

SPECIFICATION

Improved Method and Apparatus for Drilling Bore Holes

In the art of drilling wellbores for the purpose of producing hydrocarbon bearing formations found downhole therein, it is often advantageous to slant the lower marginal end of the borehole so that the pay zone is penetrated substantially horizontally and at a considerable distance radially away from the drilling rig. One of the advantages found in slanting a borehole in this manner is to enable the pay zone to be entered at a number of different locations radially spaced about the drilling rig so that a plurality of the boreholes can be formed from a common drilling location. This technique is especially advantageous when the cost of moving the drilling rig is considerable, as for example, an offshore drilling rig.

Another advantage derived from slanting the lower marginal end of the borehole horizontally respective to the pay zone is that a tremendous amount of surface area of the borehole is located directly in the pay zone; and therefore, a greater number of perforations can be formed which extend back up into the hydrocarbon bearing formation, thereby achieving a much greater production rate from the pay zone.

Where the pay of the slanted borehole is located in an unconsolidated type strata, the loose particles of the formation tend to flow through the perforations and thereby bring about many undesirable and complicated production problems which are difficult to overcome. Accordingly, it would be desirable to be able to perforate a slanted borehole in such a manner that the formation is penetrated only in a predominately downward direction; and accordingly, flow of unconsolidated material must therefore occur in an upward direction, thereby causing the solid matter which constitutes the pay zone to tend to gravitate downwardly and remain insitu respective to the formation, and this is the primary subject of this invention.

The invention comprises a method of completing a cased borehole which has a substantially vertical upper marginal end portion and a substantially horizontal lower marginal end portion, comprising the steps of:

(1) arranging shaped charges within a perforating gun such that said charges are oriented to fire radially away from the longitudinal axial center line of the gun.

(2) placing an upwardly extending guide means on said gun in opposition to said shaped charges and extending said guide means away from the gun and into close proximity of the inside peripheral wall of the casing, thereby causing the gun to gravitate towards the bottom of the casing while the shaped charges, when detonated, are directed in a downward direction radially away from the lower half of the gun.

(3) running the gun downhole into the horizontal lower marginal end portion thereof

until the gun is at a location adjacent to a hydrocarbon bearing formation to be completed, and firing the gun, thereby forming perforations which extend generally downward through the casing wall and downward out into the formation.

The invention also comprises apparatus for carrying out the method.

In one form of the invention, a tubing string is connected to a swivel, the swivel is connected to a ported sub with the sub being connected to a gun firing head, while the gun firing head is connected to detonate all of the shaped charges of the gun. A weighted object is circulated down through the tubing string, through the swivel, and impacts against the gun firing head, with circulation occurring down the tubing string, through the ported sub, and back up the casing annulus. The impact of the weighted object against the gun firing head detonates the individual shaped charges. The gun includes a plurality of charge carriers which are connected in series relationship so that a substantial length of the slanted borehole can be perforated and production thereafter controlled to avoid producing the unconsolidated material of the formation.

Accordingly, a primary object of the present invention is the provision of a system by which an unconsolidated formation of a hydrocarbon producing wellbore can be completed.

Another object of the invention is to disclose and provide a method and apparatus for completing a wellbore so that fluid can be produced from an unconsolidated formation without producing solid material therefrom.

A further object of this invention is to disclose and provide a method and apparatus by which the shaped charges of a jet perforating gun are oriented to fire in a predominantly downwardly direction when the gun is placed downhole in a slanted borehole.

A still further object of this invention is to disclose and provide a gravity oriented perforating system for a slanted well bore by which the perforations are caused to extend in a predetermined direction away from the wellbore.

These and various other objects and advantages of the invention will become readily apparent to those skilled in the art upon reading the following detailed description and claims and by referring to the accompanying drawings.

The invention will be described with reference to the accompanying drawings:—

Figure 1 diagrammatically illustrates a cross-sectional view of a slanted borehole having apparatus made in accordance with the present invention associated therewith;

Figure 2 is an enlarged, broken, part cross-sectional, elevational view of part of the apparatus disclosed in Figure 1;

Figure 3 is an enlarged, cross-sectional view taken along line 3—3 of Figure 1;

Figures 4, 5 and 6 diagrammatically illustrate various different exaggerated configurations of the apparatus disclosed in Figure 3; and,

Figure 7 is a fragmented, enlarged, cross-sectional view of a casing of a wellbore which has been perforated in accordance with the present invention.

5 Figure 1 diagrammatically illustrates a wellbore 10 which has a casing 12 extending downhole into the earth. A tubing string 14 is more or less concentrically arranged respective to the casing and also extends downhole through 10 the borehole and into proximity of a hydrocarbon containing formation. The lower marginal end 16 of the borehole has been slanted, and in the illustrative view of Figure 1 it will be appreciated that the degree of the slant has caused the lower 15 end of the borehole to assume a path which is substantially horizontal, while the upper end of the borehole is essentially vertical.

As seen in Figures 1—3, a jet perforating gun 18, made in accordance with the present 20 invention, is located downhole in the slanted portion of the borehole. The gun includes a charge carrier 20 within which there is disposed a plurality of shaped jet perforating explosive-type charges. The individual shaped charges are made 25 in accordance with the prior art. A plurality of other charge carriers 22 may be series connected with respect to the charge carrier 20. The charge carrier is provided with the usual threaded plugs 24 which form a closure member for a port 30 formed therewithin, through which the hot plasma jet exits whenever the gun is detonated.

As seen in Figures 1 and 2, a sub or coupling 26 interconnects each of the charge carriers. A sub or coupling 28 is provided with radially 35 spaced apart ports 29 and is connected to the lower end of the tubing string by means of a swivel 30. The swivel 30 can take on a number of different forms so long as it enables relatively low friction axial rotation between the charge carrier 40 and the tubing string.

Numeral 31 of Figure 1 diagrammatically illustrates the bend of the borehole which, of course, occurs over a length of several hundred feet as the vertical upper marginal end of the 45 borehole is slanted toward the illustrated horizontal lower marginal end of the borehole. In this respect, the term "slanted borehole", as used throughout this disclosure, is intended to relate to a borehole which is sloped away from a vertical 50 position sufficiently to enable the gun apparatus of the present invention to bear against the inside peripheral wall surface thereof with sufficient gravitational force to cause the gun to be oriented into an upright position. The term "upright 55 position", as used herein, is intended to mean that the shaped charges of the gun come to bear in a substantial downhole direction as contrasted to an uphole direction.

The outer housing of the charge carrier is 60 rigidly connected to an outwardly directed member 34 and 36, which is affixed to the housing and extends in opposition to the shaped charges, with the free outer end portion of the member being sized such that it is located in close 65 proximity to the inside peripheral wall surface of

the casing when the gun is in the upright position.

In the illustration of Figures 1—6 of the drawings, the individual charge carriers 20, 22 of the gun are illustrated as each having a forward 70 and rearward casing engaging member 34 and 36, 34' and 36' (not shown).

A gun firing head 38 is affixed to the forward or uphole end of the uppermost charge carrier and is connected in affixed relationship to the ported sub 75 28. The forward end 40 and rear end 41 of the orienting members are preferably curved in order to avoid engagement with any irregularity formed along the casing wall. A web 42 is rigidly affixed to the charge carrier housing and supports a load 80 bearing enlargement 43 at the free end thereof.

In Figure 1 the hydrocarbon bearing formation 25 has been penetrated at 44 by the action of the jet charges. The shaped charges have penetrated the plugs to produce a plasma jet of hot gases 85 and vaporized metal which form the tunnels 44 in the manner of Figures 1, 3 and 7.

In Figures 4, 5 and 6, the operation of the gravity orienting perforating system of the present invention is illustrated. In particular, Figure 4 90 discloses the position on the inside wall surface 46 of the casing 12 which is engaged by the casing engaging member 34 should the gun tend to axially rotate respective to the tubing 14 as the gun is run downhole. As seen in Figure 4, should 95 the gun tend to climb the sidewall of the casing, enlargement 44 will be rotated into engagement with the casing wall at 46, thereby preventing any further rotation. At the same time, the mass of the gun tends to gravitate the gun back into the 100 upright position seen illustrated in Figures 1—3.

In Figure 5 the gun has climbed the opposed sidewall of the casing, and the outer enlargement 43 of the casing engaging member again has 105 contacted the inside peripheral wall surface of the casing at 46 whereupon the mass W of the gun gravitates the apparatus in a manner such that it axially rotates back into the upright position.

Figure 6 illustrates that slight axial rotation of the gun has occurred as it is located nearly on 110 bottom dead center of the slanted portion of the borehole. As seen in Figure 6, should the gun for some reason or another further axially rotate in either direction, the enlargement 43 of the casing contacting member will engage the inside casing 115 wall at 46 to prevent further rotation thereof. Since the charges are aligned to perforate in a downward direction in Figure 6, the term "upright position" applies to this geometrical configuration of the illustration therein.

In Figure 1, a weighted object 48, in the form of a sinker bar, is circulated downhole by means of pump P located on drilling platform 50.

In Figure 3, prima cord 52 is illustrated as being looped through each of the apertures 125 located rearwardly within the shaped charges 54 in a conventional manner. Detonating means 56 forms part of the firing head and explodes the prima cord in response to the firing head being contacted or impacted by the sinker bar 48 in 130 accordance with my previously issued U.S. Patent

No. 3,706,344 and No. 4,009,757.

In Figure 7, the perforating gun of the present invention has been detonated, thereby forming holes 58 through the aluminum plugs 24, thereby forming the beforementioned tunnels 44. Upward flow of hydrocarbons from formation 25 is generally illustrated by the arrow at numeral 60. The unconsolidated formation 25' will flow in the direction of arrow 60 should the individual perforations of the pay zone be overproduced.

Looking again now to Figure 6, numeral 62 indicates a vertical line taken along the slanted portion 16 of the borehole. Numeral 64 indicates the maximum acceptable angular displacement 72 of the casing engaging member 34 from a vertical plane 62. Numeral 66 indicates a horizontal plane taken through the casing at 16, while numerals 24, 24' indicate the direction of the hot gases which result from the detonated shaped charges, and numeral 68 indicates the minimum angle between one of the hot streams of gas from one of the shaped charges and the horizontal. Numeral 70 is the angular displacement between pairs of shaped charges when more than one shaped charge is incorporated in radially spaced relationship in the illustrated manner of Figure 3, for example.

A packer 75 can be employed for completing the well in accordance with the method of the present invention.

In carrying out the method of the present invention, a borehole having a vertical, upper marginal end and a slanted, lower marginal end portion is formed into the ground, and the casing 12 is cemented into place so that the casing extends downhole through the formation 25 to be completed.

The gun is made up and attached to the tubing string 14 in the illustrated manner of Figure 1 so that the perforating apparatus can freely axially rotate with a minimum of frictional resistance respective to the tubing. The gun is run downhole on the end of the tubing string and positioned adjacent to and within the formation to be completed. A sinker bar 48 is pumped down the tubing string by connecting pump P to the uphole end of the tubing string and pumping fluid down the string, out through ports 29, up the casing annulus, and across the unset packer.

The sinker bar 48 impacts against the gun firing head 38, thereby detonating the prima cord 52 and causing all of the shaped charges to explode. The shaped charges penetrate the plugs, casing, and extend back up into the formation in the illustrated manner of Figures 1, 3 and 7. The gun can be removed from the borehole, and the well placed on production by utilizing any number of different completion techniques.

Where deemed desirable, the unset packer 75 can be employed by setting the packer immediately following perforation and the gun left downhole with production occurring through ports 29 of the sub 28. Alternatively, permanent completion techniques can be carried out in accordance with my previously issued U.S. Patent

No. 3,706,344 in conjunction with the present method and apparatus.

The present invention enables an almost unlimited number of perforations to be made along the slanted portion of a borehole, thereby effecting communication over an extremely long length of borehole formed into the formation 25, which advantageously enables a large production rate to be achieved from relatively thin pay zones.

As seen in Figures 4—6, the gun is gravitated into the upright position because of the distribution of mass respective to the casing engaging member and the center of gravity of the gun. As particularly seen in Figure 6, the gun is gravitated toward the upright position within the limits of the angle indicated by numeral 72. The relative location of the pairs of shaped charges are arranged respective to one another to penetrate the formation along the indicated angle noted by numeral 70. Accordingly, when the gun is at its maximum angle of rotation 72, there is always a minimum angle 68 at which the tunnels extend back into the formation with respect to the horizontal 66. Therefore, production must always occur from the pay zone uphole into the casing.

In practicing the present invention, it is desired that the tunnels 44 extend downwardly from the casing so that any unconsolidated material 25' remains insitu because it is held gravitated into its original position. For this reason, a large number of perforations 44 is preferred so that the aggregate rate of production of the sum of the flow through the perforations is substantial, yet the flow is held to a value required to avoid flowing any of the unconsolidated matter into the borehole.

The present invention provides an improved method of gravel packing the formation contiguous to the casing since the gravel can be forced downhole where it will gravitate into the downwardly directed tunnels 44.

The present invention can also be used in conjunction with a wireline, wherein the wireline acts as the swivel 30, and with the gun being a through tubing gun which is run through the tubing, downhole onto location by pumping the gun with pump P. In this instance, the tubing 14 must be considered representative of the wireline while the ported sub 28 is eliminated since the gun is circulated down through the tubing with fluid returning up through casing annulus. The gun is fired electrically using known wireline techniques.

Claims

1. A method of completing a cased borehole which has a substantially vertical upper marginal end portion and a substantially horizontal lower marginal end portion, comprising the steps of:

(1) arranging shaped charges within a perforating gun such that said charges are oriented to fire radially away from the longitudinal axial centerline of the gun;

(2) placing an upwardly extending guide means on said gun in opposition to said shaped charges



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perforations of the pay zone be overproduced.

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(1) arranging shaped charges within a perforating gun such that said charges are oriented to fire radially away from the longitudinal axial centerline of the gun;

(2) placing an upwardly extending guide means on said gun in opposition to said shaped charges



and extending said guide means away from the gun and into close proximity of the inside peripheral wall of the casing, thereby causing the gun to gravitate towards the bottom of the casing while the shaped charges, when detonated, are directed in a downward direction radially away from the lower half of the gun;

5 (3) running the gun downhole into the horizontal lower marginal end portion thereof until the gun is at a location adjacent to a hydrocarbon bearing formation to be completed, and firing the gun, thereby forming perforations which extend generally downward through the casing wall and downward out into the formation.

10 2. The method of Claim 1 wherein a tubing string is used to run the gun downhole, and the gun is rendered freely axially rotatable relative to the tubing by the provision of a swivel which is interposed between the gun and the lower end portion of the tubing string.

3. The method of Claim 2 wherein pairs of the charges are oriented radially relative to one another with a plurality of pairs of charges being spaced along the gun such that each pair of charges form perforations which extend less than 180° away from one another.

4. The method of Claim 2 wherein said gun is detonated by circulating a weighted object down through the tubing string until the bar strikes a firing head located on the gun, and using the force of the impact to cause the firing head to detonate the shaped charges.

5. The method of Claim 1 wherein a tubing string is used to run the gun downhole, and the gun is rendered freely axially rotatable relative to the tubing by the provision of a swivel which is interposed between the gun and the lower end portion of the tubing string;

40 said pairs of the charges are oriented radially relative to one another with a plurality of pairs of charges being spaced along the gun such that each pair of charges forms perforations which extend less than 180° away from one another;

45 and further including the step of circulating the weighted object down the tubing string by forming a flow path which extends down the tubing string into proximity of the firing head, out into the casing annulus, and back uphole to the surface.

50 6. An apparatus for carrying out the method of Claim 1 comprising a casing, shaped charges within a perforating gun such that the charges when detonated are directed in a downward

55 direction away from the lower half of the gun, an upwardly-extending guide means on the gun in opposition to the shaped charge carriers and in which guide members extend away from the gun and into close proximity to the inside peripheral wall of the casing to cause the gun to gravitate towards the bottom of the casing, the gun having a main housing within which the charge carriers are carried, a firing head attached to the uphole end of the gun and means associated with the head for detonating each of the shaped charges in a direction which includes an angle of less than 180°.

7. The apparatus of Claim 6 wherein said gun is connected to a swivel means and said swivel means is connected to a tubing string by which the gun is run downhole into proximity of the slanted portion of the borehole.

8. The apparatus of Claim 6 wherein means are provided by which a weighted object is circulated downhole into abutment with said gun firing head and said gun firing head includes means by which it fires in response to the impact force realized when the weighted object contacts the gun firing head.

9. The apparatus of Claim 6 wherein said gun is connected to a string of tubing by a swivel, and comprises a sub, including means by which the sub is connected in series relationship relative to said swivel and firing head, an outlet port formed in said sub by which fluid can flow through said tubing and through said outlet port, and means by which the gun head detonates said shaped charges responsive to impact, whereby an object can be circulated downhole into abutting engagement with the firing head thereby detonating the shaped charges.

10. The apparatus of Claim 6 wherein there is further included a swivel means, said gun is connected to said swivel means, and said swivel means is connected to the tubing string by which the gun is run downhole into proximity of the slanted portion of the borehole;

means are provided by which a weighted object is circulated downhole into abutment with said firing head and said firing head includes means by which it detonates the shaped charges in response to the resulting impact force.

11. A method of completing a cased borehole substantially as hereinbefore described.

105 12. Apparatus for completing a cased slanted well bore substantially as described with reference to the accompanying drawings.