and each envelope 71. The tubing 65 is provided with a series of perforations 83 between the disk 75 and the top of the uppermost envelope 71 and further series of perforations 85 at points opposite each formation of low permeability.

The operation of the apparatus is as follows: water, gas or other fluid which is to be used to flood or repressurize the subterranean oil producing formations is forced through inlet 1 into pipe 3 at a pressure above that required to force the fluid into the producing formations of low permeability. Pressure of the fluid in pipe 3 is maintained less than that applied through line 11. The fluid enters the annular space between the well casing 63 and tubing 65, and is forced into the topmost formation 69 of low permeability.

With valve 15 open, pressure at the inlet of line 3 is exerted through line 11 on the top of the diaphragm in housing 21 through line 33. Pressure in line 3 on the downstream side of valve 5 is exerted through line 31 on the lower side of the diaphragm in housing 21. The compression of the coil spring 25 is such that the injection pressure on the underside of the diaphragm will hold the pressure regulator 15 in open position. The fluid pressure provided through line 11 is employed to maintain the expandable envelopes 71 in an inflated condition during the injection operations. At the outset of the injection procedure when the fluid pressure is initially applied at inlet 1 the differential pressure regulator closure element 17 in differential pressure regulator 15 will be held in an open position due to the force impressed upon the lower side of the disk 75 by spring 25 and the injection fluid pressure applied through line 31. The force exerted by the spring is adjusted so that a pressure differential of from about 10 to 75 pounds per square inch above that occurring in line 3 obtains in line 11. Therefore when the injection pressure desired is obtained in line 3 the pressure differential occurring in line 11 will be sufficient to maintain the packer element 71 in an inflated condition. When the packers 71 are inflated the pressure differential is impressed upon the diaphragm in housing 21 via line 33. This force is of sufficient magnitude to overcome the force exerted on the underside of the diaphragm by spring 25 and the injection pressure provided through line 31. Accordingly differential pressure regulator 15 will be closed by closure element 17 engaging with seat 19. So long as the liminal injection pressure is ample for injection purposes differential pressure regulator 15 will remain closed. If the pressure in line 11 under these injection conditions is found to leak or to pass beyond the packer inflation system or for other reasons this change will be reflected through line 33 and closure element 17 will be unseated due to the unbalancing of the forces exerted upon the diaphragm contained in housing 21. The regulator 15 will remain open until the desired predetermined pressure differential is again obtained. At this time the pressure regulator 15 will again close. Similarly the pressure regulator 15 will function for any demand increase or decrease in the injection pressure to maintain the desired predetermined pressure differential by operating in conjunction with pressure regulator 41 which operates as a by-pass relief type pressure differential regulator. This by-pass operation is hereafter described.

As previously described, the fluid flows through line 11 into tubing 65, but cannot pass beyond the disk 75 since the disk blocks the passageway above and below it. The fluid in the tubing 65 is, therefore, caused to enter pipe 77 through perforations 79 and flow downwardly through pipe 77. The perforations 75 are placed a sufficient distance from the bottom of the tubing 75 to prevent any sediment that may collect on the disk from blocking the perforations. The fluid passing
through pipe 71, which is at a pressure above the pressure of the fluid in the annular space between the casing 63 and tubing 65, leaves the pipe 71 through outlet 89 located inside the envelopes or sleeves 71 and, since the pressure is above the pressure of the fluid outside the envelope, the envelopes are caused to expand and be held snugly against the surface of the well bore opposite the formations of high permeability. The pressure regulating valve 89 forces the fluid on the outside and the inside of the envelope need only be sufficient to hold the envelope snugly against the well bore. We have found that this pressure may vary from approximately 10 to 75 pounds per square inch, and may be higher or lower depending on the ability of the envelope to stand higher pressures and the minimum pressure necessary to expand the envelope against the surface of the well bore.

The fluid in the well bore opposite the topmost formation 65 of low permeability is forced both into the formation and through orifices 83 into the tubing 65 below the disk 75, and passes downwardly in the annular space between the tubing 65 and pipe 71, being forced out of the tubing through perforations 65 into the several layers of the formations of low permeability.

In order to further protect the envelopes or sleeves against rupture caused by too large pressure differential between the inside and outside thereof, a second pressure regulator 41 is placed between the lines 11 and 3 as previously described. The pressure regulator 41 acts upwardly or seawards when the rod 45 moves to the right. The pressure of the fluid on the downstream side of valve 5 is exerted on the underside of the diaphragm in housing 47 through line 11. Pressure on the side of the diaphragm which is higher than the pressure exerted through line 11, is exerted on the upper or right side of the diaphragm in housing 47 through line 59. The compression spring 51 is so adjusted that the force exerted by it plus the pressure in line 59 is greater than the fluid or pressure in line 11, thereby holding the regulator 41 in closed position. If for any reason the injection pressure, that is the pressure on the downstream side of valve 5, declines, as for example, due to failure of the pump or compressor, feeding liquid or gas through pipe 71 or because the fluid after a time enters the formations of low permeability more easily, the pressure exerted on the lower side of the diaphragm in housing 47 will decrease, while that pressure on the top of the diaphragm will remain constant because the fluid is trapped between the check valve 35 in line 11 and the envelopes 71. As a result thereof, the regulator 41 will open permitting fluid to flow through the line 39 into the line 3, and thereby releasing excess pressure in the envelope 71 until the differential pressure between the inside and outside of 71 returns to the desired differential for which the regulator 41 is set. Thus, sufficient differential is maintained in the envelopes 71 to keep them inflated, but the differential is not permitted to rise above a predetermined amount which would cause rupture of the envelopes.

In order to permit the envelopes 71 to be deflated, as for example, when it is desired to withdraw the envelopes from the well bore, a line 67 controlled by valve 89 is connected to line 11 on the downstream side of regulator 15. By closing valve 13, thereby preventing further entrance of fluid into the tubing 65, and opening valve 89, the pressure in the line 11 between the regulator 15 and the envelopes 71 is relieved with the result that the pressure on the outside of the envelopes 71 and the diaphragm on the inside of the envelopes causes the envelopes to collapse. In order to assist in collapsing the envelopes 71, valve 5 may be opened to increase the pressure on the outside of the envelopes.

It will be apparent that other piping arrangements in the well may be required in order to isolate the fluid pressure on the inside and the outside of envelopes 71. Some possible modified arrangements are shown in Figures 3 and 4.

Referring to Figure 3, instead of charging fluid to the sleeves or envelopes 71 through the pipe 71, the fluid may be charged to the sleeves 71 directly from the tubing 65. Tubing 65 is provided with perforations 89 inside the envelopes 71 in order to permit fluid to escape from the tubing 65 into the envelope. Pipe 71 will have an inlet 91 above the topmost sleeve 71 to permit fluid charged through the line 3 to pass downwardly through the annular space between the tubing and casing and then enter the pipe 71 and escape through outlet 93 into the formations of low permeability.

If it is desired to inject fluid into the formation below the sleeve or envelope 71 while excluding it from the formation above it, the modification shown in Figure 4 may be used. In this modification, the tubing 65 is equipped with a perforated and bulb-plugged nipple 95 below the packer 71 which is fastened to the tubing by means of coupling 86. Sealing cups 97 are provided to prevent fluid from flowing from the annular space between tubing 65 and pipe 71 into nipple 95. Tubing 65 is perforated at nipple 95. Fluid for inflating the sleeve or envelope 71 is charged from pipe 11 through the tubing 65. Fluid for injection into the formation below the envelope 71 is charged through pipe 71 and enters the formation through the perforations 98 in the nipple 95.

In the event it is desired to inject fluid into formations both above and below packer 71 using the arrangement shown in Figure 4, additional fluid can be charged through line 3 into the annulus between the casing 63 and the tubing 65. In this case, line 3 would be divided and a separate pressure-reducing valve 5, meter 8, pressure gauge 7, and check valve 9 would be provided for the two branches connecting with the casing 63 and pipe 71. The lines 59 and 31 would also be manifolded and valved so that pressure from either or both lines could be imposed on the diaphragms in the pressure regulators 15 and 41. This modification permits the volume and pressure of the fluid injected above and below the envelope to be individually controlled.

As previously pointed out, an automatic pressure regulator may be used instead of the hand-operated valve 5. By substituting a pressure-reducing regulator for the valve 5, the possibility of the envelopes 71 deflating or collapsing due to the fact that the pressure required for injection of fluid into the producing formations increased to such an extent that it closely approaches the total pressure available at the inlet of line 3 is avoided. Such a situation may arise if the face of the well bore becomes partially plugged, decreasing its permeability.

The following is a description of an actual test made using apparatus in accordance with our invention. An 8¼ inch diameter hole was drilled
to a depth of 1461 feet and the hole continued to a depth of 1555 feet with a diameter of 6\(\frac{1}{2}\) inches. Casing having an I. D. of 4.892 inches, which would expand to the 6\(\frac{1}{2}\) inch diameter of the hole, it was decided to use an expansible differential type packer in accordance with this invention. A single packer was used having an over-all length of 23 feet with 1 foot on either end being reinforced for end connection. The packer was made of rubber having a wall thickness of \(\frac{1}{8}\) inch. The outside diameter of the rubber packer was \(4\frac{1}{4}\) inches, except at the ends which had an outside diameter of \(\frac{5}{8}\) inches in order to provide clearance to fit clamps to 2 inch I. D. tubing. The packer was tested at the surface and was found to require a differential pressure of 75 pounds per square inch to fully inflate it against a 6,538 inch I. D. pipe. It was then run into the well on tubing and suspended to shut off the formation at a depth between 1462 and 1483 feet. The packer was inflated by introducing gas under pressure of 75 pounds per square inch gauge and then the injection of gas into the formation was begun at the rate of 25,000 cubic feet per day at 18 pounds per square inch while maintaining a pressure of 90 pounds per square inch in the packer. The injection pressure required to inject the gas dropped by the next day to 11\(\frac{1}{2}\) pounds per square inch. At this pressure, the pressure in the packer was 81 pounds per square inch. The pressure gradually declined until at the end of approximately a week’s time, the pressure required to inject the gas into the formation had declined to 8 pounds per square inch.

In order to deflate and raise the packer, the pressure on the inside of the packer was released by opening valve 69 and valve 5 was opened to increase the injection pressure on the outside of the envelope to 18 pounds per square inch.

It will be seen that by means of the apparatus described and shown, a means is provided for quickly sealing off formations of high permeability in order to selectively flood or repressurize oil producing formations of low permeability. By placing mechanical apparatus for controlling the pressure on the packing device at the surface of the well, any regulations required can be readily made, and in the event a defect arises in the apparatus, it is unnecessary to remove the entire packing device from the well.

I. An expansible and collapsible packer for earth bores comprising a pipe, a collapsible substantially fluid-impermeable envelope fastened to said pipe to define an enclosed space with the walls of said pipe, a first conduit connected to the pipe for supplying fluid to the bore and a second conduit for supplying fluid to the earth bore around said enclosed space, and a means for maintaining a predetermined pressure differential in the said first conduit wherein the pressure in the first conduit is continuously maintained over and above that available in the second conduit, which comprises a means for supplying fluid from a common pressure source through the first conduit connected to the inside and to the outside, respectively, of said packer, a pressure reducing valve in the second conduit supplying fluid to the outside of said packer, a first pressure differential regulator disposed in the first conduit supplying fluid to the outside of said packer being connected on the downstream side of said pressure reducing valve to said first differential pressure regulator to maintain said regulator in the open position, the conduit supplying fluid to the inside of said packer being connected to said first differential pressure regulator to maintain said regulator in a closed position, said regulator being adjusted to remain in open position until the pressure of the fluid charged to the inside of said packer exceeds the pressure of fluid charged to the outside of said packer by a predetermined amount and a second differential pressure regulator connected between said first and second conduits at points downstream of said first differential pressure regulator and said pressure reducing valve, said second regulator being activated by pressure of fluid charged to the inside and on the outside of said packer to remain in closed position until the pressure differential between the inside and outside of said packer exceeds a predetermined maximum.

II. Apparatus for maintaining a pressure differential between the inside and outside of an inflatable packer located in a well bore comprising means for supplying fluid from a common pressure source through first and second lines to the inside and to the outside respectively of said packer, a pressure reducing valve in the second line supplying fluid to the outside of said packer, an automatic pressure regulator in the first line supplying fluid to the inside of said packer, said line supplying fluid to the outside of said packer being connected on the downstream side of said pressure-reducing valve to said pressure regulator to maintain said regulator in open position, the line supplying fluid to the inside of said packer being connected to said pressure regulator to maintain said regulator in a closed position, said regulator being adjusted to remain in open position until the pressure of fluid charged to the inside of said packer exceeds the pressure of fluid charged to the outside of said packer by a predetermined amount.

III. Apparatus in accordance with claim 2 including a check valve in said line for charging fluid to the inside of said packer, said valve being located between the common pressure source and said pressure regulator.

IV. Apparatus in accordance with claim 3 including a check valve in the line for charging fluid to the inside of said packer, said check valve being located on the downstream side of the pressure reducing valve.

V. Apparatus in accordance with claim 4 including a second automatic pressure regulator, connected between said lines feeding fluid to the inside and outside of said packer at points on the downstream side of said first mentioned pressure reducing valve and said second regulator being activated by pressure of fluid on the inside and on the outside of said packer to remain in closed position until the pressure differential between the inside and outside of said packer exceeds a predetermined maximum.
6. Apparatus in accordance with claim 5 including means for releasing pressure in the line supplying fluid to the inside of the packer.

7. An expandable and collapsible packer for earth bores in accordance with claim 1 in which the pipe and the collapsible, substantially fluid-impermeable envelope fastened to said pipe to define an enclosed space with the walls of said pipe comprises a pipe adapted to extend into the earth bore, a collapsible and substantially fluid-impermeable envelope secured to the outside wall of said pipe to define a closed space with the walls of said pipe, said pipe being perforated above and below said envelope and being fitted with an annular, transverse partition superposed above said topmost perforations, a second pipe longitudinally mounted inside said first mentioned pipe and of smaller diameter than said first mentioned pipe, said second mentioned pipe extending through said transverse partition, terminating at a point above said partition and having an opening adjacent the upper end thereof and an outlet therefrom into the space between said envelope and said first mentioned pipe, said transverse partition providing a fluid-tight barrier in the annular space provided by said first and second mentioned pipes.

8. An expandable and collapsible packer for earth bores in accordance with claim 1 in which the pipe and the collapsible, substantially fluid-impermeable envelope fastened to said pipe to define an enclosed space with the walls of said pipe comprises a pipe adapted to extend into the earth bore, a collapsible, substantially fluid-impermeable envelope secured to the outside wall of said pipe to define a closed space with the walls of said pipe, said pipe being perforated within the space enclosed by said envelope to permit the passage of fluid from said envelope into the closed space defined by said envelope, a second pipe mounted longitudinally within said first mentioned pipe and of smaller diameter than that of said first mentioned pipe, the inlet and outlet of said second pipe extending through the walls of said first mentioned pipe to permit the passage of fluid through said second mentioned pipe independently of said first mentioned pipe.

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