166-308 CROSS REFERENCE SEARCH

Dec. 21, 1965 J. L. HUITT ETAL 3,224,506

SUBSURFACE FORMATION FRACTURING METHOD

Filed Feb. 18, 1963 5 Sheets-Sheet 1

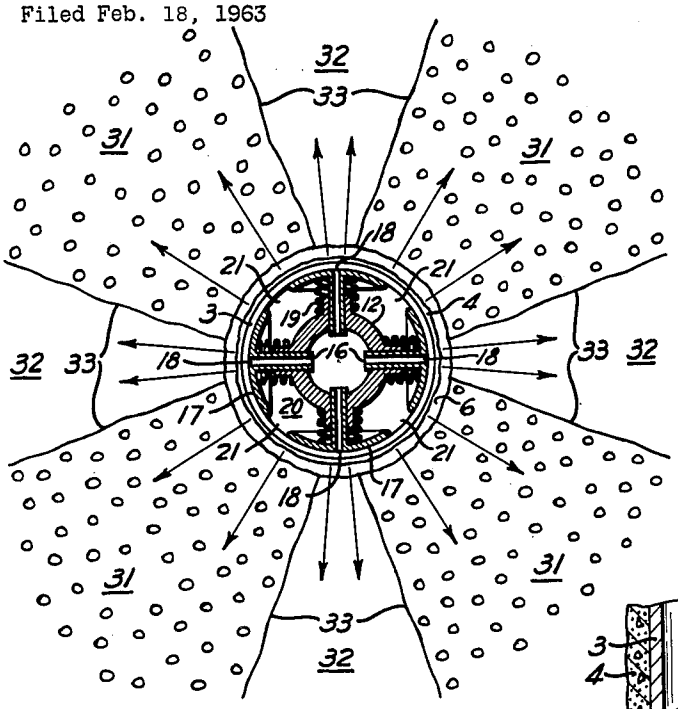


Fig. 1

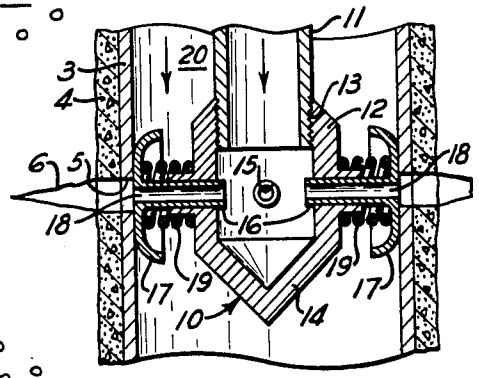


Fig. 2

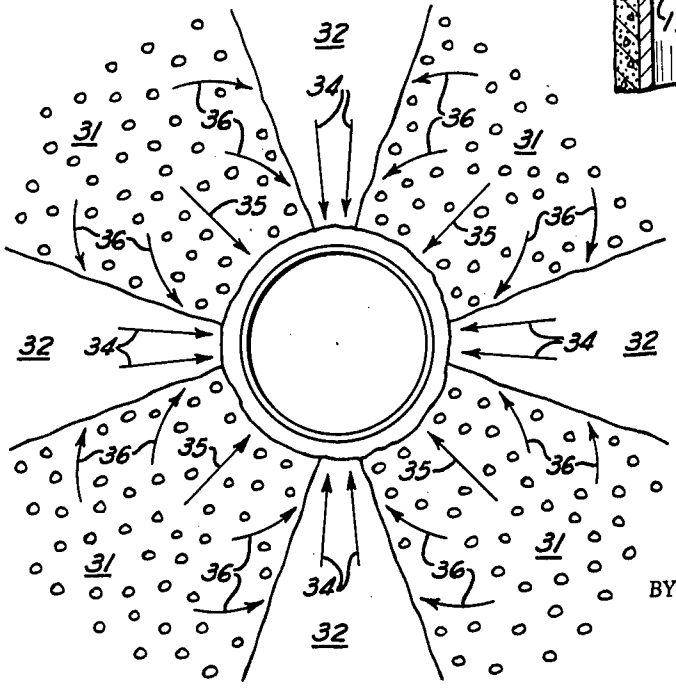


Fig. 3

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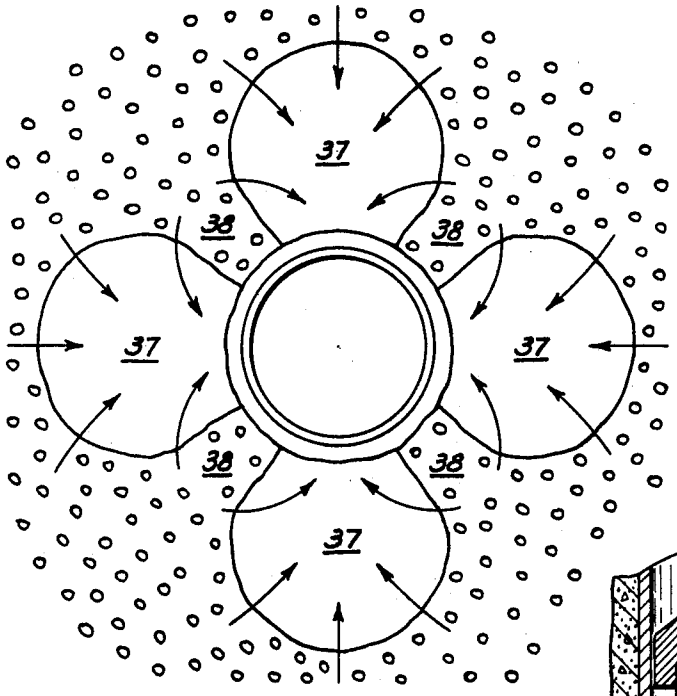


Fig. 4

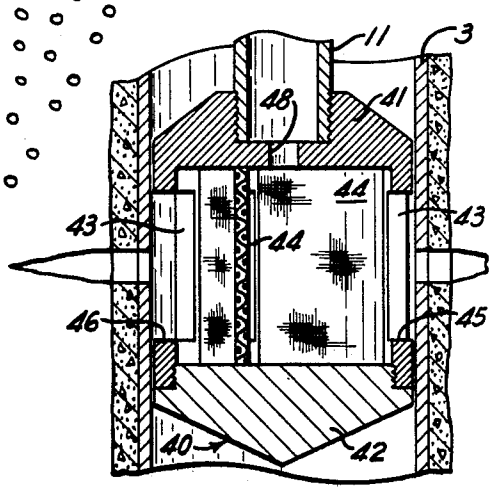


Fig. 6

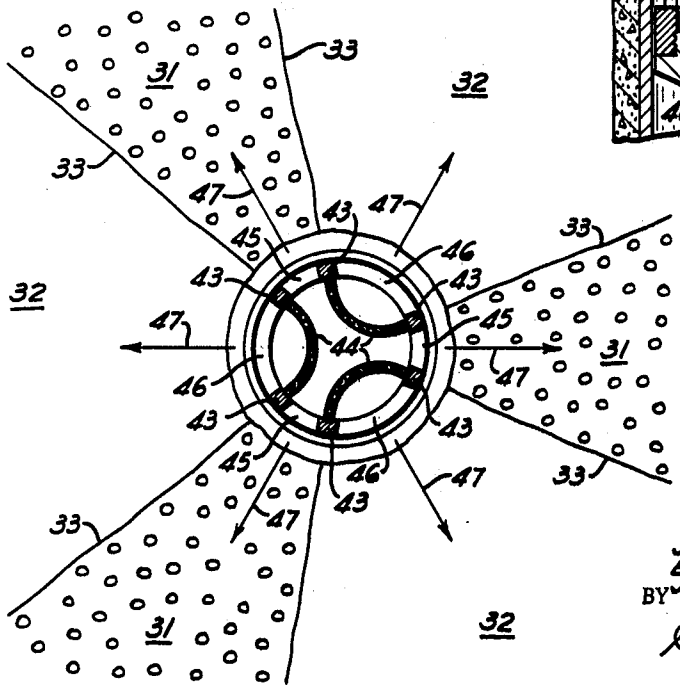


Fig. 5

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SUBSURFACE FORMATION FRACTURING METHOD

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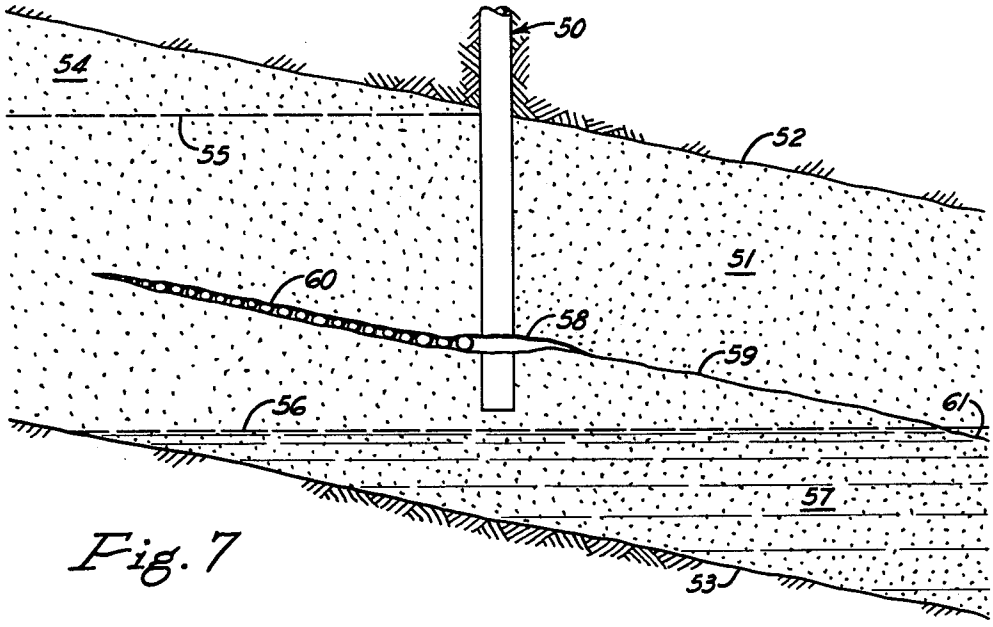


Fig. 7

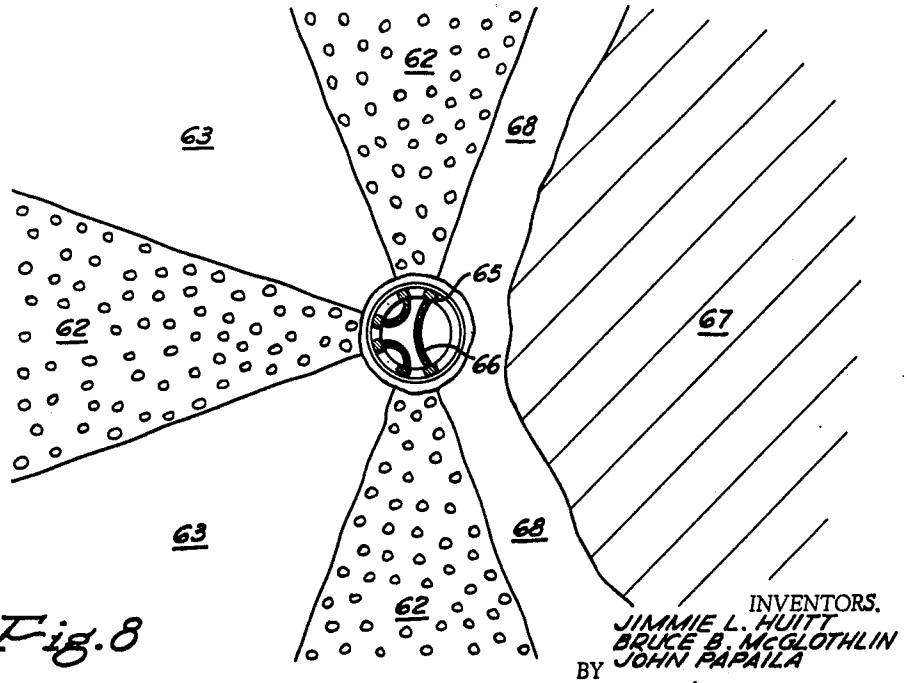


Fig. 8

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SUBSURFACE FORMATION FRACTURING METHOD

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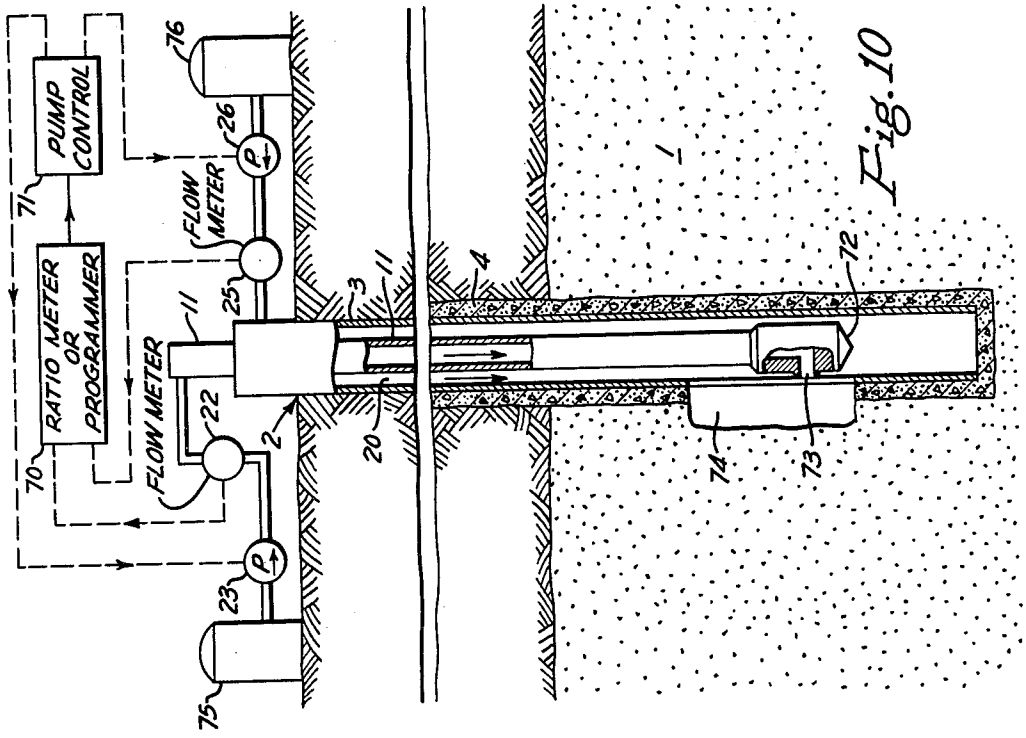


Fig. 10

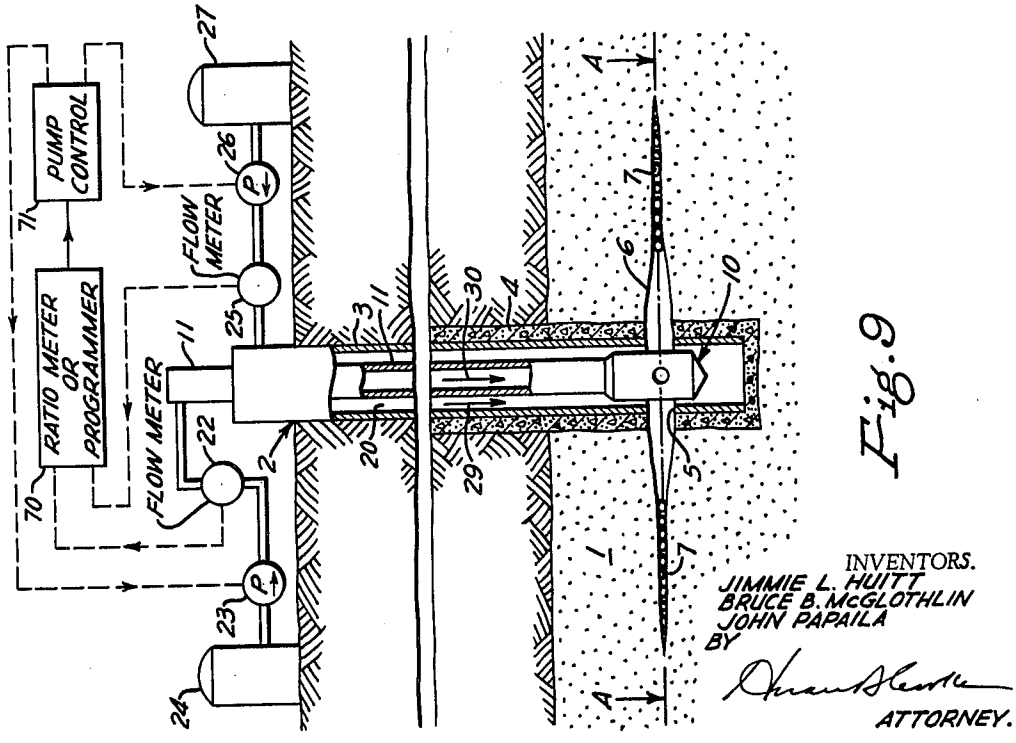


Fig. 9

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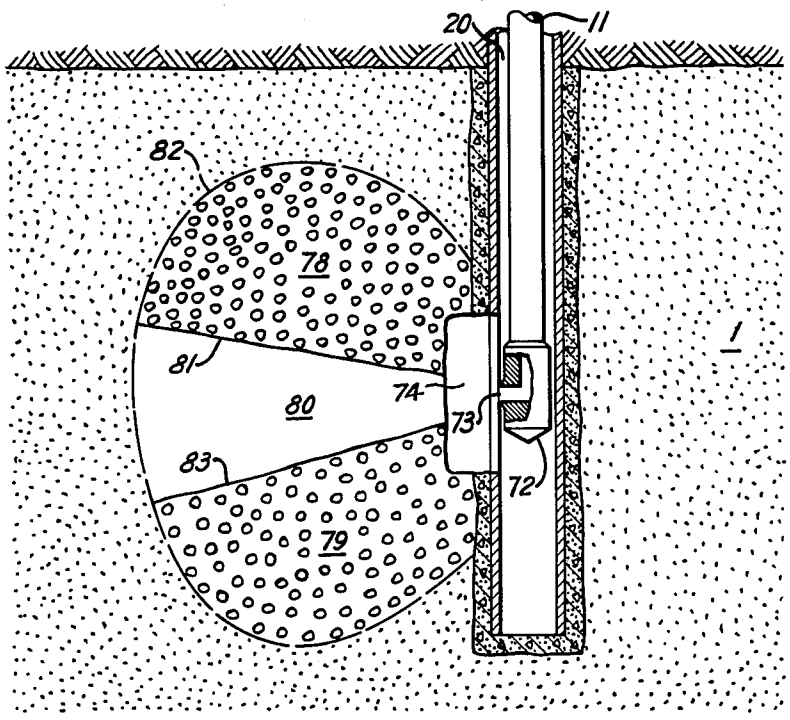


Fig. 11

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3,224,506

SUBSURFACE FORMATION FRACTURING METHOD

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6 Claims. (Cl. 166—42)

This invention relates to the art of hydraulic fracturing of a subterranean rock formation penetrated by a borehole and in particular relates to a method for creating an underground fracture having unusually high permeability so as to permit easy access of formation fluids to the borehole.

In the production of petroleum from underground petroliferous formations one of the problems encountered is that liquid petroleum contained in a reservoir rock of low permeability does not readily flow into a well bore that penetrates the reservoir rock. Various expedients have been tried in an attempt to increase the rate of petroleum recovery from such rocks but all are expensive and they are only partially successful. One of the most widely used techniques is the new well-known practice of hydraulically fracturing the petroleum-bearing formation in the vicinity of the well bore by the application of substantial hydraulic pressure to the formation. When sufficient hydraulic pressure is applied to the formation through the borehole, the rock will fracture, and by pumping the pressurizing fluid into the fracture at a rate exceeding the leakage rate the fracture can be extended to substantial distances from the well bore. In such a hydraulic fracturing operation it is customary to employ a high-viscosity low fluid-loss fracturing fluid and to pump at high rates in order to produce a fracture of substantial radius which will therefore subsequently drain a large region of the formation. Furthermore, it is customary to add a particulate propping agent to the fracturing fluid for the purpose of introducing propping particles into the fracture. The propping particles serve to hold the fracture open and prevent reclosing of the fracture when the hydraulic fracturing pressure is subsequently removed. Various materials are employed as propping agents, as for example walnut shells, sand, and the like. However, a phenomenon called "sanding out" often takes place in which the sand or other propping agent apparently packs tightly in the fracture and the fracture does not form an effective drainage channel from the formation to the well bore. While the exact nature of the "sanding out" is not completely understood, it is known that when it takes place, the flow capacity is decreased and hence the increase in well productivity is much smaller than what would have been obtained had the "sanding out" not occurred. Thus, with no propping agent or with the "sanding out," the fracture flow capacity is not sufficient to obtain the desired increase in well productivity. By employing this invention the above-described difficulties are avoided.

It is accordingly an object of this invention to provide a hydraulic fracturing method that results in a fracture of high flow capacity.

It is another object of this invention to provide a method of fracturing that avoids the deleterious effects that accompany the use of heretofore known fracturing methods.

It is another object of this invention to provide a method by means of which an improved fracturing operation may be carried out.

The method of this invention is described in the following specification of which the drawings form a part, and in which

FIGURE 1 is a diagrammatic horizontal section of the formation taken at a fracture and illustrates one form of apparatus that may be employed in carrying out this invention;

FIGURE 2 is a longitudinal section of the apparatus of FIGURE 1;

FIGURE 3 is a diagrammatic horizontal section taken at a fracture produced by an embodiment of this invention and illustrates the resulting flow of produced oil;

FIGURE 4 is a diagrammatic horizontal section taken at a fracture produced by another embodiment of this invention and illustrates the resulting flow of produced oil;

FIGURE 5 is a diagrammatic horizontal section of another embodiment of apparatus that may be employed in carrying out this invention;

FIGURE 6 is a longitudinal section of the apparatus of FIGURE 5;

FIGURE 7 is a longitudinal section through a well illustrating a special application of this invention;

FIGURE 8 is a section taken along the fracture plane of FIGURE 7;

FIGURE 9 is a diagrammatic cross-section of a well penetrating the earth and illustrates one manner in which the invention may be carried out in making a horizontal fracture, and also indicates the location of transverse sections illustrated in certain other figures;

FIGURE 10 is a diagrammatic cross-section of a well penetrating the earth and illustrates one manner in which the invention may be carried out in making a vertical fracture; and

FIGURE 11 is a diagrammatic vertical section taken on the plane of a vertical fracture produced by this invention.

In this invention a conventional well is provided which penetrates to the desired depth in the petroleum-bearing subterranean formation. The well is first prepared for fracturing in well-known manner by cutting the casing and notching the formation at the desired level in the well. Fracturing fluid is then applied at the notch under sufficient pressure to initiate a fracture in the formation at the previously formed notch. During propagation of the fracture in accordance with this invention, fracturing fluid containing propping agent is pumped into the fracture in certain regions or directions while simultaneously fracturing fluid substantially free of propping agent is pumped into the fracture in the intermediate regions or directions. By adjusting the relative injection rates of the two fluids, the spacing of the regions of the fracture respectively containing propping agent and containing no propping agent may be controlled. This invention may be applied to horizontal, vertical, or oblique fractures and various beneficial results are obtained as will become evident.

Referring first to FIGURE 9 this shows a diagrammatic cross-section of the earth having a petroleum-bearing subterranean formation **1** that is penetrated by a well **2** equipped with conventional casing **3** cemented as indicated at **4**. The well is prepared for horizontal fracturing by cutting the casing and cement at **5** at the desired depth, after which the formation is notched at **6** so as to provide a single-entry starting point for a fracture **7** to be produced by the method and apparatus of this invention as will be explained. In the ensuing explanation certain of the figures are longitudinal sections and these are taken in the manner of FIGURE 9 on the axis of the well **2**. Certain other figures employed in the explanation will be

transverse sections, and these are sections taken substantially horizontally on the plane of horizontal fracture 7 and are substantially perpendicular to the axis of the well 2. The dashed line A—A indicates in FIGURE 9 the location of the transverse sections shown in FIGURES 1, 3, 4, and 5.

Referring now also to FIGURES 1 and 2 these show respectively in transverse and in longitudinal section details of one embodiment of apparatus that may be employed in this invention for producing a horizontal fracture 7. In FIGURES 1 and 2 the well casing 3 is shown cut at 5 with the formation notched at 6. A horizontal fracture is to be produced and for this purpose an azimuthal distributing tool 10 is run into the well on tubing 11, the tool 10 being spotted opposite the notch 6, as generally indicated in FIGURE 9. In the well-known single-entry fracturing process previously used to provide the notch 6, the depth at which the notch 6 is placed is monitored by adding the successive lengths of tubing joints employed when running the notching tool into the well. By similarly monitoring the successive lengths of tubing joints, the distributing tool 10 is aligned with the notch 6 so that transverse openings 15 therein will be opposite the previously made notch 6. The azimuthal distributing tool 10 comprises a hollow body portion 12 (best seen in FIGURE 2 but not detailed in FIGURE 9) having at its upper end female threads 13 that screw onto the tubing 11, and having a closed lower end 14. The body 12 is provided with transverse openings 15, preferably three or more in number, four such openings being shown in FIGURES 1 and 2. Each opening 15 is provided with a nipple 16 that forms a sliding fit in the openings 15. The outer end of each nipple is provided with a shoe 17 rigidly fastened to the nipple as by means of threads or welds. The shoe 17 has an opening 18 that communicates with the hole in the nipple 16. The outside surface of the shoe 17 is shaped to conform to the inside cylindrical surface of the casing 3, and the top and bottom edges of the shoe 17 are rounded so as to easily ride over casing joints and other rough places on the inside surface of the casing. Each nipple 16 is provided with a spring 19 that forces the nipple and its shoe outward and thus forces the shoe 17 into engagement with the inside surface of the casing 3. The nipples 16 thus form channels from the tubing 11 and the inside of the tool 10 to azimuthal regions of the casing-cut 5 and notch 6 as best seen in FIGURE 1. The azimuthal regions 21 of the casing-cut 5 and notch 6 intermediate the shoes 17 are in direct communication to the annular space 20 between the casing 3 and the tubing 11. In this manner the azimuthal distributing tool 10 serves to segregate fluid pumped down the tubing 11 from fluid pumped down the annular space 20 It is not essential that there be a perfect hydraulic seal between the shoes 17 and the inside surface of the casing 3, because as will become evident, little hydraulic pressure differential will exist between the fluid in the annular space 20 and in the fluid emerging from openings 18. Therefore, there will be little or no tendency for fluid interchange to take place around the tool 10 and the need for perfect seals is circumvented. As best seen in FIGURE 1 the fluid pumped down the tubing 11 passes outward through the nipples 16 and the openings 18 and into a portion of the notch 6. The fluid pumped down the annular space 20 passes outward into intermediate portions of the notch 6 through the spaces 21 intermediate the shoes 17.

During the fracturing operation separate and different fluids are simultaneously or contemporaneously pumped into the well through the tubing 11 and the annular space 20 as indicated in FIGURE 9. The tubing 11 is connected by a pipe to flowmeter 22 and pump 23 whose source is tank 24. The annular space 20 is connected by a pipe to flowmeter 25 and pump 26 whose source is tank 27. In the operation of this invention the fluids pumped into the well from tanks 24 and 27 respectively are different. In

particular the fluid from tank 27 that is pumped down the annular space 20 as indicated by arrow 29 is conventional fracturing fluid that carries conventional propping material, whereas the fluid from tank 24 that is pumped down the tubing 11 as indicated by the arrow 30 is fracturing fluid that is substantially free of any propping material. The pumps 23 and 26 are operated simultaneously or contemporaneously during the fracturing operation as will become evident. Both pumping pressures exceed the fracturing pressure in order to effect propagation of the fracture. The propping material entrained in the fluid from tank 27 pumped down the annular space 20 may comprise any of the well-known particulate propping agents that are known to be capable of propping the fracture, such as sand, walnut shells, or the like. The liquid portions of the two fluids may have similar composition. In pumping the two fluids into the well the pumping rates are controlled so that a predetermined ratio of fluid flow rates is employed as will become evident later. The relative pumping rates may be constant, or may change during the course of the fracturing operation according to a predetermined program.

By way of example, FIGURE 1 illustrates the azimuthal distribution of fluids in the resulting fracture 7 when the pumping rates are controlled so as to maintain a fluid flow ratio that is substantially constant with time. Under such conditions the fluid containing propping material passing out through the spaces 21 will occupy substantially the radial sectors 31 of the fracture 7 produced, and the fluid simultaneously passing out through the openings 18 in the nipples 16 will occupy substantially the radial sectors 32 of the fracture. The ratio of the angle subtended by the areas 31 as compared with the angle subtended by the areas 32 will be substantially in proportion to the relative pumping rates of the respective fluids. Inasmuch as both the fluid that contains propping agent and the fluid that contains no propping agent are in hydraulic communication through the notch 6 there will be substantially no pressure differential between the fluids as they enter the formation to create the fracture 7. However, flow of the respective fluids into the fracture as the fracture is created will be in proportion to the relative pumping flow rates, and this will give rise to the azimuthal distribution of fluids substantially as indicated in FIGURE 1.

FIGURE 9 illustrates in block diagram form one type of control system that may be employed when a fluid distributing tool such as tool 10 is employed. The flowmeters 22 and 25 are connected to a ratio meter 70 which in turn actuates a pump controller 71 that is connected to the pumps 23 and 26 or their respective prime movers to control the respective pumping rates. As previously indicated, the pump pressures will be substantially the same since the fluids are in pressure communication in the notch 6, although slight differences in pumping pressure may exist at the well head due to different viscosities and densities between the fluids from tanks 24 and 27 causing different pressure drops and hydrostatic heads in the tubing 11 and in the annular space 20. However, the relative areas of the propped and unpropped regions of the fracture are determined by the relative volumes of the two fluids pumped into the fracture, therefore control is made responsive to this ratio. Alternatively, for certain purposes the ratio between the two pumping rates may vary with time or with integrated fluid injected, in which event the meter 70 is replaced by an appropriate programmer. It is to be understood that while a ratio meter or automatic programmer 70 is indicated in FIGURE 9 a manual type of pump control may alternatively be employed to perform the same function.

It is preferred that the fluids employed contain conventional fluid-loss preventing additives as is well known in the hydraulic fracturing art. Inasmuch as the fracture 7 itself represents a thin flat channel in which the flow is substantially radial and not to any extent tangential,

there will be substantially no intermixing of the fluids at the boundaries 33 between regions 31 and 32. FIGURE 1 is of course to a certain extent idealized since it is unlikely that the formation 1 would be sufficiently uniform to provide identical flow conditions in every radial direction. In an actual rock fracture the boundaries 33 may be somewhat irregular but they will nevertheless radiate away from the notch 6 in a generally outward direction with the propped and unpropped regions 31 and 32 having areas in proportion to the volumes of the respective fluids pumped into these regions.

As is evident from FIGURE 1, the fracture 7 produced will contain propping agent over certain azimuthal portions 31 and will be free of propping agent in the intervening portions 32. When the fracturing pressure is released, the overburden pressure on the formation of course tends to reclose the fracture, but such reclosure is prevented by the presence of the propping material in the regions 31. After the fracturing operation has been completed, the distributing tool 10 and tubing 11 may be removed from the well and FIGURE 3 illustrates the well with these removed. Alternatively, however, the tool 10 and the tubing 11 may be left in the well and either the tubing or the annular space or both may be used for oil production purposes.

Petroleum-bearing rocks that are susceptible to fracture treatment are substantially competent and have been found to be sufficiently strong so that the fracture 7 is held open in the unpropped regions 32. It is thus seen that the regions 32 provide clear channels through which the flow is unimpeded by the presence of propping particles. Such a channel will have a very high flow capacity as compared to the flow capacity of the regions 31 that contain propping particles. Due to the low flow resistance of the relatively open channels 32, the oil contained in the formation adjacent these open portions will readily flow into the well bore as indicated by the arrows 34. The oil in the formation adjacent the propped regions 31 may flow through the propped portion of the fracture 7 into the well bore as indicated by the arrows 35; however, a portion of the oil from the formation will flow along a curved path into the unpropped regions 32 as illustrated by the arrows 36, for the reason that such a flow path will present less resistance than flow through the propped portion 31 of the fracture 7. It is thus clearly seen that the fracture produced by the method of this invention provides channels having low resistance and high flow-carrying capacity from the formation 1 into the well 2.

FIGURE 4 illustrates the condition developed in the horizontal fracture 7 when the pumping rates of the pumps 23 and 26 are varied according to a particular program during the course of the fracturing operation. The equipment in the well in performing the fracturing operation for FIGURE 4 is the same as that illustrated in FIGURES 1 and 2. The operation is substantially the same as that described in connection with FIGURES 1 and 2 and the azimuthal distributing tool 10 is employed as explained in connection with FIGURES 1, 2, and 9. However, to obtain the fracture illustrated in FIGURE 4 the pump 23 which pumps fluid free of propping agent is initially shut down, and only pump 26 that pumps fluid containing propping agent is operated during the initial stages of the fracturing operation. In this manner the outer portions of the fracture in all radial directions will contain propping material. Toward the end of the fracturing operation the pump 23 is started and the pumping rate of pump 26 is correspondingly reduced, so that during the later part of the fracturing operation fluid free of propping agent is pumped through the tubing 11 concurrently with fluid containing propping agent pumped down the annular space 20. This produces regions 37 opposite the openings 18 of the azimuthal distributing tool 10 which regions are substantially free of propping agent. Thus while the two fluids are not simultaneously pumped during the entire fracturing operation, they are both pumped during at least a part of the fracturing operation and therefore may be said to be pumped contemporaneously. Accordingly the outer regions of the fracture are propped while close to the borehole there is created an alternate series of propped and unpropped regions 38 and 37. It is apparent that petroleum from the formation 1 will readily tend to flow into the unpropped regions of the fracture as indicated by the arrows in FIGURE 4. The invention in this manner produces a number of channels 37 of very low flow resistance close to the borehole where it is known that resistance to fluid flow most seriously affects the production rate of the well. The propped regions 38 of the fracture serve as supports to hold the fracture open and in a substantially competent formation the regions 38 will hold open the unpropped regions 37 of the fracture.

It is apparent that due to limits of the structural strength of the formation 1 there may be attained a horizontal dimension of the unpropped region of the fracture, which dimension may exceed the ability of the formation to hold open. This condition does not detract from the invention. If the formation fails over part of the unpropped region, the rock will cave in or subside over a part of the unpropped region. Such subsidence will form arched cracks in the rock above the unpropped portions of the fracture, and such subsidence cracks will serve as alternative flow channels through which the oil can reach the borehole almost as effectively as through the open regions 37 of the fracture itself. Accordingly, any formation that is sufficiently competent to be susceptible to a fracturing operation is also susceptible to improved production through the use of this invention.

This invention may also advantageously be carried out by employing as the distributing tool 10 the hydraulic notching tool that is initially used to cut the casing and notch the formation preparatory to the actual fracturing operation. Such a tool is described and illustrated in FIGURE 3 of an article by J. L. Huitt entitled "Hydraulic Fracturing With the Single-Point Entry Technique," published in Journal of Petroleum Technology, vol. 12, No. 3, pp. 11–13, March 1960. When such a tool is employed, the pump 23 of FIGURE 9 first pumps the hydraulic jetting fluid from another source (not shown) through the notching tool in order to cut the casing and cement and notch the formation as shown at 6 in FIGURE 9. During this preliminary operation, the tool is slowly rotated in conventional hydraulic notching procedure manner. The same tool may then subsequently be employed as the distributing tool 10 of FIGURE 9 of this invention, the tool being held stationary during the fracturing operation. By thus using the same tool for the preliminary notching operation and for the fracturing operation of this invention it becomes possible to eliminate a complete round trip with the tubing. This represents a substantial saving over the use of two different tools for notching and for subsequently distributing the fracturing fluid.

An alternative embodiment of the apparatus for carrying out this invention to create a horizontal fracture is illustrated in FIGURES 5 and 6. FIGURE 6 is a longitudinal section through the axis of the apparatus in the borehole. FIGURE 5, as previously indicated, is a transverse section taken on the fracture plane, i.e. the plane A—A of FIGURE 9. In the operation of this invention employing the azimuthal distributing tool 40 of FIGURES 5 and 6 the well is initially prepared for fracturing by cutting the casing and cement and notching the formation as previously described in connection with FIGURES 1 and 2.

The azimuthal distributing tool 40 shown in FIGURES 5 and 6 comprises an upper body portion 41 and a lower body portion 42 connected by a cage having short vertical elements indicated by the posts 43 best seen in FIGURE 5. The outside diameter of the tool is only slightly

less than that of the casing 3 to permit inserting the tool in the casing. The tool is screwed to tubing 11 and a passageway 48 is provided from the tubing 11 to the inside central portion of the tool. A number of screens 44 are provided between alternate adjacent posts 43, leaving unscrewed portions 45 intermediate the screens. In FIGURE 5 three such screens 44 are shown, but a larger number may be employed if desired, each screen being alternated with an unscreened window 45. It is apparent that the opening 48 is in unscreened communication with the windows 45, whereas the intermediate windows 46 are protected by the screens 44. The tubing 11 is connected at the surface to a pump not shown in FIGURES 5 and 6 which during the fracturing operation pumps fracturing fluid and propping material into the well through the tubing 11 and out through the windows 45 at a pressure sufficiently high to effect propagation of a fracture. At the same time the screens 44 serve to separate propping material from the fluid that traverses the screens and passes outward through the screened windows 46. Due to the arched shape of the screens 44, the particles of propping agent which are screened out do not remain on the surface of the screen 44 but are carried with other fluid containing propping material out through the unscreened windows 45. Accordingly, there are created one or more azimuthal regions of the fracture which contain fracturing fluid free of propping agent, these regions being indicated as 32 in FIGURE 5. On the other hand, the intermediate regions 31 of the fracture will contain fracturing fluid that carries propping materials. Inasmuch as the flow resistance through the screens 44 is negligible, the respective fluids will move outward in substantially the same radial distribution as the screened and unscreened portions of the azimuthal distributing tool 40, the outward flow of fracturing fluid being indicated by the arrows 47. When the fracturing pressure is subsequently released, and the tool 40 removed from the well, the unpropped regions 32 will form high-capacity flow channels from the petroleum-bearing formation to the well bore in the manner similar to that explained in connection with FIGURES 1 and 2.

Inasmuch as the tool 40 does not form a fluid-tight fit against the inner wall of the casing, it is advantageous to equip the tubing 11 with a packer (not shown) immediately above the tool 40 in order to seal off the rest of the casing from the fracturing pressure, in which event only a single fracturing pump connected to tubing 11 is required. Alternatively, the annular space 20 around the tubing 11 may be pressurized to the same pressure as the fracturing pressure in tubing 11. Since there will be substantially no flow from the annular space around the tubing 11 into the fracture, this pressurization does not require high pumping capacity. As a further alternative, the tubing 11 may be dispensed with and fracturing pressure applied to the casing with the azimuthal distributing tool 40 held in position opposite the previously made notch on the end of a wire line. It is apparent that the ratio of the flow rates of fluid containing no propping agent to fluid containing propping agent is substantially invariant with time when the tool 40 is employed.

A special application of this invention in an oblique fracture is illustrated in FIGURES 7 and 8. FIGURE 7 is a longitudinal section through the lower portion of a well 50 that penetrates a steeply dipping petroleum-bearing formation 51. As indicated in FIGURE 7, the formation 51 is highly stratified with the bedding planes substantially parallel to the upper and lower boundaries 52 and 53 of the formation 51. It may be assumed that the formation 51 is sealed off at some considerable distance to the left of FIGURE 7, as for example by a fault, as is usual for a stratigraphic trap type of reservoir. The upper portion of the reservoir may contain gas in the region 54, the gas-oil contact being indicated by the dashed line 55, below which there is oil saturation in the formation 51 down to the oil-water contact 56, below which there is water in the region 57. The method and apparatus of this invention may be advantageously employed in producing oil from such a reservoir. The well 50 is provided with a conventional casing (not shown) which is cemented in customary manner. The casing and cement are cut and the formation is notched substantially horizontally as shown at 58 preparatory to the fracturing operation. When such a highly stratified steeply dipping type of formation is fractured, the fracture plane will usually parallel the stratification, i.e. the fracture produced will generally not be horizontal but will be substantially parallel to the formation bedding planes. It is apparent that an oblique fracture such as 59 of FIGURE 7 may extend at its lower extremity 61 into the water-bearing portion 57 of the formation and this is highly undesirable. Accordingly the well is fractured employing the azimuthal distributing tool of this invention, for example a tool similar to 40 shown in FIGURES 5 and 6, modified as shown in FIGURE 8. The azimuthal distributing tool 65 is azimuthally oriented in proper manner by means of the tubing 11 to which it is fastened, so that the down-dip side 61 of the fracture is created with fracturing fluid containing no propping agent, whereas the up-dip side of the fracture 60 is created with alternate regions of propped and unpropped areas. Fracturing is then performed with the tool 65 which has almost a 180° portion that is covered by screen 66. FIGURE 8 shows the azimuthal distributing tool 65 in transverse section and properly oriented with the screen 66 facing toward the down-dip side of the well. The screen 66 will avoid placing propping agent in the down-dip region 61 of the fracture. In the up-dip region of the fracture the tool 65 will produce regions 62 containing propping agent alternated with regions 63 containing no propping agent. When the fracturing pressure is released, the propping agent in the regions 62 will hold open the nominal sized regions 63 that are free of propping agent. However, on the down-dip side there will be a very large region 67 in which no propping agent will have been injected, and this area will, particularly in the lower region far distant from the borehole, reclose upon release of the fracturing pressure. Thus the reclosure of the fracture in the large unpropped region 67 will inhibit the production of water from the lower regions 57 of the reservoir. Such arch-shaped subsidence cracks that may develop above the fracture upon subsidence will occur only in those regions of the formation contiguous to the propped areas 62 and will not extend to the lower end of the fracture 61 on the down-dip side of the borehole as viewed in FIGURE 7. On the other hand, such subsidence cracks as may occur close to the borehole above the down-dip side of the fracture, i.e. in the regions 68 of FIGURE 8, serve to enhance the flow of oil from the higher non-water-bearing regions of the formation. On the up-dip side of the borehole the alternate propped and unpropped regions 62 and 63 of the fracture will be created. By proper design of the azimuthal distributing tool 65 the unpropped areas 63 are made sufficiently small in extent to be held open and these have high flow capacity and serve as flow channels to permit easy access of the oil in the oil-producing formation to the borehole. It is apparent that by thus judiciously distributing the fracture fluid containing propping agent in desired azimuthal regions of the fracture, and avoiding the placing of propping agent in certain other desired regions of the fracture, the operator can attain especially advantageous results under special conditions. It is apparent for example, that if the fracture 59 is to be placed close to the upper boundary 52 of the formation 51, it may be desirable to leave the up-dip portion of the fracture free of propping agent in order to avoid excessive gas production.

This invention may also be employed in a vertical fracturing operation as illustrated in FIGURES 10 and 11. In FIGURE 10 the well 2 is shown penetrating a petroleum-bearing formation 1. The well is equipped with

casing 3 cemented at 4. A vertical fracture is to be made in the formation 1 and for this purpose a preparatory vertical notch 74 is made by means of a hydraulic notching tool 72 that has a jet 73 on one side. Fluid from a supply of abrasive fluid (not shown) is pumped through tubing 11 to tool 72. By means of the abrasive fluid issuing from jet 73 the casing and cement are cut and the formation is notched along a vertical line by reciprocating the tool 72 in known manner (not shown). The vertical notch 74 thus formed serves as a starting point for a vertical fracture when fracturing pressure is subsequently applied to the formation at the notch. While FIGURE 10 illustrates only a single notch 74, it is apparent that by using an appropriate notching tool more than one notch in the same or different azimuths may be created if it is desired to create more than one fracture. During the fracturing operation, the notching tool may be employed as the fluid-distributing tool of this invention without removing the tool from the well.

The tool 72 and annular space 20 are then connected as shown in FIGURE 10 and the two different fluids from tanks 75 and 76 are pumped into the formation at fracturing pressure in a manner similar to that described with reference to FIGURE 9. In the embodiment of FIGURE 10 it is preferred to pump through the tool 72 the fluid that contains no propping agent, i.e. the tank 75 will supply fluid that is free of propping agent, whereas tank 76 will supply fluid containing propping agent. The pumping rates of pumps 23 and 26 are controlled as explained in connection with the earlier figures. The pressure applied to the formation exceeds fracturing pressure so as to effect propagation of the fracture. During the fracturing operation, the opening 73 of the distributing tool is oriented to face the notch 74, and the tool 72 is held stationary.

FIGURE 11 is an idealized section taken on the plane of the vertical fracture produced by the process of this invention. This figure illustrates the fracture obtained when the fluid-distributing tool 72 is located about halfway down the vertical notch 74, and when the simultaneous pumping rates of the two fluids are approximately two parts of fluid containing propping agent and approximately one part of fluid free of propping agent. The fluid containing propping agent is injected through the annular space 20 and will occupy the upper portion 78 of the fracture area and also the lower portion 79 of the fracture area. The fluid that is free of propping agent is injected down the tubing 11 and will occupy the fracture area 80 substantially opposite the opening 73 of the fluid-distributing tool 72. This invention thus provides for making a vertical fracture with part of the fracture propped and with part of the fracture substantially free of propping particles. The propped portions 78 and 79 of the fracture will serve to hold open a substantial portion 80 of the fracture that is free of propping particles. The portion of the fracture that is free of propping particles will allow unimpeded flow of oil into the well bore. A fracture created in this manner has less resistance to fluid flow than a fracture propped in conventional manner.

In applying the process of this invention to a vertical fracture, care must be taken to avoid commingling of the two fluids in the fracture due to density differences. Particular care must be taken to avoid disturbance of the desired pattern due to settling out of the propping particles under the action of gravity. Thus, it is preferred to suspend the propping particles in a liquid of substantially equal density so as to prevent the propping particles from settling out. For example, walnut shells whose density is 1.3 g./cc. may be suspended in concentrated brine of density 1.3 g./cc. However, in many cases it may not be possible to use a fluid with the same density as the propping particles. In such cases it is desirable to use a propping-agent-carrying fluid having as high a density, viscosity, and gel strength as feasible. It is also preferred, in order to prevent the different fluid streams from mixing due to density difference, that the fluid that is free of propping agent and the propping-agent-carrying fluid be of substantially equal density and viscosity. In this manner the integrity of the portions of the fracture separated by the boundaries 81 and 83 can be maintained.

It is apparent that, if desired, the fluid-distributing tool may have two or more vertically aligned openings 73 so as to produce a corresponding number of unpropped areas opposite such openings with intervening propped areas. It is contemplated that in certain cases it will be preferred to inject propping agents having different densities into different regions of the fracture, in which event liquids of correspondingly different densities are employed to transport and separate such propping agents. Appropriate known types of tubing arrangements, packers, etc., may be provided in the well to permit the simultaneous injection of more than two segregated fluid streams into the fracture. A wide variety of well-bore arrangements are possible which make an almost equal variety of propping patterns possible, all of which lie within the scope of this invention. The fluids being injected simultaneously through the various mechanical arrangements will follow normal flow lines from the annular space or spaces and from the openings in the distributing tool into the fracture as it is propagated into the formation.

By this invention a fracture is created in which the propping particles are caused to occupy regions that are separated by regions free of propping agents. By way of example, in FIGURE 11 the regions 78 and 79 containing propping agent are separated by the region 80 that is free of propping agent, and in FIGURES 1, 3 and 5 the regions 31 containing propping agent are separated by the regions 32 that are free of propping agent. The invention is applicable to create a vertical or horizontal fracture having the desired distribution of propping agents to provide channels of exceptionally low flow resistance directly to the well.

What we claim as our invention is:

1. A method of fracturing a subterranean rock formation which comprises

applying to the formation at the desired location of the fracture a hydraulic pressure sufficient to effect fracture of the rock,

injecting a first pressurized fluid into a desired region of said fracture during propagation thereof,

simultaneously injecting a second pressurized fluid into a different desired region of said fracture during propagation thereof,

controlling the relative rates of injection of said fluids,

one of said fluids containing particulate material capable of propping said fracture,

the other of said fluids being substantially free of particulate material capable of propping said fracture, and

releasing said hydraulic pressure.

2. A method of fracturing a subterranean rock formation which comprises

applying to the formation at the desired location of the fracture a hydraulic pressure sufficient to effect fracture of the rock in a substantially horizontal plane,

injecting a first pressurized fluid into a desired arcuate segment of said fracture during propagation thereof,

simultaneously injecting a second pressurized fluid into a desired arcuate segment of said fracture during propagation thereof different from the segment into which said first fluid is injected,

controlling the relative rates of injection of said fluids,

one of said fluids containing particulate material capable of propping said fracture,

the other of said fluids being substantially free of particulate material capable of propping said fracture, and

releasing said hydraulic pressure.

3. A method of fracturing a subterranean rock formation which comprises

applying to the formation at the desired location of the fracture a hydraulic pressure sufficient to effect fracture of the rock in a substantially vertical plane,

injecting a first pressurized fluid into a first desired area of said fracture during propagation thereof,

simultaneously injecting a second pressurized fluid into a second desired area of said fracture during propagation thereof, said second area having a different vertical extent from the area into which said first fluid is injected,

controlling the relative rates of injection of said fluids,

one of said fluids containing particulate material capable of propping said fracture,

the other of said fluids being substantially free of particulate material capable of propping said fracture, and

releasing said hydraulic pressure.

4. A method of fracturing a subterranean rock formation which comprises

applying to the formation at the desired location of the fracture a hydraulic pressure exceeding the overburden pressure by a sufficient amount to effect fracture of the rock,

injecting a first pressurized fluid into a desired region of said fracture during propagation thereof,

simultaneously injecting a second pressurized fluid into a different desired region of said fracture during propagation thereof,

controlling the relative rates of injection of said fluids to be in proportion to the relative magnitudes of the areas of the fracture desired to be occupied by said fluids,

one of said fluids containing particulate material capable of propping said fracture,

the other of said fluids being substantially free of particulate material capable of propping said fracture, and

releasing said hydraulic pressure.

5. A method of fracturing a subterranean rock formation penetrated by a well bore provided with tubing smaller than the well bore which comprises

applying to the formation at the desired location of the fracture a hydraulic pressure exceeding the overburden pressure by a sufficient amount to effect fracture of the rock,

injecting via said tubing a first pressurized fluid into a desired region of said fracture during propagation thereof,

contemporaneously injecting via the annular space around said tubing a second pressurized fluid into a different desired region of said fracture during propagation thereof,

controlling the relative rates of injection of said fluids,

one of said fluids containing particulate material capable of propping said fracture,

the other of said fluids being substantially free of particulate material capable of propping said fracture, and

releasing said hydraulic pressure.

6. A method of fracturing a subterranean rock formation penetrated by a well bore provided with tubing smaller than the well bore and said tubing being provided with at least one transversely directed opening which comprises

notching the formation at the desired location by injecting an abrasive fluid through said tubing and said opening while simultaneously rotating said tubing,

discontinuing rotation of said tubing,

subsequently applying to the formation at the location of said notch a hydraulic pressure sufficient to effect fracture of the rock,

injecting via said tubing a first pressurized fluid into a desired region of said fracture during propagation thereof,

simultaneously injecting via the annular space around said tubing a second pressurized fluid into a different desired region of said fracture during propagation thereof,

controlling the relative rates of injection of said first and second pressurized fluids,

one of said fluids containing particulate material capable of propping said fracture,

the other of said fluids being substantially free of particulate material capable of propping said fracture, and

releasing said hydraulic pressure.

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