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United States Patent [19]

Strubhar et al.

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[45] **Sept. 17, 1974**

[54] **METHOD OF CREATING A PLURALITY OF FRACTURES FROM A DEVIATED WELL**

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[73] Assignee: **Mobil Oil Corporation,** New York, N.Y.

[22] Filed: **Aug. 20, 1973**

[21] Appl. No.: **389,853**

[52] **U.S. Cl.** **166/308,** 166/307

[51] **Int. Cl.** **E21b 43/26,** E21b 43/27

[58] **Field of Search** 166/308, 307, 299, 271, 166/259, 281, 283, 297, 250, 252

[56] **References Cited**

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2,927,638	3/1960	Hall, Sr.	166/308 X
2,970,645	2/1961	Glass	166/281
3,002,454	10/1961	Chesnut	166/299
3,223,158	12/1965	Baker	166/259
3,270,816	9/1966	Staadt	166/298
3,285,335	11/1966	Reistle, Jr.	166/252
3,313,348	4/1967	Huitt et al.	166/297
3,416,606	12/1968	Watanabe	166/308
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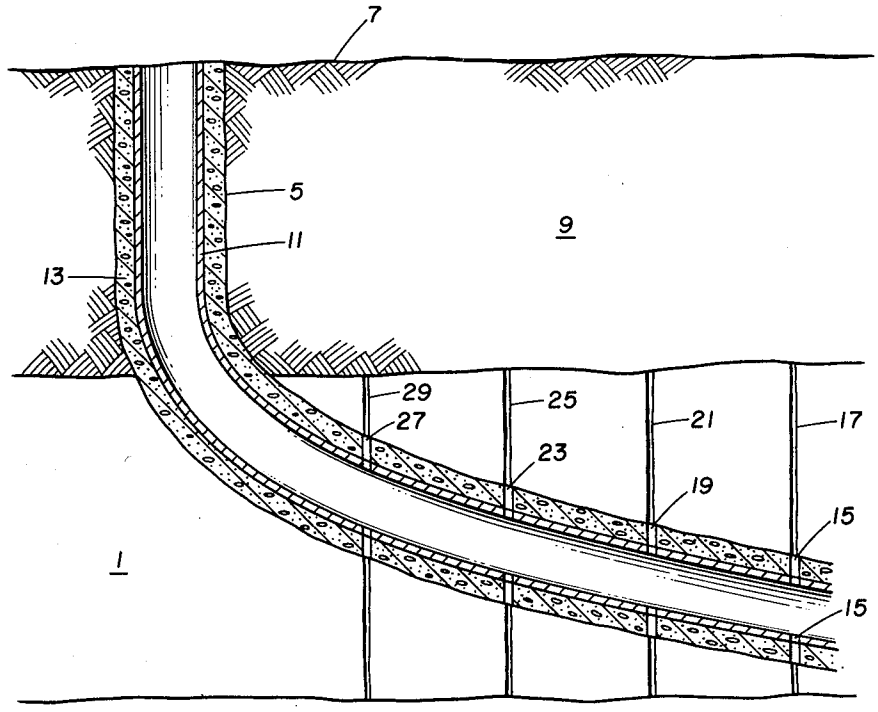
Primary Examiner—Stephen J. Novosad
Attorney, Agent, or Firm—A. L. Gaboriault; Henry L. Ehrlich

[57] **ABSTRACT**

This specification discloses a method of forming from a deviated well a plurality of vertically disposed fractures spaced a substantial distance apart in a subterranean formation having a known preferred fracture orientation. A deviated well is provided which extends from the surface of the earth and penetrates the subterranean formation at an angle of at least 10° measured from the vertical. The well is oriented such that it penetrates the subterranean formation in a direction transversely of the preferred fracture orientation. A first fracture initiation point is formed to establish fluid communication between the interior of the well and the subterranean formation. Hydraulic pressure is applied through the first fracture initiation point to the subterranean formation to form and propagate a first vertically disposed fracture into the formation in the direction of the preferred fracture orientation. Thereafter, a second fracture initiation point is formed at a predetermined horizontal distance from the first fracture initiation point. The second fracture initiation point is isolated from fluid communication with the first fracture initiation point and hydraulic pressure is applied through the second point to the subterranean formation to form and propagate a second vertically disposed fracture into the formation in the direction of the preferred fracture orientation. This procedure may be repeated as desired to form from the deviated well other vertically disposed fractures which extend into the formation in the direction of the preferred fracture orientation.

5 Claims, 4 Drawing Figures



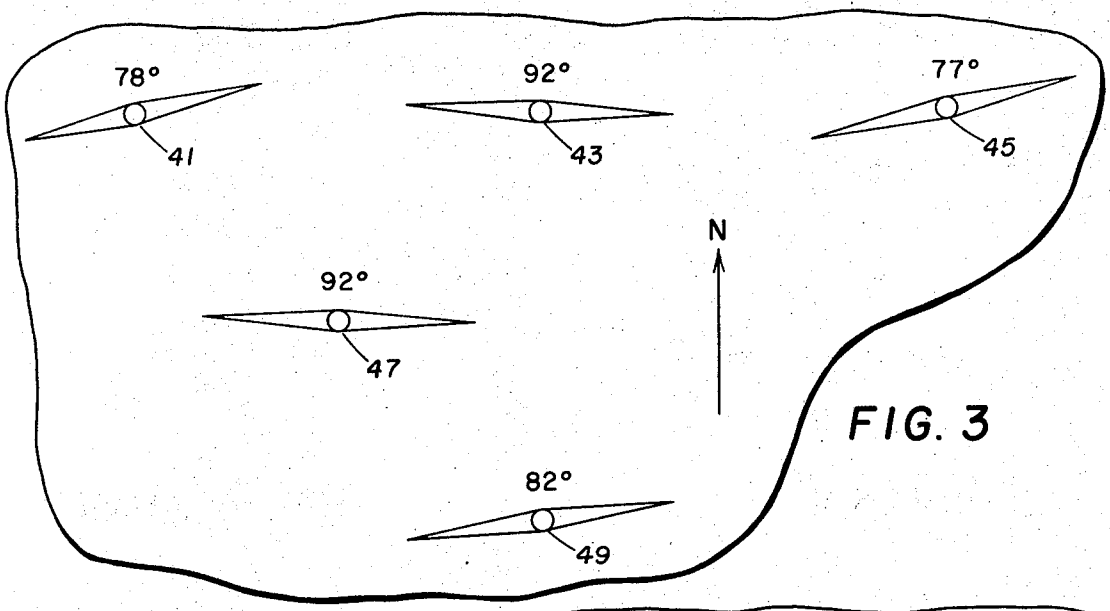


FIG. 3

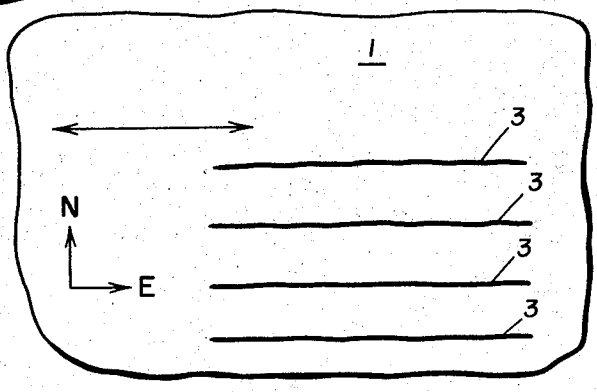


FIG. 1

FIG. 2

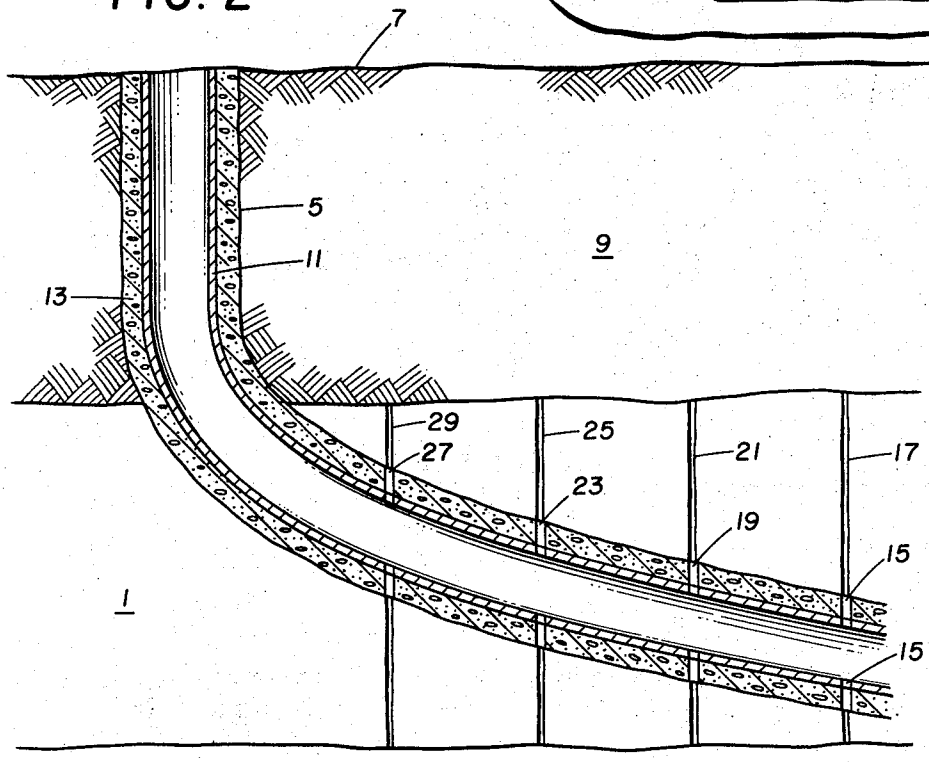
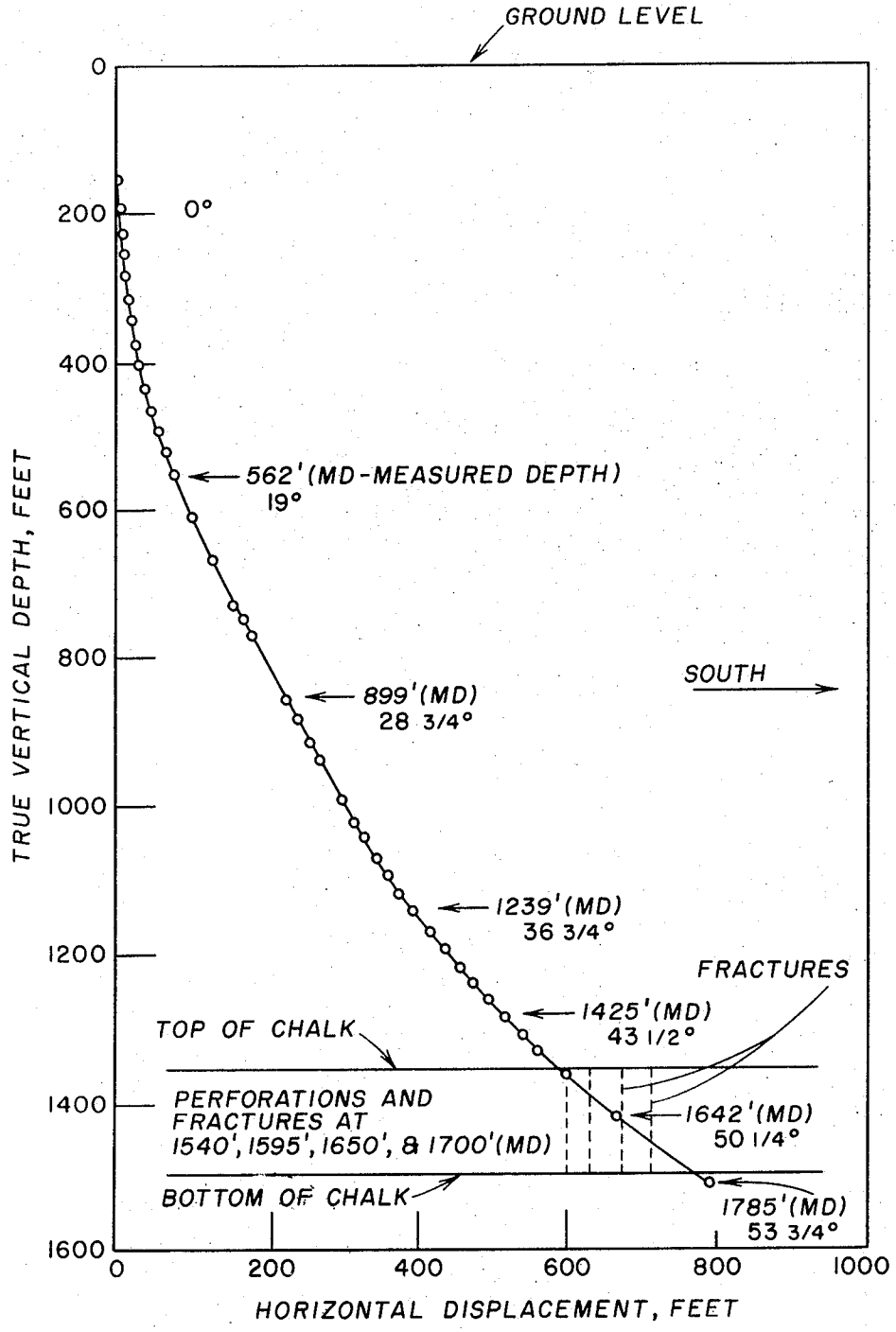


FIG. 4


GROUND LEVEL
0
200
400
600
800
1000
1200
1400
1600
0°
562'(MD-MEASURED DEPTH)
19°
899'(MD)
28 3/4°
1239'(MD)
36 3/4°
1425'(MD)
43 1/2°
1642'(MD)
50 1/4°
1785'(MD)
53 3/4°
SOUTH
FRACTURES
TOP OF CHALK
PERFORATIONS AND
FRACTURES AT
1540', 1595', 1650', & 1700'(MD)
BOTTOM OF CHALK
TRUE VERTICAL DEPTH, FEET
0
200
400
600
800
1000
HORIZONTAL DISPLACEMENT, FEET

METHOD OF CREATING A PLURALITY OF FRACTURES FROM A DEVIATED WELL

BACKGROUND OF THE INVENTION

This invention is directed to forming from a deviated well penetrating a subterranean formation having a preferred fracture orientation, a plurality of vertically disposed fractures spaced a substantial distance one from the other.

Various methods are recognized in the prior art for forming both horizontal and vertical fractures in subterranean formations by applying hydraulic pressure to the information. It is generally considered that at depth vertical fractures are formed in most formations when a sufficiently high hydraulic pressure is applied to fracture the formation. At shallower depths it is recognized that horizontal fractures may be formed in formations by applying a pressure greater than the overburden pressure. The overburden pressure is normally on the order of 1 psi per foot of overburden.

In U.S. Pat. NO. 2,952,319 to Popham, there is described a method of fracturing cased wells to assure the creation of vertical fractures. A slot is formed through the casing and the cement sheath surrounding the casing and the slot may be extended into the formation proper to assure the creation of a vertical fracture. A low fluid loss fracturing fluid is forced outward through the slot under sufficient pressure to fracture the formation. In U.S. Pat. No. 3,270,816 to Staadt there is described a method of orienting vertical fractures in a formation from two cased wells penetrating the formation such that the fractures intersect and form fluid communication between the wells. In U.S. Pat. No. 3,028,914 to Flickinger there is described a method of producing multiple fractures from a cased well. A first fracture is made and extended into a formation. The same formation or another formation penetrated by the same well may then be fractured by plugging the mouth of the first fracture, making a number of perforations concentrated within a short section in the casing, and then injecting fracturing liquid into the well and initiating a second fracture at the elevation of the second set of perforations. In U.S. Pat. No. 3,431,977 to East et al., it is noted that there exists in some formations a natural plane of weakness which under some conditions causes vertical fractures to form in this plane. In U.S. Pat. No. 3,547,198 to Slusser, there is described a method of forming two vertically disposed fractures which communicate with a cased well penetrating a subterranean formation having a preferred fracture orientation. Openings are formed through the well on opposite sides of the casing located such that they lie in a vertical plane which extends transversely of the fracture orientation. Hydraulic pressure is then applied through the openings to form a fracture at the openings on one side of the well. The openings are then temporarily sealed and hydraulic pressure is applied to form a fracture at the openings on the other side of the well. Thus, two fractures are formed adjacent opposite sides of the well and are propagated into the formation approximately parallel one to the other.

In U.S. Pat. No. 3,285,335 to Reistle, Jr., there is described a method of recovering organic carbonaceous materials from oil shale formations. In accordance with the method of Reistle, Jr. the preferred fracture orientation in an oil shale formation is determined. Reistle notes that hydraulically induced fractures in rock formations are normally oriented perpendicular to the direction of least principal stress. In tectonically inactive regions the least principal stress is substantially horizontal and the induced fractures are substantially vertical. In regions which are tectonically active, the least possible stress may be oriented in any direction between horizontal and vertical and the orientation of induced fractures will vary accordingly. Reistle describes a method of determining the preferred fracture orientation, which method involves drilling a plurality of substantially vertical boreholes from the earth's surface into the oil shale formation, exerting hydraulic pressure on the oil shale formation over a substantial portion of the length of each of the boreholes to fracture the oil shale formation, and thereafter determining the orientation in each of the boreholes of the fracture produced therein. Thereafter, a work shaft is drilled into the oil shale formation and from the work shaft a plurality of substantially horizontal shafts are drilled into the formation in order to penetrate the formation at angles not less than 30° and as near 90° as possible relative to the preferred fracture orientation of the oilshale. Thereafter, the formation is fractured from at least one of the horizontal shafts to open communication with at least one other of the horizontal shafts and thermal fluid is circulated to pyrolyze the oil shale and conduct the products of pyrolyses to the earth's surface.

In U.S. Pat. No. 3,223,158 to Baker, there is described a method of in situ retorting of oil shale wherein there is provided one or more boreholes which extend from the earth's surface into the oil shale with radially diverging borehole extensions. The lower portions of the borehole extensions are drilled so as to deviate from the vertical toward the horizontal. The oil shale adjacent to and intermediate the borehole extensions is extensively fractured by conventional fracturing means from the borehole extensions. In U.S. Pat. No. 3,002,454 to Chestnut, there is described a method of increasing the vertical permeability of laterally disposed oil well drain holes by means of an explosive method of fracturing the oil-producing formation. A vertical wellbore is bottomed above an oil-bearing zone and lateral drain holes are drilled into the oil-producing zone. The drain holes are loaded with an explosive which is detonated to form a large number of cracks and fissures which radiate outwardly from the drain holes. In U.S. Pat. NO. 3,313,348 to Huitt et al., there is described a method of creating a fracture which extends acorss bedding planes in a formation. A borehole is drilled at an angle less than 45° with the horizontal through the formation to be fractured. Thereafter, a notch is cut substantially perpendicular to the wellbore and a fracturing liquid is pumped down the well and the pressure is increased to create a fracture that extends from the extremity of the notch.

SUMMARY OF THE INVENTION

This invention is directed to a method of forming a plurality of vertically disposed fractures communicating with a well penetrating a subterranean formation having a preferred fracture orientation. A well is provided which extends from the surface of the earth and penetrates the subterranean formation at an angle of at least 10° measured fromthe vertical and extends into the formation is a direction transverse of the preferred fracture orientation. A first fracture initiation point is formed in the well to provide fluid communication in-

termediate the well and the formation. hydraulic pressure is applied via the first fracture initiation point to form and propagate a first vertically disposed fracture into the formation along the direction of the preferred fracture orientation. A second fracture initiation point is formed at a predetermined and substantial, horizontal distance from the first fracture initiation point to provide fluid communication intermediate the well and the formation. The first and second fracture initiation points are isolated from fluid communication one from the other and hydraulic pressure is applied through the second fracture initiation point to form and propagate a second vertically disposed fracture into the formation along the direction of the preferred fracture orientation. In accordance with an embodiment wherein the subterranean formation is a liquid hydrocarbon-bearing formation, the predetermined and substantial distance between the formed verticallly disposed fractures is at least 10 feet. In accordance with another embodiment wherein the subterranean formation is a hydrocarbon gas-bearing formation, the predetermined and substantial distance is at least 20 feet.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view of an earth formation having a preferred fracture orientation.

FIG. 2 is a cross-sectional view of a deviated well penetrating a subterranean formation having a preferred fracture orientation and illustrating a plurality of formed essentialy parallel fractures.

FIG. 3 is a plan view illustrating induced fracture azimuths of fractures created in an oil-bearing formation.

FIG. 4 illustrates a deviated well drilled into a subterranean formation and fractures created in accordance with the method of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

This invention is directed to a method of forming from a deviated well a plurality of vertically disposed fractures in a subterranean formation having a preferred fracture orientation.

Referring to FIG. 1, there is shown a plan view of a subterranean formation 1 that has a preferred fracture orientation essentially in an east-west direction as indicated by the plurality of fractures 3. These fractures 3 are shown for illustrative purposes and may be, for example fractures naturally existing in the subterranean formation 1, fractues which have been induced in the subterranean formation 1, or may represent zones of weakness along the preferred fracture orientation.

Methods for determining the preferred fracture orientation were described by Slusser in U.S. Pat. No. 3,547,198. As taught there the preferred fracture orientation exists because of naturaly occurring planes of weakness in the earth formations. It is known that the subterranean formations are jointed in a manner similar to surface rock. Therefore, surface measurements may be employed as a reasonably close indication of the preferred fracture orientation. The preferred fracture orientation may also be determined from measurements taken in wells penetrating the subterranean earth formations of interest. For example, impression packer surveys may be run throughout the area to determine the fracture orientation. Borehole televiewer surveys offer a particularly good method of determining the preferred fracture trends. Borehole televiewer surveys are discussed in an article by J. Zemanek et al., entitled "The Borehole Televiewer — A New Logging Concept for Fracture Location and Other Types of Borehole Inspection," Journal of Petroleum Technology, Vol. XXI (June 1969), pp. 762–774. Other methods of determining the preferred fracture orientation are described in U.S. Pat. No. 3,285,335.

Referring to FIG. 2, there is shown a well 5 extending from the surface of the earth 7 through an overburden 9 and into he subterranean formation 1 having a preferred fracture orientation. A casing 11 surrounded by a cement sheath 13 is shown within well 5.

In accordance with this invention, the well 5 is provided to extend from the surface of the earth and penetrate the subterranean formation 1. The well 5 may have casing therein as illustrated in FIG. 2 or may be completed as an open hole. The well 5 is deviated at least in the lower portion thereof such that it penetrates the subterranean formation 1 at an angle of at least 10°measured from the vertical and in an azimuth direction transversely to the preferred fracture orientation. The preferred fracture orientation of formation 1 was indicated for illustrative purposes in FIG. 1 to be in an east-west direction. Therefore, well 5 is provided to extend into the subterranean formation in a direction transversely to the east-west preferred fracture orientation. Desirably, the well 5 would penetrate the formation 1 in a direction approximately normal to the preferred fracture orientation and thus in the case of the east-west preferred fracture orientation the azimuth direction of the deviated portion of the well 5 penetrating the subterranean formation 1 is either north or south. A first fracture initiation point is formed in the well to provide fluid communication intermediate the well and the formation. In an open hole completion the fracture initiation point may be provided by a straddle packer technique wherein two packers (not shown) are used to straddle the selected fracture initiation point and wherein a tubing (not shown extends from an upper region of the well and communicates with the fracture initiation point defined by the portion of the well intermediate the straddle packers such that hydraulic pressure may be applied to the fracture initiation point to create a vertically disposed fracture in the formation. In a cased well the first and other fracture initiation points may be provided by forming openings in the casing. Hereafter this invention is described with reference to a cased well wherein the fracture initiation point corresponds with an opening provided in the casing. A first opening 15 (first fracture initiation point) is provided through the casing 11 and the cement sheath 13 such that fluid communication is established between the interior of well 5 and the subterranean formation 1. This first opening 15 may be provided, for example, by perforating the casing, forming a slot therein, or other conventional techniques for opening fluid communication between the interior of the well and the subterranean formation. Thereafter, hydraulic pressure is applied via the well 5 and the first opening 15 to form a first vertical fracture 17 which communicates with the subterranean formation and the interior of the well 5 and to propagate the fracture into the subterranean formation 1. Thereafter, a second opening 19 is provided in the casing 11 and cement sheath 13 at a predetermined and substantial, horizontal distance from the first opening 15. The first opening 15 and second opening 19 are iso-

lated from fluid communication one from the other for example by placing a packer intermediate the first opening **15** and the second opening **19,** or by filling the portion of the well intermediate the first and second openings with sand or other sealing material. Thereafter, hydraulic pressure is applied via the well **5** to form and propagate a second vertical fracture **21** into the subterranean formation **1** in the direction of the preferred fracture orientation. Thereafter, these steps may be repeated to form other desired vertical fractures in the subterranean formation. For example, other openings **23** and **27** and corresponding vertical fractures **25** and **29** are shown for illustrative purposes. The formed vertical fractures extend into the formation **1** in the direction of the preferred fracture orientation and thus are essentially parallel one with the other. The fractures may be propped to provide fracture conductivity. The fractures may also be acidized or acid fracturing techniques may be employed to provide fracture conductivity.

The openings **15, 19, 23,** and **28** are provided in the casing **11** at predetermined and substantial distances one from the other. The most desirable predetermined spacing intermediate the openings will vary depending upon the thickness of the subterranean formation **1,** the angle at which the well **5** transverses through the subterranean formation **1,** the drainage radius of the well, the type of material to be recovered from the subterranean formation, and the permeability of the subterranean formation. The horizontal spacing intermediate the formed fractures will normally be at least 10 feet in a low permeability formation containing a hydrocarbon liquid and at least 20 feet in a low permeability formation containing a hydrocarbon gas. This invention is particularly applicable for use in hydrocarbon-bearing formations having a thickness of 50 to 1,000 feet and a permeability of at least 0.0001 md. (millidarcy). Formation thicknesses of about 50 feet or greater are sufficient to enable a deviated well to penetrate the formation at an angle such that multiple vertical fractures that are essentially parallel one with the other may be formed in the formation. Though this invention could be practiced in formations having a thickness greater than 1,000 feet, the improvement over conventional fracturing techniques declines in such thick formations. This invention enables multiple vertically disposed fractures that are spaced apart a substantial horizontal distance one from the other to be created from a single deviated well in a formation having a preferred vertical fracture orientation thus enabling increased fracture surface area to be obtained. Thus, this invention enables improved recovery rates to be obtained in formations that have permeabilities as low as 0.0001 md.

The preferred fracture orientation of a subterranean foramtion remains relatively constant over a large area. Thus, the fractures **17, 21, 25,** and **29** shown in FIG. **2** are propagated into the formation **1** along the preferred fracture orientation and therefore are essentially parallel one with the other. It is highly desirable that these fractures be spaced horizontally one from the other a substantial distance such that substantial fluid communication does not develop intermediate the fractures. Thus, each fracture serves as a pressure sink in the formation. This ensures the most efficient use of the fractures formed in the formation.

FIELD TEST

A field test of this process for generating multiple vertical hydraulic fractures from a single deviated well was carried out in an active oil field. Four independently productive fractures were generated in the oil-bearing formation of the oil field. The productivity index of the four-fracture system was estimated to be several times that of conventionally fractured wells in the same field. The test demonstrated that multiple vertical fractures separated a substantial distance one from the other could be generated by hydraulic pressure from a single deviated well.

The oil-bearing formation was a chalk formation. The top of the pay in the formation was 1,350 feet below ground level and the pay thickness was 150 feet. The porosity of the formation was 25 percent and the specific permeability varied from about 0.3 to about 0.8 md.

The field where the test of this invention was carried out had been developed primarily with a 2½ acre well spacing. Borehole televiewer surveys were run in a numer of the wells which had been fractured to determine the fracture orientation azimuth. Several of these wells with the indicated fracture azimuth are shown in FIG. **3.** Well **41** has a fracture azimuth orientation of 78°, well **43** — 92°, well **45** — 77°, well **47** — 92°, and well **49** — 82°. The fracture orientation azimuth of the formation was found to be quite consistent over relatively large areas. The well survey indicated that the fracture azimuth orientation of the formation of interest was about east-west. A deviated test hole was drilled having an azimuth of south which was approximately normal to the preferred fracture orientation. The test hole was drilled to provide a maximum length of hole in the horizontal direction through the oil-containing subterranean formation. It was determined that the maximum practical hole angle through the formation was about 60° measured from the vertical when using a vertical drilling rig. Such an angle provided a sufficient length of hole through the formation to permit the placement of four vertical fractures with a horizontal spacing of about 50 feet.

The deviated test well was drilled by the alternate use of a Dyna-Drill with a bent sub and standard rotary drilling with a stiff hookup. A whipstock was not required though it could have been used and may be desirable for use in other formations. Directional surveys were run to survey the track of the deviated well. The well and completion arrangement are shown in FIG. **4.** The deviation of the well to the south was about 50° measured from the vertical when passing through the oil-bearing formation.

The well was cased in a conventional manner and the perforation program was designed to provide essentially point initiation of the fractures located at 1,540 feet, 1,595 feet, 1,650 feet, and 1,700 feet measured depth. A jet perforating tool was used and the charges were arranged to give five shots in a plane. Two of these clusters spaced 8 inches apart were used at each perforation point given 10 shots in less than a foot at the four points mentioned above. Hydraulic pressure was applied through each set of perforations to initiate a vertical fracture and to propagate the fracture into the formation. The procedure used for creating the multiple fractures was to perforate and fracture sequentially starting at the bottom perforation point.

Staging was accomplished by perforating and fracturing and then filling the wellbore with sand and gravel to a point just below the next higher perforating and fracturing point. Each fracture formed had a length of about 1,000 feet, a height of about 150 feet, and was propped for about 200 feet. The horizontal separation between the multiple fractures was about 45 feet.

In order to obtain maximum improvement in the well performance data, it is necessary that the multiple fractures behave independently. In order for them to so behave it is essential that they do not intersect for at least a considerable distance from the well. Pressure communication and production tests were carried out to determine whether the fractures were propagated into the formation essentially parallel one with the other so that they would not intersect. These tests indicated that the multiple fractures which were created from the deviated well were propagated into the formation essentially parallel one with the other and did not communicate one with the other.

This field test was considered successful in creating multiple vertical fractures from a single deviated well. In this test, the well was deviated approximately 52° from the vertical through the formation to be fractured. Four separate isolated vertical fractures were created from the single deviated well. The fractures were created about 45 feet apart horizontally and did not intersect. The productive index of the test well was several times that of conventional fractured wells in the field.

We claim:

1. A method of forming a plurality of vertically disposed fractures communicating with a well penetrating a subterranean earth formation having a preferred fracture orientation, comprising:

a. providing a well which extends from the surface of the earth and penetrates said subterranean formation at an angle of at least 10° measured from the vertical and extends into said formation in a direction transversely of said preferred fracture orientation;

b. forming a first fracture initiation point in said well to provide fluid communication intermediate said well and said foramtion;

c. applying hydraulic pressure via said first fracture initiation point to form and propagate a first vertically disposed fracture into said formation along the direction of said preferred fracture orientation;

d. forming a second fracture initiation point at a predetermined and substantial horizontal distance from said first fracture initiation point to provide fluid communication intermediate said well and said formation;

e. isolating from fluid communication said second fracture initiation point from said first fracture initiation point; and

f. applying hydraulic pressure via said second fracture initiation point to form and propagate a second vertically disposed fracture into said formation along the direction of said preferred fracture orientation.

2. A method of forming a plurality of vertically disposed fractures communicating with a cased well penetrating a subterranean earth formation having a preferred fracture orientation, comprising;

a. providing a cased well which extends from the surface of the earth and penetrates said subterranean formation at an angle of at least 10° measured from the vertical and extends into said formation in a direction transversely of said preferred fracture orientation;

b. forming a first opening in said casing to provide a first fracture initiation point;

c. applying hydraulic pressure through said first opening to form a first vertically disposed fracture communicating with said well and extending into said formation along the direction of said preferred fracture orientation;

d. forming a second opening in said casing to provide a second fracture initiation point;

e. isolating from fluid communication said second opening from said first opening; and

f. applying hydraulic pressure through said second opening to form a second vertically disposed fracture communicating with said well and extending into said formation along the direction of said preferred fracture orientation.

3. The method of claim 2 further comprising repeating steps (d)–(f) and forming as desired other vertically disposed fractures communicating with said well and extending into said formation along the direction of said preferred fracture orientation.

4. The method of claim 3 wherein said subterranean formation is a liquid hydrocarbon-bearing formation and said predetermined and substantial distance is at least 10 feet.

5. The method of claim 3 wherein said subterranean formation is a hydrocarbon gas-bearing formation and said predetermined and substantial distance is at least 20 feet.

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