MULTIPLE FRACTURING PROCESS

Inventor: William L. Hill, Richardson, Tex.
Assignee: Sun Oil Company, Dallas, Tex.
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Primary Examiner—David H. Brown
Attorney—George L. Church, Donald R. Johnson, Wilmer E. McCorquodale, Jr. and John E. Holder

ABSTRACT

A process for fracturing an earth formation includes perforating well casing along a first substantially vertical plane, and along a second substantially vertical plane located in the same interval. The perforations along the first and second planes may be of unequal sizes, with the smaller set of perforations located adjacent the zone of preferential fracturing. The smaller set of perforations are sized to insure that a fracturing fluid will enter the larger set of perforations after fracturing occurs in the preferential fracture zone.

13 Claims, 2 Drawing Figures
MULTIPLE FRACTURING PROCESS
BACKGROUND OF THE INVENTION

This invention relates to a method of fracturing earth formations, and more particularly, to a fracturing process whereby more than one fracture plane can be created in the same interval.

Fracturing an earth formation hydraulically is a well-known technique for well stimulation. The fracturing process in its simplest form comprises pumping a sand-laden fluid under pressure into the formation until the formation parts and a fissure is created. The fissure is extended by continued pumping and the sand carried by the fluid into the fissure acts as a propping agent to prevent reclosing of the fissure.

Fracturing often provides an extraordinary increase in production because of two reasons. First, it provides a large drainage area into which formations of very low permeability can slowly feed oil, thus more effectively utilizing the available reservoir energy. Secondly, damage to formation permeability immediately surrounding the wellbore is remedied, often resulting in a 10- to 50-fold production increase over pre-treatment rates of production. Such permeability damage adjacent the wellbore is fairly common, and is usually caused by solids in the drilling fluid invading the matrix of the formation. Ordinarily, where there has been no permeability damage by drilling fluids, increases in production usually range from 200-300 percent.

There are a multitude of fluids and propping agents used in wellbore fracturing. Sand, glass, plastic, nut shells, apricot pits, and other materials have been used as propping agents. The fluids used are of many types. The properties that a fracturing fluid should possess are compatibility with natural formation fluids, a capacity for carrying a propping agent, and a low leak-off rate. The leak-off rate is how fast the fluid flows from the fracture into the formation. There are oil base, water base, and acid base fluids which are utilized as fracturing fluids. Oil base fracturing fluids are frequently recommended to avoid permeability damage when the formation contains clay. Where there is water soluble salt in the formation, a water base fluid is often utilized. If the formation to be fractured is principally carbonate, an acid base fracturing fluid is usually appropriate.

Generally speaking, fractures usually occur on a vertical or horizontal plane. Most often, horizontal fractures occur at shallower depths and vertical fractures occur in deeper zones. To achieve maximum productivity and therefore oil recovery, the orientation of the fracture is often important. For example, in shallow reservoirs near depletion, an increased utilization of gravity drainage by placing a horizontal fracture at the base of the producing interval will extend the economic life of the well. Additionally, water or gas coning can often be reduced by the placement of horizontal fractures at appropriate elevations in the formation. In thick formations vertical fractures are most often desired unless there is an adjacent water or gas zone.

Where a water or gas zone is present, care should be taken to prevent a vertical fracture from reaching those zones.

Some attempts have been made to selectively orient a fracture and the method that has been used most successfully involves jetting of sand and liquid at high rates to notch the formation. Notching of the formation is necessary to overcome the tendency of the formation to fracture along the line of in situ formation stresses.

Methods have been devised to simultaneously create fractures in separate zones. One such method involves plugging the first fracture created and pressuring up again to create a secondary fracture. The principal disadvantage of this method is the uncertainty associated with determining if what appears to be a secondary fracture might in fact be the hydraulic fluid continuing to enter the previously fractured zone. After creation of a second fracture, the plugging material is removed. A system of multiple fracturing using perforation ball sealers was devised for fracturing through perforated casing. Perfora-ball sealers are used where two or more perforation zones are exposed. The fracturing fluid is used to apply pressure against both zones until the most permeable zone is fractured. When this occurs, rubber coated nylon or aluminum balls are interjected in the fracturing fluid which is flowed into the strata which has been fractured. These balls lodge in the perforations leading to the fractured zone and prevent further fracturing fluid from entering that zone. Further application of the fracturing fluid to the wellbore results in such fracturing fluid entering the unplugged perforations. Pressure on the fracturing fluid is increased until the zone opposite the open perforations is also fractured. The balls are then allowed to drop to the bottom of the wellbore or are removed to the surface by recovering them with a bailer. The disadvantage of this process is that complete shut off of the perforations opposite the initially fractured zone is not assured. The drag force of the fracturing fluid may dislodge the ball from the perforation or the balls may never have positioned themselves in all the perforations adjacent the fractured zone.

Shortly after perforation ball sealers were introduced, it was found that casing perforations can be designed to have a limited capacity to take fracturing fluid. Methods were therefore presented for achieving multiple fracturing in two or more perforated intervals by using a limited number of perforations in a well and injecting fracturing fluid into a single perforation large enough to enter all of the open perforations. In order to treat more than one perforated interval, the bottom hole pressure must be raised above the fracture initiation pressure of each successive zone to be fractured. This was accomplished by limiting the number and diameter of the perforations in a casing. These perforations act as individual bottom hole chokes by limiting the amount of fracturing fluid which will flow therethrough because of perforation friction.

An additional method for fracturing more than one zone involves the straddling of a producing interval, which is being fractured, between two packer elements. Special tools were developed containing dual packers arranged for variable spacing for implementing this process.

Although a horizontal fracture in a thin formation generally provides for optimum drainage of such formation, thicker zones contained in deep formations would not be so effectively drained. Generally because of the compressive force of overburden rock, the deeper zones usually are fractured in a vertical plane. Thus, if only one fracture is created in that zone, there
are areas of the producing formation that would not be appreciably helped. If additional vertical fractures can be created which are angled from the initial fractured zone, improved productivity would result. It is therefore an object of the present invention to provide a system for creating more than one vertical fracture in a single producing interval.

SUMMARY OF THE INVENTION

With this and other objects in view, the present invention contemplates creating more than one vertical fracture in a producing interval which is penetrated by a cased wellbore. The well casing is perforated along a first and second vertical plane. A fracturing fluid is injected into the wellbore under sufficient pressure to fracture the more easily fractured zone of the producing interval. The fracturing fluid pressure is then increased until sufficient pressure is applied to the formation exposed by the vertical set of perforations adjacent the unfractured zone.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross section of a wellbore in a formation which has been fractured; and FIG. 2 is a portion of the wellbore shown in cross section in FIG. 1, which has been rotated and shown in perspective view.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows an earth formation 12, which has been penetrated by a wellbore. Casing 18 has been set in the wellbore, and is cemented to the borehole wall 16. The casing 18 has perforations 26 and 24 located near the center of formation 12, which has an upper boundary 28 and a lower boundary 30. This boundary is usually the interface between two types of earth formations, a fault plane, a difference in permeability or other interface boundaries such as adjacent water or gas zones. Tubing 20 is shown on the inside of casing 18 and terminating slightly above the perforations 24 and 26. Perforations 24 are of a larger diameter than perforations 26. Packer 22 is located at the lower end of tubing 20, and operates to seal the space between casing 18 and tubing 20 for a short interval near the bottom of tubing 20. In the formation 12 is a fractured area shown at 14, extending from both sides of the casing 18 adjacent perforations 26.

In the fracturing process disclosed herein, the location, number and size of perforations helps create a multiplicity of vertical fractures in the same producing interval. The number and size of perforations 24 and 26 facilitate the use of limited entry.

Limited entry is a technique whereby the size of the perforations limits the amount of fracturing fluid which may flow therethrough. This technique has been used to initiate fractures in vertically separated formations. The friction caused by the fracturing fluids flowing through a perforation varies directly with the rate at which the fracturing fluid is pumped through the perforations. By increasing the injection rate, the perforation friction will be increased, thus the perforation acts as a bottom hole choke.

Small diameter perforations are preferred in limited entry treatments to increase perforation friction and to lower the hydraulic horsepower requirements. It is noted that approximately twice as much fluid can be injected through a ¼ inch hole as through a ½-inch hole. Therefore, a ¼ inch perforation is generally used in limited entry techniques.

When more than one perforated interval is being fractured, the bottom hole treating pressure must be raised above the fracture initiation pressure of each successive interval to be treated. The bottom hole treating pressure is then raised above the pressure necessary to fracture the more easily fractured zone exposed by the perforations. After fracturing the first zone, sufficient fracturing fluid must be available to the other perforated interval so that it too may be fractured. If the perforations are of a number and size such that a limited amount of fracturing fluid will flow therethrough, then sufficient fluid will be available to treat the unfractured formation adjacent the other perforated intervals.

To achieve a multiplicity of vertical fractures in the same zone, each of the perforations 24 and 26 are oriented vertically in order to influence the direction of fracture. In FIG. 1 the casing 18 is perforated along two planes with 10 perforations in each plane. There are five perforations 26 located along a vertical line on one side of the casing 18 and five other perforations 26 in the casing 18 on the opposite side. Similarly, five vertically aligned perforations 24 are positioned in a plane substantially perpendicular to the plane of perforations 26. Not depicted in FIG. 1 are five perforations in casing 18 opposite those shown at 24.

Once the casing has been perforated, a fracturing fluid is pumped through tubing 20 and applies pressure against the formation adjacent perforations 24 and 26. Generally, the formation adjacent one of the sets of perforations 24 and 26 will fracture prior to the other. This portion of the formation is termed the preferential fracturing zone. The fracturing fluid pressure is increased until such fracture occurs. In FIG. 1, this fracture is shown at 14. A sufficient volume of fracturing fluid is needed to supply the full capacity of the perforations 26, with sufficient fluid remaining so that fracturing fluid is available for the formation adjacent perforations 24. The pressure on such fluid is then increased to a point sufficient to fracture the formation adjacent perforations 24.

The results obtained by this procedure are more readily seen in FIG. 2. In FIG. 2 is seen a portion of casing 18 which is cemented to borehole wall 16. Perforations 24 and 26 are shown in the sidewall of casing 18. Formation 12 located adjacent the casing 18 contains vertical fractures 14 and 32 extending radially from the borehole. These vertical fractures define planes which are generally perpendicular to each other. Similar fractures would extend from perforations located in the casing opposite perforations 24 and 26. Thus, fracture 14 is equivalent to the part of fracture 14 to the right of the wellbore in FIG. 1. Fracture 32 cannot be seen in FIG. 1 as it would extend into the page from perforations 24. Thus, four fractures extend away from the wellbore. Additional sets of perforations could be created in casing 18 so as to provide for additional fractures in the formation 12.
Since perforation friction relates to the rate of fracturing fluid flowing therethrough, the optimum system must be determined by trial and error or be based on charts available from service companies. A typical flow capacity through a ½ inch perforation would be approximately 1.3 barrels per minute at pressures of 200 – 300 psi. Fluid velocity, hydrostatic pressure, and friction loss in the pipe extending to the surface must be determined to determine the amount of fracturing fluids which will flow through a given size perforation at a set pressure of fracturing fluid. The number and size of perforations are limited by the pump capacity and the working pressure of the casing or tubing. The working pressure limitation may be alleviated by not using the packer 22 shown in Fig. 1, so that fracturing fluid flows down not only the tubing 20, but also the annulus between the tubing 20 and casing 18.

Because of information gained from offset wells or general geological information in the area, the in situ formation stresses may be known prior to perforating and fracturing. The formation will fracture in a segment which is perpendicular to the plane of least stress, and this segment is known as the preferential fracturing plane. If this preferential fracturing plane is known, one of the vertical sets of perforations should be directed toward that segment of the formation. This set of perforations should be of a number and size to limit the amount of fracturing fluid which will flow therethrough. The limited amount of fluid passing through the perforations open to the preferential fracturing plane ensures sufficient fracturing fluid for the other sets of perforations. The usual size of perforations used to limit fluid flow is ½ inch diameter. At flow rates and pressures normally used in fracturing, a substantial pressure drop occurs in the fluid passing through a ½ inch perforation.

The remaining sets of perforations should be of a larger size so the pressure drop across them will not be as great. This sizing will reduce horsepower requirements necessary to create a multiplicity of fractures.

Although, in the discussion related to Figs. 1 and 2 there were fractures described extending from four sets of vertical perforations along two planes, it is contemplated that two or more sets of vertical perforations can be created in the casing at desired positions. Care should be taken that the sets of vertical perforations would not tend to create fractures along planes that are close to coinciding. If oriented closely together, it is likely that fracturing fluid directed to the unfractured zone would go to the previously made fracture because of a breakdown of the formation between the two planes. The optimum configuration for a fracture pattern in some formations might, for example, be three fractures equally spaced around the wellbore. In such a situation, each vertical set of perforations would not have a vertical set of perforations located in the same plane located on the opposite side of the casing.

Additionally, the vertical distance between individual perforations in a vertical set of perforations should be of sufficient distance to prevent fragmentation of the cement behind the casing. If the cement were to fragment, the fracturing fluid entering all perforations would seek out the zone previously fractured because of the breakdown of the area adjacent the outside of the casing.

After the fractures have been created in formation 12 and are being propped open by the propping agent in the fracturing fluid, an explosive slurry may be injected into the fracture to create further fracturing by detonation of the explosive. After explosive fracturing, the well can be returned to production and an increase in production should result because of the reservoir fluid flowing into the fractures 14 and 32 by reservoir pressure and subsequently flowing to perforations 24 and 26 by way of the highly permeable fracture zones 14 and 32.

While particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects, and therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. A process of fracturing an earth formation penetrated by a wellbore having well pipe therein comprising: perforating the well pipe along a first vertical plane with perforations having a first total diameter; perforating the well pipe along a second vertical plane with perforations having a second total diameter; injecting a fracturing fluid into the wellbore at a pressure exceeding the fracturing pressure of the preferential fracturing zone of the formation adjacent a set of perforations; and increasing the pressure on the fracturing fluid to a point where the secondarily preferential fracturing zone of the formation is fractured.

2. The process of claim 1 wherein the intersection of the first and second vertical planes form an angle of at least 45°.

3. The process of claim 1 wherein the perforations made along the first plane are positioned opposite the preferential fracturing plane of the formation and are of a smaller total diameter than the perforations made along the second vertical plane.

4. The process of claim 1 wherein the perforations along the first and second planes are of such number and size so as to restrict the amount of fracturing fluid which will pass therethrough so that the second plane of perforations will receive pressurized fracturing fluid after a fracture occurs along the preferential fracturing zone.

5. The process of claim 1 including the steps of injecting an explosive fluid into the fractured zones and detonating the explosive fluid to further fracture the formation.

6. A process of providing multiple fractures in an earth formation penetrated by a cased wellbore comprising: perforating the casing along a first substantially vertical plane with the perforations sized to restrict the amount of fluid which can be flowed therethrough; perforating the casing along a second vertical plane angled from the first vertical plane with the perforations along the second vertical plane also sized to restrict the amount of fluid which can be flowed therethrough; applying pressurized fracturing fluid to the formation through the perforated casing at a pressure exceeding the fracturing pressure of the preferential formation fracturing plane and increasing the flow rate of the fracturing fluid in excess of the amount which the perforation adjacent the preferential formation fracturing
plane can take, so that there is sufficient excess pressure to fracture a second fracturing plane.

7. The process of claim 6 including the step of determining the preferential formation fracturing plane prior to perforating the cased wellbore and aligning the perforations along the first vertical plane with such preferential fracturing plane.

8. The process of claim 6 including the steps of terminating the injection of pressurized fracturing fluid; injecting an explosive material into the fractures; and detonating the explosive material.

9. The process of claim 6 including the steps of perforating along additional vertical planes prior to the step of applying a pressurized fracturing fluid.

10. The process of claim 6 wherein the perforations along the first vertical plane are located adjacent the preferential formation fracturing plane and have a lesser total diameter than those perforations along the second vertical plane.

11. The process of claim 9 wherein the intersection of the first, second, and third plane of perforations form angles of approximately 120°.

12. A process of fracturing an earth formation penetrated by a cased wellbore comprising: determining the direction of least in situ formation stress; perforating the casing along a first substantially vertical plane which is perpendicular to the least in situ formation stress; perforating the casing along a second substantially vertical plane intersecting the first plane at an angle in excess of 45°; applying a fracturing fluid against the formation at a pressure in excess of the fracturing pressure of the portion of the formation exposed by the first plane of perforations; and increasing the fracturing fluid pressure in excess of the fracturing pressuring of the remaining portion of the formation exposed by the second plane of perforations.

13. The process of claim 12 wherein the perforations in the first plane are smaller than the perforations of the second plane, and are of a number and size that allows only a limited amount of fracturing fluid therethrough, and the flow rate and pressure of the fracturing fluid are of a magnitude that the formation behind the second plane of perforations may be fractured after the formation behind the first plane of perforations has been fractured.

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