SHAPED CHARGE PERFORATING APPARATUS AND METHOD
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ABSTRACT OF THE DISCLOSURE

Apparatus for perforating oil and gas wells and the like and methods for completing such wells in an unconsolidated formation. The apparatus includes one or more shaped charges having inert particles located therein arranged to be carried, upon detonation of the charge, into the perforation formed by the charge and also including a carrier for positioning the shaped charge in the well. The method includes the steps of positioning the shaped charge and carrier in the well adjacent the unconsolidated formation to be perforated and detonating the charge to simultaneously form the perforation and place the inert particles in the perforation to form a permeable bridge therein.

This invention relates generally to improved methods and apparatus useful in perforating oil and gas wells and the like. More particularly, but not by way of limitation, this invention relates to improved perforating apparatus and methods for completing a well in an unconsolidated formation.

Generally, in the completion of oil and gas wells and the like, an elongated metal casing is positioned in the well bore. Due to the irregularity of the well bore and due to the difference in diameter between the well bore and the metal casing, a cementitious material is usually pumped into the annular space. The cementitious material serves to permanently fix the metal casing in the well bore and to prevent migration of well fluids through the annular space. It is obvious that the metal casing and the cementitious material disposed adjacent a productive formation will prevent the flow of fluids from the formation into the interior of the casing. Therefore, the practice has been to perforate the casing, cementitious material, and the formation by the use of either shaped charge or bullet perforators. The perforators are lowered into the casing to a position adjacent the productive formation and then fired from the surface through an appropriate electrical circuit.

The aforesaid procedure has been very successful, but a great deal of difficulty has been encountered when the productive formation consists of an unconsolidated sand or similar substance. The particle size of unconsolidated sands will vary between \( \frac{2}{3} \) of an inch and \( \frac{3}{4} \) of an inch while the diameter of the perforation made with the usual perforators will be somewhere between \( \frac{1}{2} \) and \( \frac{3}{4} \) of an inch. As is obvious from the foregoing, even the largest sand particles are very small as compared to the smallest diameter of perforation made by conventional perforating apparatus. Thus, as well fluids are produced through the perforation into the interior of the casing, sand particles will, more than likely, be produced therewith. If a sufficient quantity of sand is produced into the casing, the sand may accumulate therein and completely block the production of well fluids or if pumping or valve apparatus is disposed in the well, the sand may have a serious erosive effect thereon.

One attempt made to solve the foregoing problem utilizes an array of very small bullet perforators fired simultaneously in a prearranged pattern. Although the perforations made are too large in diameter to be useful in preventing the migration of sand into the casing, the bullet charges will, when fired into friable cementitious material, shatter the cementitious material forming a permeable bridge in the perforations to inhibit the migration of the unconsolidated sand.

Another attempted solution involves the use of shaped charges constructed to provide small diameter perforations. However, the diameter of the perforations are still sufficiently large so that they do not effectively inhibit the flow of sand into the casing. Unlike the bullet perforators, the shaped charges form a clean hole or perforation and do not shatter the cementitious material even when the material is friable. Therefore, small perforations formed by shaped charges have not been effective to inhibit the flow of sand into the casing.

Very often in the completion of wells, a relatively small diameter production tubing will be run within the casing. Packers, of a type well known in the art, or other similar apparatus, are usually utilized to hold the tubing in the casing and to prevent the flow of fluid through the annular space between the tubing and casing. In such instances, the perforating apparatus must be run through the tubing prior to reaching the zone to be perforated. Usually, the tubing terminates above the producing formation so that the perforating apparatus is disposed within the relatively large diameter of the casing when the perforator is fired.

To make the most efficient use of perforators, it is desirable to be able to control the distance from the shaped charge or bullet to the casing, that is, to control the standoff. Manifestly, perforating apparatus small enough to be run through the tubing will have a considerable standoff when located in the casing and will not provide the optimum conditions for firing the bullets or shaped charges to perform the perforating operation in the most efficient manner.

Summary of the invention

Generally, this invention provides improved perforating apparatus including a carrier arranged to be moved through the well bore; a plurality of shaped charges carried by the carrier, each charge being oriented in a direction whereby the detonation thereof forms an explosive jet that perforates the formation, each charge including a plurality of inert particles arranged to be carried into the perforations forming a permeable bridge therein; and, ignition means for detonating the charges.

In another aspect, this invention contemplates the construction of a shaped charge that includes a plurality of inert particles that are carried into the perforation and that are sized and shaped to form a permeable bridge therein.

Also, this invention provides a collapsible carrier whereby shaped charges may be lowered through relatively small diameter tubing and positioned in relatively larger diameter casing for efficiently performing the perforating operation. Additionally, this invention contemplates the construction of another carrier for the shaped charges that includes a member constructed from sheet explosive that holds an array of charges and provides for their simultaneous detonation.

One object of the invention is to provide an improved method of completing a well at an unconsolidated formation wherein permeable bridges are formed in the perforations to inhibit the migration of sand therefrom.

Another object of the invention is to provide an improved perforating apparatus wherein a selected array of shaped charges may be simultaneously detonated from a plurality of such arrays.

Still another object of the invention is to provide an improved perforating apparatus arranged to form relatively small diameter perforations and to form permeable bridges therein.
The foregoing and additional objects and advantages of the invention will become more apparent as the following detailed description is read in conjunction with the accompanying drawings wherein like reference characters denote like parts in all views and wherein:

FIGURE 1 is a cross sectional view of a shaped charge constructed in accordance with the invention;

FIGURE 2 is a cross sectional view similar to FIGURE 1, but illustrating another embodiment of shaped charge also constructed in accordance with the invention;

FIGURE 3 is a vertical cross sectional view illustrating perforating apparatus constructed in accordance with the invention disposed in a casing well bore;

FIGURE 4 is a cross sectional view taken substantially along the line 4—4 of FIGURE 3;

FIGURE 5 is an elevational view of another embodiment of perforating apparatus also constructed in accordance with the invention and disposed in a well bore;

FIGURE 6 is an enlarged cross sectional view of a portion of the apparatus of FIGURE 5 taken substantially along the line 6—6 of FIGURE 5; and

FIGURE 7 is a fragmentary pictorial view illustrating a modification of the member for holding the shaped charges utilized in the perforating apparatus of FIGURE 5.

Shaped charge

Referring to the drawing and to FIGURE 1 in particular, shown therein and generally designated by the reference character 10 is a shaped charge constructed in accordance with the invention. The shaped charge 10 includes a hollow body 12, an explosive material 14 partly filling the interior of the hollow body 12, and a cap 16 closing one end of the hollow body 12.

The explosive material 14 has a conical cavity 18 in the end thereof adjacent the cap 16. A liner 20, which is also of conical configuration, is located in the hollow body 12 in juxtaposition with the surface of the explosive material 14 forming the cavity 18. The liner 20 may be constructed from relatively thin sheet metal, but is preferably constructed from a granular metal as disclosed in U.S. Patent No. 3,255,659 issued on June 14, 1966 to Alexis A. Venghaissi.

A plurality of particles 21 are located between the surface of the explosive material 14 and the liner 20. The particles 21 are preferably formed from an inert material and preferably have at least one dimension that is not less than one-half the diameter of the perforation that is formed upon detonation of the shaped charge 10.

FIGURE 2 illustrates another embodiment of shaped charge generally designated by the reference character 22. This shaped charge 22 includes a hollow body 12 and explosive material 14. One end of the hollow body 12 is closed by a cap 24, which is constructed similarly to the cap 16 but, as is apparent from a comparison of FIGURES 1 and 2, is more elongated to provide additional standoff for the shaped charge 22 for reasons that will be explained more fully hereinafter.

The opposite end of the hollow body 12 is closed by a sealing cover 26. The sealing cover 26 is optional, but its use is preferred when the shaped charge 22 is used in open or capsule type carriers wherein the explosive material 14 would otherwise be exposed to well fluids.

As illustrated in FIGURE 2, the shaped charge 22 also includes the conically shaped cavity 18 that is formed in the explosive material 14 and a conical liner 28 disposed in juxtaposition therewith. A plurality of particles 30 are disposed in the liner 28. As previously mentioned with respect to FIGURE 1, the liner 28 is preferably formed as taught in U.S. Patent No. 3,255,659.

As will be understood by those skilled in the art of shaped charges, the conical cavity 18 in the charges 10 and 22 produces the so-called Munroe effect upon detonation that results in a high energy jet of sufficient energy magnitude to form perforations. Preferably, the shaped charges 10 and 22 are of a size that will result in the formation of a perforation having an average diameter of 0.50 inch. The particles 21 and 30 in the shaped charges 10 and 22, respectively, are arranged to be carried into the perforation formed by the charges and are of such size and shape that they will form a permeable bridge therein for reasons that will be discussed.

Perforating apparatus of FIGURE 3

FIGURE 3 illustrates perforating apparatus generally designated by the reference character 32 and disposed in a casing 34. As shown therein, the casing 34 is located in a well bore 36 and is retained therein by cementing material 38 disposed in the annular space between the wall of the well bore 36 and the exterior of the casing 34.

The lower end of a relatively small diameter tubing 40 is illustrated as being disposed within the casing 34. The tubing 40 is retained in a central position in the casing 34 by a packer 42 that also serves to prevent the flow of fluid through the annular space between the tubing 40 and the casing 34.

The perforating apparatus 32 is suspended in the casing 34 on a wire line or cable 44 that extends upwardly through the tubing 40 to the surface (not shown) of the well bore 36. The cable 44 has sufficient mechanical strength to support the perforating apparatus 32 and also contains the necessary electrical conductors (not shown).

The lower end of the cable 44 is connected to an adapter 46 that forms the upper end of the perforating apparatus 32.

The perforating apparatus 32 also includes a pair of shaped charge holding members 48 that are disposed in generally parallel spaced relationship and extend substantially parallel to the longitudinal axis of the casing 34. The upper end of each of the shaped charge holding members 48 is connected by a hinge 50 with a linkage member 52. The opposite end of each of the linkage members 52 is connected by a hinge 54 with the adapter 46.

The lower end of each of the shaped charge holding members 48 is connected by a hinge 56 with a linkage member 58. The lower end of the linkage members 58 are pivotally joined by a hinge 60. The hinged connecting structure joining the shaped charge holding members 48 provides an articulated linkage wherein the shaped charge holding members 48 can move relatively together and relatively apart in substantially parallel relationship.

A spring 62 is illustrated as being connected with the adapter 46 and having its free end portions in engagement with the linkage members 52. The spring 62 constantly biases the linkage members 52 and the holding members 48 relatively apart.

Similarly, a spring 64 encircles the hinge 60 and has its free end portions in engagement with the linkages 58. The spring 64 serves to bias the linkages 58 and the holding members 48 relatively apart thus maintaining the shaped charge holding members 48 in substantially spaced, parallel relationship.

As illustrated in FIGURE 3 and also in FIGURE 4, the shaped charge holding members 48 each includes a plurality of the shaped charges 22. Manifestly, the shaped charge 10 could be utilized in lieu of shaped charge 22 as could any of the well-known constructions of shaped charge. Preferably, the shaped charges 22 include a sealing cover, such as the cover 26 shown in FIGURE 2, so that the explosive material 14 will not come into contact with fluids in the well bore 36.

The shaped charges 22 are each connected with some means for detonating the shaped charges. For example, FIGURES 3 and 4 illustrate a Primacord 66 connecting each of the charges 22 with a respective one of a pair of boosters 68 and detonators 70. The detonators 70 are connected with wires 72 that extend upwardly through the adapter 46 and the cable 44 to a source of electrical energy (not shown) located on the surface (not shown) adjacent the upper end of the well bore 36. As is well known,
electric current passing through the conductors 72 ignites the detonators 70, boosters 68 and the interconnected Primacord 66. Manifestly, the ignition of the Primacord 66 ignites the shaped charges 22 essentially simultaneously due to the high explosive nature of the Primacord 66.

Operation of the embodiment of FIGURE 3

To utilize the perforating apparatus 32, the shaped charges 22 are disposed in the shaper 102 and charge holding members 48 in accordance with the desired perforation pattern and number of perforations to be formed. The adapter 46 is connected with the cable 44 and the perforating apparatus 32 is then extended into the tubing 40. As will be apparent from viewing FIGURE 3, the holding members 48 are moved relatively together, compressing the springs 62 and 64 to permit the insertion of the apparatus 32 into the relatively small diameter tubing 40.

The apparatus 32 is then lowered through the tubing 40, passing through the open end thereof into the relatively large diametrical opening 34. When the apparatus 32 is disposed adjacent the formation to be perforated, its downward movement is arrested and the apparatus 32 is suspended on the cable 44 in the well bore 36. The conductors 72 are then energized igniting the detonators 70, boosters 68 and the Primacord 66. When the Primacord 66 detonates, the shaped charges 22 are simultaneously detonated to form a plurality of perforations 74 as illustrated in FIGURES 3 and 4.

As the shaped charges 22 detonate, the perforations 74 are formed through the casing 34, the cementitious material 38, and extend into the formation surrounding the well bore 36. Simultaneously, the inert particles 30 are carried into the perforations 74 as illustrated in FIGURE 4, forming permeable bridges therein to prevent or at least inhibit the migration of unconsolidated materials from the formation through the perforations 74 into the interior of the casing 34.

Generally, detonation of the shaped charges 22 integrates a large portion of the shaped charge holding members 48 dropping the linkages 58 into the lower portion of the well bore 36. For this reason, the linkages members 52 and 58 and the shaped charge holding members 48 are preferably constructed from a material that is easily drivable, such as aluminum, or one of the plastics. After the detonation of the shaped charges 22, the portion of the apparatus 32 remaining intact can be readily withdrawn by withdrawing the cable 44 therefrom as is well known in the art.

It should be evident from the foregoing that utilizing the relatively small shaped charges 22 permits their close spacing in the holding members 48 whereby the formation is perforated by a large number of relatively small perforations 74, that is, the formation is saturated with small diameter perforations 74 whereby a flow area of relatively large size is obtained. It will also be noted, that the shaped charges 22 are properly positioned relative to the casing 34, that is, they will have the desired standoff to perform the perforating operation in the most effective manner due to the preselected length of the cap 24 (see FIGURE 2). Thus, while the shaped charges 22 form relatively clean perforations 74, the perforating apparatus 32 is effective in unconsolidated formations to form the desired perforations while inhibiting the flow of sand from such formations due to the permeable bridge formed by the inert particles 30.

Perforating apparatus of FIGURE 5

FIGURE 5 illustrates another embodiment of perforating apparatus generally designated by the reference character 100. As shown therein, the perforating apparatus 100 is suspended in a well bore 102 on a cable 104. The cable 104 includes members of sufficient structural strength to support the perforating apparatus 100 as well as including the necessary electrical conductors for detonating the perforating apparatus 100 as will be described.

The perforating apparatus 100 also includes an adapter 106 that is connected with the cable 104 and a selective ignition control device 108 that is constructed as described in U.S. Patent No. 3,221,655, issued Dec. 7, 1965 to Alexis A. Venghittis. Connected with the lower end of the selective ignition control means 108 is a plurality of identically constructed shaped charge carriers 110.

As is evident from viewing FIGURE 5, the shaped charge carriers 110 are arranged in end-to-end relationship. The number of shaped charge carriers 110 utilized depends upon the number and concentration of perforations desired. Manifestly, and although not illustrated, spacers can be utilized between the shaped charge carriers 110 to provide any desired spacing.

FIGURE 6 illustrates in detail the construction of the shaped charge carriers 110. As shown therein, each of the shaped charge carriers 110 includes a tubular housing 112 having a closed upper end 114 and a threaded lower end 116. A plug 118 is threaded into the lower end 116 of the housing 112 thereby closing the lower end 116 thereof. The upper end 114 of the tubular housing 112 is partially threaded as shown at 120 to receive the plug 118 forming a portion of the adjacent shaped charge carrier 110.

The tubular housing 112 is provided with a plurality of apertures 122 that extend through the wall thereof. Closure members 124 are pressed into the apertures 122 to close the apertures 122 against the entrance of well fluids. The tubular housing 112 is constructed to withstand the pressures encountered within the well bore 102.

A cylindrical shaped charge holding member 126 is disposed substantially coaxially within the tubular housing 112 with its upper end abutting the end 114 of the housing 112 and its lower end abutting the plug 118. The cylindrical holding member 126 is provided with a slot 128 for receiving one end of a partially threaded pin 130 to align the charge holding member 126 in the housing 112 for reasons that will be described. The partially threaded pin 130 extends through the wall of the tubular housing 112 and into the slot 128 as shown.

A plurality of shaped charges 10 are located in the holding member 126 and each is aligned with a respective one of the apertures 122. The alignment of the shaped charges 10 with the apertures 122 is assured by the relationship of the slot 128 and the partially threaded pin 130.

As illustrated in the upper portion of FIGURE 6, electrical conductors 132 and 134 extend through an opening 136 formed in the side wall of the tubular housing 112. The opening 136 is provided to protect the electrical conductors from damage as the perforating tool 100 passes through the well bore 102.

The conductor 132 extends through the wall of the tubular housing 112 and is connected with a detonator and booster 138 which is in turn connected with a Primacord 140. The Primacord 140 is connected with each of the shaped charges 10 within a single carrier 110 whereby all the shaped charges 10 contained therein will be simultaneously detonated. As shown in the lower portion of FIGURE 6, the conductor 134 extends through the tubular housing 112 of the subjacent carrier 110 and, although not shown, will be connected to the shaped charges therein as previously described. It will of course be understood that the electrical conductors 132 and 134 are electrically interconnected with the electrical conductor 138 contained in the cable 104 and extend to the surface (not shown) adjacent the well bore 102 wherein they will be connected to a source of electrical potential (not shown).
Operation of the perforating apparatus of FIGURE 5

The perforating apparatus 100 is lowered into the well bore 102 on the cable 104 until it is adjacent the formation or zone to be perforated. When the zone to be perforated is reached, the perforating apparatus 100 is suspended by the cable 104 and the downward movement thereof terminated.

One of the conductors, conductor 132 for example, is energized through the selective ignition control 108 as described in the previously mentioned Venghiattis Patent No. 3,221,655 to detonate the shaped charges 10 contained in the interconnected shaped charge carrier 110. It should be emphasized that only the shaped charges 10 in the selected carrier 110 will be detonated.

When the shaped charges 10 detonate, the explosive jet formed thereby perforates the cover 124 and extends into the formation forming the number and arrangement of perforations therein as predetermined by the number and distribution of charges in the carrier 110. Manifestly, the perforating apparatus 100 may also be used in cased and cemented wells as previously described in connection with the perforating apparatus 32.

After the shaped charges 10 have been detonated in a selected one of the carriers 110, the remaining carriers 110 may be actuated to detonate the shaped charges 10 contained therein or the perforating apparatus 100 may be raised or lowered to a different formation prior to the detonation of the shaped charges in each of the carriers 110.

As will be understood from the foregoing detailed description of the shaped charges 10, they are very small and capable of forming relatively small perforations whereby a large number of the shaped charges 10 may be contained within a single carrier 110. Thus, the formation adjacent the shaped charge carrier 110 will be saturated with relatively small perforations formed by the shaped charges 10.

FIGURE 7 illustrates a modification of the shaped charge apparatus 100. More specifically, FIGURE 7 illustrates a shaped charge holding member, designated by the reference character 150, that can be utilized in lieu of the shaped charge holding member 126. Although only a portion of the cylindrical charge holding member 150 is illustrated it will be understood that it will extend the full length of the tubular housing 112 as did the holding member 120. The shaped charge holding member 150 is constructed from a sheet explosive and thereby eliminates the necessity for the Primacord 140 illustrated in FIGURE 6.

It will be noted in FIGURE 7 that the conductor 132 and the detonator and booster 138 are connected directly to the holding member 150. The shaped charges 10 are planted directly in the holding member 150 and are arranged to be simultaneously detonated thereby upon detonation of the detonator and booster 138.

Manifestly, the operation of the perforating apparatus with the shaped charge holding member 150 therein will be substantially the same as with the shaped charge holding member 126 therein. The charge holding member 150 has the advantage of eliminating the necessity for interconnecting the shaped charges 10 with the Primacord 140. Thus, there is less chance of detonation failure when using the holding member 150.

It will also be understood that the perforating apparatus 100 utilizing either the shaped charge holding member 126 or the shaped charge holding member 150 can be effectively utilized to perforate unconsolidated sands as previously described in connection with the perforating apparatus 32. The shaped charges 10 also include the inert particles 21 (see FIGURE 1) so that the perforations formed thereby will also include a permeable bridge to inhibit the flow of sand through the perforations.

It will be understood that the embodiments described in detail hereinafore are presented by way of example only and many changes and modifications can be made thereto without departing from the spirit of the invention or from the scope of the annexed claims.

What is claimed is:
1. A shaped charge for perforating an unconsolidated formation surrounding a well bore, said charge comprising:
   a tubular body member;
   an explosive material located in said tubular body member, said explosive material having a concave, generally conical end surface;
   a generally conical liner disposed in said body member in juxtaposition with the conical end surface on said explosive material; and
   a plurality of inert particles located in said body member and arranged to be entrained in the jet formed by the detonation of said charge and carried into the perforation forming a permeable bridge therein.
2. The shaped charge of claim 1 wherein said inert particles have at least one dimension at least one-half the average diameter of the perforation formed by said charge, whereby said particles form a permeable bridge therein to inhibit the flow of sand into the well bore.
3. The shaped charge of claim 1 wherein said particles are disposed between said liner and explosive material.
4. The shaped charge of claim 2 wherein said particles are embedded in said liner.
5. Perforating apparatus for use in completing a well in an unconsolidated formation comprising:
   a carrier means arranged to be moved through the well bore;
   a plurality of shaped charges carried by said carrier means and oriented in a direction whereby the explosive jet from each said charge perforates the formation surrounding the well bore, each said charge including a plurality of inert particles arranged to be carried into the perforations forming a permeable bridge therein; and
   ignition means for detonating said shaped charges.
6. The perforating apparatus of claim 5 wherein said carrier means includes:
   a pair of shaped charge holding members disposed in generally parallel relationship;
   first linkage means pivotally connected with one end of each shaped charge holding member and including resilient means biasing said charge holding members relatively apart; and
   second linkage means, pivotally connected with the other end of each shaped charge holding member and including resilient means biasing said charge holding members relatively apart, whereby said charge holding members move relatively together to pass through a relatively small diameter portion of the well bore and are moved apart when in relatively larger diameter portions of the well bore.
7. The perforating apparatus of claim 5 wherein said carrier means includes:
   a tubular housing having upper and lower closed ends and having a plurality of apertures extending transversely through the wall of said housing; and
   closure means closing each of said apertures and generally cylindrical shaped charge holding means located substantially coaxially in said housing and holding each said shaped charge in alignment with a respective one of said apertures.
8. The perforating apparatus of claim 7 wherein:
   said holding means is constructed from a sheet explosive; and
   said ignition means extends into said housing and is connected with said sheet explosive.
9. The perforating apparatus of claim 5 wherein said carrier means includes:
   a plurality of tubular housings, each said housing
9 having upper and lower closed ends and a plurality of apertures extending through the wall thereof, said housings being connected in end-to-end relationship, closure means closing each of said apertures, and a generally cylindrical shaped charge holding member substantially coaxially located in each said housing; and, said ignition means includes:

selective ignition control means attached to said carrier means, and

detonation means located in each said housing operably connected with said shaped charges and with said control means, whereby the shaped charges in a selected housing are simultaneously detonated.

10. A method of completing a well that extends through an unconsolidated formation that includes the steps of:

positioning a shaped charge having inert particles therein adjacent the formation;

perforating the unconsolidated formation by detonating said charge; and

simultaneously forming a permeable bridge in said perforation by depositing a plurality of said inert particles in said perforation to inhibit migration of portions of the unconsolidated formation into the well.

11. A method of completing a well extending through an unconsolidated formation comprising the steps of:

positioning a casing in the well adjacent said formation;

depositing a cementitious material in the annular space between said formation and said casing;

positioning an array of shaped charges having inert particles therein in the casing adjacent said unconsolidated formation;

perforating said casing, cementitious material, and formation by detonating said shaped charges; and, simultaneously forming a permeable bridge in said perforations by depositing a plurality of said inert particles in said perforations to inhibit the migration of portions of the unconsolidated formation into the well.

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