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METHOD AND APPARATUS FOR PERFORATING WELLBORES AND CASINGS

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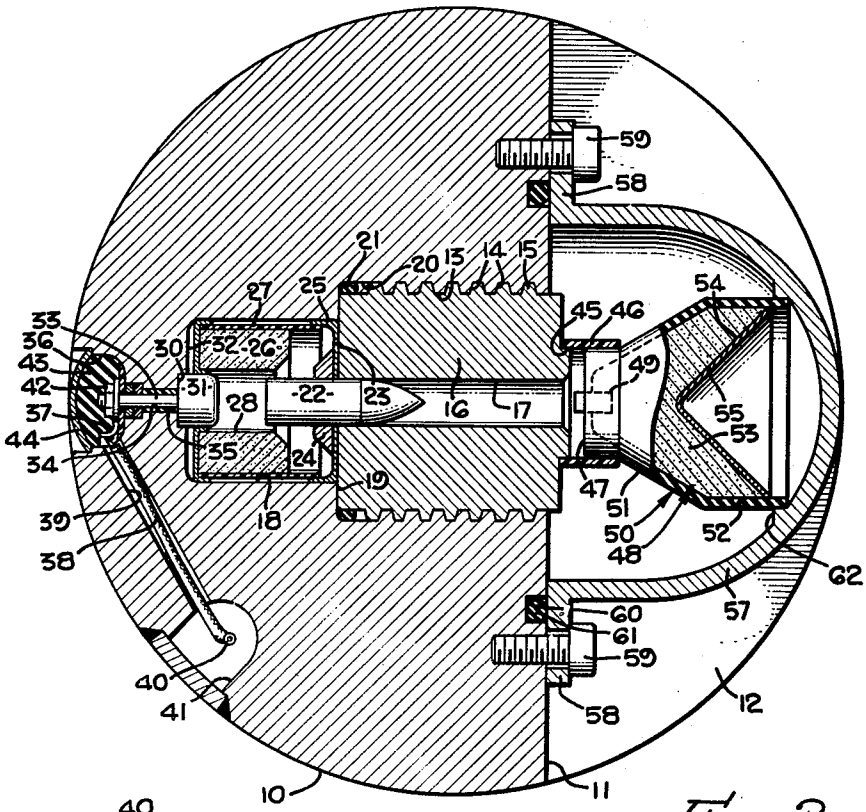

FIG. 2.

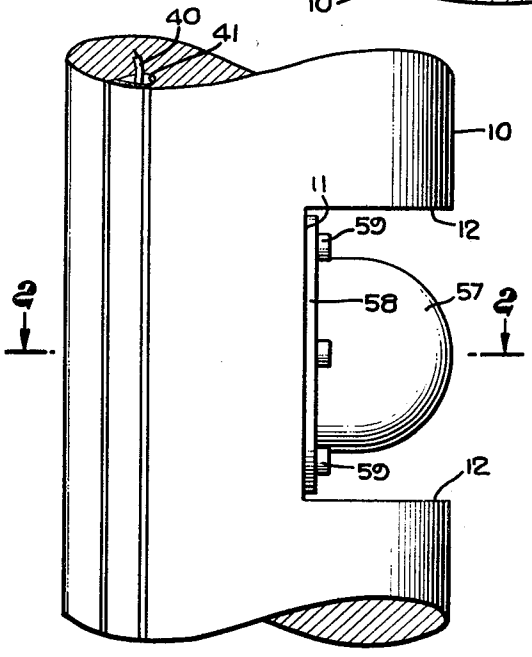

FIG. 1.

JOHN J. UDRY
INVENTOR.

BY Lyle Dillon
ATTORNEY

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METHOD AND APPARATUS FOR PERFORATING WELLBORES AND CASINGS

John J. Udry, Van Nuys, Calif., assignor, by mesne assignments, to Borg-Warner Corporation, Vernon, Calif., a corporation of Illinois

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5 Claims. (Cl. 102—20)

This invention relates in general to the perforation of well casings for the purpose of admitting production fluid into the well from the surrounding formation, and is more particularly related to methods and apparatus for improving the character of the perforation and depth of penetration of the formations surrounding a well borehole. This is a continuation of my copending application Serial No. 217,967 filed March 28, 1951 now abandoned.

As a means of permitting the entrance and enhancing the flow of production fluid into a cased well, it has long been conventional practice to perforate the well casing in situ within the well borehole at a point in the well opposite the formations from which production is desired. Such perforation was originally accomplished by mechanically actuated means lowered into the well, but this method had, as one of its several disadvantages, the inability to penetrate the surrounding cement and formations. Subsequent practice has been to subject the well casing and the well borehole to the penetrating action of bullets fired by means of explosive charges from a perforating gun suspended in the well borehole, and this had the advantage of not only perforating the well casing, but also the surrounding cement and formations to a considerable lateral depth. In more recent developments of perforation by explosive force, shaped explosive charges have been used, in which the force of the high velocity jet from the shaped charge is alone sufficient to effect the perforation of both the casing and the surrounding cement and well formations to considerable lateral depth.

Both bullet perforation and shaped charge perforation for the before-mentioned purposes have been highly successful and are widely used, particularly in the oil fields for the simultaneous perforation of well casings and surrounding bore formations, as well as for the perforation of the surrounding cement with which the casing or the several concentric strings of casings may be cemented in place in the well borehole. Each of such methods of perforation has its own characteristic advantages and disadvantages. In each case, a single penetration is made into the formation, the depth and contour of which are determined in part by the physical nature of the formation and in part by the penetrating characteristics of the bullet or the shaped charge jet, as the case may be. The resultant formation disturbance at and adjacent the resultant penetration is in each case individually typical of the perforation method selected. I have discovered, however, that, by the combined use of a shaped charge and a penetrating bullet, the character of the penetration and the formation disturbance adjacent the penetration are different from those produced by either bullet or shaped charge alone. In particular, the flight characteristics of a bullet fired in conjunction with the discharge of a shaped charge in the manner herein disclosed are different from those of either a bullet or a shaped charge fired alone, and the resulting character of the formation penetration is superior in both apparent permeability and porosity of the formations so perforated.

It is, therefore, one of the primary objects of the present invention to provide a means for well perforating whereby the wellbore and/or casing is subjected to the combined penetrating action of both a bullet and a shaped charge.

A further object of the invention is to provide a method and apparatus by which a wellbore formation may be perforated to provide an improved type of formation disturbance adjacent the penetrated area, partaking of the advantages of the effect of both bullet and shaped charge.

With respect to the apparatus itself, it is one of the primary objects of the present invention to provide a novel and improved well perforating gun by means of which a given point in the well casing and/or formation may be subjected to the substantially simultaneous penetrating effect of both a bullet and a shaped charge jet.

As a corollary to the above, it is an object of the present invention to provide a gun perforator having means for firing substantially simultaneously and coaxially both a bullet and a shaped charge into and through a single perforation made thereby.

Other objects of the invention are to provide a novel, simple and improved gun perforator, the construction and arrangement of which result in superior penetrating power.

These and other objects, advantages, and features of novelty of the present invention will be evident from a consideration of the following specification taken in conjunction with the accompanying drawing.

In the drawing, which illustrates a preferred embodiment and mode of operation of the invention and in which like reference characters designate the same or similar parts throughout the several views:

Figure 1 is a fragmentary longitudinal elevational view of the gun body; and

Figure 2 is an enlarged cross-sectional view of the apparatus taken on line 2—2 of Figure 1.

The apparatus is as follows:

Referring to the drawing, the general assembly of the body of the perforating gun is indicated by the numeral 10. The body 10 is preferably of cylindrical form, substantially circular in cross-section as shown in Figure 2, and of such length as the desired number and location of gun units therein may require. In the present disclosure, only one typical perforating gun unit is illustrated, but it is to be understood that a plurality of such units may be incorporated in a single gun body and may be spaced and arranged along the length thereof as desired. Frequently, such units are positioned in spiral arrangement along the cylindrical gun body, and such is here contemplated. However, since the units may be individually mounted in individual gun bodies, or arranged in various groups, spacings, and relationships as desired, and since the present invention is in no way limited to any particular disposition, number, or arrangement of the gun units, a fragmentary showing of the gun body containing only one typical gun unit is shown. While the body may be formed of shatterable or brittle material, such as cast iron, to disintegrate upon discharge of the units, it is preferably formed of more durable material, such as steel, which will withstand the shock of individual or simultaneous discharge of the gun units so that it may be reloaded and repeatedly used.

At the location of the gun unit, the cylindrical body 10 is transversely slotted or recessed to form a longitudinal plane surface 11 bounded by top and bottom laterally extending walls 12 preferably, although not necessarily, disposed in parallel planes normal to the surface 11 and perpendicular to the axis of the body 10. Extending inwardly from the center of the surface 11 is a radially directed bore having inner and outer coaxial portions 18 and 13, respectively, the inner portion 18, which serves as a bullet propellant charge chamber, being of

reduced diameter relative to that of said outer portion 13 and forming at the juncture thereof an annular shoulder 19. The outer bore 13 is provided with internal threads 14 adapted to threadedly engage external threads 15 of a cylindrical gun barrel 16, which is thereby screwed into the bore 13 to seat firmly against the shoulder 19. The barrel 16 is provided with a bullet bore 17 extending coaxially therethrough from end to end. An annular recess 20 is formed between the thread-free rearward extremity of the bullet barrel 16 and outer bore 13 adjacent the annular shoulder 19, in which is located an O ring or the like packing means 21. The purpose of the packing means 21 is to prevent leakage of well fluid and propellant gases between the threads 14, 15 and the propellant charge chamber 18.

When the gun is loaded, as illustrated in Figure 2, a propellant charge of a suitable powder or other deflagrating or explosive material is located within the charge chamber 18, as shown at 26, and when ignited serves to expel a bullet, as shown at 22, outwardly through the bore 17 of the barrel 16. The propellant charge is preferably molded, compressed, or otherwise suitably consolidated to form an annular body having a centrally located opening 28 therethrough. In the present form of the invention, the bullet 22 and its propellant charge 26 may be assembled as a single cartridge unit. The bullet 22 is supported at its mid-section, partially within the barrel 17 and extending rearwardly therefrom into the charge chamber 18, by a sealing disc or diaphragm 23, together with a frusto-conical restraining annulus 24, through both of which the bullet may be tight press fitted to be retained until the cartridge is fired. The disc 23 and ring 24 may be separate, but are preferably securely united as by welding or the like and, if desired, may be formed as a single integral part. The periphery of the disc 23 is formed with an inwardly or rearwardly directed sealing flange 25 which fits snugly within the forward portion of the cylindrical side walls of the chamber 18. The inside face of the flange 25 tapers rearwardly away from the body of the disc and receives therein the forward end portion of a cylindrical powder container shell 27 which serves to enclose the annular shaped body of the bullet propellant 26. The central opening 28 of the annular propellent charge encircles the inner end of the bullet 22.

For igniting the powder 26, an igniter head 30 is located within a shallow recess 31 formed centrally of the rear end wall 32 of the charge chamber 18, the igniter head 30 extending inwardly therefrom into the rear portion of the central opening 28 of the propellant charge body 26. An electrically conductive stem 33 is attached to and extends coaxially rearwardly from the igniter head 30 through a passage 34 which is provided with an internal insulating sleeve 35. The outer threaded end of the stem 33 extends into a recess 36 formed in the external wall of the body 10 at a point diametrically opposite the surface 11, and is provided within the recess with a connector means 37 to which may be secured an insulated conductor wire 38 which extends from the said recess 36 through a lateral duct 39 to a firing control cable 40 contained within a longitudinal cable recess 41. A nut 42 engages the threaded outer end of the stud 33 and is secured within the recess 36 by encasement within a sealing plug 43, which in turn is retained and sealed fluid-tight within the recess by a convex cover plate 44. By this arrangement, replacement of the igniter head 30 may be accomplished after firing of the gun, by first removing the barrel 16 and then reaching through the bores 13 and 18 and grasping the igniter head 30 with a suitable tool and unscrewing the expanded igniter head and its stem from the nut 42, and replacing it with a new igniter in the same manner.

For a more detailed description of the bullet gun perforator portion of the apparatus hereinbefore described as suitable in connection with this invention, reference may be had to the copending application of Forrest V. Porter, Serial No. 460,086.

The forward or muzzle end of the barrel 16 which is shown as protruding slightly from the surface 11, has formed on it a central boss 45 encircling the bullet bore 17. Mounted upon the boss 45 and engaging the annular shoulder formed thereby is a tubular spacer nipple 46. Seated within the outer end of the spacer nipple 46 is the inner cylindrical end portion 47 of the container of a shaped charge 48. The nipple 46 serves to support the inner end of the shaped charge in coaxial alignment with and in predetermined spaced relation to the outer muzzle end of the barrel bore 17, thus determining the axial spacing of the inner end portion of the shaped charge with respect to the outer end of the barrel and the bullet 22. A suitable detonator cap 49 is located centrally at the inner end 47 of the shell of the shaped charge 48 and in coaxial alignment with the bullet bore 17, in position to be struck and detonated by impact of the bullet as and when the bullet is fired from the gun barrel 17. The detonator extends through a suitable central opening in the end 47 of the shell into the rear portion of the shaped charge explosive.

The shaped charge 48 may have various forms now well known in the art, but as here illustrated it is contained within a relatively thin shell 50 having the beforementioned inner rearward cylindrical portion 47, an intermediate frusto-conical portion 51, and an outer or forward cylindrical portion 52. The walls of the shell 50, as well as the surface of the inner end 47, are preferably composed of a frangible material, such as a suitable plastic or like substance, within which is pressed or molded the high explosive material 53 constituting the shaped charge. The forward end of the body of the explosive 53 is formed with a concavity 54 preferably conical in shape and preferably covered or lined with a conical liner 55 made of a suitable metal such as, for example, copper.

The forward end of the outer cylindrical portion 52 of the shell of the shaped charge 48 is supported by, and the charge as a whole is encased within, a relatively thin, approximately hemispherical shaped housing 57, preferably made of a frangible material, such as cast iron or the like. The base of the housing 57 carries a radial flange 58 through which bolts 59 extend into threaded holes in the surface 11 of the gun body 10 for securing the housing in place upon the surface 11. An annular groove 60, within which is located an O ring 61 is located under the flange 58 for providing a fluid-tight seal between the housing and the surface 11. Within the housing 57 an annular shoulder 62 is provided for engaging the outer edge of the cylindrical portion 52 of the shell 51 of the shaped charge 48 to secure the same in coaxial alignment with the bullet bore 17 of the gun unit.

For a more detailed description of the general construction and materials employed in shaped charges of the type herein described by way of illustration, reference may be made to the patents to Davis et al. No. 2,399,211 and Muskat et al. No. 2,494,256.

The operation of the apparatus is as follows:

When the well casing or borehole formation is to be perforated, the gun body is lowered, by means of a conductor cable in a manner well known in the gun perforating art, into the well borehole to the depth where perforation is desired. In the contemplated form of the invention, the body is, as hereinbefore mentioned, an elongated cylinder carrying or containing a plurality of gun units of the type here shown, each unit usually being positioned with its axis directed radially with respect to the longitudinal axis of the gun body. With the gun body so located, an energizing electrical impulse is transmitted through the supporting conductor cable and thence by suitable connector means through conductors 40 and 38 to and through the stem 33 of the igniter 30, and return through ground. The propellant charge 26, being thus

ignited, propels the bullet 22 outwardly at high velocity through the bullet bore 17.

As the bullet 22 emerges from the muzzle end of the bore 17 following the ignition of the charge 26, its nose strikes the detonator 49, instantly detonating the shaped charge 48. When the charge 48 is detonated, the housing 57 is disintegrated, and a piercing jet composed of gaseous products of the detonated explosive material therein, together with molten and atomized particles of the conical liner 55, is projected forwardly in a direction coincident with the axis of the bullet bore, and this jet and the bullet perforate the surrounding casing or casings, cement, and formation. From a study of casings and formations pierced by such combined action of the bullet and shaped charge fired in the manner thus described, it appears that the rapid detonation of the shaped charge is such as to cause the piercing jet thereof to slightly precede the flight of the bullet so as to pierce any casing present in the well and also to pierce the surrounding formation to considerable depth in advance of the bullet. In any event, the combined action of the shaped charge jet and the bullet is so nearly simultaneous as to produce a piercing action superior to that produced by either instrumentality alone or to that produced by the separate successive action of jet and bullet or bullet and jet.

Characteristic of the results thus far obtained by the present method is the formation of a duct of considerably greater diameter than that formed by either the bullet or the shaped charge alone, indicating an apparent spinning or tumbling of the bullet, possibly induced by the shaped charge jet. Such action of the bullet is also indicated by discovery of the spent bullet in the test formation in a position reversed from that in which it was fired. By such wabbling or tumbling action of the bullet, apparently induced by the action of the shaped charge jet, a jagged, enlarged bore of apparently superior permeability characteristics results. From such experiments it appears that, as hereinbefore suggested, the leading portion of the jet precedes the bullet and pierces and displaces sufficient formation to permit tumbling action of the bullet to be induced by the trailing portion of the jet into which the bullet enters. However, the invention herein described is not to be limited in any manner by any theory of its operation.

While the apparatus as herein described has been found to accomplish the objects of this invention, various modifications thereof may be possible. For example, modifications of the propellant charges, both for the bullet and the shaped charge, will probably result in slight variations in the character of the perforations attained. Likewise, variations in the bullet size and weight, barrel length, bullet restraint, and the like may also provide other slight variations in the results obtained. If desired, the shaped charge may be fired by other means than the bullet so long as the timing relative to the firing of the bullet propellant charge is properly controlled to approximate the conditions obtained by the apparatus herein described. In any event, the primary inventive concept will be practiced in the approximately simultaneous firing of a bullet and a shaped charge coaxially at the same point in a well casing or formation.

From the foregoing it will be seen that the present invention provides a novel and improved method of and apparatus for the perforation of well casings and/or wellbore formations. In the use of the term "well casings and/or formations," it is understood that the piercing of plural concentric casings is contemplated, as well as the piercing of cementitious material which may be placed between such concentric casings or which may be exterior of either a single casing or the outermost casing of a concentric series thereof.

In the practice of the present invention, both as to method and as to apparatus, it will be understood that numerous changes, modifications, and the full use of equivalents may be resorted to by those skilled in the art without departure from the scope of the invention as defined in the appended claims.

What is claimed is:

1. A perforating gun comprising: a gun body; a bullet-receiving gun bore in said body; a bullet in said gun bore; a charge of propellant powder arranged to propel said bullet from the outer end of said gun bore; an outwardly facing shaped charge on said body and positioned in coaxial alignment with and adjacent the outer end of said gun bore; and a detonator cap detonable by impact of a bullet propelled from said gun bore and capable upon detonation of detonating said shaped charge, said cap being carried by the rearward end of said shaped charge and positioned to be actuated by impact from a bullet propelled out of said bore.

2. A perforating gun comprising: a gun body; a bullet-receiving gun bore in said body; a bullet in said bore; a charge of propellant powder arranged to propel said bullet from the outer end of said gun bore; an outwardly facing shaped charge on said body and positioned in coaxial alignment with and adjacent the outer end of said gun bore and spaced from said bullet a portion of the length of said gun bore, the rearward end of said shaped charge thereby being positioned to be struck by said bullet when said bullet is propelled out of said bore, the bullet and products of said shaped charge being thereby adapted to commingle; and a detonator cap detonable by impact of said bullet and capable upon detonation of detonating said shaped charge, said cap being in the rearward end of such shaped charge and positioned to be actuated by the resultant impact from said bullet.

3. In a device of the character described: a gun body; a barrel-receiving bore extending inwardly from an exterior surface of the said body; a barrel having a bullet bore therethrough mounted in said barrel-receiving bore; an outwardly facing shaped charge positioned in coaxial alignment with and adjacent the outer end of said bullet bore, such shaped charge thereby being adapted to be detonated by impact from a bullet propelled from said bullet bore; a barrel-engaging nipple supporting the inner end portion of said shaped charge; frangible, fluid-tight enclosing means for the outer end of said barrel, said shaped charge, and said nipple; means supporting said enclosing means on said gun body; and means on said enclosing means supporting the outer end portion of said shaped charge.

4. A perforating gun comprising: a gun body; a bullet receiving gun bore in said body; a bullet in said bore at the rearward end thereof; means including a charge of propellant powder arranged to expel said bullet from the outer end of said gun bore; an outwardly facing shaped charge of high explosive positioned in coaxial alignment with and adjacent the outer end of said gun bore and spaced from said bullet a portion of the length of said gun bore; and a detonator cap detonable by impact of said bullet and capable upon detonation of detonating said shaped charge, said cap being carried by the rearward end of said shaped charge in detonating relation thereto and positioned to be impacted by said bullet when the latter is propelled out of said bore.

5. In a device of the character described: a gun body; a barrel-receiving bore extending inwardly from an exterior surface of the said body; a barrel having a bullet bore therethrough mounted in said barrel-receiving bore; an outwardly facing shaped charge positioned in coaxial alignment with and adjacent the outer end of said bullet bore; a bullet-impact-sensitive detonator cap capable upon detonation of detonating said shaped charge, said cap being carried by the rearward end of said shaped charge in detonating relation thereto and in coaxial alignment with said bullet bore, said cap thereby being adapted to be detonated by impact from a bullet propelled from said bullet bore; a barrel-engaging nipple supporting the inner end portion of said shaped charge; frangible, fluid-

tight enclosing means for the outer end of said barrel, said shaped charge, and said nipple; means supporting said enclosing means on said gun body; and means on said enclosing means supporting the outer end portion of said shaped charge.

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