METHOD FOR FLOTATION COMPLETION FOR HIGHLY DEVIATED WELLS

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

INVENTOR

BURTON W. AULICK

ATTORNEYS
METHOD FOR FLOTATION COMPLETION FOR HIGHLY DEVIA TED WELLS

Burton W. Aulick, Midland, Tex., assignor to Halliburton Company, Duncan, Oklahoma, a corporation of Delaware

Filed Oct. 17, 1967, Ser. No. 675,808

Int. Cl. E21b 37/10, 33/14

U.S. Cl. 166—285

11 Claims

ABSTRACT OF THE DISCLOSURE

Well completion method and apparatus for highly deviated wells. Cement slurry is placed in the bore hole before the casing string is run. The cement is a delayed setting type cement. The casing contains fluid having a substantially lower density than that of the slurry. The fluid in the casing provides a buoyancy effect on the casing for floating the casing through the deviated zone. In a modified form of the invention, a buoyancy chamber is provided adjacent the lower end of the string in which the buoyancy fluid is contained. Centralizers are provided on the exterior of the casing and are spaced longitudinally from each other. The centralizers along the buoyancy chamber are spaced apart at greater intervals than the centralizers above the buoyancy chamber. An improved casing-cement bond is achieved due to a pressure differential between the exterior and the interior of the casing when the casing is run in the cement slurry. The hydrostatic pressure of the slurry urges the casing radially inward, but after the cement hardens, the pressure in the casing increases, thereby urging the casing outwardly against the hardened cement.

BACKGROUND OF THE INVENTION

This invention relates to well operations, and more particularly, to completing highly deviated wells.

Techniques have been developed for directional drilling of bore holes to reach a subterranean location that is offset from a vertical axis that extends downwardly from the drill rig. By using deflection tools, a bore hole may be deviated to a considerable extent. In a highly deviated open bore hole, it is often difficult to lower the casing string through the deviated zone without caving in the wall of the bore hole, or the casing pipe becoming stuck against the wall of the bore hole. In attempting to pump cement slurry out through the lower end of the casing string and then up through the annulus which is filled with mud as in conventional practice, the weight of the slurry in the casing causes the casing pipe to be deflected toward the lower side of the bore hole in the highly deviated zone. These conditions may cause lost circulation and non-uniform distribution of cement slurry around the casing.

In view of the problems associated with well completions in highly deviated bore holes, it is an object of this invention to provide an improved method for running casing pipe in highly deviated bore holes and for completing highly deviated wells.

It is a further object of this invention to provide a method for improving the bond between the casing pipe and the cement in highly deviated wells.

It is a still further object of this invention to provide a method for maintaining a casing string at approximately the center of the bore hole throughout the entire length of a highly deviated bore hole.

SUMMARY OF THE INVENTION

These objects are accomplished in accordance with a preferred embodiment of the invention by pumping cement slurry into a highly deviated open bore hole. The cement slurry is preferably of the delayed setting type. The casing string is then made up with a float shoe on the bottom of the string and the string is filled with a fluid that has a substantially lower density than that of the cement slurry in the bore hole. The casing string is run in the bore hole which has been at least partially filled with the delayed setting cement slurry. Preferably, the centralizers are provided throughout the length of the casing string. The buoyancy effect of the lower density fluid in the string causes the casing pipe to be buoyed up as it passes through the deviated interval of the bore hole, thus avoiding extreme centralizer deflection, differential sticking, or other problems encountered with conventional techniques. When the lower end of the casing string is spaced a predetermined distance above the bottom of the hole, further movement of the casing is stopped and sufficient time is allowed for the slurry to harden.

Since the cement slurry has been placed in the bore hole before the casing is run the fluid pressure in the casing adjacent the producing formation may be substantially less than the hydrostatic pressure of the cement slurry on the outside of the casing at the depth of the producing formation. This pressure differential urges the casing radially inward. The cement then hardens. The fluid pressure in the casing subsequently increases, for example, during subsequent operation of the produced fluid. The casing is urged to expand circumferentially, thereby improving the cement-casing bond.

In a modified form of the invention, a retrievable bridge plug is positioned in the string above the float shoe when the slurry is being made up. The packer rings of the bridge plug are expanded against the interior of the casing pipe before the casing is run in the bore hole. The bridge plug is preferably provided with a bypass or equalizing valve which allows fluid communication to be established within the casing string above and below the bridge plug before the expandable packer rings on the bridge plug are retracted. The interior of the casing string between the bridge plug and the float shoe forms a buoyancy chamber that is filled with air or other suitable fluid having a considerably lower density than that of the cement slurry in the bore hole. The length of casing between the bridge plug and the float collar is preferably greater than the distance from the bottom of the bore hole to the top of the producing formation. Centralizers are provided on the casing string at greater intervals over the portion of the casing string between the bridge plug and the float collar than they are in the portion of the casing string above the bridge plug. The casing string is run in the bore hole which has been at least partially filled with the delayed setting cement slurry. The interior of the casing string above the bridge plug is filled with fluid. The buoyancy chamber causes the casing pipe to float as it passes through the deviated zone, thus avoiding extreme centralizer and casing deflection. When the lower end of the casing string is spaced a predetermined distance above the bottom of the hole, further movement of the casing is stopped and sufficient time elapses to allow the slurry to harden.
When the cement in the annulus has hardened, a tubing string with an overshot on the lower end is lowered through the casing to engage the retrievable bridge plug and to open the bypass valve. The air or other fluid that is trapped in the buoyancy chamber below the bridge plug then escapes through the bypass valve and the fluid above the bridge plug flows into the space occupied by the buoyancy fluid. When the pressure above and below the bridge plug is approximately equalized, the bridge plug is released and pushed down through the casing to a position between the float shoe and the lowermost producing formation. The bridge plug packer rings are again expanded and the overshot is disconnected from the bridge plug. The lower end of the tubing string is then raised a few feet above the lowermost producing formation, and a perforating gun is run through the tubing string until it is positioned at the depth of the producing formation. After the casing has been perforated, the tubing string may be again lowered to engage the retrievable bridge plug to collapse the packers and raise the bridge plug to a position above the perforated zone, but below the next higher producing zone. The perforating operation may then be repeated at this zone and in the same manner perforations may be made successively in the higher zone of the producing formations.

DESCRIPTION OF THE DRAWINGS

This preferred embodiment of the invention is illustrated in the accompanying drawings in which:

FIG. 1 is a schematic view of a highly deviated bore hole in the process of being drilled;

FIG. 2 is a schematic view of the bore hole as in FIG. 1, but showing the casing string being lowered in the bore hole which is partially filled with cement slurry;

FIG. 3 is a schematic view as in FIG. 1, but showing the bore hole after the cement has hardened and prior to perforating;

FIG. 4 is a schematic view of the bore hole as in FIG. 1 after perforating the casing;

FIG. 5 is a side elevational view of a centralizer on the exterior of the casing string;

FIG. 6 is an enlarged schematic view of the lower portion of the bore hole, showing the casing string positioned at the bottom of the hole, while the cement slurry is hardening;

FIG. 7 is an enlarged schematic view of the lower portion of the bore hole as in FIG. 3; and

FIG. 8 is an enlarged schematic view of the lower portion of the bore hole as in FIG. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, a conventional derrick 2 is shown schematically as representative of a rotary drilling rig and associated apparatus. As in conventional practice, a surface casing 4 is cemented at the top of the bore hole 6. A rotary drill bit 8 is mounted at the lower end of a string of drill pipe 10. The drill string 10 may include a knuckle joint, or other directional drilling tool to cause a portion of the bit to be inclined at an angle to the vertical axis of the top portion of the bore hole 6. A highly deviated well may be inclined at an angle of as much as 60° from the vertical or more. The bore hole 6 illustrated in FIG. 1 has a typical deflection pattern for directional drilling. FIG. 2 shows an inclined deflection zone 12 and a final deflection zone 14. In some directional wells, the final deflection zone may return the lower portion of the bore hole to a vertical, or approximately vertical orientation.

After the bore hole 6 has been drilled to total depth, the drill string 10 is raised to the surface and the drill bit 8 is removed from the string. The drill string 10 is then run in the bore hole 6 again. Of course, a tubing string could be substituted for the drill string, if desired. The lower end of the drill string 10 is open and cement slurry is pumped down the drill string 10 where it flows out of the bottom of the string and upwardly through the annulus between the exterior of the drill pipe and the wall of the bore hole. Usually the drill pipe has a smaller diameter than the casing and by placing the cement slurry through the drill pipe, frictional pressure of the circulating fluids in the annulus is minimized. Also, placement of the slurry through the drill pipe helps control the rate at which the heavier slurry displaces the mud hydrostatically.

The delayed setting cement slurry 16 which is shown schematically in FIG. 2 partially fills the bore hole and the upper portion of the bore hole is filled with drilling mud 18. The volume of the slurry 16 should be sufficient to fill the annulus to the top of the bore hole when the casing string is run approximately to the total depth, or to whatever depth it is desired to cement the casing in the bore hole. Drilling mud follows the cement slurry in the drill string to approximately equalize the height of the slurry inside and outside of the drill pipe.

The delayed setting cement slurry must be capable of remaining fluid for a sufficiently long time to allow making up and running in the casing string, with the casing string being isolated and made available to allow for difficulties that may be encountered in running the casing. A wide range of properties can be designed for the delayed setting slurry, with consideration being given to filtration, fluidity control, retardation and ultimate strength. Preferably, a specific slurry should be designed to suit the particular well conditions. A typical delayed slurry may have a volume of about 2 cubic feet per sack of cement, a fluid time of 30 hours, fluid loss of less than 100 cc. per 30 minutes, as measured by the API cement test on a 325 mesh screen and 1000 p.s.i. differential pressure. In order to assure that the cement through the producing zone provides adequate isolation of the formations, the slurry should have a density of at least 13 lbs. per gallon.

After the desired quantity of slurry has been placed in the bore hole, the drill pipe is removed from the bore hole, and the casing string is made up quickly. The casing string, as shown in FIGS. 2 and 6, has a float shoe 22 at the lower end. The float shoe is a conventional tool used in cementing and includes a one-way valve which prevents fluid flow upwardly into the interior of the casing pipe, but allows fluid to flow downwardly out of the lower end of the pipe. Although only a single valve is shown at the lower end of the casing string, additional one-way float collars may be provided one or two joints above the float shoe. The float collar has a one-way valve similar to the valve in the shoe 22. The purpose of providing both a float shoe and a float collar is that if one of the valves should fail, the other valve will control the flow of fluid at the lower end of the casing string. To simplify the description, the casing string is described as having only a float shoe.

In making up the casing string, at least a portion of the casing string is filled with a fluid that has a substantially lower density than that of the cement slurry in the bore hole. The bore hole connections may permit running the casing in the bore hole with the entire casing filled with a buoyant fluid. In that case the fluid causes the casing to be floated through the inclined portion of the bore hole. When the lower end of the casing reaches the bottom of the bore hole, movement of the casing is stopped and a cementing job is accomplished for a cement to harden. Subsequently conventional completion operations may be carried out.

Due to the deviation pattern, depth, or other conditions of the bore hole, it may be desirable to confine the buoyant fluid within a chamber of a predetermined length in the casing. In such a modified operation, the fluid is confined in a chamber in the casing by means of a retrievable bridge plug 24 that is positioned in the casing at a substantial distance above the float shoe 20 or above the float collar, if one is used.
packer rings on the bridge plug are expanded to seal the interior of the casing string and thereby to form a buoyancy chamber in the casing between the bridge plug and the float shoe. The buoyancy chamber may be filled with air at atmospheric pressure, air under pressure, nitrogen under pressure, salt water, or other suitable fluid. The particular fluid used in the buoyancy chamber depends on the conditions in the bore hole. In deep wells, for example, it is necessary to pressurize the fluid in the chamber to prevent the pipe from collapsing. The fluid in the reservoir, must have a substantially lower density than the cement slurry.

An example of a bridge plug which might be used for this purpose is disclosed in Phenix Pat. No. 3,189,096. Other types of retrievable bridge plugs that may be used are cup type bridge plugs which are provided with cup type sealing elements, double acting hook wall slips and a dual wedge arrangement for anchoring the tool against the pressure from either above or below the tool. The bridge plug 24 preferably has an equalizing valve which may be operated to provide fluid communication through the bridge plug when the packer rings are expanded. This valve allows equalization of fluid pressure above and below the bridge plug before collapsing the packer rings. The bridge plug 24 also should be provided with an overshot to allow ready separation of a tubing string through the tubing string. These features are disclosed in the Phenix patent. While the casing is being run in the bore hole, the interior of the casing above the bridge plug 24 is filled with water or other treatment fluid.

The remainder of the casing string is made up of a series of pipe joints to provide a string of sufficient length to reach a depth below the producing formation. Centralizers 26, as shown in FIG. 5, are secured to the exterior of the casing pipe 20 at regular intervals. The centralizers are of conventional construction, with one end 28 being latched around a collar or limit ring 30 and the opposite end 32 being freely slidable along the exterior of the casing string 20 to accommodate flexing of the bowed springs 34. The centralizers are preferably provided on the exterior of the casing throughout the entire length of the casing.

When the bridge plug 24 is used the spacing of the centralizers 26 is an important feature. In FIG. 6, the centralizers 26 are shown schematically to indicate that they are spaced apart from each other a greater distance throughout the buoyancy chamber section, than they are above the bridge plug 24. Preferably, the centralizers 26 are spaced at about twice the distance from each other in the buoyancy chamber section, as compared to the centralizer spacing above the bridge plug. It has been found that a suitable spacing for the centralizers is 120 feet apart in the buoyancy chamber zone and 60 feet apart above the retrievable bridge plug. It is desirable to use as few centralizers as are necessary to cause the casing to be positioned in the center of the bore hole. Due to the floatation effect of the buoyancy chamber, it is possible to space the centralizers more widely apart than in the conventional practice.

A radioactive marker may be included in the casing collar immediately above the retrievable bridge plug to provide a reference point during subsequent logging and perforating operations.

There are several advantages in at least partially filling a highly deviated bore hole with cement slurry before running the casing string in the bore hole. This technique provides a more uniform distribution of cement slurry around the casing due to the movement of the casing pipe through the slurry. Also, due to the pipe movement, there is less tendency for mud pockets to form. Furthermore, must of the cement slurry is left at the surface, thereby reducing the amount of cement slurry. Improved control of casing insertion and reduction of the resultant pressure surges which may cause loss of circulation are also achieved by this technique, since the casing is lowered into the heavier cement slurry during the later portion of the operation, thereby obtaining the benefit of more buoyancy.

The buoyant effect that is achieved by the difference in density between the cement slurry in the annulus and the fluid in the interior of the buoyancy chamber in the casing string provides better centralizing of the casing, than in conventional techniques where the heavy cement slurry is pumped down through the casing string while the lighter mud is in the annulus surrounding the casing.

When the casing string has reached the bottom of the bore hole, the string is picked up several feet off the bottom and is hung in accordance with conventional practice at the well head. The casing remains undisturbed until the cement has hardened. This may take as long as three hours or more, depending upon the type of delayed setting cement that is used.

After the cement has hardened, a tubing string 36 is made up with a retrievable bridge plug overshot 38 which cooperates with the retrievable bridge plug 24, and an overshot is disclosed in the Phenix patent, but if another type of retrievable bridge plug is used, a corresponding overshot may be substituted for that disclosed in the Phenix patent. As shown in FIG. 7, the overshot 38 is provided at the lower end of the tubing string 36. By manipulation of the tubing string, the overshot may be engaged with the bridge plug 24 and the equalizing valve in the bridge plug is opened to allow the water or other treatment fluid in the casing 20 to flow through the bridge plug into the buoyancy chamber section of the casing string. The bridge plug may then be released by manipulation of the tubing string 34 and the bridge plug is pushed down through the casing string to a position below the lowest producing zone of the formation, preparatory to perforating at the producing zone. The bridge plug may again be expanded to seal the lower end of the casing string. The tubing string is then released from the retrievable bridge plug and the tubing is raised until the lower end of the tubing string is spaced an appreciable distance above the bridge plug. Preferably, two or more casing collars should be exposed below the lower end of the tubing string. Using conventional well logging techniques, the position of the bottom of the tubing string can be correlated with the casing and the surrounding formation, so that the perforating gun may be accurately positioned between the lower end of the tubing string and the bridge plug.

When the interior of the casing is filled with air or other suitable fluid, the casing pipe is stressed in radial compression due to the difference between the hydrostatic pressure of the cement slurry on the outside of the pipe and that of the fluid in the inside of the pipe. The pipe remains in its deflected condition until the cement hardens. Then, when the bridge plug 24 is released, or if the bridge plug is not used, subsequent completion operations cause the pressure in the interior of the casing pipe to increase. When the pressure differential is thereby reduced, the pipe is urged against the hardened cement thereby providing an effective seal between the exterior of the casing pipe and the cement.

Due to the highly deviated pattern of the bore hole, it may be impossible to run a perforating gun 40 to the depth of the producing formation. As shown in wire line 42. The perforating gun 40 can be placed at the desired depth, however, by circulating fluid through the tubing string to pump the perforating gun down to the desired depth, as shown in FIG. 8. The producing zone can then be perforated according to the conventional practice. Other well treatment methods, such as shooting the entire string of casing on a tool joint, may be carried out after perforation. The next higher zone may be perforated by again connecting the overshot with the retrievable bridge plug to collapse the bridge plug and reset it at the next higher elevation di-
rectly below the next producing formation or zone. Thus, the bridge plug isolates the perforated zones, while the higher zones are being perforated and treated. The well may then be completed to place the well on production.

The method of this invention provides for uniform distribution of cement slurry around the casing and centralization of the casing in highly deviated bore holes. The buoyant effect of the fluid in the casing string greatly reduces the chances of encountering differential sticking of the casing against the bore hole wall in the deflection zones. In the modified form of the invention, whereby the bridge plug is used to form a buoyancy chamber at the lower end of the casing, there are certain advantages that are not obtained by filling the entire string with a buoyant fluid. For example, in deep wells it may be necessary to place the buoyant fluid under pressure to prevent collapse of the casing. Usually, it is more practical to confine the fluid for this purpose. Also it may be desirable to run the casing with the lower end of the casing string having a greater buoyancy than the remainder of the casing string. Furthermore, it has been found that the buoyancy chamber avoids the tendency of the casing string to stick at the final deflection zone (FIG. 1). Other advantages include improving the integrity of the cement in the annulus and improving the bond between the cement and the casing pipe.

While this invention is illustrated and described in accordance with a preferred embodiment, it is recognized that variations and changes may be made therein, without departing from the invention, as set forth in the claims.

1. A method of completing a well in a bore hole in the earth, said bore hole having a substantially vertical portion above a deviated and uncased portion, such that a non-buoyant casing would stick in said deviated portion if said casing were run in said bore hole while said hole is mud filled, said method comprizing:

(a) conducting cement slurry into said bore hole to fill said deviated portion of said bore hole, and
(b) lowering a casing string in said bored hole, said casing string having a fluid therein at least at the lower end thereof of substantially lower density than said slurry to provide a buoyancy effect, at least the lower end of said casing string displacing said cement slurry around said casing string while lowering said casing string through said deviated portion of said bore hole, whereby said buoyancy effect floats said casing string through said deviated portion.

2. The method according to claim 1 including filling said casing with said fluid before lowering said casing, and increasing the pressure of the fluid in said casing string after said cement is hardened, whereby said casing string tends to expand circumferentially to improve the bond between the casing and the cement.

3. The method according to claim 1 including applying centralizers to said casing string before running said casing string in said bored hole, said centralizers being positioned along the lower end of said casing string.

4. A method of completing a well in a bore hole in the earth, said bore hole having a substantially vertical portion above a deviated and uncased portion, such that a non-buoyant casing would stick in said deviated portion if said casing were run in said bore hole while said hole is mud filled, said method comprizing:

(a) conducting cement slurry into said bored hole to fill said deviated portion of said bored hole, and
(b) lowering a casing string in said bored hole into said cement slurry, said casing string having a fluid therein of substantially lower density than said slurry to provide a buoyancy effect, confining said fluid in a buoyancy chamber adjacent the lower end of said casing string.

5. The method according to claim 1 including maintaining said fluid in said chamber at a lower pressure and density than said cement slurry, while lowering said casing string to said depth, and increasing the fluid pressure in said casing string after said slurry hardens, thereby improving the seal between the casing and the cement.

6. The method according to claim 5 wherein said fluid is a gas and including releasing said gas from said chamber after said cement has hardened.

7. A method of completing a well in a bore hole in the earth, said bore hole having a deviated and uncased portion, comprising:

(a) conducting cement slurry into said bored hole to fill said deviated portion of said bored hole, and
(b) lowering a casing string into said bored hole into said cement slurry, applying a plurality of centralizers to said casing string prior to lowering said string in said bored hole, said casing string having a fluid therein of substantially lower density than said slurry to provide a buoyancy effect, confining said fluid in a buoyancy chamber adjacent the lower end of said casing string, said centralizers being spaced apart from each other a greater distance along the portion of said string coextensive with said buoyancy chamber than the spacing between said centralizers above said buoyancy chamber,
(c) said casing lowering including displacing at least the lower end of said casing string through said cement slurry in said deviated portion of said bored hole, whereby said confined fluid provides flotation of said casing string through said deviated portion.

8. A method of completing a well in a bore hole in the earth, said bore hole having a deviated and uncased portion, comprising:

(a) conducting cement slurry into said bored hole to fill said deviated portion of said bored hole, and
(b) lowering a casing string in said bored hole into said cement slurry, applying a plurality of centralizers to said casing string prior to lowering said string in said bored hole, said casing string having a fluid therein of substantially lower density than said slurry to provide a buoyancy effect, confining said fluid in a buoyancy chamber adjacent the lower end of said casing string, said centralizers being spaced apart from each other a greater distance along the portion of said string coextensive with said buoyancy chamber than the spacing between said centralizers above said buoyancy chamber,
(c) said casing lowering including displacing at least the lower end of said casing string through said cement slurry in said deviated portion of said bored hole, whereby said confined fluid provides flotation of said casing string through said deviated portion.

9. The method according to claim 8 including lowering a tubing string in said casing string, said bridge plug means including an equalizing valve, said tubing string having an overshot for engaging said bridge plug means to selectively expand and collapse said plug means and to operate said valve, manipulating said tubing string while said overshot is in engagement with said plug means to open said valve and to collapse said plug means, thereby equalizing fluid pressure in said chamber with the pressure in said casing string above said bridge plug.

10. The method according to claim 9 including lowering said tubing string subsequent to said manipulating step, separating said overshot from said plug means, and utilizing said tubing string in a subsequent well completion operation.

11. The method according to claim 10 including pumping a perforating gun down said tubing string subsequent to separating said overshot from said plug means by circulating fluid down said tubing string and back to the
9

Top of the casing string through the annulus between the casing string and the tubing string.

References Cited

UNITED STATES PATENTS

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Date</th>
<th>Inventor</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,107,327</td>
<td>2/1938</td>
<td>Creighton</td>
<td>166—27</td>
</tr>
<tr>
<td>2,392,352</td>
<td>1/1946</td>
<td>Wright</td>
<td>166—27</td>
</tr>
<tr>
<td>2,935,129</td>
<td>4/1960</td>
<td>Allen et al.</td>
<td>166—35</td>
</tr>
<tr>
<td>3,195,631</td>
<td>7/1965</td>
<td>Smith</td>
<td>166—241, 315</td>
</tr>
<tr>
<td>3,398,794</td>
<td>8/1968</td>
<td>Fox</td>
<td>166—46 X</td>
</tr>
<tr>
<td>3,417,816</td>
<td>12/1968</td>
<td>Morris et al.</td>
<td>166—27 X</td>
</tr>
</tbody>
</table>

10

OTHER REFERENCES


STEPHEN J. NOVOSAD, Primary Examiner
I. A. CALVERT, Assistant Examiner

U.S. Cl. X.R.