METHOD AND APPARATUS FOR OBTAINING AN IMPROVED GRAVEL PACK

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References Cited
UNITED STATES PATENTS
2,652,117 9/1953 Arendt et al..................166/278
3,404,735 10/1968 Young et al..................166/295
3,483,926 12/1969 Bruist..................166/297

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ABSTRACT
This specification discloses a process for providing a gravel pack adjacent a subsurface formation in a well having a string of casing therein. In carrying out this process, first perforations are formed through the casing adjacent the subsurface formation and materials are flowed therethrough to provide a consolidated gravel pack. Second perforations are thereafter formed through the casing to extend into and terminate within the consolidated gravel pack. Also disclosed is a well tool which may be employed in carrying out this process. This well tool is comprised in combination of an elongated body housing a means for forming perforations in casing in a well, which body has a recess in the lower end thereof. A plug is provided which is adapted to be set in the casing, which plug has fixed to the upper side thereof a protrusion that is adapted to be positively engaged by the recess.

6 Claims, 4 Drawing Figures
METHOD AND APPARATUS FOR OBTAINING AN IMPROVED GRAVEL PACK

BACKGROUND OF THE INVENTION

This invention relates to well completion methods and apparatus and, in particular, to the placement of a gravel pack within a well.

In the completion of wells drilled into the earth, a string of casing is normally run into the well and a cement slurry is flowed into the annulus between the casing string and the wall of the well. The cement slurry is allowed to set and form a cement sheath which bonds the string of casing to the wall of the well. Perforations are provided through the casing and cement sheath adjacent the subsurface formation.

Fluids, such as oil or gas, are produced through these perforations into the well. These produced fluids may carry entrained therein sand, particularly when the subsurface formation is an unconsolidated formation. Produced sand is undesirable for many reasons. It is abrasive to components found within the well, such as tubing, pumps, and valves, and must be removed from the produced fluids at the surface. Further, the produced sand may partially or completely clog the well, thereby making necessary an expensive workover. In addition, the sand flowing from the subsurface formation may leave therein a cavity which may result in caving of the formation and collapse of the casing.

Various means including gravel packs have been used to control the flow of sand from subsurface formations. A particular type of gravel pack often used is a consolidated gravel pack. In forming such a pack, perforations are normally provided through the casing and cement sheath adjacent the producing formation. Fluid may be circulated through these perforations to provide a cavity in the producing formation. Thereafter, granular material in a carrier solution is injected through these perforations and packed tightly adjacent the producing formation. The granular material is then consolidated, thereby forming a consolidated pack. Such a process is available from Halliburton Services under the trade name of "Conpac" and is described in U.S. Pat. No. 3,404,735 to Bill M. Young et al. In carrying out the "Conpac" process, a resin coated sand in a special carrier fluid is pumped against the formation to achieve a "sand-out". The treated pack sand is then catalyst-hardened into a permeable mass.

Consolidated gravel packs have been found to be beneficial in preventing sand from being produced from subsurface formations. However, when these packs are formed about perforated casing, the consolidated granular material forms a partial plug that fills the perforations formed through the cement sheath and the casing. This partial plug greatly reduces the fluid transmission capacity of the perforations provided in the casing and thereby reduces the total flow which can be realized from a producing formation through a fixed number of perforations.

SUMMARY OF THE INVENTION

In accordance with an embodiment of this invention, a gravel pack is provided in a well adjacent a subsurface formation, which well has a string of casing therein. In carrying out the invention, first perforations are formed through the casing and material is flowed through the first perforations to provide a consolidated gravel pack adjacent the subsurface formation. Thereafter, second perforations are formed through the casing to extend into and terminate within the consolidated gravel pack.

In a preferred embodiment, the second perforations are of smaller size than the first perforations and are formed to extend through the first perforations in the casing and to extend into and terminate within the consolidated gravel pack.

In a further aspect of this invention there is provided a well tool which is particularly well suited for carrying out the process of this invention. This well tool is comprised in combination of an elongated body having therein means for forming perforations in casing and having in the lower end thereof a recess adapted to positively engage a protrusion; and a plug adapted to be set in the casing and having fixed to the upper side thereof a protrusion.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view which illustrates a well that extends into an unconsolidated formation and has a perforating tool oriented therein.

FIG. 2 is a schematic view which illustrates a consolidated gravel pack formed adjacent the unconsolidated formation.

FIG. 3 is a schematic view which illustrates another embodiment of this invention.

FIG. 4 is a schematic view which illustrates a well having therein a perforation orientation plug and a perforation tool adapted to engage the perforation orientation plug.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

This invention concerns a method for controlling the production of sand from subsurface formations.

A well is drilled into the earth and into a subsurface formation such as an unconsolidated formation from which fluids are to be produced. A string of casing is run into the well and a cement slurry is injected into the annulus and allowed to set, thereby forming a cement sheath which bonds the string of casing to the wall of the well. Thereafter, in carrying out this method, first perforations or openings are formed through the casing and cement sheath adjacent the unconsolidated formation, and material is flowed through these perforations to form a consolidated gravel pack adjacent the unconsolidated formation. This consolidated gravel pack extends into and partially plugs the perforations formed through the casing and cement sheath. Thereafter, second perforations or openings are formed through the casing and cement sheath, which second perforations extend into and terminate within the gravel pack.

Referring to FIG. 1, there is shown a well 1 extending into a subsurface unconsolidated formation 3. A string of casing 5 is supported in the well by a cement sheath 7. An orientation plug 9 having a protrusion such as an orientation wedge 10 fixed to the upper side thereof is positioned in well 1 slightly below the portion of formation 3 to be perforated. A perforating tool 11, having projectiles 14 and an orientation recess 13 adapted to engage the orientation wedge 10, is positioned in the well 1 such that the orientation recess 13 engages the orientation wedge 10. Perforating tool 11 is then fired,
forcing projectiles 14 into formation 3 and forming first perforations 15. Thereafter, the perforating tool 11 is removed from the well and a consolidated gravel pack is formed about the casing, as illustrated by consolidated gravel pack 17 of FIG. 2. The perforating tool 11 is then rerun into the well and second perforations 21 as illustrated in FIG. 3 are formed to extend into and terminate within gravel pack 17.

It is desirable in the process of forming the consolidated gravel pack 17 adjacent to formation 3 that the formation 3 be washed through the perforations, thereby forming a cavity in formation 3 about casing 5. Thereafter, material such as granular material or particulated solids is injected via a carrier solution through perforations 15, FIG. 2, and consolidated to form consolidated gravel pack 17. A particular process by which the consolidated gravel pack 17 may be formed is described in U.S. Pat. No. 3,404,735. In accordance with this process, a predetermined amount of resin or consolidated fluid is dispersed in a quantity of an oil-base liquid hydrocarbon. Subsequently, a quantity of particulated solids is introduced into the resin-oil dispersion, thus coating the solids with resin. The oil-resin-solids mixture is then introduced into well 1 and injected through perforations 15 until a sand-out or pack-out occurs and the desired amount of resin-coated solids is deposited in the well about casing 5. Any excess solids are removed from the well by reverse circulating the solids out with limes or oil or by any other suitable means. An oil overflow-catalyst solution is then injected through perforations 15. The catalyst solution cures the resin around the packed solids and formation sand to cure or harden into a hardened, highly permeable sheet or mass capable of allowing production of formation fluids free of formation solids. Particulated solids such as those used in sand packing procedures in an amount of about one pound of solids per gallon are proportioned into the resin-oil mixture. A 40–60 mesh (U.S. Sieve Series) sand or a mixture of 25 percent 4–8 mesh sand and 75 percent 40–60 mesh sand is satisfactory. A service for forming such a pack is offered by Halliburton Services, Incorporated under the trade name of “Conpac” and is described on page 2422, Volume 2, 29th Revision of the COMPOSITE CATALOG OF OIL FIELD EQUIPMENT AND SERVICES.

Referring to FIG. 4, there is shown a more detailed view of the orientation plug 9 and perforating tool 11 in well 1. The orientation plug 9 may be a bridge plug that is set on slips and that has an orientation protrusion 10 fixed to the upper side thereof. The orientation protrusion 10 preferably is wedge-shaped, as shown, in order to readily facilitate the positive engagement thereof by a corresponding orientation recess 13 provided in the lower end of perforating tool 11. The perforating tool 11 may be any of the well-known means for forming perforations in casing such as means employing projectiles, for example bullets or shaped charges. These projectiles are supported by perforating tool 11 such that they may be fired in a predetermined direction with respect to perforating tool 11 through ports 12 and thereby form perforations in casing 5. Preferably these projectiles are arranged as illustrated by ports 12 to form perforations symmetrically about orientation recess 13. This enables first perforations to be formed in casing 5, perforating tool 11 to be disengaged from orientation protrusion 10 and re-engaged therewith without regard to angular displacement and second perforations formed, which second perforations coincide with the first perforations. It will be recognized that centralizers (not shown) or other means may be employed to centralize the tool 11 and thereby ensure that the tool 11 is arranged at the same vertical angle each time it is engaged with orientation plug 9.

As shown in FIG. 2, consolidated gravel pack 17 extends into and fills perforations 15 formed through cement sheath 7 and casing 5. This filling of perforations 15 with consolidated gravel pack 17 greatly reduces the well productivity over that which would be realized if perforations 15 were free of granular material. This reduction in well productivity is illustrated by considering a typical example which compares the well productivity when the perforations are filled with formation sand and with gravel. It is customary in perforating a well that a hole be formed having a diameter of one-half inch and a length of 1 to 1½ inches through the casing and cement sheath. A perforation having these dimensions and filled with the formation sand which has an average permeability to oil of 800 millidarcies would transmit a maximum of about 1 barrel per day of 0.5 centipoise liquid into the wellbore with a 75 psi differential pressure across the perforation. A 16,000-millidarcy gravel would transmit about 20 barrels per day under similar conditions. The usual perforation density is about 4 shots per foot. Therefore, a production rate of from 4 to 80 barrels per day per foot would be obtained, depending upon whether the perforations are filled with formation sand or with injected gravel. Increasing the differential pressure across the sand-filled or gravel-filled perforation has progressively less effect on oil-flow rate since turbulent flow is established with higher differential pressures and gas coming out of solution would reduce the permeability to oil of the material filling the perforations. Removal of the material filling perforations 15 through casing 5 and cement sheath 7 would greatly increase the well productivity of the perforations over that possible when the perforations are so filled.

In accordance with an embodiment of this invention, perforating gun 11 is reloaded with a less powerful charge than was used in forming first perforations 15 and with projectiles 19 which are of a smaller size than projectiles 14 that were used in forming perforations 15. Projectiles 19 are positioned in perforating gun 11 such that the center lines of projectiles 19 coincide with the former location of the center lines of projectiles 14. Perforating gun 11 is then fired, forming second perforations 21 by forcing projectiles 19 through the gravel pack material filling perforations 15 and into the consolidated gravel pack 17 where the travel of projectiles 19 terminates. The less powerful charge ensures that projectiles 19 will not penetrate through consolidated gravel pack 17 and into unconsolidated formation 3, thus ensuring that the second perforations 21 terminate within consolidated gravel pack 17. The smaller projectiles 19 enable the removal of the consolidated gravel pack material filling the first perforations without undue shattering of the gravel pack.
As illustrated in FIGS. 2 and 3, the consolidated gravel pack 17 has the greatest horizontal thickness opposite perforations 15. This is because, in forming a cavity in formation 3 and in forming the consolidated gravel pack 17, material is injected through perforations 15 where it impacts upon formation 3 adjacent perforations 15. Further, in forming consolidated gravel pack 17, there is a tendency for the granulated material to settle away from the upper extension of the cavity. Therefore, the horizontal thickness of consolidated gravel pack 17 may be a minimum near the upper perforations 15.

In accordance with a preferred embodiment of this invention, perforating tool 11 is loaded to fire projectiles 19 and form second perforations 21 only in the lower portion of the consolidated gravel pack 17 leaving the uppermost perforations 15 partially plugged. This ensures that projectiles 19 do not extend through consolidated gravel pack 17 and into unconsolidated formation 3.

It is recognized, of course, that the second perforations formed by projectiles 19 could be formed through casing 5 and cement sheath 7 and into consolidated gravel pack 17 at other locations than through the original perforations 15. However, since the greatest horizontal thickness of consolidated gravel pack 17 exists about original perforations 15, it is preferred that the perforating tool 11 be so oriented that projectiles 19 pass through the original perforations 15 formed through casing 5 and cement sheath 7.

Another embodiment of this invention is illustrated in FIG. 3. In accordance with this embodiment, a packer 20 is set in casing 5 to seal upper perforations 15. This eliminates flow through those perforations adjacent the portion of the gravel pack having the least horizontal thickness, thereby eliminating the possibility that unconsolidated sands from formation 3 will be produced through these upper perforations into casing 5. Thereafter, as illustrated by FIG. 3, second perforations 21 are formed through the consolidated gravel pack material filling the lower perforations 15, which second perforations terminate within the consolidated gravel pack 17. This opening of original lower perforations 15 by second perforations 21 greatly increases the well productivity.

What is claimed is:

1. A method of providing a gravel pack in a well adjacent a subsurface formation, said well having a string of casing therein, comprising:
   forming first perforations through said casing adjacent said subsurface formation;
   flowing material through said first perforations to provide a consolidated gravel pack adjacent said subsurface formation; and
   forming second perforations through said casing, which second perforations extend into and terminate within said consolidated gravel pack.

2. The method of claim 1 further comprising sealing those first perforations located adjacent the upper portion of said pack.

3. The method of claim 1 wherein said second perforations are formed through said first perforations in said casing.

4. The method of claim 3 wherein said second perforations are of a smaller size than said first perforations.

5. A method of providing a gravel pack in a well adjacent a subsurface formation, said well having a string of casing therein, comprising:
   positioning in said well a perforation orientation plug below said zone to be perforated;
   positioning in said well a perforation tool in engagement with said perforation orientation plug;
   providing first perforations in said casing;
   flowing material through said first perforations to provide a consolidated gravel pack adjacent said subsurface formation;
   repositioning in said well said perforation tool in engagement with said perforation orientation plug; and
   providing second perforations extending through said first perforations and terminating within said consolidated gravel pack.

6. A method of providing in a well a gravel pack adjacent a subsurface formation, said well having a string of casing therein, comprising:
   positioning in said well in fixed relationship to said casing a plug having an orientation protrusion fixed thereto and extending upward therefrom;
   positioning-in said well a perforating tool having an orientation recess provided in the lower portion thereof, said recess engaging said orientation protrusion whereby said perforating tool is oriented in a fixed position with respect to said casing;
   forming first perforations through said casing;
   withdrawing said perforating tool from said well;
   flowing material through said first perforations to provide a consolidated gravel pack adjacent said subsurface formation;
   repositioning in said well said perforating tool and reorienting said perforating tool in said fixed position with respect to said casing; and
   forming second perforations which extend through said first perforations in said casing and terminate within said consolidated gravel pack.

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