Nov. 20, 1962 H. A. BOURNE, JR 3,064,733

APPARATUS AND METHOD FOR COMPLETING WELLS

Filed Oct. 29, 1959 4 Sheets-Sheet 1

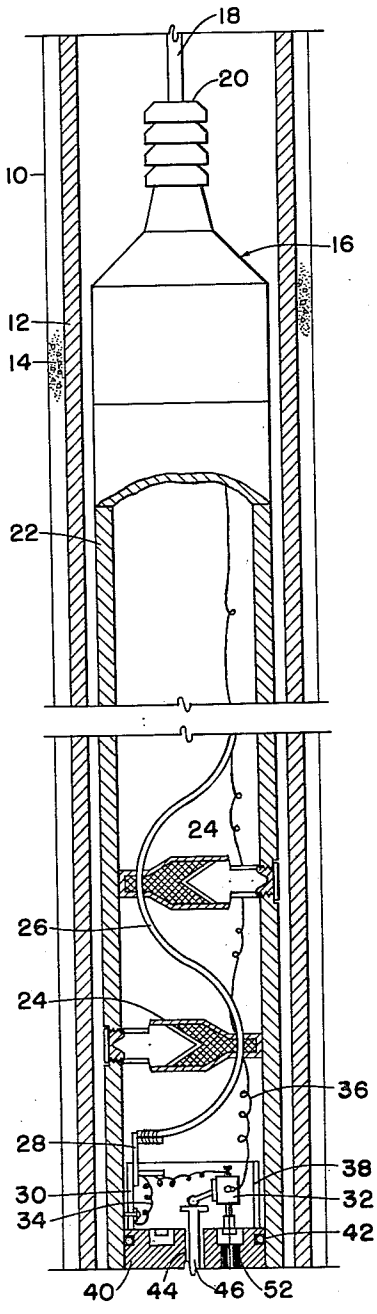


FIG. 1

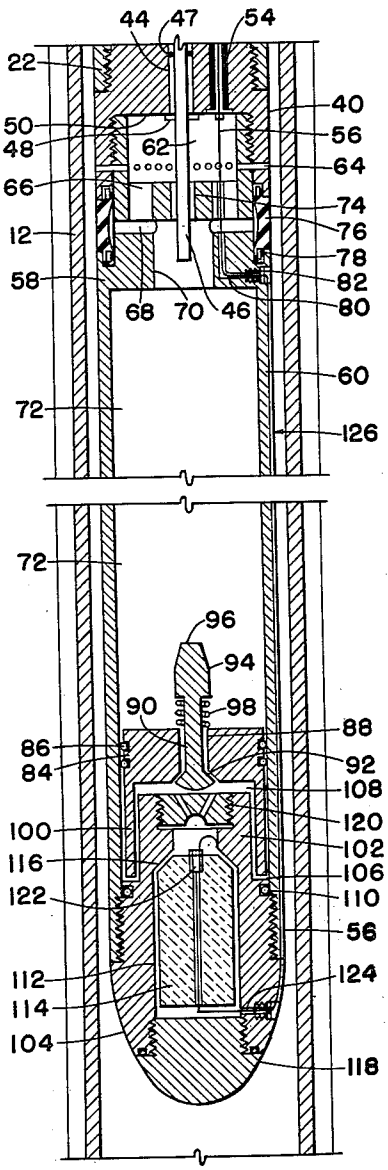


FIG. 2

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Filed Oct. 29, 1959 4 Sheets-Sheet 2

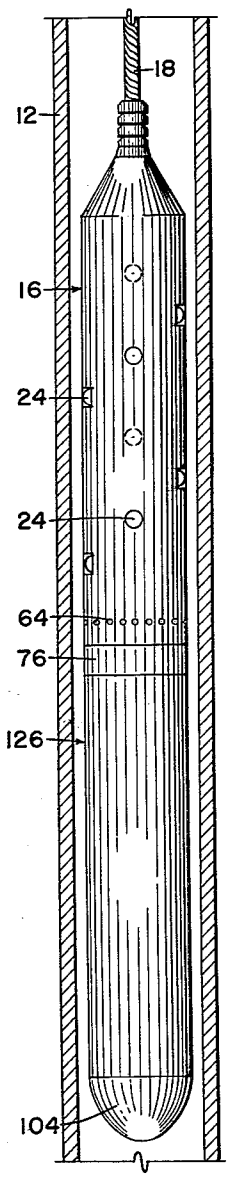


FIG. 3

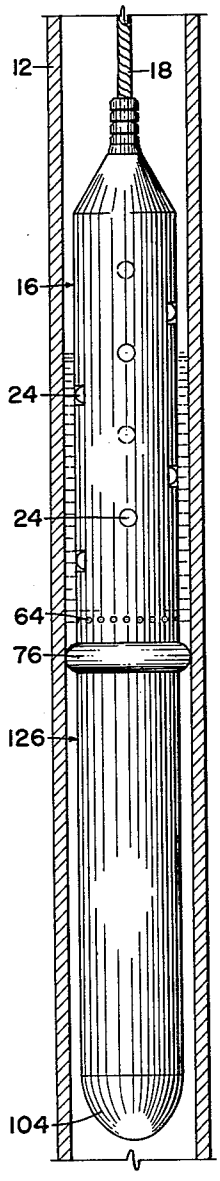


FIG. 4

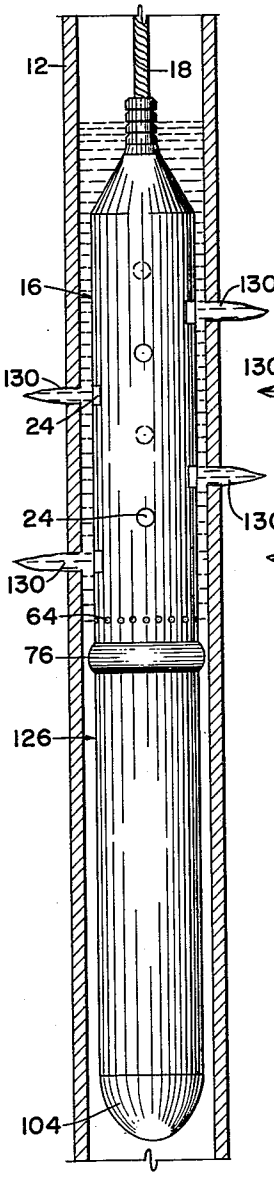


FIG. 5

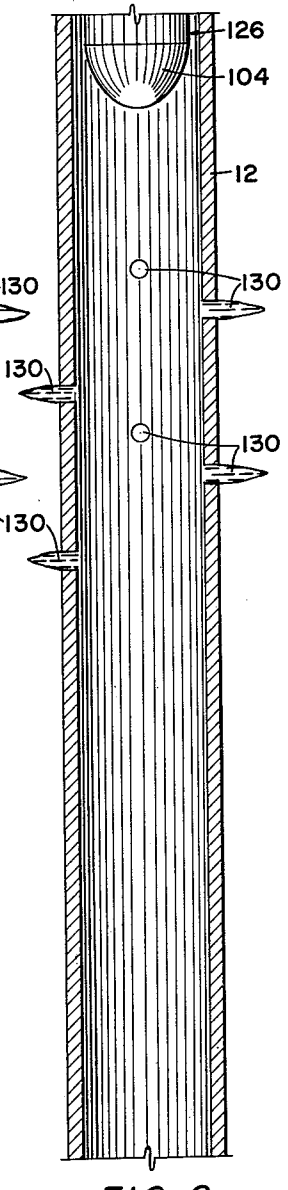


FIG. 6

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APPARATUS AND METHOD FOR COMPLETING WELLS

Filed Oct. 29, 1959 4 Sheets-Sheet 3

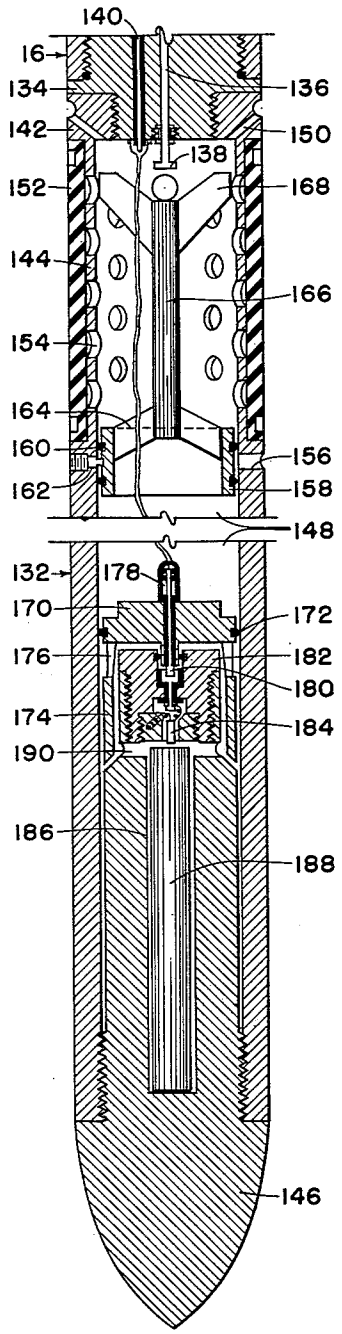


FIG. 7

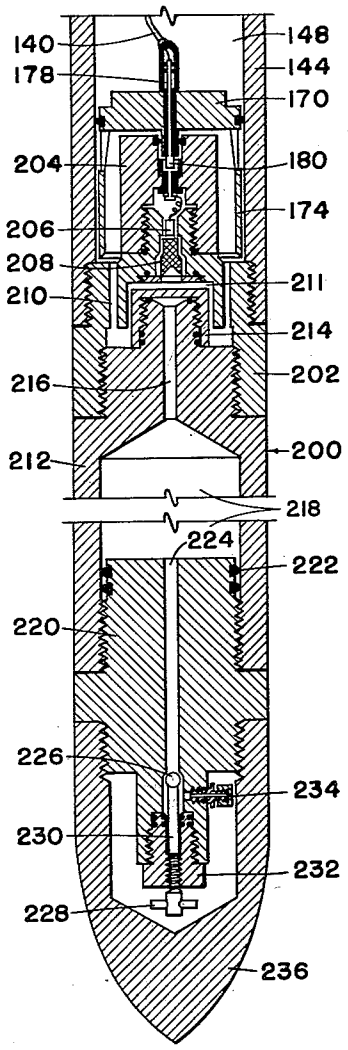


FIG. 8

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Nov. 20, 1962 H. A. BOURNE, JR 3,064,733

APPARATUS AND METHOD FOR COMPLETING WELLS

Filed Oct. 29, 1959 4 Sheets-Sheet 4

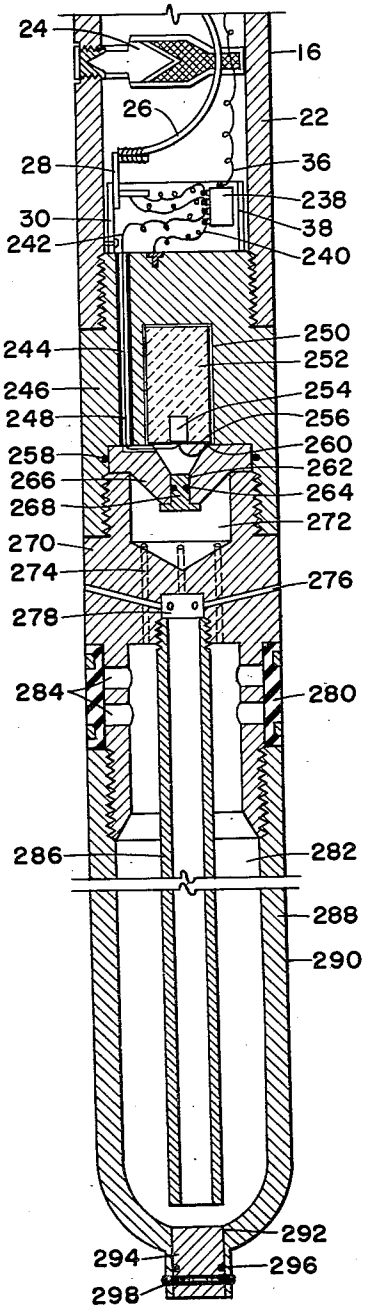


FIG. 9

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APPARATUS AND METHOD FOR COMPLETING WELLS

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Filed Oct. 29, 1959, Ser. No. 849,602
8 Claims. (Cl. 166—55)

This invention relates to an improved method and apparatus for completing oil and gas wells. This invention is a continuation-in-part of my co-pending application, Serial No. 631,606 entitled, Apparatus and Method for Completing Wells," filed December 31, 1956, now abandoned.

As is well known in the art, many oil and gas wells are completed by perforating either the casing or the open well bore in the depth intervals where it is expected that oil and gas will be produced. The perforating may be accomplished by means of bullets, shaped charges, or punch-type perforators. A perforating gun containing the desired perforating means is lowered through the well bore on the lower end of a suitable cable and positioned opposite the formation to be perforated. Ordinarily, the drilling mud used in drilling the well is maintained in the well bore during the perforating operation to maintain a hydrostatic pressure in excess of the formation pressure. The drilling fluid or mud invariably contains solid materials which are normally used to provide a low loss of fluid from the drilling mud to the various formations. In addition, some muds contain solids for density control. These solid materials will enter the perforation during and subsequent to the perforating operation to effectively plug off the channels or holes made by the perforating means and thus inhibit the flow of formation fluids into the well bore. Some of the plugging material may be removed under producing conditions; but in many cases, it remains in the perforations permanently. Many drilling muds have water as a primary constituent, and the water is forced into the perforations under hydrostatic pressure, entering the portion of the formation surrounding each perforation. Frequently water causes native clays in the producing formation to swell, resulting in a permanent reduction in formation permeability near the perforation.

The plugging problem arising when drilling mud is retained in a well as the well is being perforated has been recognized by those skilled in the art. Heretofore, however, the solutions to the problem which has been advanced involve the replacement of either all or a substantial portion of the drilling mud from the well bore, and the substitution of the drilling mud with a more desirable perforating fluid. In the use of such solutions, a tubing is ordinarily run into the well bore either to the bottom of the well or to a position below the formation which is to be perforated. The desirable perforating fluid is then forced downwardly through the tubing and upwardly in the annulus between the tubing and the well casing (or the well bore), thus displacing the drilling mud. After the desired amount of drilling mud has been displaced, the tubing must be removed from the well and then the perforating gun is lowered to the desired position and fired. It will be apparent that, with this type of operation, a very substantial amount of the drilling mud must be displaced to assure that the desirable perforating fluid will occupy the entire zone which is to be perforated. The operation also involves the time-consuming and expensive job of running and removing a complete string of tubing into the well bore prior to the actual perforating operation. Unless the displacing fluid in this operation has a density equal to or in excess of that of the drilling fluid, there is no assurance that the displacing fluid will remain in place while the tubing is being pulled and prior to the perforating process.

The present invention contemplates a method wherein the perforating gun is lowered through the drilling mud to the desired perforating position. The drilling mud immediate surrounding the perforating gun is then displaced by an optimum perforating fluid and subsequently thereafter the gun is fired while said perforating fluid is in position surrounding the gun. Thus the perforating means will not force drilling mud into the perforations, and the perforations will be immediately filled with an optimum fluid to exclude the plugging action of the usual drilling mud. As to apparatus, we contemplate a novel attachment for a perforating gun which functions to retain a supply of optimum perforating fluid with the gun and to expel the optimum perforating fluid upwardly around the gun prior to the perforating operation, whereby the desirable benefits described above will be attained.

An important object of this invention is to improve oil and gas well-completion techniques.

Another object of this invention is to prevent the plugging of perforations by drilling mud or materials contained in the drilling mud during the completion of oil and gas wells.

A further object of this invention is to displace drilling mud from around a perforating gun with an optimum perforating fluid during the perforating of a well.

Another object of this invention is to displace the drilling mud from around a perforating gun by means of a minimum of equipment and manipulations of instruments in and out of the well bore during a perforating operation.

A still further object of this invention is to provide an attachment for a perforating gun whereby the drilling mud may be displaced from around the perforating gun prior to firing the gun in a well bore.

Other objects and advantages of the invention will be evident from the following detailed description, when read in conjunction with the accompanying drawings, which illustrate my invention.

In the drawings:

FIGURE 1 is a vertical sectional view through a portion of a well bore having a perforating gun suspended therein, with a portion of the perforating gun being shown in section to illustrate details of construction.

FIGURE 2 is a continuation from the lower end of FIGURE 1 illustrating my preferred perforating fluid placement tool attached to the lower end of the perforating gun.

FIGURES 3, 4, 5, and 6 illustrate the various steps involved in practicing the method of the present invention.

FIGURE 7 is a vertical sectional view through a modified perforating fluid placement tool.

FIGURE 8 is a vertical sectional view through still another modified perforating fluid placement tool.

FIGURE 9 is a vertical sectional view through still another modified perforating fluid placement tool.

Referring to the drawings in detail, and particularly to FIGURE 1, reference character **10** designates a well bore having the usual well casing **12** secured therein by means of a cement sheath, partially shown at **14**, in the annulus between the well bore **10** and the casing **12**. It will be understood that although we have shown the use of a well casing **12**, the present invention is applicable to wells completed open-hole wherein no casing is used through the potentially producing formations. Of course, the cement sheath **14** is merely illustrative of a typical well installation and is not limiting on the present invention.

A perforating gun, generally designated by reference character **16**, is suspended in the well casing **12** by means of a cable **18**. The cable **18** is of a type which will support the perforating gun **16**, and through which suitable electric leads or wires (not shown) extend to provide a conduction of electric current from the surface of the well to

the perforating gun 16. The upper end of the cable 18 is ordinarily connected to a suitable firing mechanism or instrument truck (not shown) at the surface of the well for actuating the perforating gun 16. The lower end of the cable 18 is connected to the perforating gun 16 by means of a suitable cable connector 20.

The perforating gun 16 comprises a suitable tubular housing 22 having a series of shaped charge-type perforators 24 therein in the usual manner. It will be understood that the shaped charge-type perforators 24 may be replaced with any other suitable type of perforating means, such as bullet perforators (not shown). A fuse 26 extends lengthwise through the gun housing 22 and through the firing ends of the perforators 24 to fire the perforators 24 in rapid succession. A suitable detonator 28 is connected to the lower end of the fuse 26 and is secured in the lower end portion of the housing 22 by means of a suitable bracket 30. The detonator 28 is electrically connected to a single pole, double throw switch 32 and a suitable ground wire 34 leading to the housing 22. A lead wire 36 extends upwardly from the center pole of the switch 32 to the cable 18, and thence to the surface of the well, whereby the center pole of the switch 32 will be energized when a suitable electrical current is supplied from the surface installation. The switch 32 is secured in the lower end portion of the housing 22 opposite the detonator 28 by a suitable bracket 38. The switch 32 is preferably of the toggle type, wherein the switch arm will provide electrical communication between the lead 36 and the detonator 28 when the lever is in its upper position, as will be more fully hereinafter set forth.

A plug 40 (see also FIGURE 2) is secured in the lower end of the perforating gun housing 22 and extends upwardly into the gun housing to a point immediately below the switch 32. It is preferred that the plug 40 be sealed to the inner periphery of the gun housing 22 by a suitable sealing ring 42, whereby drilling mud and the like will not leak into the gun housing 22 and interfere with the operation of the perforating gun. A bore 44 extends vertically through the central portion of the plug 40 to slidingly receive a push rod 46. However, the rod 46 is sealed to the walls of the bore 44 by a sealing ring 47. The upper end of the push rod 46 is suitably shaped to contact and actuate the lever of the switch 32, and the lower end of the push rod 46 extends a substantial distance below the plug 40. A suitable flange-type stop 48 is formed on an intermediate portion of the push rod 46 below the lower face 50 of the plug 40, for purposes which will be hereinafter set forth. A second bore 52 extends vertically through the plug 40 to receive suitable insulation 54 and a lead 56 depending from the lower end of the switch 32. The lead 56 extends through the insulation 54, whereby a potential imposed on the lead 56 will not be short circuited through the plug 40.

The lower end of the plug 40 is counterbored and internally threaded to receive the upper head 58 of a lower tubular housing 60. The upper end of the head 58 is also counterbored to provide a chamber 62 immediately below and in communication with the lower end face 50 of the plug 40. A series of discharge ports 64 extend through the walls of the head 58 from the chamber 62 in circumferentially spaced relation. The discharge ports 64 communicate with mating ports extending through the lower skirt portion of the plug 40, whereby communication is established from the chamber 62 to the annulus between the plug 40 and the casing 12.

A plurality of vertical ports 66 extend downwardly through the head 58 from the chamber 62 to communicating transversely extending ports 68. The ports 68 in turn communicate with a centrally located passageway 70. For purposes of description, the passageway 70 may be considered as an extension of the main chamber 72 of the housing 60. The push rod 46 extends downwardly through the chamber 62 and loosely through a bore 74 in the head 58 into the passageway 70, whereby the lower

end of the push rod 46 will be exposed to the main chamber 72 of the housing 60.

An expandable packer 76 is disposed around the outer periphery of the head 58 immediately below the lower end of the plug 40. The packer 76 may be suitably secured to the lower end of the plug 40 and an upwardly extending shoulder 78 of the housing 60 in a position directly opposite the transverse ports 68. The packer 76 is of a size to expand and engage the inner periphery of the well casing 12 when fluid under pressure is forced outwardly through the transverse ports 68 into contact with the packer.

The lead 56 extends on downwardly through the head 58 and may be extended through one of the vertical ports 66 and then through an L-shaped passageway 80 to the outer periphery of the head 58 near the lower end thereof. A suitable insulating plug 82 is secured around the lead 56 at the point where the lead emerges from the head 58 and the lead 56 will be suitably insulated from the head 58 throughout the length of the head. From the insulated plug 82, the lead 56 preferably extends downwardly along the outside of the housing 60 to the lower end of the housing.

The main chamber 72 of the housing 60 is of substantial length and is provided to contain a supply of optimum perforating fluid, as will be more fully hereinafter set forth. A piston 84 is reciprocably disposed in the main chamber 72 and is sealed to the inner periphery of the chamber by suitable sealing rings 86. The piston 84 has a bore 88 extending vertically through the central portion thereof to slidingly receive a valve rod 90 which has a valve head 92 on the lower end thereof. The lower end of the bore 88 is suitably tapered to receive the valve head 92 when the valve 90 is in its uppermost position, as shown, to prevent an upward flow of fluid through the piston 84. An enlarged head 94 is provided on the upper end of the valve 90 and is of a diameter to enter the upper extension 70 of the main chamber 72, as will be more fully hereinafter set forth. The upper end 96 of the head 94 engages the lower end of the push rod 46, when the head 94 enters the chamber extension 70 to raise the push rod 46. A suitable compression spring 98 surrounds the valve rod 90 and is anchored between the head 94 and the upper end of the piston 84 to yieldingly retain the valve 90 in its upper position, with the valve head 92 in contact with the valve seat at the lower end of the bore 88.

A tubular skirt 100 is provided on the lower end of the piston 84 to telescope over the reduced upper end 102 of a bottom plug member 104. The skirt 100 is preferably of a length to contact the upwardly facing shoulder 106 formed on the plug 104 at the lower end of the extension 102, prior to the time the piston 84 will contact the upper end of the extension 102, whereby a space 108 is provided between the piston 84 and the upper end of the extension 102 when the piston is in its lowermost position.

The lower plug 104 is threadedly secured in the lower end of the housing 60, and is preferably sealed to the inner periphery of the housing 60 by a suitable sealing ring 110 to prevent the escape of fluid from the main chamber 72. A bore 112 extends vertically through the lower plug 104 to receive a charge 114 of slow burning powder. The powder charge 114 is retained in the bore 112 by a shoulder 116 at its upper end and a second lower plug 118 at its lower end. The plug 118 is threaded into the lower end of the bore 112 and is preferably sealed to the lower plug 104. A perforated retainer 120 is threadedly secured in the upper end of the vertical bore 112 a short distance above the powder charge 114 to diffuse the gas evolved upon detonation of the charge 114 as will be more fully hereinafter set forth.

A suitable detonator 122 is disposed in the upper end of the powder charge 114 and is suitably grounded to the lower plug 104. The lead 56, extending from the switch 32, is directed through a passageway 124 in the lower por-

tion of the plug 104 and then upwardly through the center of the powder charge 114 to the detonator 122. The lead 56 will, of course, be insulated from the lower plug 104 and the powder charge 114.

For clarity of description, all of that structure extending from the intermediate plug 40 downward will be designated by reference character 126 and referred to herein as the perforating fluid placement tool.

Operation

Before running the perforating gun 16 and the attached fluid placement tool 126 in the well casing 12, the main chamber 72 of the fluid placement tool is filled with an optimum perforating fluid, and the piston 84 is positioned in the lower end of the chamber 72, with the skirt 100 in contact with the shoulder 106 of the lower plug 104. The perforating fluid placed in the chamber 72 may be any suitable type of petroleum oil, either refined or crude, which has a low fluid loss. It is preferred that the fluid loss qualities of the perforating fluid be less than 2 cc. when tested by the standard A.P.I. fluid loss test for drilling fluids. It is also preferred that the perforating fluid have a suitable gelling agent, such as an alkali metal soap, incorporated therein, whereby the viscosity of the fluid will be substantial when the fluid is at rest. In any event, the perforating fluid should have a viscosity greater than the viscosity of the drilling mud which is to be displaced from around the gun 16 in the casing 12. Also, the perforating fluid should contain no solid material which cannot be washed off the face of a formation by formation fluids entering the well. Fluids of this type are well known to the art of well completion.

Prior also to running the gun 16 in the casing 12, the switch 32 is set in such a position that the switch lever will be extended downwardly to place the lead 36 in contact with the lead 56; and the push rod 46 should be in its lowermost position with the upper head of the push rod in contact with the upper end of the intermediate plug member 40. With the perforating gun 16 and the fluid placement tool 126 assembled in this manner, they may be run into the casing 12 on the lower end of the cable 18.

The method of this invention is best illustrated in FIGURES 3 through 6. As shown in FIGURE 3, the perforating gun 16, having the fluid placement tool 126 secured on the lower end thereof, is run into the well casing 12 on the cable 18 until the perforating gun 16 is at the level where it is desired to perforate the casing 12. The current source at the surface of the well is then placed in operation to direct electric current downwardly through a lead in the cable 18 and the lead 36 (FIGURE 1) to the center pole of the switch 32. The current will proceed on downwardly through the lead 56 (FIGURE 2) to the detonator 122. Whereupon, the detonator 122 will be fired to ignite the powder charge 114. As the powder charge 114 burns, gas will be forced upwardly through the perforated retainer 120 into the space 108 and against the lower face of the piston 84. The pressure of the generated gas will be sufficient to force the piston 84 upwardly through the chamber 72 to displace the perforating fluid from the chamber 72.

As the perforating fluid is forced upwardly, it first flows through the passageway 70 and then outwardly through the ports 68 into contact with the packer 76 and then upwardly through the ports 66, chamber 62, and discharge ports 64. Since the discharging perforating fluid flows through ports 64, the back pressure exerted by the perforating fluid in chamber 62 and ports 68 will be increased to such an extent that the packer 76 will be expanded into sealing contact with the inner periphery of the casing 12. This position of the packer 76 is illustrated in FIGURE 4.

The perforating fluid is forced on upwardly and out through the discharge ports 64 into the annulus between the perforating gun 16 and the well casing 12. The packer 76 prevents a downward flow of the perforating fluid; and since, the perforating fluid has a higher viscosity than the drilling mud normally surrounding the perforating gun 16, the perforating fluid will displace the drill mud upwardly from around the perforating gun 16. A quantity of drill mud substantially equal to the perforating fluid displaced from the chamber 72 is allowed to flow from the well head (not shown). FIGURE 4 also illustrates the perforating fluid being thus forced upwardly around the perforating gun 16 to effectively displace all drilling mud from around the gun.

As the piston 84 (FIGURE 2) reaches the upper end of the chamber 72 and the perforating fluid has been substantially discharged from the chamber 72, the upper end 96 of the valve head 94 will contact the lower end of the push rod 46. Thus, flange stop 48 will fail in shear and the push rod 46 will be raised to contact and throw the lever of the switch 32 to an upper position. When the switch 32 is thrown, the current from the lead 36 is directed to the detonator 28 for igniting the fuse 26 and firing the shaped charges 24. The shaped charges 24 provide high velocity jets which pierce the casing 12 as well as the cement sheath 14 and enter the formation surrounding the well bore 10. Such perforations are illustrated by reference character 130 in FIGURE 5. It will be apparent that since the optimum perforating fluid surrounds the entire perforating gun 16 when the shaped charges 24 are fired, the perforations 130 will be filled with the optimum perforating fluid, and the low fluid loss characteristics of the optimum perforating fluid limits the amount of the perforating fluid which will be lost to the formation through the perforations 130. The perforating fluid also may contain an oil soluble plastering material which will lay a coat or blanket around the inner periphery of the perforations 130, if desired.

Prior to the reversing or throwing of the switch 32, the upper end 96 of valve 90 must contact the lower end of push rod 46 causing it to move upward. Push rod 46 under an upward load shears free from flange stop 48 and moves upwardly with the same speed as valve 90. As the upper portion 94 of valve stem 90 enters recess 70 the reduced clearance between the head 94 and bore 70 results in a restriction in flow from chamber 72 to ports 68. The flow area between head 94 and bore 70 is less than the combined flow area of ports 64. When this occurs, the rate of fluid ejection from chamber 72 is reduced and packer 76 begins to retract inwardly. Push rod 46 is forced upward and throws the toggle cam of switch 32 upwardly, resulting in the switching of lead 36 (still hot) to detonator 28 which fires the shaped charges. The upper end 96 of valve stem 90 contacts the upper end of chamber 70 almost immediately after detonation of the perforating charges. When this occurs, valve stem 90 is restrained from further upward movement. Piston 84, still under the influence of expanding gas, continues to move upward causing the lower valve head 92 to move off its seat. Gas under pressure then flows past valve 92; through relief passage 88; thence between upper end 94 and the walls of chamber 70, ports 68, ports 66, chamber 62, ports 64; and into the annular space between the plug 40 and the casing 12.

As indicated above, it is preferred that the packer 76 be retracted at least a short distance prior to or simultaneous with the firing of the perforating gun 16, whereby the greatly increased pressure around the perforating gun resulting from the firing will not tend to injure or rupture the packer 76. If the packer 76 is retracted substantially simultaneously with the firing of the perforating gun, the perforating fluid surrounding the perforating gun will not have had an opportunity to be displaced by drilling mud, either from above or below the gun; and the perforating fluid will be in the proper position for filling the perforations 130. The operation of retraction of the packer 76 and creation of the perforations 130 is illustrated in FIGURE 5.

After the perforating gun 16 is fired, the entire apparatus is removed from the well casing 12 by raising the cable

18. The packer 76 will have been completely deflated and will not interfere with this removal operation. The removal of the perforating gun 16 and fluid placement tool 126 is illustrated in FIGURE 6. After the apparatus has been removed from the well, the perforating fluid remaining in the perforations 130 will be gelled and will not be easily removed by circulation of the drilling mud in the casing 12. When the well is subsequently placed on production, the formation fluids will flow through the perforations 130 into the casing 12 and effectively wash the perforating fluid from the perforations. In other words, the perforating fluid will effectively prevent the entrance of drilling mud into the perforations, yet may be removed from the perforations by the inward flow of formation fluids. As previously indicated, if the perforating fluid contains a plastering agent, it should be oil soluble in order to be fairly rapidly dissolved by formation fluids, whereby the formation fluids will readily flow through the perforations into the well as soon as the well is placed on production.

A modified perforating fluid placement tool is shown in FIGURE 7 and is generally designated by reference character 132. The tool 132 comprises an upper plug 134 having external threads on its upper end for connection with the lower end of a perforating tool 16 in a manner similar to that previously described. The plug 134 has a push rod 136 extending loosely therethrough to function in the same manner as the push rod 46 described and shown in the embodiment of FIGURES 1 and 2. The lower end of the push rod 136 is positioned only a short distance below the plug 134 and preferably has a head 138 formed thereon. An insulated lead 140 also extends upwardly through the plug 134 for connection with a single-pole, double-throw switch (not shown) in the perforating gun 16 in the same manner as previously described.

The lower end portion of the plug 134 is reduced in diameter and threaded to receive the upper end 142 of a tubular housing 144. The lower end of the housing 144 is closed by a solid plug 146, whereby the interior of the housing 144 defines an enlarged chamber 148.

A plurality of circumferentially spaced discharge ports 150 extend through the head portion 142 of the housing 144 to provide communication between the chamber 148 and the outer periphery of the housing. It is preferred that the discharge ports 150 extend upwardly at an angle, whereby fluid forced outwardly through the ports will be directed upwardly around the perforating gun 16. An inflatable packer 152 is secured around the outer periphery of the housing 144 immediately below the discharge ports 150. The packer 152 is formed out of a resilient material and is of a size to engage the inner periphery of a well casing or well bore when in an expanded position. A plurality of ports 154 extend through the walls of the housing 144 opposite the packer 152 to provide communication between the chamber 148 and the inner surface of the packer. It is preferred that a large number of the ports 154 be provided, whereby pressure imposed on fluid in the chamber 148 will be effectively transmitted to the packer 152.

A plurality of relief ports 156 extend transversely through the wall of the housing 144 immediately below the packer 152 for purposes which will be hereinafter set forth. The relief ports 156 are normally covered by a sleeve 158 having a pair of spaced sealing rings 160 around the outer periphery thereof in sealing engagement with the inner periphery of the housing 144. The sealing rings 160 are spaced apart a sufficient distance to straddle the relief ports 156 and effectively prevent the leakage of fluid from the chamber 148 through the relief ports 156 when the sleeve 158 is in the position shown in FIGURE 7. The sleeve 158 is held in its normal position over the relief ports 156 by means of a shear plug 162 threadedly secured in the wall of the housing 144. A spider 164 extends inwardly and upwardly from the sleeve 158 to support a tripping bar 166. The tripping bar 166 has a plurality of circumferentially spaced guides 168 on the upper end portion thereof to retain the bar in the central portion of the chamber 148. The guides 168 merely slide along the inner periphery of the housing 144 when the bar 166 is raised or lowered. The bar 166 is utilized to contact the head 138 of the push rod 136 and raise the push rod for actuation of the perforating gun 16, as will be more fully hereinafter set forth.

A piston 170 is slidingly disposed in the chamber 148 below the sleeve 158. The piston 170 is sealed to the inner periphery of the housing 144 by a suitable sealing ring 172 and has a skirt 174 extending downwardly therefrom. A plurality of ports 176 extend transversely through the piston skirt 174 for purposes which will be hereinafter set forth. The lead 140, previously described as extending through the plug 134, extends on downwardly through the chamber 148 and then through the piston 170 by means of an insulated rod 178. The lower end of the conductor rod 178 is inserted in a suitable electrical connector 180 carried in an extension 182 of the lower plug 146. The connector 180 is in turn connected to a suitable detonator 184 carried in the extension 182 below the connector 180.

A bore 186 extends downwardly into the lower plug 146 from the extension 182 to receive a charge 188 of slow burning powder. The charge 188 is of a length to extend into contact with the detonator 184, whereby the charge 188 will be ignited when the detonator 184 is fired. A plurality of transverse ports 190 extend through the sides of the plug 146 near the upper end of the bore 186 to discharge gases resulting from burning of the charge 188. The ports 190 communicate with the chamber 148 below the piston 170, whereby gases evolved from the powder charge 188 will tend to raise the piston 170 in the chamber 148.

Before running the perforating fluid placement tool 132 in a well, the piston 170 is placed in its lowermost position, as shown in FIGURE 7, with the conductor rod 178 in engagement with the electrical connector 180. The chamber 148 is filled with an optimum perforating fluid of the type previously described, and the switch of the perforating gun 16 is positioned such that current supplied to the supporting cable of the perforating gun will be directed downwardly to and through the lead 140. The perforating gun 16 and fluid placement tool 132 are then run into a well bore in the same manner as previously described. When current is supplied to the perforating gun, it flows through the lead 140, the conducting rod 178, and connector 180 to the detonator 184. Upon firing of the detonator 184, the powder charge 188 will be ignited and gas will be evolved under high pressure through the ports 190 to act on the lower face of the piston 170.

As the piston 170 is forced upwardly through the chamber 148, the perforating fluid will be displaced from the chamber through the discharge ports 150. Simultaneously, the increased pressure of the perforating fluid will be transmitted through the ports 154 to expand the packer 152 into engagement with the surrounding casing or well bore. As the piston 170 reaches the upper end of its stroke, it contacts the lower end of the sleeve 158 and ruptures the shear plug 162, whereby the sleeve 158 will be raised simultaneously upon further upward movement of the piston 170. The rod or bar 166 will be raised with the sleeve 158 into contact with the head 138 of the push rod, 136. Thus, the switch of the perforating gun 16 will be thrown to fire the gun and perforate the casing and formation surrounding the well bore, while the perforating fluid surrounds the perforating gun. The perforating fluid discharged through the ports 150 will be directed upwardly by the packer 152 to displace drilling mud from around the perforating gun 16 in the same manner as previously described.

Substantially simultaneously with the firing of the perforating gun 16, the lower sealing ring 160 of the sleeve 158 is raised above the relief ports 156. Whereupon. the

chamber 148 is placed into communication with the well bore below the packer 152 through the relief ports 156 and ports 176 in piston 170. Thus, the pressure imposed on the opposite side of the packer 152 will be balanced; and the packer will tend to retract out of engagement with the inner periphery of the casing or well bore. Then the high pressures created by firing the perforating gun 16 will not rupture or injure the packer 152.

Subsequent to the perforation of the well, the perforating gun 16 and perforating fluid placement tool 132 are removed from the well in the same manner as previously described.

Another modified perforating fluid placement tool is partially shown in FIGURE 8 and is generally designated by reference character 200. The tool 200 resembles the previously described tool 132 (FIGURE 7), in having the tubular housing 144 and piston 170 reciprocally disposed in the housing 144. The piston 170 carries the conductor rod 178 for connection at its upper end with the lead 140 and at its lower end to the connector 180 in the same manner as previously described. All portions of the perforating tool 200 in and connected with the upper end portion of the housing 144 are the same as described in connection with FIGURE 7.

The tool 200 differs from the previously described tool 132 in having an intermediate plug 202 threadedly secured in the lower end of the housing 144. An extension 204 is threadedly secured on the upper end of the intermediate plug 202 and is of a diameter to extend upwardly into the skirt 174 of the piston 170. The extension 204 is also utilized to support the connector 180. A detonator 206 is secured in the upper end of the plug 202 below the connector 180, and a suitable shaped charge 208 is disposed immediately below the detonator 206 in such a position to be fired when the detonator 206 is ignited. A plurality of circumferentially spaced passageways 210 extends vertically through the plug 202 to provide communication between the chamber 148 and a counterbore 211 in the plug 202 immediately below the charge 208, for purposes which will be hereinafter set forth.

A tubular extension 212 is threadedly secured in the lower end of the intermediate plug 202 and extends upwardly into the counterbore 211 of the plug 202 to a position adjacent the shaped charge 208. The upper end portion of the cylinder 212 is reduced in diameter and externally threaded to receive an expendable cap member 214. The cap 214 is positioned immediately below and in line with the shaped charge 208. The expendable cap 214 is sealed to the upper end of the cylinder 212 and closes off the upper end of a passageway 216 extending upwardly from the inner chamber 218 of the cylinder 212. It will also be observed that the counter bore 211 in the lower end of the plug 202 is of a larger diameter than the cap 214, whereby the upper end of the cap 214 is in communication with the vertical passageways 210.

A filling head 220 is threadedly secured in the lower end of the cylinder 212 and is sealed to the inner periphery of the cylinder by sealing rings 222 to effectively close off the lower ends of the chamber 218. A passageway 224 extends vertically through the central portion of the head 220 and has a stop valve 226 interposed in the lower end thereof. The stop valve 226 is operated by a suitable hand wheel 228 mounted on the lower end of the valve operating rod 230. The rod 230 extends through a suitable packing gland 232 secured in the lower end of the head 220. A gas-charging valve 234 of any suitable design is secured in the side of the lower end portion of the head 220 in communication with the passageway 224 below the stop valve 226, whereby the chamber 218 may be charged with gas when the stop valve 226 is open. A suitable cap 236 is threadedly secured on the head 220 to protect the hand wheel 228 and gas-charging valve 234 when the tool is run in a well bore.

In preparing the tool 200 for use in a well, the cap 236 is removed and the stop valve 226 is opened. A suitable supply of high-pressure gas, such as helium or nitrogen, is then fed through the charging valve 234 and passageway 224 into the chamber 218. Any high-pressure gas may be utilized, although it is preferred that the gas be inert in order that it will not form an explosive mixture in the well. The gas is injected into the chamber 218 until the pressure of the gas substantially exceeds that which is required to raise the piston 170 against the hydrostatic head of the drill mud in the well. The stop valve 226 and charging valve 234 are then closed and the cap 236 is reassembled on the filling head 220. The chamber 148 of the housing 144 is filled with an optimum perforating fluid in the same manner as previously described.

When current is passed through the lead 140, conductor rod 178 and connector 180 to the detonator 206, the detonator will be fired to ignite or fire the shaped charge 208. The high velocity jet created by the shaped charge 208 will pierce the expendable cap 214 directly above the vertical passageway 216 in the upper head portion of the cylinder 212. When this occurs, the high-pressure gas from the chamber 218 will be discharged through the passageway 216, chamber 211, and passageways 210 to act on the lower face of the piston 170. Whereupon, the piston 170 will be raised in the chamber 148 to displace the perforating fluid upwardly in the same manner as previously described.

The reduced pasageways 210 and the reduced passageway provided by the chamber 211 are utilized to throttle the high-pressure gas discharging from the chamber 218, whereby a sudden pressure will not be imposed on the lower face of the piston 170 and cause damage. It will be apparent that the chamber 218 must be of substantial length to contain a sufficient supply of gas for raising the piston 170 in the chamber 148; however this is not a limiting factor on the use of such a tool, since the tool may be made of any suitable length without interfering with the perforating operation.

Another modified perforating fluid placement apparatus shown in FIGURE 9 is generally designated by reference character 290 which encompasses all of the structure extending downwardly from the perforating means such as a string of charges 24 within tubular housing 22 of gun 16.

Placement tool 290 comprises an upper plug 246 having external threads on its upper end for connection to the lower end of perforating gun 16 in a manner similar to that previously described. Plug 246 is concentrically counterbored in order that a bore 250 partially extends vertically through the central portion of the plug to receive a charge 252 as a source of energy, such as a slow burning powder or a compressed gas.

Plug 246 is adapted to receive a charge retaining means 266 in another concentric counterbore, and is internally threaded therein to receive a plug 270. Charge 252 is maintained in position by charge retaining means 266 having shoulders 260, sealing means 258 and a bore 262 adapted to receive a flanged plug 268 having sealing means 264. A separate bore 244 extends completely through plug 246 in a vertical manner to receive a suitable insulation means 248 and a lead wire 242.

The lead wire 242 depends from a switching means 238 in the lower portion of perforating gun 16 which is secured to housing 22 as described above. (See FIGURE 1.) Switching means 238 is a switch having a first and a second position, such as a multiple terminal stepping switch. A lead wire 36 extends upwardly from a pole of the switch to cable 18 and thence to the surface of the well whereby switch 238 is energized when suitable electrical current is supplied from a surface installation (not shown).

Switch 238 is electrically connected in a first position to a detonator 254 by wire 242 which passes through bore 244 enabling the detonator to be energized by an operator at the surface. Detonator 254 is connected by a ground wire 256 to charge retaining means 266 to assure a com-

plete circuit. Switch 238 is connected by a suitable ground wire 240 to plug 246 and electrically connected in a second position to a detonator 23 which is in turn connected to fuse 26 as disclosed hereinbefore.

Detonator 254 is in communication with charge 252 and capable of igniting it to combust with rapidity to produce gases. Charge retaining means 266 keeps the charge in place and plug 268 prevents undesirable fluids from contacting the charge. Means 266 is maintained in position by a plug 270 which is partially counterbored at the upper end to provide a bore 272 in the upper portion and is externally threaded at both ends to attach to plug 246 and a housing 288. Plug 270 is also counterbored at the lower end to provide a partial vertical bore or chamber 282 and complete vertical bores 274 as a series of passageways or vertical ports. Plug 270 is further concentrically counterbored from the lower end to provide a bore 278 which is adapted to receive transfer means.

The gases which expand into bore chamber 272 can communicate into the series of pasageways 274 vertically through plug 270 which is attached at the lower end by threaded means to housing 288. A suitable packing means 280 is attached to plug 270 which is laterally bored in the lower portion to provide a series of ports 284. Gases can communicate through passageways 274 into chamber 282, within plug 270 and housing 288, and through ports 284, thereby causing packing means 280 to be expanded outwardly into the annular space between the apparatus 290 and the well casing or bore. Chamber 282 is capable of containing perforating fluid which also communicates with a transfer tube 286. The upper end of transfer tube 286 is connected to the adaptable portion of bore 278 within plug 270 which also contains a series of discharge ports 276 extending laterally in an outward and slightly upward manner through plug 270.

Housing 288 has an aperture 292 at the lower end wherein a plug 294 is inserted in 292 and maintained in position by a shear pin 298. Sealing means 296 maintain the chamber 282 in a sealed condition during the displacement of the perforation fluid from chamber through transfer tube 286 and into the well bore. Excess pressure in chamber 282 due to plugging of a passageway, port or such will cause pin 298 to be sheared releasing plug 294 thereby conserving the tool.

The displacement of the desirable perforating fluid into the well bore is as indicated above and especially in FIGURES 3–6 of the drawing.

Before lowering the perforating fluid placement tool 290 into a well, the chamber 282 is filled with an optimum perforating fluid of the type hereinbefore described. The fluid can be filled directly into the upper end of housing 288 prior to threading the housing and plug 270 together, or it can be injected into apperture 292 after the apparatus is completely assembled, whereafter plug 294 is properly inserted. Powder charge 252 is inserted into bore 250 and detonator 254 is affixed to the charge and connected to switching means 238 in the first position by wire 242. Charge retaining means 266 is then inserted into bore 272 with the flanged plug 268 properly sealed in place, whereafter plug 270 is attached to plug 246 by threaded means and the filled chamber 282 is attached to plug 270 by threaded means.

The tool is then lowered into a well and positioned by cable means previously described to the desired position. Electrical energy is transmitted through cable 18 and lead wire 36 to switching means 238 in its first position so connection is complete to detonator 254 which ignites powder charge 252, whereafter switching means 238 assumes the second position. Expanding gases from charge 252 displace flanged plug 268 from the charge retaining means 266 and pass through bore 272 and the series of passageways 274 into chamber 282. Gaseous pressure within chamber 282 causes the perforating fluid to be diverted through ports 284 causing packing means 280 to be expanded to seal the annular space within the well casing or bore below the perforation gun.

As gases continue to fill chamber 282 the perforating fluid is moved upwardly in transfer tube 286 to the bore 278 where it passes through the series of discharge ports 276 outwardly and upwardly into the annular space surrounding the perforating device above the packing means 280. This causes the fluid from chamber 282 to displace the undesirable fluids from the annulus about the peforation gun 16 upwardly in such a manner that the gun is completely encased in the desirable fluid.

Thereafter, switching means 238, in its second position, is energized and the detonator 28 is actuated which in turn ignites fuse 26 and causes the charges 24 to be activated. Thus the well casing is perforated in the presence of the optimum fluid and the gun and placement tool are removed from the well bore as previously described.

From the foregoing, it will be apparent that the present invention provides a novel method nad apparatus for completing oil and gas wells wherein the maximum production obtainable through a perforating operation will be attained. It will also be apparent that the objectives set forth in the forepart hereof are obtained.

Changes may be made in the combination and arrangement of parts or elements and steps as heretofore set forth in the specification and shown in the drawings without departing from the spirit and scope of the invention as set forth in the following claims.

I claim:

1. An attachment for a gun used in perforating wells, comprising a housing attachable to the lower end of the gun, said housing having a cylindrical chamber therein and a plurality of circumferentially spaced outlet ports at the upper end of the chamber, a piston reciprocally disposed in the chamber, an energy source in the housing arranged to raise the piston through the chamber, a hydraulically actuated packer on the housing below said outlet ports in communication with the chamber, and a firing mechanism for the gun in the housing arranged to be actuated by the piston as the piston reaches the upper end of the chamber.

2. An attachment as defined in claim 1 characterized further in that the energy source comprises a slow burning explosive.

3. An attachment as defined in claim 1 characterized further in that the energy source comprises a compressed gas.

4. An apparatus for perforating a casing or the like filled with a contaminated fluid, comprising an elongated housing, said housing having a chamber therein for containing a supply of perforating fluid, said housing also having a plurality of circumferentially spaced outlets at the upper end of said chamber for the discharge of the perforating fluid, a plurality of explosive actuated perforators carried in the housing above said chamber, a hydraulically expandable packer carried by the housing in communication with said chamber and below said outlets, a piston reciprocally disposed in said chamber, an energy source in the housing below said piston for moving the piston upwardly through said chamber to expand the packer and displace the contaminated fluid from around the perforators with perforating fluid, and firing means in the housing arranged to be actuated by said piston as said piston reaches the upper end of said chamber for firing said perforators subsequent to displacement of the contaminated fluid from around said perforators.

5. An attachment for a gun used in perforating wells, comprising a housing attachable to the lower end of the gun, said housing having a cylindrical chamber therein for containing a supply of perforating fluid and a plurality of circumferentially spaced outlet ports above said chamber, a transfer tube fixedly disposed in the upper end of the chamber in communication with said outlet ports and the lower end of said chamber, an energy

source mounted in the housing above and in communication with said chamber being arranged to displace said fluid from said chamber through said transfer tube, a switching means for activating said energy source communicating therewith, and a hydraulically actuated packer mounted on the housing below said outlet ports in communication with the chamber.

6. An attachment as defined in claim 5 characterized further in that the energy source comprises a slow burning explosive.

7. An attachment as defined in claim 5 characterized further in that the energy source comprises a compressed gas.

8. An apparatus for perforating a casing or the like filled with a contaminated fluid, comprising an elongated housing, said housing having a chamber therein for containing a supply of perforating fluid, said housing also having a plurality of circumferentially spaced outlets above said chamber for the discharge of the perforating fluid, a plurality of explosive actuated perforators carried in the housing above said chamber, a hydraulically expandable packer carried by the housing in communication with said chamber and below said outlets, a transfer tube fixedly disposed in the upper end of said chamber in communication with said outlet ports and the lower end of said chamber, an energy source mounted in the housing above and communicating with said chamber, thusly said source communicates with said chamber, said packing means, the lower end of said tube, and said outlet ports, and switching means mounted in the housing communicating with and adapted to successively actuate the energy source and the perforators.

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