

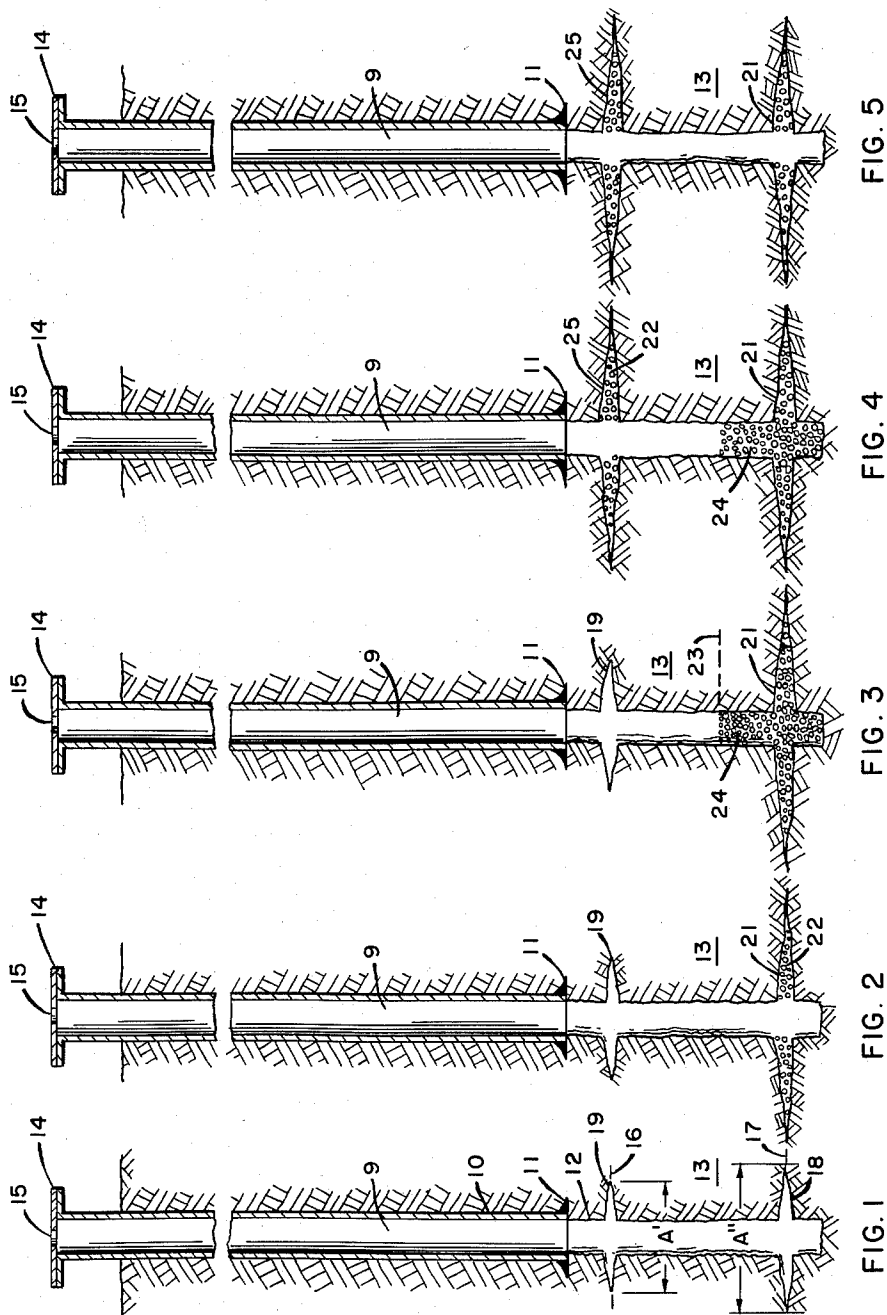
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PRODUCING MULTIPLE FRACTURES IN A WELL

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PRODUCING MULTIPLE FRACTURES IN A WELL

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This invention relates to an improved method for hydraulically fracturing a well and relates more particularly to the production of fractures hydraulically at a multiplicity of selected elevations in a well.

Several fractures extending from a well back into a producing formation are often considered desirable or even necessary to drain the formation efficiently. Various methods for producing multiple fractures in a well have been proposed. All of these generally involve the production of a first fracture by application of a hydraulic pressure to a well, the subsequent sealing or plugging of that fracture and then the injection of additional fracturing fluid to produce another fracture at another location in the well. One difficulty with the previously proposed methods is that there has been no way to control the position of these fractures.

It is, therefore, an object of this invention to provide an improved method of producing multiple fractures in a formation penetrated by a well including the production of such fractures at previously selected elevations in the well. Specifically, it is an object of this invention to produce fractures hydraulically at a multiplicity of selected elevations in a well by first weakening the formation at the elevations where each fracture is desired and then producing the fractures. Other objects of this invention will be apparent from the following description. In this description reference will be made to the accompanying drawings in which:

Figure 1 is a cross-sectional view of a well and the surrounding formations showing one of the first steps in the process of this invention; and

Figures 2, 3, 4 and 5 are similar views showing typical consecutive steps in said process.

This invention, in brief, may be described as a method for producing fractures hydraulically at a multiplicity of selected positions in a formation penetrated by a well including the steps of undercutting or otherwise weakening the formation at the positions where fractures are desired, the formation being weakened to varying degrees so that fractures can be produced selectively by first fracturing the weakest section, plugging that fracture, and then again fracturing the formation and plugging the fractures consecutively at the next weakest section.

Referring now to Figure 1 for a more detailed description of this invention, well 9 has an upper section lined by a casing 10 and below the cased section and the casing shoe 11 an open hole section 12 within the producing formation 13 in which it is desired to produce multiple fractures. A tubing head 14 with a fluid inlet 15 is located at the surface of the upper end of the well casing. The tubing head permits lowering a tubing string into the well and is adapted to provide a seal around and to support the tubing, as well-known. Generally, after a well is drilled into the producing formation 13 and the elevations 16 and 17 at which fractures are to be produced in the formation have been determined, the formation is undercut at those elevations. The formation may be undercut laterally from the well by any of a number of

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means including, for example, lowering a mechanical under-reamer into the well on a string of tubing, and reciprocating or, in the preferred embodiment, rotating the under-reamer at the lower elevation 17 until the desired depth of undercut 18, having an area indicated by A', is obtained. The mechanical under-reamer is then raised to upper elevation 16 and again rotated until the desired depth of undercut 19, having an area indicated by A'', is obtained. Areas A' and A'' are desirably substantially different, A'' being substantially greater than A', so that when fracturing fluid is subsequently injected into the well and pressure is applied, the opposite vertical forces produced on the bottom and top of the undercut area are substantially greater in the lower undercut 18 than in the upper undercut 19. Even if fluid is injected "down the hole" with no means to isolate the selected zone, these greater initial forces cause the formation to be fractured first at the lower elevation 17. Alternate means of undercutting the formation include, for example, jetting an abrasive-laden fluid or acid into the formation as the jet is rotated around the well at different depths or the discharge of annular or jet-shaped explosive charges with the jets directed radially against the walls of the well. Obviously in some cases the undercuts in the producing formation 13 may be produced even though the well has been cased through the formation by merely milling, burning or abrading away the casing at the elevations where the undercuts are desired. In either case the undercuts, preferably all of the undercuts which are desired, are first produced, each undercut having a different area in a plane perpendicular to the axis of the well. The area of the minimum undercut should be at least 10 percent and preferably about 25 percent or more greater than the area of the well. Similarly, the larger undercut or undercuts should be at least 10 percent and preferably 25 percent or more greater than the area of the next smaller undercut so that the normal variations in the strength of the rocks will not override the effect of the undercuts. The undercutter may then be removed from the well or, in some cases particularly where the undercutter is run on the tubing, the tubing and undercutter may be left in the well so the tubing is available for later use.

Fracturing fluid is then injected into the well, preferably "down the hole," so that all of the permeable producing formation 13 penetrated by the well 9 is exposed to or contacted by fracturing fluid. This fracturing fluid may comprise any of the well-known fracturing fluids, for example water or oil, preferably gelled or thickened to produce initially a low penetrating fluid having a low filtrate rate and to be capable of removal from a formation by producing the well. After the well has been filled with this fracturing fluid, pressure is applied and when the pressure of the fluid acting on the upper and lower surfaces of undercut 18 is great enough to initiate a fracture annularly at the vertex of the undercut, the effective overburden above the lower elevation 17 is raised permitting the fracturing fluid to enter the initiated fracture. Injection of the fracturing fluid at high rate and high pressure then causes a lower fracture 21, as indicated in Figure 2, to be extended radially into the formation 13 to any desired depth depending upon the amount and physical characteristics of the fluid injected. Formation propping agents such as sand particles 22 may be carried with the fracturing fluid into the fracture to support the effective overburden and maintain a high permeability channel from the lower part of formation 13 into the well.

Since fractures in a formation, once initiated, tend to be extended in preference to the initiation of other fractures, the lower fracture will continue to take fracturing fluid as long as that fluid is injected unless the fracture

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becomes plugged as by the well's being sanded up to prevent access to the lower fracture. The quantity of sand which is typically injected as a propping agent varies from about one-half pound of 20-40 mesh U.S. sieve to about two or more pounds per gallon of the fracturing fluid. A very high concentration of sand, particularly in thin fracturing fluids tends to deposit sand in the well. When it is desired to plug or "sand out" a fracture, particularly a fracture at the bottom of a well, the concentration of this sand may be increased to as much as 10-15 or more pounds per gallon of the fracturing fluid so that the fracture and the bottom of the hole become filled with sand to plug the bottom fracture 21 as indicated in Figure 3. Alternatively, instead of placing sand in the fracturing fluid at a concentration sufficiently high to cause it to sand out, injection of the fracturing fluid containing the sand or other propping agent may be discontinued and sand or other plugging materials may be injected into the well, preferably at low pressure and in a thin slurry of oil or water or other fluid, or the sand may be merely dumped into the well with a bailer or the like to produce one type of bottom plug in the well. Preferably, the well is filled with a plug 24 to an elevation 23 which is two or more feet above the elevation of the lower fracture 21. While this plug may comprise any plugging material such as sand as indicated, other plugging materials such as oil soluble solids, e.g., granulated naphthalene or the like, may be substituted. Similarly, a bridging plug may be set at or the well may be filled to the intermediate elevation 23 above the lower fracture 21 and below the upper undercut 19 with cement or other settable materials such as sulfur so that the lower fracture is protected and cannot be further extended when fracturing fluid is again injected into the well.

With the lower fracture 21 thus protected by the plug 24 in the lower part of well 9, another quantity of fracturing fluid is injected into the well and pressure is applied. As pressure is built up on this second quantity of fracturing fluid, opposite forces which tend to fracture formation 13 selectively at upper elevation 16 are exerted on the upper and lower surfaces of the upper undercut 19. These forces first initiate a fracture at the vertex of the undercut and then, with the fracturing fluid following the initiated fracture, an upper fracture 25 as shown in Figure 4 is extended into the formation to any desired distance. Sand or other propping agent 22 may be incorporated in the second quantity of fracturing fluid to support the effective overburden at the upper elevation and produce a highly permeable flow channel in an upper horizon from the producing formation 13 into the well. This channel or fracture, like the lower channel, is probably, but not necessarily, a flat, annular and substantially circular "sand bar" symmetrical horizontally about well 9.

While only two formation fractures may thus be produced at select elevations in a well, it will be apparent that any number of such fractures may be produced at higher elevations by first plugging the well as by filling it with a plugging agent to an elevation above the elevation of the last-produced fracture and then injecting another quantity of fracturing fluid into the well, applying pressure to initiate and extend a fracture, plugging the well again to prevent access to the last-produced fracture, etc. After the desired number of fractures have been produced in formation 13, the plugging material 24 is desirably removed so that the well is open to the lower fracture 21 as shown in Figure 5. In the case of a well plug, e.g., a plastic or a coal tar derivative, which is soluble in the fluid, e.g., oil, produced by the fractured formation 13, the well plug will obviously be automatically removed by merely flowing the well or otherwise causing fluid to enter the well from the surrounding formation. Where the plug is not soluble in the fluids produced by the fractured formation, as for example

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where the plugging material is sand, it may be removed by bailing, by circulation, or the like. Similarly, when the plug is insoluble and is set in the well, as for example a hydraulic cement plug, such a plug may be removed by redrilling the well to bottom or to below the bottom fracture.

After the plugging material has been removed from the well, both the lower fracture 21 and the upper fracture 25 are exposed to and in fluid communication with the well so that fluids flow freely into the well, thus substantially increasing the productivity of various zones in the fractured formation 13.

In the preferred embodiment as described above, the formation is desirably fractured a multiplicity of times with the first fracture near the bottom of the formation and subsequent fractures at progressively higher elevations in the formation. This permits the previously produced fractures to be plugged more readily by merely depositing plugging material in the bottom of the well to the desired elevation. In this instance, as indicated, the areas of the undercuts progressively decrease from the bottom of the well upward so that a fracture is produced preferentially at the lowest undercut in the formation above the top of the plug.

I claim:

1. A method of hydraulically fracturing a formation penetrated by a well at a multiplicity of selected elevations comprising in sequence undercutting said formation at the lowest of said selected elevations for a substantial distance around said well to produce an undercut having an area A'' in a plane substantially perpendicular to the axis of said well, undercutting said formation at at least one of said selected elevations above said lowest elevation for a substantial distance around said well to produce an undercut having an area A' in a plane substantially perpendicular to the axis of said well, said area A'' being substantially greater than said area A', injecting a first quantity of fracturing fluid into said well and into said undercuts in said formation, simultaneously applying sufficient pressure to said fracturing fluid in said undercuts to produce and extend a first fracture at said area A'' into said formation, temporarily sealing said first fracture to an extent sufficient to withstand subsequent fracturing pressures in said well, injecting a second quantity of fracturing fluid into said well and into said formation under sufficient pressure to produce and extend a second fracture at said area A', and producing said well.

2. A method according to claim 1 wherein said seal is insoluble in the fluids produced by said formation which includes the step of redrilling said well to said lowest elevation to remove said seal from said well.

3. A method of hydraulically fracturing an oil producing formation penetrated by a well at a multiplicity of selected elevations comprising under-reaming said formation at one of said selected elevations to produce a first undercut having an area A'', under-reaming said formation at at least one other of said selected elevations above said first undercut to produce a second undercut having an area A', said area A'' being substantially greater than said area A', injecting a first quantity of fracturing fluid into said well and into a multiplicity of said undercuts, applying pressure to said fracturing fluid to produce an axial force across each of said undercuts, said pressure being great enough to initiate a first fracture in said formation at said area A'', injecting fracturing fluid into said first fracture to extend said first fracture into said formation, temporarily sealing said first fracture to an extent sufficient to withstand subsequent fracturing pressures in said well with an oil-soluble sealing agent, injecting a second quantity of fracturing fluid into said well and into said second undercut to produce an axial force across said second undercut great enough to initiate a second fracture in said formation at said area A', removing the temporary seals from said fractures and producing said well.

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4. A method according to claim 3 wherein said first undercut is sealed by filling said well with said oil-soluble sealing agent to an elevation above the elevation of said first undercut and below said second undercut.

5. A method of sequentially hydraulically producing a multiplicity of fractures in a formation penetrated by a well at selected positions, comprising first undercutting said formation at said selected positions, each undercut thus produced in said formation having a substantially different cross-sectional area laterally of said well from any other undercut in said formation, said cross-sectional area varying directly with the depth of said well, whereby the formation at a given undercut is weakened to a degree different from that of the other of said undercuts, depositing a first quantity of fracturing fluid in said well at the elevation of said selected positions, applying

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sufficient pressure to said fracturing fluid simultaneously at said selected positions to produce a first fracture in said formation at the lowermost undercut, temporarily sealing said first fracture to an extent sufficient to withstand subsequent fracturing pressures in said well, repeating the above cycle whereby a fracture is produced at the undercut immediately above said first fracture, removing said seals, and producing said well.

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