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(71) Applicant (for SM only): **SHELL OIL COMPANY**
[US/US]; One Shell Plaza, P.O. Box 2463, Houston,
Texas 77252-2463 (US).

(71) Applicant (for all designated States except US): **SHELL
INTERNATIONALE RESEARCH MAATSCHAPPIJ
B.V.** [NL/NL]; Carel van Bylandtlaan 30, NL-2596 The
Hague (NL).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **ALGU, Devendra
R.** [US/US]; 3648 Lake Lynn Drive, Gretna, Louisiana
70056 (US). **HEATHMAN, James Frank** [US/US];
23022 Lanham Drive, Katy, Texas 77450 (US).

(74) Agent: **WATKINS, Marcella D.**; Shell Oil Company,
One Shell Plaza, P.O. Box 2463, Houston, Texas
77252-2463 (US).

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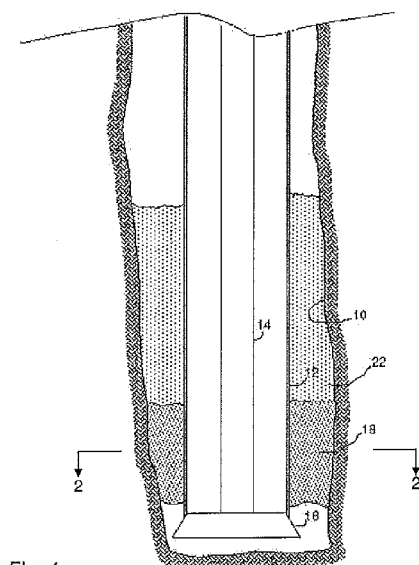


Fig. 1

(57) Abstract: A method for improving zonal isolation between formations along a borehole, comprises a) providing a pipe in the borehole, wherein at least a portion of the pipe lies between the formations, b) providing a body of cement in the annulus between the borehole wall and said pipe portion, c) allowing the body of cement to cure until it has reached at least 70 Bearden units consistency, and d) expanding said pipe portion so as to decrease the cross-sectional area of the annulus between the borehole wall and said pipe portion.



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EXPANSION AGAINST CEMENT FOR ZONAL ISOLATION

RELATED CASES

This application claims benefit of U.S. Application Serial No. 61/165128, filed on March 31, 2009, which is incorporated herein by reference.

FIELD OF THE INVENTION

[0001] The invention relates to the use of cementitious materials outside of a downhole tubular as a means for providing zonal isolation after expansion of a tubular.

BACKGROUND OF THE INVENTION

[0002] In the context of oil and gas drilling, cementitious materials, including but not limited to Portland cements, resins, blast-furnace slag, and blends of those materials, are typically placed in the annulus between the casing and the wellbore so as to isolate and protect the casing during drilling, completion, and operation of the well. Once pumped in place and allowed to harden, these materials provide isolation between the various formations and between the formations and surface such that the hydrocarbons can be safely produced, or alternatively the wellbore can be used for injection operations.

[0003] After cement has hardened in a wellbore, it is well known that the hardened cement may not fill the annuls as completely as desired. In addition the hardened cement may be subjected to mechanical damage – stress fractures and/or separation from the casing wall (debonding) - such that hydraulic isolation may be jeopardized. Likewise, during the process of expanding tubulars that are surrounded by hardened cement, mechanical failure of the cement may cause zonal isolation is lost. Thus, it is desirable to provide a system by which a tubular can be expanded in a wellbore and still maintain annular hydraulic isolation.

[0004] Drilling operations that include the use of expandable tubulars are becoming more common. Expansion can be carried out using a top-down technique, in which an expansion tool starts at the upper end of the expandable tubular and is pushed through the tubular until it has expanded the full length of the tubular, or using a bottom-up technique, in which an expansion tool starts at the bottom of the tubular and is pulled upward through the tubular. Regardless of which technique is used, if the tubular is not anchored, it will move with the expansion tool. Without movement of the expansion tool relative to the tubular, expansion will not occur.

[0005] In top-down expansion techniques, the downward force of the expansion tool on the tubular can be resisted by anchoring the tubular to an adjacent tubing string or applying an upwards force by some other means. In bottom-up expansion, however, it is typically desirable to leave the top end of the tubular free to move within the borehole, so as to allow for the axial shrinkage of the tubular will occur during expansion. Therefore, it may not be practical to use top-anchoring techniques and it may be desirable to anchor the lower end of the tubing instead.

[0006] One way to perform a bottom-up expansion is to use a mechanical jack. The mechanical jack works within the tubular and expands a section of the tubular without requiring additional outside forces to be applied to the tubular. The localized expansion serves to anchor the tubular string in the wellbore sufficiently that the expansion tool can then be pulled through the tubular. Thus, a jack can be used to expand and anchor the lower end of a tubular for a bottom-up expansion. Another well-established method for expanding tubulars in a wellbore uses only hydraulic pressure.

[0007] Despite the state of the art, it remains desirable to provide a means for achieving zonal isolation in situations where it is not practical to access the annulus.

SUMMARY OF THE INVENTION

[0008] In accordance with preferred embodiments of the invention, means are provided for means for achieving or improving zonal isolation in situations where it is not practical to access the annulus, such as when cement has already hardened in the annulus.

[0009] In certain embodiments of the invention zonal isolation between formations along a borehole is improved by a) providing a pipe in the borehole, wherein at least a portion of the pipe lies between the formations, b) providing a body of cement in the annulus between the borehole wall and said pipe portion, c) allowing the body of cement to cure until it has reached at least 70 Bearden units consistency, and d) expanding said pipe portion so as to decrease the cross-sectional area of the annulus between the borehole wall and said pipe portion.

[0010] Step d) may eliminate fluid channels in the cement body and/or increase the density of the cement body. Step c) may or may not cause the second cement body to fracture. The method may further include providing a second cement body in the annulus, wherein the second cement body has a longer cure time than the first cement portion. The second cement body is not necessarily cured when step d) is carried out.

[0011] At least one of the cement bodies may contain ringing gels and/or other polymers.

[0012] The method may further include the step of providing an exit path for water expelled from the cement during expansion.

[0013] In some embodiments, the hardened cement material is designed to have specific mechanical properties such that it can withstand sufficient forces to allow the tubular to be radially expanded to a larger diameter. Some embodiments of the invention include a two-slurry approach in which a relatively rapid-hardening cement slurry is placed in the annulus around the lower portion of the tubular to be expanded, and a second, slower-setting slurry is placed around a second portion of the tubular and does not harden until after the expansion process is complete.

[0014] In other embodiments, one or both cement slurries are designed to have mechanical properties such that the slurry placed around the bottom of the tubular provides the means to anchor the tubular during initiation of expansion, but without resulting in mechanical failure of one or both cement sheaths. In further embodiments, either cement slurry may contain elastomeric materials that swell if contacted by wellbore or subterranean fluids such as water, hydrocarbon, gas, and/or drilling fluids, etc., and re-establish annular hydraulic isolation, even if the presence of mechanical damage to the hardened cement.

[0015] As used in this specification and claims the following terms shall have the following meanings:

[0016] The word “anchor” refers to a system or device that provides sufficient engagement between the tubular and the borehole wall to allow an expansion tool to move relative to the tubular and thus to expand the tubular.

[0017] As used herein, “liner” and “casing” are used interchangeably, inasmuch as aspects of the invention that relate to casings also relate to liners, and vice versa.

[0018] Unless otherwise indicates, as used herein the terms “bottom,” “lower,” and “downhole” refer to locations that are farther from the surface, even if the borehole is not vertical.

[0019] It is further understood that said cement formulations may contain any additives that are known in the art to achieve specific slurry properties necessary for pumping and placement, including additives and gases for foamed cements.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] For a more detailed understanding of the invention, reference is made to the accompanying wherein:

Figure 1 is a schematic illustration of the bottom of a borehole in which an expandable liner and a tubing string are present.

Figure 2 is a schematic cross-section along lines 2-2 of Figure 1.

Figure 3 is a schematic cross-section showing the system of Figure 2 post-expansion.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0021] Referring initially to Figures 1 and 2, a borehole 10 may contain an expandable liner 12 and a tubing string 14. An expansion device 16 is affixed to the lower end of the tubing 14. Expansion device 16 is illustrated as an expansion cone, but may be any suitable device that is capable of incrementally radially expanding the expandable liner as the device moves through the casing. This assembly may further include an eccentric guide nose, stabilizer above the cone, autofill float collar, a dart catcher, two darts, safety joint, debris catcher and drill pipe to surface (all not shown), such as are known in the art. The equipment is made up and lowered into the hole with the drill pipe.

[0022] If the upper end of liner 12 (not shown) is free to move within the borehole, then upward force applied to expansion device 16 will merely move liner 12 upward and will not result in expansion. In order to provide the requisite movement of expansion device 16 relative to liner 12, it is necessary to anchor liner 12 in the borehole.

[0023] If the requisite anchoring of the tubular is not accomplished by mechanical means at the upper end of the liner, such as an engagement with the lower end of the adjacent upper tubular, or by mechanical means at the lower end of the liner, such as by use of a jack, then the anchoring may be provided by the cement. In the discussion below, discussions of cement refer to cement in the annulus between liner 12 and borehole 10 as shown at reference numeral 18. Specifically, the cement may provide a mechanical engagement between the outside of the tubular and the inside of the borehole wall. If the cement is the sole anchoring means, the mechanical engagement must be sufficient to restrain the tubular against the strong upward force that is applied at the initiation of expansion. Apart from or in addition to being used as an anchoring means, cement is also typically used to seal the annulus.

[0024] In preferred embodiments, the cement is mixed and pumped downhole. It is preferably separated from the other fluids by the two darts as it is pumped. The first dart lands in the dart catcher, indicating that the cement is about to enter the annulus. Extra fluid is pumped until the second dart lands, indicating that all the cement is in the annulus. Pumping is preferably stopped after a few barrels are pumped to clear the drill string of any cement. Once the pumping stops, the float collar acts as a back pressure valve to prevent the cement from flowing back up the drill string. After a predetermined amount of time to allow

the cement to at least partially cure, casing expansion is initiated by pulling on the drill string to start movement at the cone. The safety joint is preferably included in the assembly to enable easy release from the drill string if there are any problems with the tools or operations.

[0025] It has been discovered that it is possible to improve zonal isolation in an area that has been cemented, by expanding a tubular against the cement, as shown in Figure 3. If the cement is crushed, it may increase in density, closing channels or pockets that might otherwise allow fluid flow in the annulus. Thus, if the cement can be expanded so as to decrease its cross-sectional area, i.e. by decreasing the area of the annulus, defects in the cement may be eliminated and a superior seal formed in the annulus.

[0026] It has further been discovered that cement that has been allowed to at least partially cure before expansion may provide a superior annular seal after expansion. Thus, in preferred embodiments, the cement is allowed to hydrate to a point at which its pumpability is at least 70 Bearden units of consistency (Bc). Once the cement has cured to this point, an expansion device is advanced through the liner, thereby causing a radially outward expansion of the liner. If the formation is sufficiently resistant to compaction, radial expansion of the liner will cause a reduction of the cross-sectional area of the annulus, pulverizing and compacting the cement.

[0027] Because the expansion pulverizes the cement, any channels or pockets that may have initially been present in the annulus cement are eliminated and zonal isolation in the expanded region is improved. Thus, the present invention can be used to cure defective cement seals, which may be located by logging or indicated by the presence of fluid flow in the annulus.

[0028] Some embodiments of the invention include a two-slurry approach in which a more-rapidly-setting cement slurry is placed in the annulus around a first portion of the tubular to be expanded, thereby providing an optional anchor, and a second, slower-setting slurry is placed around a second portion of the tubular and does not harden until after the expansion process is complete, so that formation isolation is enhanced. The second slurry may be provided above the first in the annulus, as shown at 22 in the Figure, or below it. In these embodiments, the faster-setting cement portion may be fractured during the expansion process but may nonetheless retain its ability to anchor the tubular.

[0029] In embodiment where both fast- and slow-setting cements are used, the cure time for each cement portion will depend on various factors, including downhole temperature, cement water content, and the presence of additives. It is preferred that these factors be controlled, to the extent possible, such that the fast-setting cement portion sets within a first pre-determined

time window and the slow-setting cement portion sets within a second pre-determined time window that is longer than the first pre-determined time window. By way of example only, the first cement may cure in less than 12 hours, while the slow cement may cure in no less than 50 hours.

[0030] In other embodiments, one of the cement slurries may be designed to have mechanical properties such that the slurry placed around the bottom of the tubular provides the means to anchor the tubular during initiation of expansion, but can be radially expanded without resulting in mechanical failure of one or both cement sheaths. The formation of a cement layer that can be radially expanded without fracturing can be accomplished by use of various blends of latexes, rubber particles, fibers, and binders that cure in place, such as hydraulic cements, cross-linked polymers, resins, rubber, and the like.

[0031] The parameters that preferably controlled in this embodiment include the shear bond between the pipe and the cement, and the mechanical properties of the cement itself, including its Young's Modulus, Poisson ratio, cohesion, and friction angle. Methods for determining desired ranges for these properties and for controlling them in the cement are known to those of skill in the art.

[0032] In certain embodiments, the cement portion that is used to anchor the expandable liner can include a crosslinked polymer gel, including those known in the art as ringing gels. Examples of suitable polymers include those disclosed in U.S. Patent 7,267,174. In preferred embodiments, the cement portion that anchors the expandable liner comprises a cross-linked polymer and a suitable cementitious material, including but not limited to Portland cement, pozzolan, and/or slag.

[0033] In some embodiments, the cement does not fully cure before expansion occurs, so the cement portion that functions as an anchor is only partially cured. In such cases, it is preferred to calculate the minimum length of tubing that must be cemented, using parameters such as those set out above. A cement that provides a high shear bond to the pipe may require only a relatively short length of cemented pipe for to provide the anchoring force, while a cement that does not achieve as much shear bond at the time of expansion will require contact with more of the surface area of the tubular and thus a greater axial portion of the annulus.

[0034] The following Example illustrates some of the foregoing concepts.

Example 1

[0035] A 9 5/8-inch, 43.5 lb/ft casing section 24-inches long was placed inside an outer jacket of 13 3/8-inch casing. Before installation, the outside of the 9 5/8-inch pipe was

blasted with medium grit aluminum oxide to increase the roughness of the pipe, thus improved shear bond between the pipe and the cement. The annular gap was filled with a cement slurry composed of API Class H Portland cement + 73% fresh water + 0.6% Hydroxyethyl cellulose (viscosifier) + 0.2% fluid loss agent, mixed at 13.8 lb/gal. The cement was cured at 170°F and atmospheric pressure for approximately 8 hrs, at which time samples indicated a compressive strength of 579 psi. At this time a force was applied to the 9 5/8-inch casing while holding the outer jacket and cement stationary. The force required to break the shear bond between the cement sheath and the 9 5/8-inch casing was recorded as 38,200 lbs, which equates to 68.2 psi. This information is then used to determine the length of cemented casing required to act as the anchor to perform the expansion. For example, 100 ft of cemented casing would be expected to withstand 2.4 millions lbs of tensile force.

[0036] It is understood that anchor slurries in accordance with the present invention can be composed of any Portland or non-Portland cementitious material, and likewise make use of any mixing fluids and additives that are known in the art to provide a pumpable slurry that can be placed in the wellbore as desired. Further, it is also understood that the composition may contain any additive or combination thereof as is known in the art to achieve specific mechanical properties such as but not limited to elastomers, polymers, copolymers, latexes, binding agents, fibers, salts, and aggregates. Examples of suitable polymers include the PermSeal[®] and H₂Zero[®] products available from Halliburton, Houston, Texas.

[0037] In still further embodiments, either cement slurry may contain elastomeric materials that swell if contacted by wellbore or subterranean fluids (water, hydrocarbon, gas, and/or drilling fluids, etc.) and re-establish annular hydraulic isolation, even in the presence of mechanical damage to the hardened cement. Such swellable elastomers are known to those skilled in the art.

[0038] Regardless of which cement properties are selected for implementation of the present invention, it may also be desired to increase the shear bond of the cement to the pipe so that it is less likely to separate from the surface of the tubular in the presence of shear forces. Techniques for achieving this are well known in the art and include but are not limited to the addition of post-set expanding agents (manganese oxide, tricalcium aluminate, salts) to the cement slurry, plastic set expanders (foam, reactive gas generators), and surfactants.

Expelled Water

[0039] It has further been discovered that when an expansion device is pulled through a portion of a tubular that is anchored in cured cement, the compression force applied to the

cement is great enough to force unreacted water out of the cured cement. As is known by those skilled in the art, most hydraulic cements use only a portion of the water present to react, and the remainder of that water is present only to aid in mixing and placing the slurry. The amount of water expelled from the cement during the expansion process may be significant. If no escape path is provided, this trapped water may result in challenges such as excessive force required to perform the expansion, even beyond the capabilities of the drilling rig, or a pressure increase sufficient to damage the pipe, even to the point of collapse. It is recognized that some portion of, and in some cases all, of this unreacted water may escape to the formation via either natural permeability, or natural or induced fractures. However, this outlet may not always exist or be present in such a volumetric flow rate to accommodate the desired expansion rate. It is believed that significant advantages may be realized by providing a pathway by which such expelled water can escape from the compression zone.

[0040] One way to provide a pathway for the expelled water is to provide an in-place sacrificial collapse volume in the cement sheath. With this method, as the expansion occurs and the annular gap between the casing and formation or between casings is reduced, the sacrificial collapse volume provides an in situ compressible volume, thus a means to prevent trapped pressure build up during the expansion process. One method to provide this collapsible volume to the cement sheath are foamed cement, in which the cement is foamed with a gas such as air or nitrogen during pumping so that after it hardens the cement sheath includes a volume fraction of compressible gas. Another means of providing for in situ collapse can be achieved by including hollow microspheres in the cement blend such, as the borosilicate hollow microspheres available from companies such as 3M Corporation. It will be obvious to one skilled in the art that either of these methods also reduces the volume of unreacted water per volume of set cement, and that the sacrificial collapse volumes can be customized on a well-by-well basis. Further, it will be obvious that the collapsible cement sheath may also include other mechanical modifiers such as but not limited to the previously-mentioned rubber particles, copolymers, latex, insitu gas generating compounds, and other means.

[0041] Other means to provide a pathway for hydraulic relief to the annular gap behind the expandable tubular include but are not limited to shunt tubes, rupture disks, volume chambers, and the like that will be apparent to one skilled in the art.

[0042] In one preferred embodiment, it may be desirable to prepare the wellbore in such a way to initiate volume relief. This may be accomplished by several means, including but not limited to exerting hydraulic pressure in the wellbore prior to expansion to initiate wellbore

failure. In another embodiment, the formation may be affected by creating stress risers via hydrojetting the formation prior to running the expandable tubular in the wellbore. This would create a weakness in the formation and allow it to more easily fail due to pressure buildup during the expansion process, but not necessarily fail prior to that point and thus allowing the wellbore to be more easily controlled, circulated, and cemented.

[0043] In some preferred embodiments, the cement in the annulus is overdisplaced, so that the lower end of the expandable tubular is surrounded by drilling fluid, cement spacer, or other noncementitious fluid at the bottom of the hole. Further, this fluid may also consist of a hydraulic cement that has a longer set time than the anchoring cement above it. This process is preferred so as to allow the initiation of the expansion process to occur with less force.

[0044] In some preferred embodiments, it may be desired to pump an additional hydraulic cement or other fluid after the expansion process has been completed. The purpose of this fluid would be to ensure that the rubble cement in the annulus of the expanded tubular does not leak or otherwise allow communication of fluids behind the expanded tubular from deeper formations. This practice is commonly referred to by those skilled in the art as a shoe squeeze.

[0045] It will be understood that the cement anchoring techniques disclosed herein can be used alone, or in combination with other anchoring techniques, such as jacks or hangers. Likewise, the techniques disclosed herein can be repeated for successive lengths of expandable liner, and each length may be expanded to the same inside diameter, so that a monodiameter borehole is formed.

C L A I M S

1. Method for improving zonal isolation between formations along a borehole, comprising:
 - a) providing a pipe in the borehole, wherein at least a portion of the pipe lies between the formations;
 - b) providing a body of cement in the annulus between the borehole wall and said pipe portion;
 - c) allowing the body of cement to cure until it has reached at least 70 Bearden units consistency; and
 - d) expanding said pipe portion so as to decrease the cross-sectional area of the annulus between the borehole wall and said pipe portion.
2. The method of claim 1 wherein step d) eliminates fluid channels in the cement body.
3. The method of claim 1 wherein step d) increases the density of the cement body.
4. The method of claim 1, further including the step of providing a second cement body in the annulus, wherein the second cement body has a longer cure time than the first cement portion.
5. The method of claim 4 wherein the second cement body is not cured when step d) is carried out.
6. The method of claim 4 wherein at least one cement body contains polymers.
7. The method of claim 6 wherein at least one cement body contains ringing gels.
8. The method of claim 4 wherein step c) does not cause the second cement body to fracture.
9. The method of claim 1, further including the step of providing an exit path for water expelled from the cement during expansion.

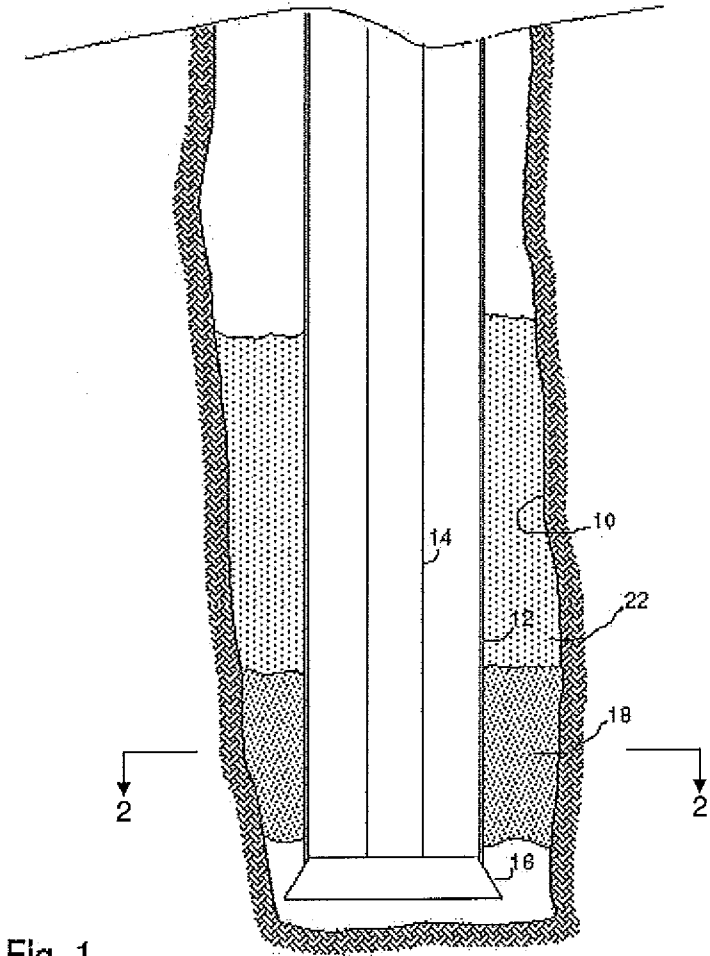


Fig. 1

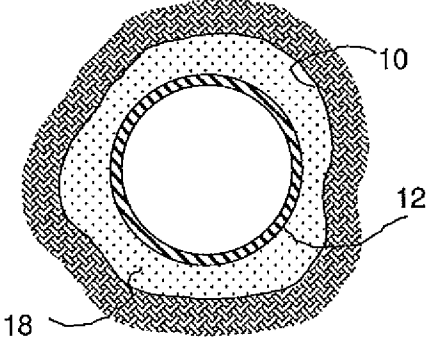


Fig. 2

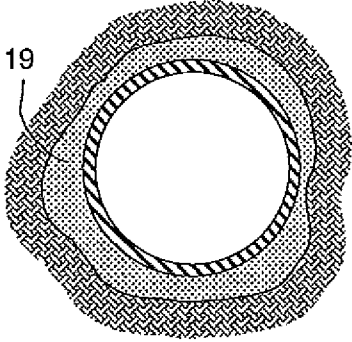


Fig. 3