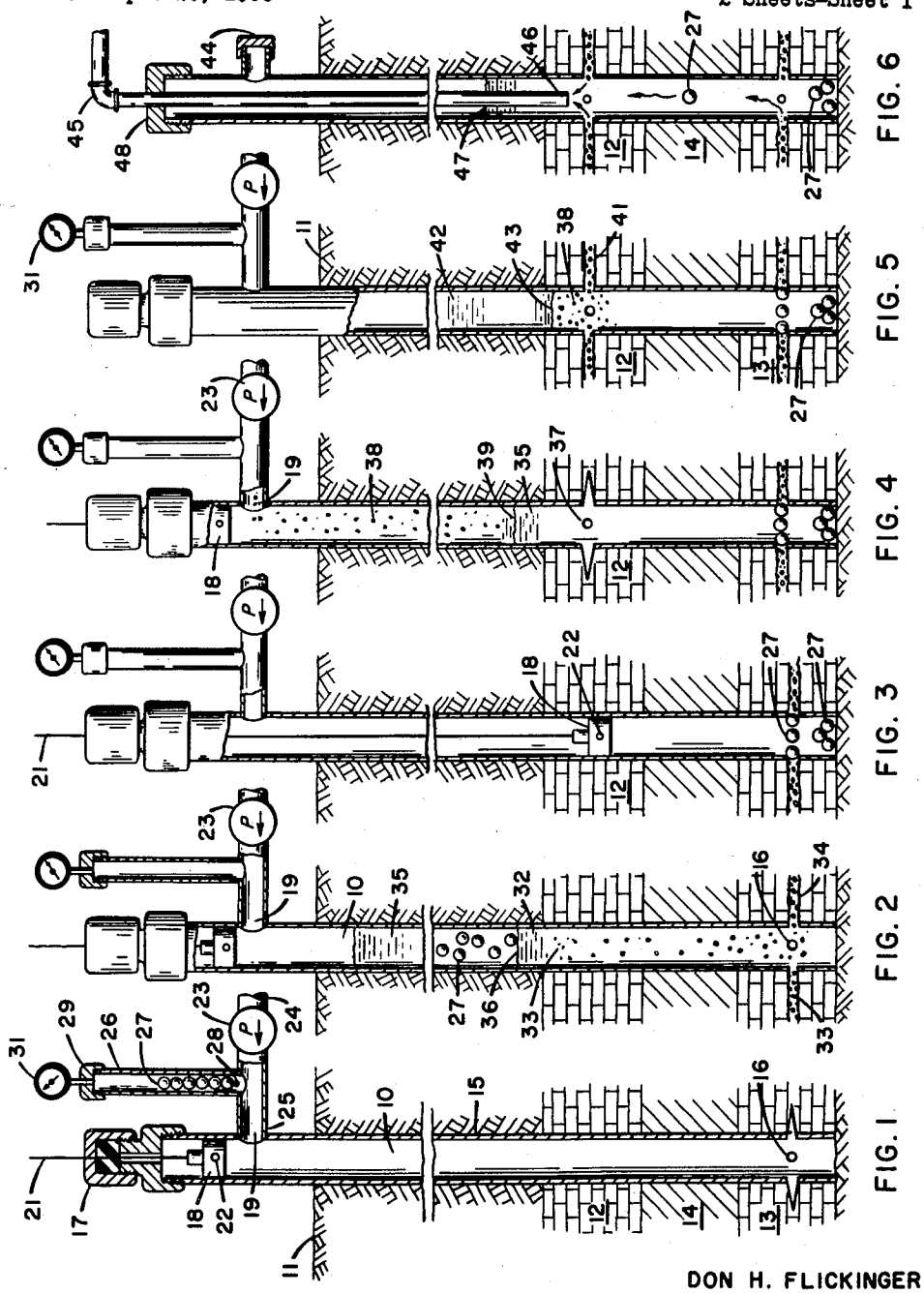
CROSS REFERENCE SEARCH ROOM

April 10, 1962 D. H. FLICKINGER 3,028,914

PRODUCING MULTIPLE FRACTURES IN A CASED WELL

Filed Sept. 29, 1958 2 Sheets-Sheet 1




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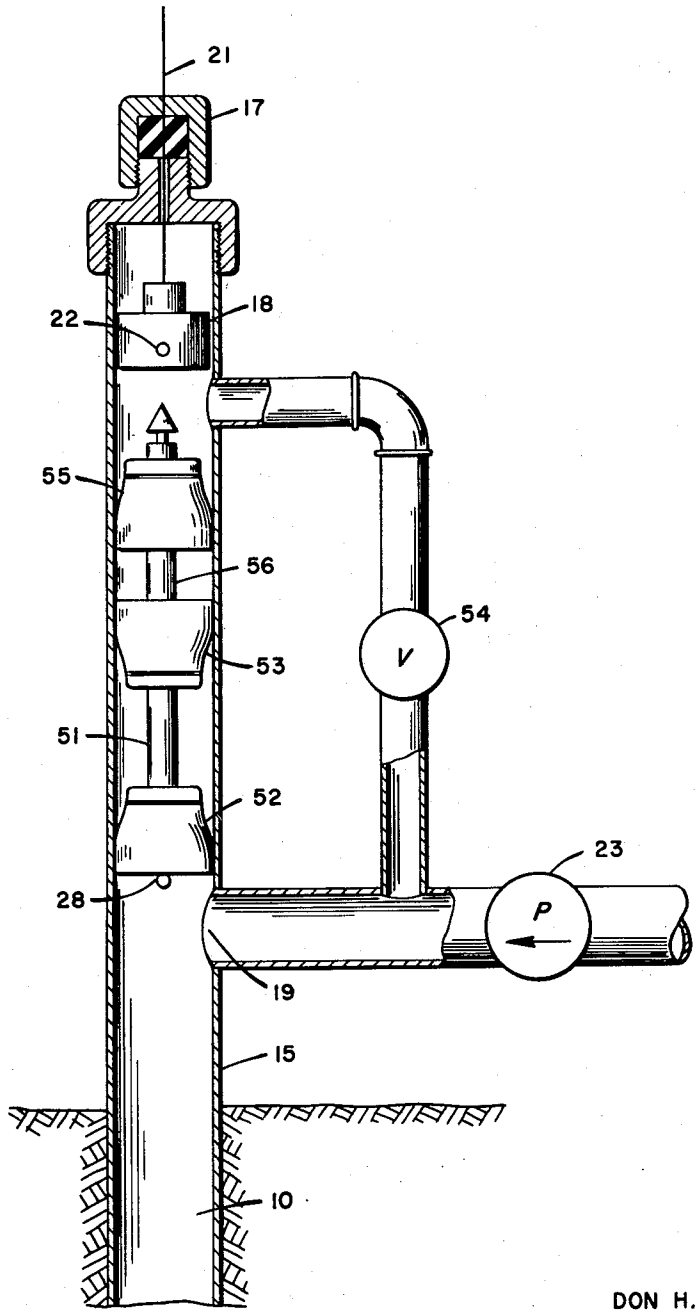



FIG. 7

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# 3,028,914
# PRODUCING MULTIPLE FRACTURES IN A CASED WELL

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4 Claims. (Cl. 166—42)

This invention relates to an improved process for increasing the recovery of fluid from a well. More particularly, this invention pertains to a process for hydraulically fracturing or otherwise injecting a treating fluid into the formations penetrated by a cased well.

In the hydraulic fracturing process, a low-penetrating fluid is injected into a formation at high rate to produce a fracture which desirably extends into the formation for a great distance to thereby increase the effective permeability of the formation affected by the fracturing process to formation fluids so that those fluids flow into the well more easily. In the process as applied to open-hole completions, i.e., to fracturing a formation in the open hole below the casing, it has been shown (see, for example, U.S. Patent 2,838,116, Clark et al.), that since a greater pressure is required to initiate a fracture than to extend that fracture into the formation, normally only one fracture is produced; and unless all previously produced fractures are at least temporarily plugged, it is improbable that a new fracture can be initiated. When wells are completed with the casing set through the producing formation or formations, the casing is typically perforated throughout each producing zone with about three or four perforations per foot. The casing opposite each producing formation may thus be perforated either by jet or bullet perforators with as many as a hundred or more holes, depending upon the thickness of the producing formation. I have found that when a cased well has been completed by this procedure, the productivity increase or fracture efficiency is often less than in the case of an open-hole completion. It is apparently impossible to extend a fracture into a formation behind a casing to as great a depth as can be attained in open-hole completions. As a partial explanation for this difference, I have found that each perforation has a limited flow capacity. When liquid flow through a perforation reaches its critical velocity, flow through that perforation cannot be further increased; it is flowing at capacity. If the pump capacity is greater than the capacity of the perforations receiving fluid, another perforation is broken down and commences to take the treating fluid. If the two perforations are not in communication behind the pipe, each one treats a separate section of a formation or even a separate formation. Separate fractures may even be produced. In the case of formation fracturing, the flow capacity of each perforation is generally insufficient to extend the fracture into the formation to as great a depth as can otherwise be attained in an open-hole completion. This low fracture efficiency is thus attributed to the excessive number and wide spacing of the perforations which may take the injected fluid and the fact that with such wide spacing, the fluid discharged through the various perforations does not combine and produce a single fracture. In substance, I have found that by first perforating the casing with a great number of widely spaced holes which are spread over a great vertical distance, the perforations are generally not in communication behind the pipe. I have found, furthermore, that due to the limited capacity of each perforation and the lack of communication between perforations behind the pipe, several fractures may be produced simultaneously in one or more formations behind the pipe. The rate of fluid injection into each fracture is therefore lower than desirable and, consequently, assuming a fracturing liquid which leaks away to some extent into the formation, the ability to extend each of the fractures into the formation is somewhat hampered.



It is therefore an object of this invention to provide an improved method for injecting a treating fluid into the formations penetrated by a cased well. It is a more specific object of this invention to provide a process wherein the formations penetrated by a cased well can be fractured with one or more deep-penetrating fractures. It is still a more specific object of this invention to provide an improved hydraulic fracturing process for wells which have been completed with the casing extending through the producing formation and perforated in a producing zone wherein the fracturing efficiency is increased by limiting the number of casing perforations which can take fluid at any one time and by grouping or concentrating those perforations so that they are all in communication behind the casing. Other objects of this invention will become apparent as the process is further described hereinafter and by reference to the accompanying drawings in which:

FIGURE 1 is a cross-sectional view of a cased well showing surface equipment employed in the process;

FIGURES 2–6 are cross-sectional views of the well shown in FIGURE 1, showing in sequence the steps of my preferred process; and

FIGURE 7 is a cross-sectional view of the wellhead shown in the preceding figures, showing an alternate apparatus for plugging casing perforations.

In brief, this invention may be described as a well completion process in which a treating fluid is injected into a particular formation penetrated by a cased well after other formations or sections of the same formation have been treated. In its more specific aspects, fractures are produced by first temporarily plugging existing fractures, then making a multiplicity of casing perforations concentrated in a short section of the casing so that the perforations are in fluid communication behind the pipe, and then injecting a fracturing fluid into the well at a high rate and at a high pressure to fracture the formation at the elevation of the perforations with a single deep-penetrating fracture. As applied to producing multiple fractures in a cased well, a first formation fracture is first made and extended into a formation as desired by pumping a first quantity of fracturing fluid into that formation at a high rate. The same formation or another formation penetrated by the same well may then be fractured by plugging the mouth of the first fracture, then making a number of perforations, concentrated within a short section, in the casing, and then injecting another quantity of fracturing liquid into the well at a high pressure and at high rate while the first fracture is plugged so that a second fracture is initiated at the elevation of the second set of perforations and is extended into that formation to any desired depth. After one or more fractures have thus been produced in the formation or formations through which the cased well extends, these formations may be produced through all of the casing perforations and adjacent fractures in the usual manner as by pumping, flowing, or the like. The temporary plugs placed in or over the first set of perforations or at the mouth of the first fracture or fractures while the last fracture is produced are unplugged, i.e., the bridging elements are removed, by flow of fluid from the fractured formation into the well to permit recovery of fluid from the various formations fractured.

Reference will now be made to FIGURE 1 for a more detailed description of a schematic representation of a suitable apparatus for carrying out the steps of the process. A well **10** drilled down from the earth's surface

11 extends through or penetrates an upper producing formation 12 and a lower producing formation 13. These producing formations are separated by an impermeable nonproductive zone 14 and are therefore not in fluid communication with each other. In situations like this the well may either be dually completed, i.e., the production from each zone may be kept separate, or these two zones may be commingled in the well. Casing 15, often referred to as the producing string, extends from the surface down through the upper producing formation 12 and into or even through the lower producing formation 13. It is typically cemented in the well by pumping cement up around the casing between the well wall and the casing to an elevation above the top producing formation 12 so that the upper and lower producing formations are not in fluid communication through the well behind the pipe in the nonproductive zone 14. The casing is then perforated in one of the producing zones, for example, in the lower producing formation 13 with a first set of perforations 16 which, as indicated previously, are desirably concentrated or groups within a very short vertical section of the pipe. In the preferred process, the casing is perforated with an annular type jet or bullet perforator which has a number of jet charges or bullets at one elevation circumferentially spaced at a distance at least as great as a plug diameter so that a multiplicity of holes, e.g., 4–10 or more, are produced preferably simultaneously in a ring around the pipe. Several of these multijet perforators spaced vertically as close as possible, but at a distance at least as great as the diameter of the plugs, may be employed so that as many as 15–30 or more holes may be produced in the casing within a vertical space of a foot or less. The lower producing formation may then be produced through this first set of perforations or it may be fractured therethrough so that its productivity is increased.

When it is desired to complete the well in the upper producing formation 12, the surface apparatus, schematically shown in FIGURE 1 above the surface 11, is installed at the upper end of the casing 15. This surface apparatus includes a stuffing gland 17 on the upper end of the casing 15. A lubricator including valves, as is well known in this art, may be installed between the upper end of the casing and the stuffing gland so that well apparatus, such as a casing perforator, bridging plugs, or the like, may be run into and removed from the casing while the well is under pressure. A casing perforator 18 is suspended in the upper end of the casing above the casing inlet 19 by a wire line 21 which extends through the stuffing gland 17. This casing perforator has a number of circumferentially disposed jet charges 22 around its periphery with the jets directed outwardly so that when the casing perforator is detonated it will produce a number or set of holes in the casing all at about the same elevation and preferably in a ring. A high-pressure, high-volume pump 23 and its suction line 24 are connected to treating fluid supply tanks (not shown). This pump discharges the well treating fluid into the well through flow line 25 and casing inlet 19. A bridging material hopper 26 connected at the lower end into flow line 25 extends a sufficient distance to provide room for the desired number of perforation sealers or other fracture bridging elements, in this case balls 27, which are stacked in the hopper and supported on a pin 28. After the balls are dropped into the hopper, the hopper is closed on the top of a cap 29. A pressure gauge 31 is connected in the system at some point downstream from the discharge of pump 23, for example, in the cap 29, to indicate the pump discharge pressure. Assuming that the casing has first been perforated opposite the lower producing formation 13 as indicated, after the apparatus has been thus assembled and the pump suction 24 connected to a supply tank containing the treating fluid, viz., fracturing liquid, a first quantity of fracturing liquid 32, preferably having granular props such as sand 33 suspended therein, is pumped into the well and through this lower set of perforations 16 to produce a first fracture 34. The sand 33 is deposited in this fracture, as is well known in the art, to prevent the fracture from collapsing after pressure is removed and to thereby maintain a highly permeable fracture.



The quantity of fracturing liquid and the rate of injection thereof may be varied over a substantial range depending upon a number of elements including the area of fracture desired. The rate of injection of the fracturing fluid is desirably correlated with the size and number of perforations 16. I have found that a typical perforation through casing and the material behind the casing, i.e., a perforation ⅜–½ inch in diameter, has a flow capacity of from about 1 to about 1½ barrels per minute. Even with a substantial increase of pressure within the casing, the flow rate cannot be materially increased. Since the viscosity of the fluid and the size and shape of perforations often vary considerably from the average, in some cases it is desirable to determine beforehand by surface tests the flow capacity with the particular treating fluid of the perforations produced with the perforator to be used in perforaing the well casing. Knowing the flow capacity of each perforation, the desired number of properly grouped holes can be shot in the casing more efficiently to utilize the capacity of pump 23.

After the desired quantity of fracturing liquid 32 has been injected into the well, the suction line 24 of pump 23 is connected to a supply of follower fluid which is typically a solids-free or clean fluid, such as oil or water, and this follower liquid 35 which may form an interface 36 with the fracturing liquid displaces the fracturing liquid down the well and into the first formation fracture 34. At about the time pump 23 discharges the first of the follower fluid 35 into the casing inlet 19, the pin 28 is removed from the bottom of the hopper 26, allowing the balls 27 or other plugging or bridging element or elements to fall out of the hopper and be dispersed in the follower fluid. These balls, which desirably have a density about equal to the density of the follower fluid, are then carried by the follower fluid down the well and, being larger than the perforations 16, are deposited on the upstream side of the perforations, as indicated in FIGURE 3, closing the perforations. The number of balls injected is typically substantially greater than the number of open perforations so that after all of the perforations have been plugged, there is a surplus of balls which may fall to the bottom of the well. The surface pressure indicated by the pressure gauge 31 will then reflect a sudden increase in pressure, giving an indication that the perforations are sealed.

It is an important element of this invention that any other formations or sections of formations which are to be treated, are treated while these bridging elements are in place and the first or all previous perforations and fractures are sealed or plugged at the well. Therefore, after the first set of perforations has been plugged, a differential pressure is maintained across the perforations with a higher pressure in the casing than outside so that the sealing or bridging elements plugging the perforations are held in position within the casing over the perforations. The pressure on the inside of the casing at the elevation of the perforations should be greater than the formation pressure in the lower producing formation so that there is no tendency for fluid to flow from that formation into the well and displace the bridging elements up the well or, in the case of the balls, off of the perforations. While this pressure is being maintained, or the perforations are otherwise sealed, casing perforator 18 is lowered into the well on wire line 21 to a position in which the charges 22 are at the elevation in the upper producing formation 12 at which the casing is to be perforated. The second set of perforations 37 is then made in the casing at the desired elevation. The perforator is withdrawn from the well into the casing above the casing inlet 19. The pump suction 24 is again con-

nected to the fracturing fluid supply and a second quantity of fracturing liquid **38** is injected into the well. It may form an interface or a short mixing zone **39** with the follower fluid **35** as it displaces that follower fluid into the upper producing formation **12**. The second quantity of fracturing liquid then enters the upper producing formation through the second set of perforations **37** and produces a second fracture **41** in the upper producing formation, as indicated in FIGURE 5. As in the case of the first fracture, the quantity of fracturing liquid injected into this second fracture and the rate of injection may also be varied over a wide range. The rate however is, as indicated previously, preferably correlated with the capacity of pump **23** to obtain maximum efficiency. After the second fracture **41** has been extended the desired distance into the upper producing formation **12**, the fracturing liquid remaining in the well may be displaced into that fracture by connecting the suction of pump **23** to the supply of follower fluid and injecting a second quantity **42** of this follower fluid into the well. These two fluids may also form an interface or short mixing zone **43** in the well which is displaced by the follower fluid down to the elevation of the second fracture and, if desired, some of the second quantity of follower fluid may be injected into the second fracture.

While the process has been described by reference to two producing formations and the creation of one fracture in each, it is apparent that the same procedure can be employed to form any number of fractures in any number of formations. Regardless of the number of fractures, when another fracture is to be formed, an important element is that the casing be perforated only over a narrow zone at the elevation where the next fracture is to be formed and that all fractures previously produced be plugged.

After the last fracture has been created, the pump **23**, the hopper **26**, and the pump discharge line **25** may be removed from the casing inlet **19** and this inlet may be plugged with a cap **44**, as indicated in FIGURE 6. In some cases, the well may be produced through the casing and the pump discharge line. Preferably, however, the casing inlet is capped and a string of tubing **45** is run into the well to a point at which the bottom end of the tubing **46** is at an elevation below the liquid level **47** in the well. This tubing string is hung in the casing on a tubing head **48**. Both the upper and lower producing formations **12** and **13**, respectively, and any other producing formations opening into the well, may then be produced through the tubing either by flowing, pumping, or the like as is well known in this art. After liquid from each of these producing formations commences to flow into the well, i.e., as the pressure differential across the perforations is reversed and the pressure in the formation becomes greater than the pressure in the well, the perforation sealers are displaced from the perforations and either carried up the well with the produced liquid or dropped to the bottom of the well. In the case of bridging materials which are soluble in the produced liquids, these materials are quickly dissolved as the liquid flows through the mouth of each fracture and thus removed so as not to restrict flow of fluid into the well.

As indicated above, perforation sealers or bridging elements for plugging previously produced flow channels in a well may take various forms. An alternative type of perforation sealer is shown in FIGURE 7. In this embodiment, the sealer comprises a packer having cup-type packer elements mounted on a mandrel **51**. Each of the elements is large enough in diameter to form a fluid seal with the casing. The lower cup-type packer element, sometimes referred to as a swab-cup, opens downward, i.e., is concave downward. An upper cup-type packer element **53** which is also connected to the mandrel is spaced from the lower packer element by a distance great enough to span a set of casing perforations, typically 2–3 feet or more. This upper packer element faces opposite to the bottom element, i.e., opens upwardly. The packer is initially placed in the upper end of the casing **10** and supported on a pin **28** or on the lower valve of a lubricator as is well known in the art. After the desired quantity of treating fluid is injected into the casing through the casing inlet **19**, pin **28** is removed and flow of the fluid is diverted through the bypass line and valve **54** so that the packer enters the casing below the inlet. After the packer passes the inlet it is carried with the fluid, which cannot pass the upper up-turned cup-type packer element **53**, down the well until the lower packer element **52** passes the last perforation. When it passes the last perforations, the packer is stopped in the well. The upper packer element **52** is then above the perforations so that the packer straddles the perforation and prevents fluid from entering.

This type packer may thus be used to seal a lower set or several lower sets of perforations while the casing is perforated and the formation behind those perforations is treated at an upper elevation. When all informations have been treated and the well is produced, all of the packers above the lowest producing formation are lifted by the well fluids and displaced to the top of the well. The bottom packer may be left in the well, it may be fished out of the well, or by placing a downwardly opening cup-type packer element **55** on an upper extension **56** to the mandrel **51**, the bottom packer may also be lifted out of the well by the well fluids.

From the foregoing it can be seen that, while reference has generally been made to the preferred type of apparatus, various types of apparatus can be employed in this process and, furthermore, that the process as described is susceptible of a wide variety of variations. This invention should therefore be construed not to be limited by the above description, but should be construed to be limited only by the scope of the appended claims.

I claim:

1. A process for treating a first formation in a cased well having casing perforations opposite another formation comprising the steps of injecting into said well a fluid containing sufficient substantially impermeable perforation bridging elements to plug all previously produced perforations, displacing said first fluid through said previously produced perforations into said another formation until flow through said previously produced perforations has been stopped by said bridging element and maintaining said previously produced perforations in a plugged condition by holding a pressure in said well greater than the formation pressure, producing a multiplicity of perforations in said casing opposite said first formation, said multiplicity of perforations being grouped sufficiently to be in fluid communication with one another behind said casing, and then injecting a treating fluid into said first formation under sufficient pressure to produce a fracture therein.

2. A process for treating a first formation and a second formation penetrated by a cased well comprising producing a first set of perforations in the casing opposite said first formation, said first set of perforations being grouped sufficiently to be in fluid communication behind said casing, injecting a quantity of a treating fluid into said well and thence into said first formation through said first set of perforations, disposing sufficient substantially impermeable bridging plugs in a liquid to seal all of said first set of perforations, displacing said liquid and said bridging plugs down said well and into said first formation to cause said bridging plugs to seal all of said first set of perforations, forming a second set of perforations in said casing opposite said second producing formation while maintaining a pressure in said casing opposite said first formation at least as great as the pressure within said first formation, said second set of perforations being grouped sufficiently to be in fluid communication with one another behind said casing, inject-

ing a quantity of a treating fluid into said well and thence into said second formation through said second set of perforations, and producing said well to remove said bridging plugs from said first set of perforations and to remove fluid from said first formation and said second formation.

3. A process for producing a multiplicity of fractures in the formations penetrated by a cased well comprising producing a first set of perforations in the casing opposite a first producing formation by perforating said casing a multiplicity of times within a vertical distance sufficiently short so that said perforations are in fluid communication behind said casing, injecting a quantity of fracturing liquid into said first producing formation through said first set of perforations at sufficient rate to fracture said first producing formation, disposing substantially impermeable perforation bridging plugs larger than any of said perforations in a fluid, the number of bridging plugs being greater than the number of said perforations in said first set of perforations, displacing said fluid and said bridging plugs down said well and into said first set of perforations to plug said first set of perforations, producing a second set of perforations in said casing opposite a second producing formation by perforating said casing a multiplicity of times within a vertical distance sufficiently short so that said perforations are in fluid communication with one another behind said casing, injecting a quantity of fracturing liquid into said well and displacing said quantity of fracturing liquid into said second producing formation through said second set of perforations at sufficient rate to fracture said second producing formation, maintaining a fluid pressure in said well opposite said first producing formation greater than the pressure in said first producing formation after said first set of perforations is plugged and until after at least part of said quantity of fracturing liquid is displaced into said second formation to hold said bridging plugs in position and plug said first set of perforations while said second formation is fractured, and then producing said well to unplug said first set of perforations.

4. A method of increasing the productivity of a multiplicity of producing formations penetrated by a cased well comprising producing a first set of perforations in the well casing opposite a first producing formation, said first set of perforations being grouped vertically sufficiently to be in fluid communication behind said casing, the



injecting a quantity of fracturing liquid into said first formation through said well and said first set of perforations at a rate sufficient to form a fracture in said first formation, disposing a multiplicity of substantially impermeable perforation sealers larger than said perforations in a quantity of fluid, the number of said perforation sealers being greater than the number of perforations in said first set of perforations, displacing said quantity of fluid down said well and into said first formation through said first set of perforations to deposit the entrained perforation sealers on the inner ends of the perforations in said first set of perforations and plug said first set of perforations, forming a second set of perforations in said casing opposite a second producing formation while maintaining a pressure in said casing at the elevation of said first set of perforations greater than the external pressure on said casing to hold said perforation sealers on the inner ends of said perforations in said first set of perforations, said second set of perforations being grouped vertically sufficiently to be in fluid communication behind said casing, injecting a quantity of fracturing liquid into said second formation through said well and said second set of perforations at a rate sufficient to form a fracture in said second formation, and then reducing the pressure in said casing and producing said well to cause fluid in said first formation to displace said perforation sealers from the inner end of said perforations in said first set of perforations and to cause fluid in said first formation and in said second formation to flow into said well through said fractures in said first and second formations.

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# CERTIFICATE OF CORRECTION

Patent No. 3,028,914 April 10, 1962

Don H. Flickinger

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 21, for "groups" read -- grouped --; line 65, for "of" read -- with --; column 6, line 20, for "informations" read -- formations --; line 47, for "element" read -- elements --; column 7, line 46, strike out "the".

Signed and sealed this 7th day of August 1962.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents