

[54] **FRACTURING TO INTERCONNECT WELLS**

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[58] Field of Search.....166/271, 308, 252, 256, 254, 166/298, 259, 245

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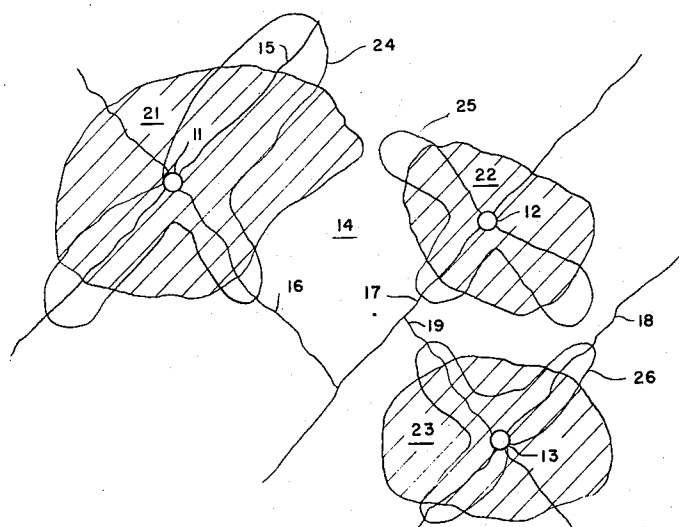
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[57] **ABSTRACT**

Wells in a substantially impermeable subterranean earth formation that tends to fracture along non-intersecting vertical planes of natural weakness are interconnected by initially fracturing at least one of the well boreholes along its vertical plane of natural weakness, filling the fracture with a granular material, and refracturing the well borehole by pumping in a viscous fluid at a rate causing the pressure to rise above the pressure at which the first fracture was formed. The last-mentioned fracture is extended into communication with an adjacent well or a fracture extending from the adjacent well.

12 Claims, 4 Drawing Figures



SHEET 1 OF 2

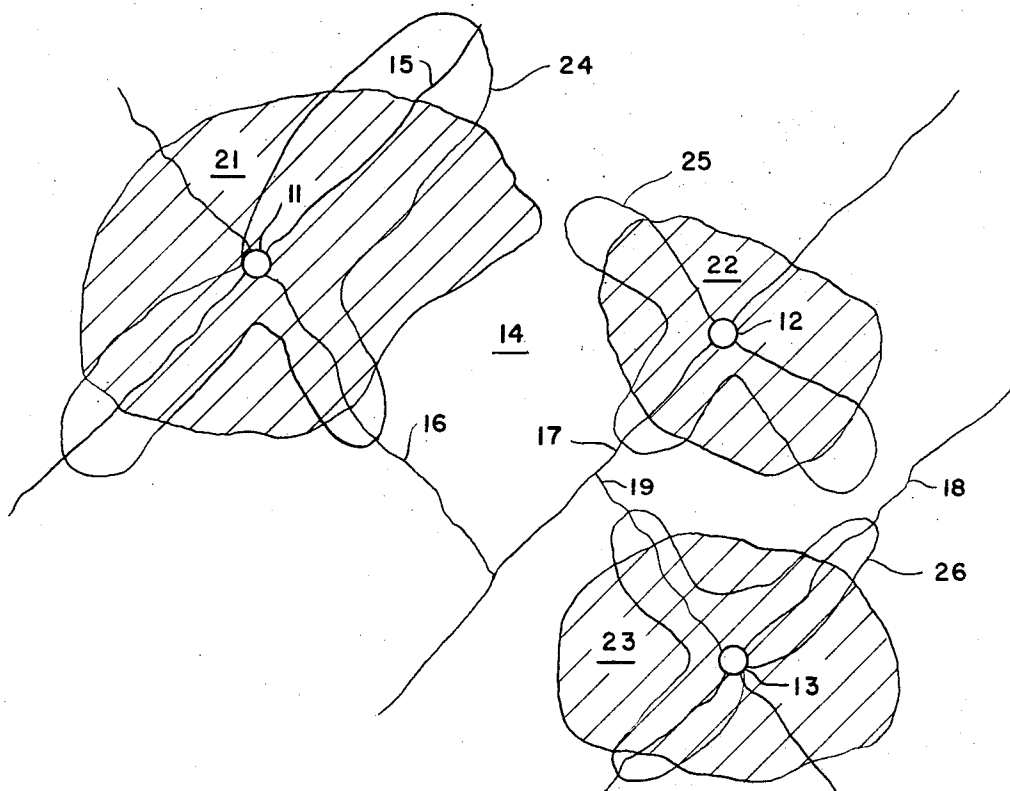


FIG. 1

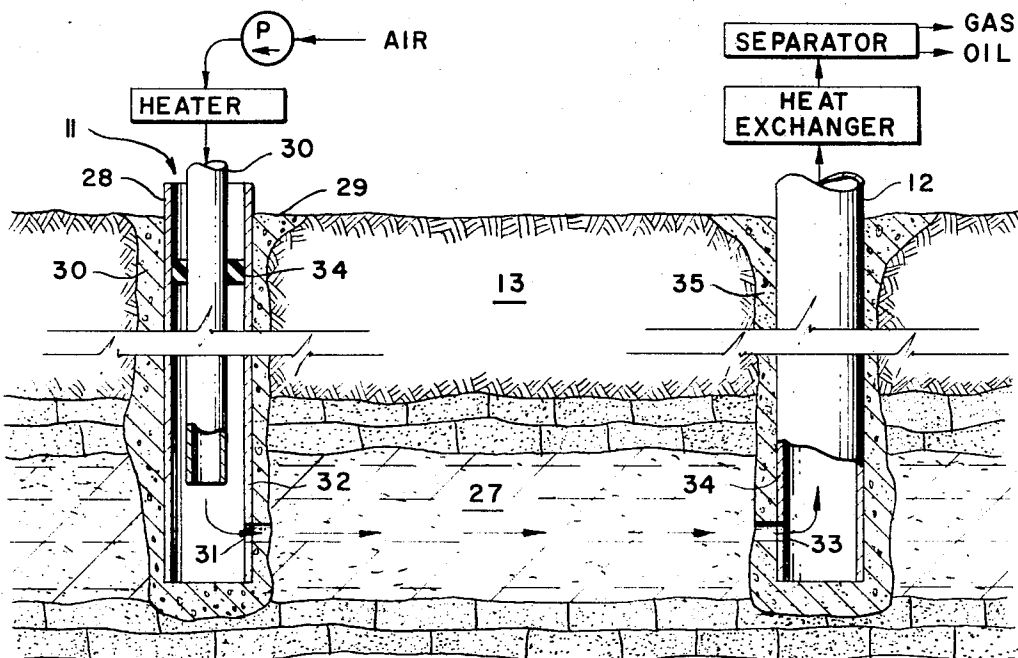


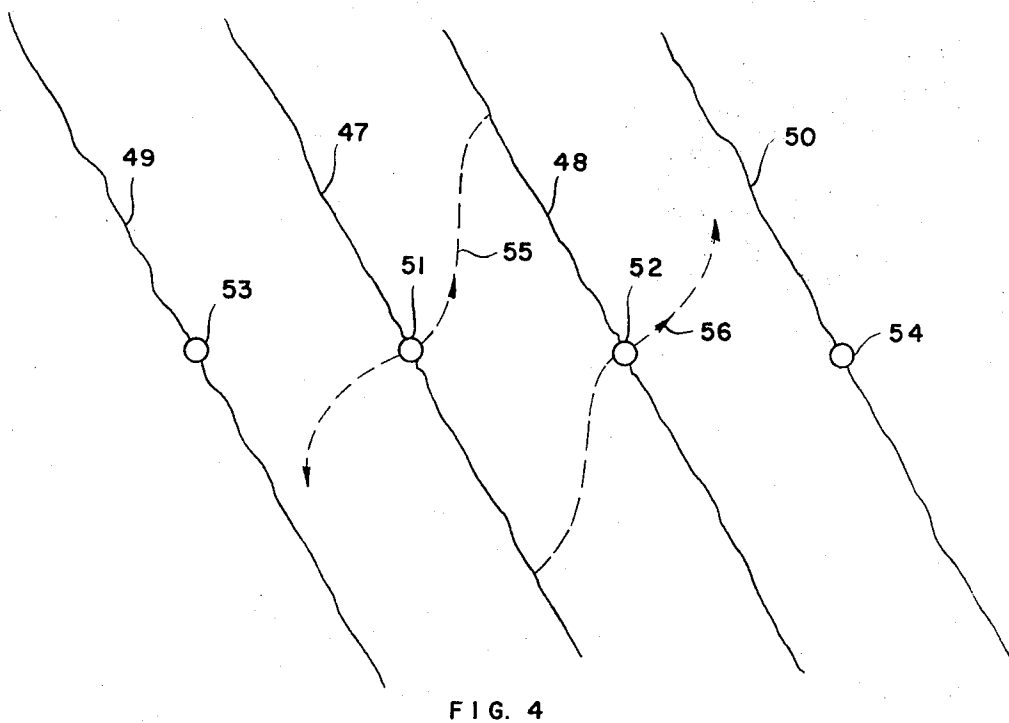
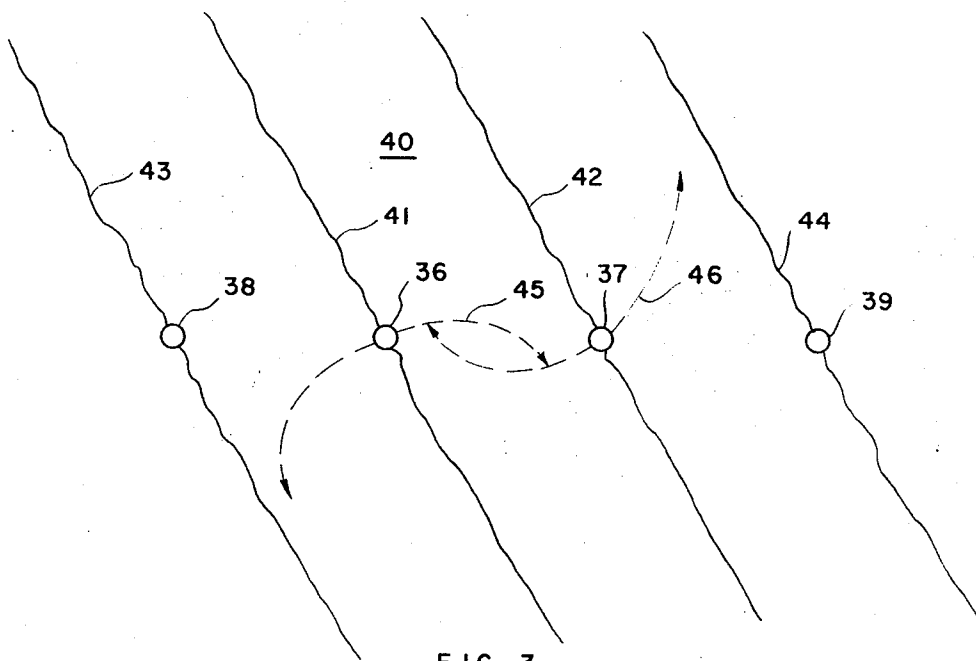
FIG. 2

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FRACTURING TO INTERCONNECT WELLS**CROSS-REFERENCE TO RELATED PATENT APPLICATION**

This application is a continuation-in-part of patent application, Ser. No. 850,712, filed Aug. 18, 1969, now abandoned.

BACKGROUND OF THE INVENTION**1. Field of the Invention**

This invention relates to the method of interconnecting a pair of well boreholes; and, more particularly, interconnecting well boreholes by means of fractures that extend through a substantially impermeable subterranean earth formation.

2. Description of the Prior Art

It is known that it is extremely difficult to recover liquifiable components from deposits of various substantially impermeable subterranean formations such as oil shale, coal, coral beds, deposits of cinnabar, etc. under conditions in which the deposits are normally present in these formations. Various proposals have been made, such as described in a U.S. Pat. No. 3,284,281, to recover oil from oil shale. Therein shale oil is produced from an oil shale formation through fractures interconnecting wells. It has been well established that at depths greater than, say, a few hundred feet, most subterranean earth formations will fracture vertically upon the application of sufficient fluid pressure to a well borehole extending into such formations. It is not easy, however, to generate vertical fractures that communicate between adjoining well boreholes in the same subterranean earth formation.

In a U.S. Pat. No. 3,431,977 to East et al., a vertical fracture is extended in a selected direction within a subterranean earth formation by notching the formation communicating with a well borehole extending into the earth formation, vertically fracturing the formation, sealing the fracture with cement or finely divided solid particles that form an impermeable solid mass, and then renotching and refracturing the formation along the selected direction. The renotching and refracturing steps are proposed as an improvement to a series of certain prior art methods for notching to guide the initiation of a fracture and extending the fracture along a selected direction. Such retreatment is proposed in order to overcome the tendency of fractures to form along a natural plane of weakness and force a fracture to extend along a selected direction. This prior art method and similar prior art methods seek to accomplish the necessary adjusting of the compressive stresses in the earth formations surrounding a well borehole by forming both notches and impermeable plugs in the earth formation in the immediate vicinity of the well borehole.

SUMMARY OF THE INVENTION

It is an object of this invention to provide an improved method for interconnecting wells extending into a substantially impermeable subterranean earth formation wherein fractures formed in the formation tend to form along non-intersecting vertical planes of natural weakness.

It is a further object of this invention to provide an improved method for establishing well-interconnecting flow paths through fractures formed in a substantially impermeable subterranean earth formation.

These and other objects are preferably accomplished by initially fracturing along its natural vertical plane of weakness at least one well borehole extending into a substantially impermeable subterranean earth formation wherein fractures formed therein tend to form along non-intersecting planes of natural weakness, filling the fracture with granular material, and refracturing the well borehole by pumping therein a viscous fluid at a rate causing the pressure to rise above the pressure at which the first fracture was formed. If the last-mentioned fracture is horizontal, it is extended into communication with an adjacent well borehole. If it is vertical, an adjacent well borehole is fractured along its natural vertical plane of weakness and this fracture and the second-mentioned fracture are extended until they intersect thus providing communication between the well boreholes.

Thus, the method of my invention compressively stresses the earth formations at a significant distance from the well borehole as opposed to prior art methods. It is particularly applicable to the formation of a well-interconnecting path of fluid communication within a subterranean earth formation that is normally substantially impermeable, such as a subterranean oil shale formation. My method utilizes the fact that, in such a formation, substantially none of the fluid which enters the fracture is lost by leakage through the walls of the fracture. Within a fracture that has been conditioned by filling it with a permeable mass of solid granules, the resistance to flow through the interstices between the granules provides a means for producing a high compressive stress in regions many feet away from the borehole of a well. This extensively distributed pressurization is then increased until a new fracture is formed throughout this relatively extensive region of applied compressive stress. The new fracture is initially formed along the borehole, where the fluid pressure is highest, and is extended throughout the stressed region along a plane that may be either vertical or horizontal but is generally perpendicular to the plane of natural weakness within the earth formations. If the reformed fracture (which is generally perpendicular to the natural plane of weakness) is horizontal, its extension is likely to provide a flow path to an adjacent well borehole. Alternatively, if it is vertical, its extension is likely to provide an interconnection with a fracture (along the natural plane of weakness) that is formed within an adjacent well borehole. If the well interconnection is not provided by the conditioning and refracturing within one well borehole, nor by fracturing an adjacent well borehole along the natural plane of weakness, the conditioning and refracturing are repeated, preferably in the initially refractured well borehole, until well-interconnecting flow paths are formed.

In a normally impermeable earth formation, the well-interconnecting flow paths formed by the method of my invention are unobviously advantageous. The fracture, which was conditioned by filling it with a permeable mass of granules through which a viscous liquid was injected at a high rate in order to induce the refracturing, provides an alternately directed flow path through

which fluid can be injected into the earth formation, at the option of the well operator. For example, by throttling the outflow through the well boreholes, a less viscous fluid may be injected to displace the viscous fluid through the mass and into a further extension of the fracture. Alternatively, the composition of the viscous fluid used in the refracturing step may be one having a time-breaking, temperature-breaking, or chemically breakable viscosity. Alternatively, the granules with which the fracture is packed may comprise selectively soluble particles such as carbonates, metals, etc., which may be dissolved in order to increase the permeability of the porous mass within the fractures.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a top plan view of a preferred arrangement of well boreholes extending into a subterranean earth formation;

FIG. 2 is a vertical sectional view of two of the well boreholes of FIG. 1; and

FIGS. 3 and 4 are plan views similar to that of FIG. 1 showing further applications of the teaching of my invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawing, FIG. 1 shows a plurality of well boreholes 11 through 13 extending into an earth formation 14 overlying a normally impermeable subterranean earth formation such as an oil shale formation (Not shown). The underlying oil shale formation is one in which fractures formed therein tend to form along non-intersecting vertical planes of natural weakness.

Thus, a generally vertical fracture 15 is first formed along a substantially vertical plane by initially fracturing well borehole 11 along its plane of natural weakness thus forming vertical fracture 15. Such a fracture may be formed by any technique for applying a fluid pressure above the breakdown pressure of earth formation 14 but below the overburden pressure of earth formation 14. Of course, although three such well boreholes 11 through 13 are illustrated in FIG. 1, obviously a plurality of such well boreholes may be opened into the selected earth formation and treated simultaneously or sequentially, in any order.

Thus, in a preferred procedure for interconnecting well boreholes 11 through 13, vertical fracture 15 is extended from well borehole 11 for a significant distance along a natural vertical plane of weakness within the subterranean earth formation. Conventional subterranean stress analysis techniques and/or techniques for measuring the orientation of fractures may be utilized to determine the direction along which the fracture 15 is extended. Vertical fracture 15 is then propped open by pumping therein a relatively fine granular material, such as sand particles, at a pressure sufficient to fill fracture 15 over a considerable distance, as for example, at least 100 feet.

The earth formations at a significant distance from well borehole 11 are compressively stressed by pumping a relatively viscous fracturing fluid, such as a viscous oil or a chemical polymer solution, into well borehole 11 and through the permeable mass of granu-

lar material in fracture 15. The viscous fluid inflow rate is then increased until the injection pressure exceeds the pressure at which the first fracture 15 was formed and a new fracture 16 is formed along a direction generally vertical and substantially perpendicular to that of fracture 15, probably close to 90° to fracture 15. The viscous fluid may be pumped into the second fracture 16 in order to extend it a considerable distance in the subterranean earth formation.

If the second formed fracture 16 is horizontally extending, it may be extended into communication with well borehole 12 by continuing the injection of viscous fluid until communication is established between the horizontally extending fracture 11 and well borehole 12. However, if the fracture 16 is vertically extending, such as illustrated in FIG. 1, communication may be established between well boreholes 11 and 12 by fracturing well borehole 12 along its natural plane of weakness thus forming vertical fracture 17 which is generally parallel to fracture 15. The fracture 17 is then extended, such as by injecting a viscous fluid therein, until fractures 16 and 17 intersect as illustrated in FIG. 1.

In like manner, inter-communication may be provided between well boreholes 12 and 13 by fracturing well borehole 13 along its natural plane of weakness thus forming vertical fracture 18, and subsequently filling fracture 19 in the manner discussed hereinabove with respect to well borehole 11.

The method described hereinabove may be repeated at other well boreholes extending into the subterranean earth formation. By this method, all the fractures so formed eventually intersect at some point in the earth formation, thus providing intercommunication between all the well boreholes. It is not necessary to notch the earth formations surrounding the well boreholes, either vertically or horizontally. Since it is desired to establish multiple paths of fluid communication through the formation, it is not desirable to seal the fractures. It is simpler, and generally more economical, than any permanent sealing method to inject therein a coarse sand, as for example, coarser than about 150 mesh, and allow this sand to fill the initial fracture 15. A very viscous liquid (e.g., more than about 100 centipoises) then develops sufficient pressure drop in the first fracture 15 to enable generation of the second vertical fracture 16. Both fractures 15 and 16 are then permeable. In a consolidated material, such as oil shale, the fractures once formed tend to remain open. Other propping materials which may be used are granular limestone or marble chips, or aluminum filings. These materials, after being injected into the first fracture 15, may then be dissolved by acid, to increase their permeability, subsequent to forming the second and any later fractures, thus establishing a good path of communication. By conducting these steps at other well boreholes, it is possible to establish interwell communication.

The fluid used to form the initial fractures 15, 17 and 18 at each of well boreholes 11 through 13 may be hot or unheated water or any gas and/or liquid that is heated, if desired, at the surface of earth formation 14, in the respective well boreholes and/or in situ, e.g., by underground combustion, in the subterranean earth formation.

Once inter-well communication has been established, a reacting fluid may be flowed there-through. The composition of the reaction fluid is preferably adjusted to the extent required to circulate fluid that removes solid materials from the walls of the interconnecting fractures without a significant reduction in the average rate of flow between well boreholes 11 through 13, so that the effective permeability of the interconnecting fractures, as for example fractures 16 and 17, is increased relative to fluid flowing between well boreholes 11 and 12. Solid-material-removing components may be incorporated into the reacting fluid being circulated through the interconnecting fractures without interrupting the flow to an extent that permits the fractures to close and reseal. In treating a subterranean oil shale formation, such components may comprise hot benzene, steam, or other solvent, or nitric acid, of a lower temperature than the hot fracturing fluid. Nitric acid has the advantage of reacting with the organic matter as well as the carbonate present in the subterranean earth formation. The injection of such a reacting fluid leaches out part of the kerogen adjoining the faces of the interconnecting fractures. The injection at a lower temperature and at substantially the same injection pressure permits the fractures to open slightly for better passage of the fluids. The temperature of the solid-material-removing fluid may be increased as the permeability of the interconnecting fractures, fractures 16 and 17, for example, is increased until the circulating fluid becomes hot enough to liquefy the liquefiable components of the subterranean earth formation.

Following or during the hot solvent injection as discussed hereinabove, acid may be injected to react with part of the rock matrix along the fracture walls. This acid injection renders the channels even more permeable.

After all the steps discussed hereinabove are carried out, an underground combustion process, as is well known in the art, which develops considerably higher temperatures, may be undertaken. The steps of leaching out part of the kerogen and the rock generally make closure of the fracture paths during combustion very unlikely. In this manner, it is possible to treat a substantial part of the formation by underground combustion.

Thus, as illustrated in FIG. 1, uniform temperature zones 21 through 23 may be seen surrounding well boreholes 11 through 13, respectively. Also, advancing combustion fronts 24 through 26, initiated and alternately advanced, for example, by means well known in the art, may be formed about well boreholes 11 through 13, respectively.

FIG. 2 shows permeable channel 27 formed in the subterranean earth formation of FIG. 1 by the foregoing method of this invention. Only two of the well boreholes of FIG. 1 are shown in FIG. 2 for convenience of illustration. Injection well borehole 11 is preferably equipped with casing 28 cemented therein and sealed with cement, as at cementing 29. A tubing string 30 is disposed in well borehole 11 and packed off at packer 34. Conventional heating, pumping, heat exchanging and separating equipment are associated with well boreholes 11 and 12 for injecting fluid from well borehole 11 through perforations 31 in well

borehole 11, through the permeable channel 27 created by intersecting fractures, such as 16 and 17, into well borehole 12 through perforations 33 therein. Well borehole 12 is preferably cased with casing 34 surrounded by cement 35. Since certain subterranean earth formations, such as oil and shale deposits in Colorado, Utah, and Wyoming, are practically impermeable except for certain natural vertical fractures, the method of this invention improves injectivity and fluid communication between two or more wells from a succession of vertical fractures.

Referring now to FIG. 3, the techniques of my invention may be used to provide fluid communication between substantially parallel fractures. Thus, well boreholes 36 through 39, extending into an earth formation 40 overlying a subterranean earth formation, are fractured initially, by conventional fracturing techniques, thereby forming fractures 41 through 44, respectively. The fractures 41 through 44 will most likely be substantially vertical and will be oriented along the natural plane of weakness of the formation 40, as indicated. A coarse propping agent is now pumped into all fractures 41 through 44, and a viscous liquid is injected into them. The pressure in well boreholes 38 and 39 is limited to approximately the initial fracturing pressure. The pressure in well boreholes 36 and 37 is raised until well boreholes 36 and 37 again fracture. Due to the presence of the stress field set up in formation 40 due to pressure from the parallel fractures 41 through 44, the second set of fractures 45 and 46, at well boreholes 36 and 37 respectively, tends to be substantially perpendicular to the first set at the respective fracturing well boreholes. As liquid is injected into well boreholes 36 and 37 at this higher fracturing pressure, the fractures from these well boreholes tend to seek the regions of higher stress near the respective opposite well boreholes, i.e., the fracture from well borehole 36 tends toward well borehole 37, and similarly for the fracture from well borehole 37. As these approach each other, as indicated by the dotted lines in FIG. 3, the stressed regions near the growing fractures will tend to orient these fractures to connect with each other. If necessary to maintain the injection pressure at sufficient levels, this second set of fractures 45 and 46 may also be propped open. Any fractures which propagate from well boreholes 36 and 37 towards the fractures from well boreholes 38 and 39 eventually reach the latter fractures if the well borehole spacing is not too large (e.g., 50-100 feet). This procedure may be repeated at well boreholes 38 and 39 and any other adjacent well boreholes (not shown).

Rather than propagate into regions of comparatively high stress as illustrated in FIG. 3, the fractures may tend towards the adjoining original fracture system, possibly tending toward alignment parallel to this latter set until they are close to it. Thus, as illustrated in FIG. 4, initial fractures 47 through 50 are formed at well boreholes 51 through 54, respectively, in the manner discussed hereinabove. Then the second set of fractures are formed, that is, fractures 55 and 56 at well boreholes 51 and 52, respectively, they tend towards the initial fractures (i.e., fracture 55 tends toward initial fractures 48 and 49 and fracture 56 tends toward fractures 47 and 50). Thus, the formation of interconnecting flow paths is created between adjoining frac-

tures when fractures 55 and 56 are extended as indicated by the dotted lines in FIG. 4. This type of well intercommunication becomes feasible when the initially formed fractures, as for example, fractures 47 through 50, are close enough to each other. In the well arrangements of both FIGS. 3 and 4, production of fluids may be obtained in the manner discussed hereinabove with respect to the well arrangement of FIGS. 1 and 2.

What is claimed is:

1. A method for interconnecting at least a pair of well boreholes extending into a substantially impermeable subterranean earth formation wherein fractures formed therein tend to form along non-intersecting planes of natural weakness, said method comprising the steps of:

initially fracturing the formation adjacent at least one of said well boreholes along its plane of natural weakness;

filling the fracture formed along the plane of natural weakness of said formation with a permeable mass of a relatively fine granular material;

refracturing said formation adjacent said first well borehole by pumping through said well borehole and into said first-mentioned fracture a viscous fluid at a rate sufficient to cause the pressure in said well borehole and in at least some of said first-mentioned fracture to rise above the pressure at which said first-mentioned fracture was formed whereby a second fracture is formed along a plane which intersects said plane of natural weakness; said viscous fluid having a viscosity such that the pressure in said first-mentioned fracture adjacent said well borehole as said viscous fluid flows at said rate through said permeable mass of granular material in said first-mentioned fracture is sufficient to provide a region of high compressive stress adjacent said well borehole; and
providing communication with at least a second well borehole between said latter-mentioned fracture and said second well borehole.

2. The method of claim 1 wherein the step of providing communication with at least a second well borehole includes the step of extending said latter-mentioned fracture into communication with said second well borehole.

3. The method of claim 1 wherein the step of providing communication with at least a second well borehole includes the steps of:

fracturing the formation adjacent said second well borehole along its natural plane of weakness; and
extending the last two mentioned fractures until communication is provided between said well boreholes.

4. The method of claim 3 wherein the step of extending said last two fractures includes the step of extending said fractures by pumping a fluid therein.

5. The method of claim 3 including the step of flowing through said fractures interconnecting said well boreholes a fluid adapted to remove solid materials from the walls of said fractures interconnecting said well boreholes.

6. The method of claim 5 including the step of injecting an acid adapted to react with the solid material forming the walls of said fractures through said fractures after flowing said fluid therethrough.

7. The method of claim 5 including the step of recovering from the fluid being flowed through said well borehole interconnecting fractures, at least some of the components of solid materials removed from the wells of said fractures by said fluid.

8. The method of claim 1 wherein the step of filling said fracture with granular material includes the step of filling said fracture with dissolvable granular material over a distance of about one hundred feet from said first-mentioned well borehole.

9. The method of claim 1 including the step of pumping fluid into said last-mentioned fracture thereby extending said last-mentioned fracture within said subterranean earth formation.

10. The method of claim 1 wherein the step of initially fracturing at least one of the formation adjacent said well boreholes includes the step of injecting a heated fluid through said earth formation at a pressure above the breakdown pressure of said subterranean earth formation but below the overburden pressure thereof until a substantially vertical fracture is formed therein.

11. A method for interconnecting a plurality of well boreholes extending into a substantially impermeable subterranean earth formation wherein fractures formed therein tend to form along non-intersecting planes of natural weakness, said method comprising the steps of:

initially fracturing the formation adjacent said well boreholes along planes of natural weakness to form non-intersecting fractures;

filling the fracture formed along the plane of natural weakness in said formation adjacent at least a first of said well boreholes with a permeable mass of a relatively fine granular material;

refracturing the formation adjacent said first well borehole by pumping through said first well borehole and into said granular material filled fracture a viscous fluid at a rate sufficient to cause the pressure in said well borehole and in at least some of said first-mentioned fracture to rise above the pressure at which said first-mentioned fracture was formed, whereby a second fracture is formed in said formation adjacent said first well along a plane which intersects said plane of natural weakness; said viscous fluid having a viscosity such that the pressure drop as said viscous fluid flows at said rate through said permeable mass of granular material in said first-mentioned fracture is sufficient to provide a region of high compressive stress adjacent said first well borehole;

providing communication between said first well borehole and at least a second well borehole of said plurality of well boreholes through said second fracture.

12. The method of claim 11 wherein communication between said first well borehole and at least a second well borehole is provided by:

filling the fracture formed along the plane of natural weakness in said formation adjacent said second well borehole with a permeable mass of a relatively fine granular material;

refracturing the formation adjacent this second well borehole by pumping into said granular material filled fracture in the formation adjacent said second well borehole said viscous fluid at a rate sufficient to cause the pressure to rise above the

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pressure at which said granular material filled fracture was formed, whereby a second fracture is formed in the formation adjacent said second well borehole along a plane which intersects said plane of natural weakness; and
extending the fractures formed in the formation ad-

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jacent said first and second well boreholes in planes which intersect said plane of natural weakness until said extended fractures intersect and thereby provide communication between said first and second well boreholes.

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