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(54) Title: SYSTEM AND METHOD FOR ENHANCED WELLOBRE PERFORATIONS

(57) Abstract: An apparatus for perforating a subterranean formation may include a casing, an energetic material, a liner, and an acid-generating material. The casing may have a slotted end configured to receive a detonator cord, and an open end. The energetic material may be disposed in the open end and in ballistic. The liner may enclose the open end, and the liner may include an acid-generating material that is configured to form an acid upon detonation of the explosive material.
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— with international search report (Art. 21(3))
BACKGROUND OF THE DISCLOSURE

1. Field of Disclosure
[0001] The present disclosure relates to an apparatus and method for perforating a well casing and/or a subterranean formation.

2. Description of the Related Art
[0002] Hydrocarbon producing wells typically include a casing string positioned within a wellbore that intersects a subterranean oil or gas deposit. The casing string increases the integrity of the wellbore and provides a path for producing fluids to the surface. Conventionally, the casing is cemented to the wellbore face and is subsequently perforated by detonating shaped explosive charges. When detonated, the shaped charges generate a jet that penetrates through the casing and forms a tunnel of a short distance into the adjacent formation. Often, the region that is perforated, and in particular the walls of the tunnel, may become impermeable due to the stress applied to the formation by the perforating jet as well as stresses that may be caused during the firing of the perforating gun. The loss of permeability and other harmful effects, such as the introduction of debris into the perforation, may adversely affect the flow of hydrocarbons from an intersected hydrocarbon deposit.
[0003] In aspects, the present disclosure addresses the need for perforating devices and methods that provide cleaner and more effective well perforations.
SUMMARY OF THE DISCLOSURE

[0004] The present disclosure provides devices and methods for efficiently perforating a formation.

[0005] In aspects, the present disclosure provides a system for perforating a formation intersected by a wellbore.

[0006] In aspects, the present disclosure further provides a method for perforating a formation intersected by a wellbore.

[0007] The above-recited examples of features of the disclosure have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features of the disclosure that will be described hereinafter and which will form the subject of the claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] For detailed understanding of the present disclosure, references should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals and wherein:

FIG. 1 is a schematic sectional view of one embodiment of an apparatus of the present disclosure as positioned within a well penetrating a subterranean formation;

FIG. 2 is a schematic sectional view of a portion of a perforating gun shown in Fig. 1; and

FIG. 3 is a sectional view of a liner made in accordance with one embodiment of the present disclosure.
DETAILED DESCRIPTION OF THE DISCLOSURE

[0009] Aspects of the present disclosure provide shaped charges that treat a tunnel formed by a perforating jet with an acid. The acid may be generated, in part, by one or more components making up a liner of the shaped charge. The acid is generated upon an energetic material of the shaped charge being detonated. The acid does not exist prior to detonation of the shaped charge. Further, the amount of acid generated is sufficient to perform a specified operation. In some embodiments, the acid may corrode or dissolve foreign matter such as human-made debris so that this foreign matter may be expelled out of the tunnel by the flowing formation fluid. In other embodiments, the acid may corrode or dissolve a naturally occurring material such as rock or earth surrounding the tunnel. In still other embodiments, the acid may increase the permeability or porosity of the formation to enhance fluid mobility.

[0010] Referring now to FIG. 1, there is shown a well construction and/or hydrocarbon production facility 10 positioned over a subterranean formation of interest 12. The facility can be a land-based or offshore rig adapted to convey a tool, such as a perforating gun train, in a well bore 16. The wellbore 16 can include open hole sections and/or cased and cemented sections. The facility 10 can include known equipment and structures such as a platform 18 at the earth's surface 20, a derrick 22, a wellhead 24, and casing 26. A work string 28 suspended within the well bore 16 from the derrick 22 is used to convey tooling into the wellbore 16. The work string 28 may include drill pipe, coiled tubing, wire line, slick line, or any other known conveyance means. Further, the work string 28 may be pulled through the wellbore by a device such as a wellbore tractor (not shown), which may be advantageous in extended reach wells or deviated wells. The work string 28 can include telemetry lines or other signal/power transmission mediums that establish one-way or two-way telemetric communication from the surface to a tool connected to an end of the work string 28. A suitable telemetry system (not shown) can be known as mud pulse, electrical signals, acoustic, or other suitable systems. For
illustrative purposes, there is shown a telemetry system having a surface controller (e.g., a power source and/or firing panel) 30 adapted to transmit signals via a cable or signal transmission line 31 disposed in the work string 28. The signals can be analog or digital signals. In one embodiment of the present invention, a perforating gun 32 is coupled to an end of the work string 28. The perforating gun 32 may be the apparatus used to transport the device described in Fig. 1 into the borehole.

[00011] The perforating gun 32 may be an explosive train assembly that includes a detonator, detonating cord, and one or more shaped charges 33. When detonated in the wellbore, the charges will produce holes through the casing, cement, and into the surrounding formation. This detonation establishes communication between the formation and wellbore, providing a path for the formation fluids and gasses to be produced. The explosive train assembly may designed to operate in a predetermined timed sequence. Electric detonators may be used to detonate the detonating cord, which in turn detonates the charges in order from the top down or bottom up. Below is an exemplary method of deployment of a perforating gun 32 that may utilize one or more detonators according to the present disclosure.

[00012] Referring to FIG. 2, a transverse cross section of a perforating gun assembly 32 is shown. The perforating gun assembly 32 has a tubular carrier 34 and a cylindrical charge tube 36 concentrically disposed within the tubular carrier 34. The outside diameter of the charge tube 36 is such that an annular space 38 is created between the charge tube 36 and the carrier 34. An explosive shaped charge 40 has a frusto-conical charge case 42. The charge case 42 is typically formed from steel, die cast aluminum, or zinc alloys and has an interior surface or wall 44 that defines a hollow interior of the charge case 42. The charge case 42 is open at the outer end and tapers inward. Disposed within the interior of the case 42 is a liner 48 having a generally conical or frusto-conical configuration. The liner 48 tapers inward from a base 50, located at the outer end, to a nose portion 52. The liner 48 is open at the base 50 and has a hollow interior. Disposed between the liner 48 and interior wall 44 of the casing 42 is an explosive material 54. The explosive material 54
extends from the interior of the case 42 through channel formed in the innermost end of the case 42. The case 42 receives a detonating cord 56 for detonating the explosive material 54 (Fig. 3) of the shaped charge 40.

[00013] FIG. 3 illustrates a sectional view of a liner 48 made in accordance with one embodiment of the present disclosure. When the shaped charges (FIG. 2) of the perforating gun assembly (FIG. 2) are detonated, the thermal energy and shock wave released by the explosive material 54 transforms the liner 48 into a molten jet that penetrates through the casing (not shown) in the wellbore and into the surrounding formation to form a perforation.

[00014] In embodiments of the present disclosure, the detonation of the explosive material 54 initiates the generation of one or more acids that are deposited into the tunnels formed by the jets. An illustrative tunnel is shown in Fig. 1 with numeral 60.

[00015] In one embodiment, the liner 48 may include an acid-generating material 50 for generating an acid. Specifically, the liner includes enough acid-generating material to generate enough acid to be functionally effective. By functionally effective, it is meant that the tunnel treated by the acid has a property or characteristic (e.g., permeability) that has been altered by a predetermined or desired amount. The acid-generating material 50 may be formed by the interaction of a first component and a second component. The first component may be or include a proton donor or positive ion. The second component is generally an aqueous solvent, in either liquid or gaseous form. It should be understood that the second component may store the aqueous solution in a solid form (e.g., a hydrate). The solid may be processed to form a liquid or a gas that interacts with the first component to form the acid.

[00016] In one arrangement, the acid-generating material 50 may include all the components needed to form an acid, e.g., the first component and the second component. In another arrangement, the liner 48 may include the first component that interacts with the second component in the gun 32 to form the acid. For example, the second component may be a material used to at least partially form the casing 42. Also, the second component may be a solid, liquid, or gas, located external to the liner 48 but internal to the carrier 34. In
yet another variant, the second component may be a well fluid external to the
carrier 34. In another arrangement, the liner 48 may include a first component
that interacts with a naturally-occurring second component that is external to
the carrier 34 and may be located in the wellbore 16 and / or the formation 12.
The term "naturally occurring" refers to materials such as water, brine, and
hydrocarbons that reside in the formation 16.

[00017] An acid may be defined as a substance that may act as a Lewis
acid or Bronsted-Lowrey acid, including acids typically in the form of an
aqueous solution. In one non-limiting instance, the acid-generating material
may include a first component that may be configured to form an acid upon
detonation of the explosive material. The first component may disassociate
from the acid-generating material; upon disassociation, the first component
may interact with the second component to form an acid.

[00018] The acid-generating material may include a catalyst configured to
interact with a first component for generating an acid. The first component
may be configured to react with a second component, e.g. a solvent, external
to the liner for forming an acid in aqueous solution. The solvent or second
compartment may be in the borehole, in the formation, or both.

[00019] In some embodiments, the acid generating material may include
one or more components, such as but not limited to a proton donor or positive
ion, a proton acceptor or negative ion, a catalyst, or materials that would aid in
the acid formation upon detonation of the explosive material. It will be evident
to those skilled in the art as to which aspects of the acid generating material
may function as the proton donor (cation) or proton acceptor (anion). The
components of the acid generating material may be or include, but are not
limited to alumina, zeolites, sodium metabisulfite, potassium metabisulfite,
copper(II) sulfate, vanadium (V) oxide, phosphorus chloride, thionyl chloride
family, acyl chloride family, alkyl halide family, alkenyl halide family, aryl
halide family, phosphorus, cobalt, chromium, manganese, peroxide family,
naphtha, acetaldehyde, calcium fluoride, viton, TEFLEX™, oxalic acid,
anhydrous glycerol, ethyl isonitrile, ethyl amine, chloroform, formyl fluoride,
sodium formate, hydrocyanic acid, nitrophosphate, tricalcium phosphate, and
combinations thereof. The acids generated may be, but not limited to, phosphoric acid, sulfuric acid, acetic acid, formic acid, phosphonic acid, and combinations thereof.

In some embodiments, the material 50 may be formulated to only react when exposed to a catalyst 52. The catalyst 52 may be disposed in an isolating material 54. The isolating material 54 initially prevents the interaction of the catalyst 52 with the other materials in the liner 48. The isolating material 54 may be selected to release the acid-generating material upon the occurrence of one or more conditions. For example, the isolating material 54 may be a metal that has a melting point below the temperatures encountered when the explosive material 44 is detonated. One illustrative, but not exclusive, isolating material is zinc. Upon detonation of the charge 40, the isolating material 54 may burn away, melt, dissolve, disintegrate or otherwise undergo a change in condition that allows the catalyst 52 to interact with the acid-generating material 50.

It should be appreciated that the isolating material 54 may also be used to isolate either or both of the first component and the second component. By isolation, it is meant that either or both of the components do not interact prior to detonation of the perforating gun. In certain embodiments, a catalyst material may be used to isolate either or both of the first component or the second component.

The liner 48 may also include a matrix material such as powder metals or powder metals blended with ductile materials such as aluminum, zinc, copper, tungsten, lead, bismuth, tantalum, tin, brass, molybdenum, etc. Materials such as plasticizers or binder may also be included in a material matrix of the liner 48. The liner 48 may also be formed of malleable solid or sheet metals such as copper, zinc, and Pfinodal.

The foregoing description is directed to particular embodiments of the present disclosure for the purpose of illustration and explanation. It will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible without departing
from the scope of the disclosure. Thus, it is intended that the following claims
be interpreted to embrace all such modifications and changes.
THE CLAIMS

1. An apparatus for perforating a subterranean formation, comprising:
   - a casing having a slotted end configured to receive a detonator cord, and an open end;
   - an energetic material disposed in the open end; and
   - a liner enclosing the open end, the liner including:
     - an acid-generating material that is configured to form an acid upon detonation of the explosive material.

2. The apparatus of claim 1, wherein the acid-generating material includes at least a first component, the first component being configured to react with a second component external to the liner.

3. The apparatus of claim 2, wherein the second component is in the borehole.

4. The apparatus of claim 2, wherein the second component is in the formation.

5. The apparatus of claim 2, further comprising a catalyst for generating the acid.

6. The apparatus of claim 1, wherein the acid-generating material includes a second component.

7. The apparatus of claim 1, wherein the acid-generating material includes
a first component and a second component.

8. The apparatus of claim 7, further comprising an isolating material isolating the first component from the second component.

9. The apparatus of claim 1, wherein the first component is selected from a group consisting of: alumina, zeolites, sodium metabisulfite, potassium metabisulfite, copper(II) sulfate, vanadium (V) oxide, phosphorus chloride, thionyl chloride family, acyl chloride family, alkyl halide family, alkenyl halide family, aryl halide family, phosphorus, cobalt, chromium, manganese, peroxide family, naphtha, acetaldehyde, calcium fluoride, viton, Teflon™, oxalic acid, anhydrous glycerol, ethyl isonitrile, ethyl amine, chloroform, formyl fluoride, sodium formate, hydrocyanic acid, nitrophosphate, tricalcium phosphate, and combinations thereof.

10. The apparatus of claim 1, wherein the first component forms the acid by interacting with a second component selected from a group consisting of: alumina, zeolites, sodium metabisulfite, potassium metabisulfite, copper(II) sulfate, vanadium (V) oxide, phosphorus chloride, thionyl chloride family, acyl chloride family, alkyl halide family, alkenyl halide family, aryl halide family, phosphorus, cobalt, chromium, manganese, peroxide family, naphtha, acetaldehyde, calcium fluoride, viton, Teflon™, oxalic acid, anhydrous glycerol, ethyl isonitrile, ethyl amine, chloroform, formyl fluoride, sodium formate, hydrocyanic acid, nitrophosphate, tricalcium phosphate, and combinations thereof.

11. An apparatus for perforating a subterranean formation, comprising:
   - a casing having a slotted end configured to receive a detonator cord, and an open end;
- an energetic material disposed in the open end; and
- a liner enclosing the open end, the liner including:
  - an acid-generating material that includes a first component and a second component, the first component disassociating to form an acid when exposed to the second component.

12. The apparatus of claim 11, wherein the acid generating material is selected from a group consisting of: alumina, zeolites, sodium metabisulfite, potassium metabisulfite, copper(II) sulfate, vanadium (V) oxide, phosphorus chloride, thionyl chloride family, acyl chloride family, alkyl halide family, alkenyl halide family, aryl halide family, phosphorus, cobalt, chromium, manganese, peroxide family, naphtha, acetaldehyde, calcium fluoride, viton, Teflon™, oxalic acid, anhydrous glycerol, ethyl isonitrile, ethyl amine, chloroform, formyl fluoride, sodium formate, hydrocyanic acid, nitrophosphate, tricalcium phosphate, and combinations thereof.

13. The apparatus of claim 11, wherein the second component is an aqueous fluid.

14. The apparatus of claim 11, wherein the second component is in the borehole.

15. The apparatus of claim 11, wherein the second component is in the formation.
INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 13/22296

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - E21B 43/1 (2013.01)
USPC - 166/297

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8): E21B 43/1 (2013.01)
USPC: 166/297

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
IPC(8): E21B 43/1 1S (2013.01)
USPC: 166/298, 55, 55.2, 300, 307; 166/S

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase; Google/Inventions; Google/Scholar; EPO Espacenet
Search terms: Wellbore, borehole, downhole, subterranean, acid, detonate, charge, explode, explosion, blast, form, create, generate, produce, cause, mix, activate, perforate, release, component, react, liner, lining, casing, formation, cord, drill

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>US 7,819,064 B2 (SAENGER et al.) 26 October 2010 (26.10.2010), col 1, Ins 6-11; col 3, Ins 35-41, 52-57; col 4, Ins 49-56, 66-67; col 5, Ins 1-6, Fig. 2</td>
<td>1-15</td>
</tr>
<tr>
<td>Y</td>
<td>US 2009/0166038 A2 (PAULS et al.) 02 July 2009 (02.07.2009), para [0002], [0029], [0034]</td>
<td>9, 10, 12, 13</td>
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<tr>
<td>A</td>
<td>US 7,909,115 B2 (GROVE et al.) 22 March 2011 (22.03.2011), col 1, Ins 26-33</td>
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<td>A</td>
<td>US 3,188,955 A (BROWN) 15 June 1965 (15.06.1965), col 2, Ins 19-25</td>
<td>1-15</td>
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</table>

Further documents are listed in the continuation of Box C.

* Special categories of cited documents:
  "A" document defining the general state of the art which is not considered to be of particular relevance
  "E" earlier application or patent but published on or after the international filing date
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  "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
  "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
  "&" document member of the same patent family

Date of the actual completion of the international search
11 March 2013 (11.03.2013)

Date of mailing of the international search report
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Name and mailing address of the ISA/US
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