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PERFORATION AND CLEANING OF WELLS

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FIG. 4.

FIG. 6.

FIG. 5.

FIG. 7.

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This invention relates to improved apparatus and methods for perforating a well bore wall, and for cleaning the pores of the formation surrounding a well. The present application is a continuation-in-part of my co-pending application Serial No. 752,478, filed August 1, 1958, on "Cleaning Of Wells and Surrounding Earth Formation With Gases" and now abandoned.

In perforating the wall of a well bore by conventional methods, it is customary to utilize either a gun perforator which fires a bullet outwardly into the bore wall, or a jet perforator which directs a jet of high temperature gases against the bore wall. One of the objects of the present invention is to provide an improved method and apparatus which is capable of increasing the depth to which such a gun perforator or jet perforator can penetrate a well bore wall, so that the effect of a perforating operation in opening up the bore wall to fluid flow is considerably enhanced. In this way, the rate of production of a well can in many cases be greatly increased, and the period can be extended during which a well will produce effectively before requiring another perforating operation.

A further object of the invention is to provide a method and apparatus which will function, on one lowering into a well, to first perforate the well bore wall, and then emit compressed gases through the perforations deeply into the surrounding earth formation, to thereby clean and open the pores of the formation in a manner greatly facilitating the flow of production oil therethrough.

Some of the gases thus forced into the pores of the earth formation may be of very high temperature, to melt or soften accumulations which may be present in the pores of the formation, and to thus facilitate the opening of the pores by the pressurized gases. These high temperature and high pressure gases may be produced by a propellant charge, which is fired in such timed relation to the perforator units as to cause the gases to flow outwardly into the formation through the perforations formed thereby.

In performing a well cleaning operation utilizing the high temperature gases from a propellant charge of the above discussed type, the firing of the propellant charge in the well tends to produce a very sudden shock, which shock may damage the cleaning tool or the well liner if the propellant charge is too powerful. This danger is increased when a column of liquid is present in the well, because the liquid then tends to very abruptly halt the expanding gases in a manner maximizing the resultant shock. With this in mind, a further object of the present invention is to provide a method and apparatus for perforating and cleaning a well in the previously discussed manner, but in which special provision is made for minimizing the initial shock produced by a propellant charge of a given size, so that a relatively large and highly effective charge can be employed, to produce a very effective and thorough cleaning action extending deeply into the earth formation without danger of damaging either the tool or the well. More particularly, this result is achieved by the provision of a body of compressed gas in the tool, adapted to be freed from the tool and into the well in a unique and highly effective relationship to the firing of the combustible or explosive charge. To attain this desired result, this compressed gas is freed from the tool in a manner such that it flows outwardly into the earth formation in advance of the gases from the propellant charge, with the result that the compressed gases are able to initiate movement of the well fluid outwardly into the formation prior to the time that the high temperature gases from the propellant charge are emitted from the tool, to in this way cushion the shock caused by these high temperature gases. As a result, a much larger combustible charge can be employed than has heretofore been possible. In the preferred arrangement, two combustible propellant charges are provided, and are fired in sequence, so that the shock produced by the second of these charges is further cushioned by the gases developed by the first charge.

For the purpose of localizing the application of the gas force to a predetermined zone in the well, the tool desirably includes packer means, which are adopted to close off the well bore in a manner preventing escape of the treating gases from the desired zone. These packer means may include two vertically spaced packers, adapted to be expanded outwardly to their sealing positions of engagement with the bore wall by the force of gases developed in the tool upon firing the propellant charge.

The above and other features and objects of the present invention will be better understood from the following detailed description of the typical embodiments illustrated in the accompanying drawings, in which:

FIG. 1 shows a tool embodying the present invention, and positioned at the production zone within a well; FIG. 2 is an enlarged partially sectional view of the tool and well liner shown in FIG. 1; FIG. 3 shows the tool after firing of the perforating units, and after firing of the first propellant charge; FIG. 4 is a transverse section taken on line 4--4 of FIG. 2; FIG. 5 is a view showing the lower portion of the tool, with the piston returned to its upper position by the gases of the lower charge; FIG. 6 is a view similar to FIG. 2 but showing a variational form of the invention; and FIG. 7 is an enlarged horizontal section taken on line 7--7 of FIG. 6.

Referring first to FIG. 1, I have represented at 10 an oil well containing the usual casing 11, carrying a liner 12 at the location of the oil producing formation 13. Positioned in the well, within the interior of the liner 12 at the production zone, there is shown a tool 14 constructed in accordance with the present invention, and adapted to serve the dual purposes of perforating liner 12 and cleaning waxes, paraffins, and other accumulations from within the pores of producing formation 13. Liner 13 may be initially unperforated, or it may be a liner which has previously been perforated but in which the apertures have become clogged with waxes, etc. The tool 14 of FIG. 1 is suspended on a conventional wire line 15, which has associated with it electrical conductor wires 16 leading downwardly from the surface of the earth for conducting current to the tool to fire the contained perforator units and its other combustible or propellant charges. These leads 16 are connected at the surface of the earth to any suitable source of electrical energy, represented at 17 and under the control of a firing switch 18.

Referring now to FIG. 2, the tool 14 includes a vertically elongated tubular rigid metal body generally indicated at 19, and formed of a series of threadedly interconnected sections 20, 21, 22, 23, 24, 25, and 26. All of these various sections are formed of sufficiently strong metal, in sufficient thickness, to effectively withstand the relatively high pressures and forces which are exerted on the body by the contained compressed gases, and by the various combustible charges. The threaded connections 26, 27, 28, 29, 30 and 31 between successive sections of the body, as well as a threaded joint 131 between the
lowermost section 26 and a bottom externally rounded nose plug 32, are all sufficiently tight joints to form effective fluid tight seals, preventing leakage of any gases or well fluid between the interior and exterior of the body, at the locations of these joints. The uppermost body section 26 and its uppermost circular aluminum closure disc 48, typically carrying an annular O-ring 49 for engaging an inner surface of part 25 in annular fluid tight relation. Charge 44 is adapted to be fired by a firing cap or primer 50, which may extend upwardly into a recess 51 in disc 48, and which is adapted to be fired by a downwardly projecting pin 52 carried by a piston 53. This pin is adapted to punch an opening through the very thin portion 153 of disc 48, and thereby to engage and fire cap 50, to in turn ignite charge 44. The burning of charge 44 of course opens the closure 48 in section 26, and normally acts to virtually disintegrate part 54.

As has been previously mentioned, when the tool is initially lowered into a well, it contains a body of highly compressed gases which are to be released into the formation to reduce the shock caused by firing of the main combustible propellant charge 44. These gases are contained within the body sections 22, 23 and 24, vertically between aluminum seal member 38 and a frangible shear disc 82 directly above piston 53. While I have typically shown only three body sections 22, 23 and 24 at this location, it is to be understood that actually there would in many cases be provided a much greater number of these sections, each of an overall length to contain a proper amount of compressed gas for performing a particular desired well treating operation.

The piston member 53 is mounted for vertical movement within body section 25, whose inner cylindrical surface 54 is of a diameter only slightly greater than the outer cylindrical surface 55 of piston 53. The piston may have a number of elastomeric O-rings 56, for forming an effective fluid tight seal with the cylinder or barrel 25. During assembly of the device, piston 53 is adapted to be yieldingly detained in its FIG. 2 initial position at the upper end of barrel 25 by one or more ball detents 57, spring pressed outwardly by a coil spring 58 confined within a recess 59 in the piston.

Piston 53 contains an inner recess or passage 65 at its upper side, within which there is received a ball check valve 66 which seats downwardly against an annular seat or land 67 formed at the lower end of recess 65. A cage or web structure 68 at the upper end of recess 65 retains ball 66 within the recess, while still allowing limited upward movement of the ball off of seat 67. Gases from the underside of piston 53 can pass upwardly to the opening within seat 67 through a pair of passages 69, which may diverge to avoid interference with the pin 52 for firing the cap 50 of the lower propellant charge 44. As will be apparent, the ball check valve 66 will pass gases upwardly through the piston relatively freely, and yet will prevent downward movement of gases through the interior of the piston by engagement of check valve 66 with seat 67.

The body section 24 which is located just above the piston containing section 25 serves as the body of a perforator, for forming perforations 71 in liner 12 and in the surrounding formation. Part 24 is imperforate except at the locations of a number of shear plugs or frangible plugs 75, which may be sheared into openings 76 formed in the wall of part 24. At the inner side of each of the plugs 75, there is mounted a perforating unit 77, typically taking the form of a "shaped charge" of the type commonly used for perforating well liners. Each of these charges consists of a body of explosive or highly combustible material which is so shaped as to produce a radially outwardly directed jet of high velocity and high temperature gases, directed through the corresponding apertures 76, and capable of effecting a jet perforating operation on the liner 12 and the surrounding formation, to form the perforations 71 radially opposite apertures 76.
These high velocity jets produced by charges 77 have sufficient force to blow the plugs 75 out of their respective apertures 76, either by shearing the threads of the plug or by breaking the plug if it is of a frangible type. However, the plugs 75 and their threads have sufficient strength to withstand the pressure to which they are subjected prior to firing of charges 77. While the diagramming typically illustrates perforators 77 as taking the form of "shaped charges," it is contemplated that perforators may instead be conventional gun perforators, if desired, of a type acting to form perforations by actually firing bullets radially outwardly through the liner and into the formation.

The charges 77 may be arranged in sets of 4, as seen in FIG. 4, with the 4 charges of each set offset 90° from each other circularly about the vertical axis of part 24. A pair of positioning or retaining rods 78 and 79 hold the shaped charges 77 in place, with two of the charges being typically held outwardly against the corresponding plugs 76 at the opposite ends of each of the rods. The two rods may be interconnected at their centers 80, if desired. Enough of these sets of shaped charges 77 are provided to form the desired number of perforations 71 in liner 12.

The charges 77 are adapted to be fired by a fuse 81, which connects directly to, and is fired by, the firing cap 137 of upper propel lent charge 35. The fuse 81 is a very fast burning fuse, which the tool 14 permits the shaped charges 77 substantially simultaneously with cap 137. Also, the shaped charges 77 are of the usual very rapidly burning type, so that they have performed their perforating operation before the upper propel lent charge 35 (which is slow burning) has produced any very great increase in pressure within body sections 22, 23, and 24.

To assure this sequence of operation, fuse 137 may be a delay type of fuse, acting to introduce a predetermined delay interval (say 1/2 of a second) between the firing of charges 77 and the subsequent firing of charge 35.

The shear disc 82 serves to prevent downward actuation of piston 53 by the compressed gases which are contained in sections 22, 23, and 24, or by the firing of perforating units 77. Shear disc 82 may be circular and have its periphery clamped vertically between the lower end of part 24 and an annular upwardly facing shoulder formed on part 25. This clamping of the periphery of disc 82 between parts 24 and 25 forms a fluid seal, so that the compressed gases cannot pass downwardly through or past disc 82 and to the piston 53. The disc 82 is formed of a material (for instance, thin aluminum) which is capable of withstanding the pressures of the compressed gas in the tool above disc 82 and any increase in pressure produced by perforators 77, but is not capable of withstanding the pressure of the compressed gas plus the increase in pressure created by firing of charge 35. Thus, when charge 35 is fired, the resultant increase in pressure causes disc 82 to shear near its periphery, and thereby allow the force of the gases above disc 82 to pass downwardly against piston 53. The gas pressure then forces the piston 53 downwardly within body section 25, and into engagement with the upper end of gun 26, to bring pin 52 into firing contact with cap 30.

While any of various different types of combustible or explosive propellant material may be utilized for the charges 35 and 44, it may be stated generally that these charges are preferably so selected as to produce gases in very large quantity and preferably over a relatively long period of time. The ideal propellants are those usually referred to as "slow burning" and which contain negligible materials. The burning speed of the propellant or powder may typically be between about 0.2 of an inch and one foot per second.

A typical gas generating material may comprise a mixture of petroleum tar with or without some nitrocellulose distributed throughout the tar to increase the burning rate. Also, the tar may be mixed with other materials adapted to produce large quantities of gases on firing, such as waxes (e.g. sealing wax), and in some cases sulphur or other materials which may be added to slow the burning as desired. The charge may have a fusible extending vertically therethrough, and formed typically of a mixture of iron oxide, magnesium powder, and aluminum, in equal parts by weight. The size of the two charges 35 and 44 will depend upon the size and depth of the bore hole, and upon the length of the formation to be penetrated or purged, as well as upon the pressure and temperature conditions which prevail at the production zone.

In referring to the gas contained within body sections 22, 23 and 24 as highly compressed gas, it is meant that this gas is preferably at a pressure which is many times normal atmospheric pressure. Desirably, this pressure is much greater than the pressure of the well fluid at the production zone level in the well. Also, it may be stated that the pressure of the gas within body sections 22, 23 and 24 should for best results be at least about 2000 pounds per square inch, say between about 2000 and 18,000 pounds per square inch. This gas may in some cases be a gas such as nitrogen which is inert with respect to the materials and fluids encountered in an oil well, or the gas may be compressed air or compressed oxygen to cause localized burning deep within the surrounding earth formation upon firing of the tool.

To now discuss the method of using the tool of FIGS. 1-5, assume that the well 10 is filled with well fluid, and that it is desired to perforate liner 12 and to purge or clean the production zone 13. The first step is of course to properly load the tool 14 with perforators 77 and explosive charges 35 and 44, and with a highly compressed gas contained within body sections 22, 23 and 24.

The shaped charge 77 and charges 35 and 44 may be positioned in the tool by detaching guns 21 and 26 from the rest of the apparatus at joints 27 and 31 respectively. The tool is then assembled, and the compressed gas may be filled into body sections 22, 23 and 24 in any suitable manner, as by a filling valve connection represented at 161. Assume that the charges 35 and 44 are formed of petroleum tar having some nitrocellulose distributed therein, as discussed above. Also, assume that nitrogen is utilized as the compressed gas within body sections 22, 23 and 24, and is compressed to a pressure to supply 4000 pounds per square inch, with the well pressure itself at the production zone being about 2500 pounds per square inch.

The tool 14 is then lowered into the well, to the location represented in FIG. 1, and switch 18 is then closed to electrically activate cap 137. This cap ignites under propellant charge 35, and also ignites the various shaped charges 77 by means of fuse 81. As previously mentioned, the cap may be designed to introduce a delay between the firing of perforators 77 and charge 35 (say a delay of 1/4 of a second), or the firing of these units may be simultaneous if desired. However, even if the ignition of charges 77 and 35 is simultaneous, the rapid burning characteristics of fuse 81 and shaped charges 77 will still cause the shaped charges to fire completely (and form perforations 71) before the slow burning propellant material 35 has caused very much of an increase in pressure within sections 22, 23 and 24.

After the perforations 71 have been formed in this manner, the continued burning of propellant charge 35 causes an increase in pressure within body sections 21, 23, 24 and 24, which increases in pressure expands upper packer 41 against the liner in sealing relation (as seen in FIG. 3), and which prevents the escape of the compressed gases initially contained in the device. As will be apparent, as soon as plugs 75 are forced from their apertures 76 by charges 77, the compressed gases of course commence to flow outwardly from within the tool through apertures 76 and through perforations 71 into the earth formation. This move-
ment of the compressed gases commences an outward movement of the well fluid into the formation. The subsequent increase in pressure by gases produced by charge 35 assists in forcing all of the initially compressed gases out of the tool, to force most of those gases out through perforations 76 to the earth. When the pressure within sections 22, 23 and 24 reaches a predetermined value, that pressure ruptures the fragile disc 82, and then forces piston 53 downwardly as seen in FIG. 3. When the piston reaches its lowermost position, the pin 52 engages cap 50, to fire the lower propellant charge 44. The gases from charge 44 exert a force that lifts the piston 53 back upwardly as seen in FIG. 5, to its initial position, and those gases also flow through passages 69 and 65, and past check valve 66, to pass upwardly through the interior of the piston for discharge from tubular section 72 through apertures 76. Thus, the large volume of high temperature and high pressure gases from lower charge 44 are emitted from the tool after or following the emission of the initially compressed gases, so that those compressed gases act as a cushion to reduce the shock produced by the very heavy propellant charge 44. Also, the gases from charge 44 of course expand the lower packer sleeve 72 outwardly from the body of the tool, which is capable of being seen in FIG. 12, to contain an open passage 69a extending entirely therethrough. At the lower end of this passage, the firing pin 52a, for firing lower charge 44a, is mounted to the piston by a web structure 152a. When upper charge 155a is fired, the passage 69a offers sufficient resistance to the flow of gases downwardly therethrough to cause the piston to be actuated downwardly by the gases. When charge 44a is then fired, the gases from that charge flow upwardly through passage 69a for discharge through the apertures 76a in body section 24a.

In the device of FIGS. 6 and 7, the four shaped charges 77a at each level may be contained within a plurality of interconnected mounting tubes, including a first tube 177a containing one of the charges, and two additional tubes 277a welded to tube 177a and projecting perpendicularly thereto. When plugs 75a are screwed into their respective elongated tube 76a, they are tightened against tube 177a, and 277a to hold them in place. The plugs have reduced thickness wall portions 176a, which are located opposite charges 77a, and which are adapted to be broken or opened by the force of the gases produced by charges 77a. The tube 177a may contain an opening 181a near its upper end for passing fuse 81a to the various charges 77a.

1. Apparatus to be lowered into a well, said apparatus comprising a vertically elongated tubular body having a portion forming a chamber containing a mass of highly compressed gases, said body having a side wall containing a plurality of apertures through which said gases may escape when the apertures are open, plugs initially closing said apertures, perforator units contained in said body opposite said plugs and adapted when fired to force the plugs open and form perforations in the well bore wall about said body, a first propellant charge in communication with said chamber at a first end of the body adapted when fired to force said gases from the chamber and through said perforations into the surrounding formation, a second propellant charge in communication with said chamber at the second end of the body and adapted when fired to emit high temperature gases into the well and through said perforations behind said compressed gases, upper and lower bore sealing packers positioned to be forced against the bore wall by the gases of said second propellant charges respectively, means for communicating the gases of said two charges to said packers respectively, and means for firing said perforator units and said two charges in a predetermined timed relation such that first the perforator units form said perforations and release said compressed gases, and then the high temperature gases from said two propellant charges follow the compressed gases through the perforations.

2. Well apparatus as recited in claim 1, in which said last mentioned means include fuse means for firing said perforator units and said first propellant charge, a piston in the tool positioned to be movable vertically by the force of the gases produced by said first charge, and means for firing said second charge in response to said movement of said piston.

3. Apparatus as recited in claim 1, in which said first and second propellant charges are respectively above and beneath said perforator units.

4. Well apparatus as recited in claim 1, in which said last mentioned means include fuse means for firing said perforator units and said first propellant charge, a piston in the tool positioned to be movable vertically by the force of the gases produced by said first charge, and means for firing said second charge in response to said movement of said piston, said perforator units being located vertically between said two propellant charges, and said piston being located vertically between said perforator units and said second charge.

5. Apparatus to be lowered into a well, said apparatus comprising a vertically elongated tubular body having a portion forming a chamber containing a mass of highly compressed gases, said body having a side wall containing a plurality of initially closed apertures, perforator units contained in said body and adapted when fired to open said apertures and thereby free said gases from the body and to form perforations in the well bore wall about said body, a propellant charge in the body in communication with said chamber and adapted when fired to force said gases from the chamber through said apertures and through said perforations into the surrounding formation, and means for firing said perforator units and said charge in a predetermined timed relation such that first the perforator units form said perforations and release said compressed gases from said chamber, and then high temperature gases from said charge follow the compressed gases from said chamber through said apertures and then through the perforations.

6. Apparatus to be lowered into a well, said apparatus comprising a vertically elongated tubular body having a portion forming a chamber containing a mass of highly compressed gases, said body having a side wall containing a plurality of initially closed apertures, perforator units contained in said body and adapted when fired to open said apertures and thereby free said gases from the body and to form perforations in the well bore wall about said body, a first propellant charge in communication with said chamber at a first end of the body adapted when fired to force said gases from the chamber through said apertures and through said perforations into the surrounding formation, a second propellant charge in communication with
said chamber at the second end of the body and adapted when fired to emit a large volume of high temperature gases into the well through said apertures and then through said perforations behind said compressed gases, and means for firing said perforator units and said two charges in a predetermined timed relation such that first the perforator units form said perforations and release said compressed gases, and then the high temperature gases from said two propellant charges follow the compressed gases through the perforations.

7. Apparatus as recited in claim 6, in which said last mentioned means include a piston located vertically between said units and said second charge and movable vertically by the force of the gases from said first charge, and means actuable by said piston upon said vertical movement to fire said second charge.

8. A well tool to be lowered to a predetermined zone within a well, said tool including a perforating device adapted when fired to form perforations in the well bore wall, said tool forming a chamber containing a body of highly compressed gases adapted to be freed from the chamber and into the well at a location to pass through said perforations and deeply into the surrounding formation, said compressed gases being at a pressure at least about as high as 2000 p.s.i., a propellant charge carried by the tool adapted when fired to emit high temperature gases from the tool, and means for firing said perforating device and said propellant charge and freeing said compressed gases in predetermined timed relation so that first the perforations are formed, then the compressed gases flow through the perforations by virtue of the differential between the pressure of said gases and the pressure of the well at said zone, and then the high temperature gases flow through the perforations and into the formation behind said compressed gases.

9. A well tool as recited in claim 8, including two vertically spaced bore sealing packers carried by said body for closing off the upper and lower ends of said zone, and means for communicating gas pressure from said charges to at least one of said packers, said one packer being adapted to be expanded against the bore wall by said gas pressure.

10. A well tool to be lowered to a predetermined zone within a well, said tool including a perforating device adapted when fired to form perforations in the well bore wall, said tool forming a chamber containing a body of highly compressed gases adapted to be freed from the chamber and into the well at a location to pass through said perforations and deeply into the surrounding formation, a propellant charge carried by the tool adapted when fired to emit high temperature gases from the tool, means for firing said perforating device and said propellant charge and freeing said compressed gases in predetermined timed relation so that first the perforations are formed, then the compressed gases flow through the perforations, and then the high temperature gases flow through the perforations and into the formation behind said compressed gases, a second propellant charge carried by the tool and spaced vertically from the first charge, an element mounted between the two charges and exposed to and movable vertically by the gases produced upon firing of the first charge, and means operable to automatically fire the second charge in response to said movement of said element.

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