July 10, 1956 L. F. BONNER 2,753,940

METHOD AND APPARATUS FOR FRACTURING A SUBSURFACE FORMATION

Filed May 11, 1953 2 Sheets-Sheet 1

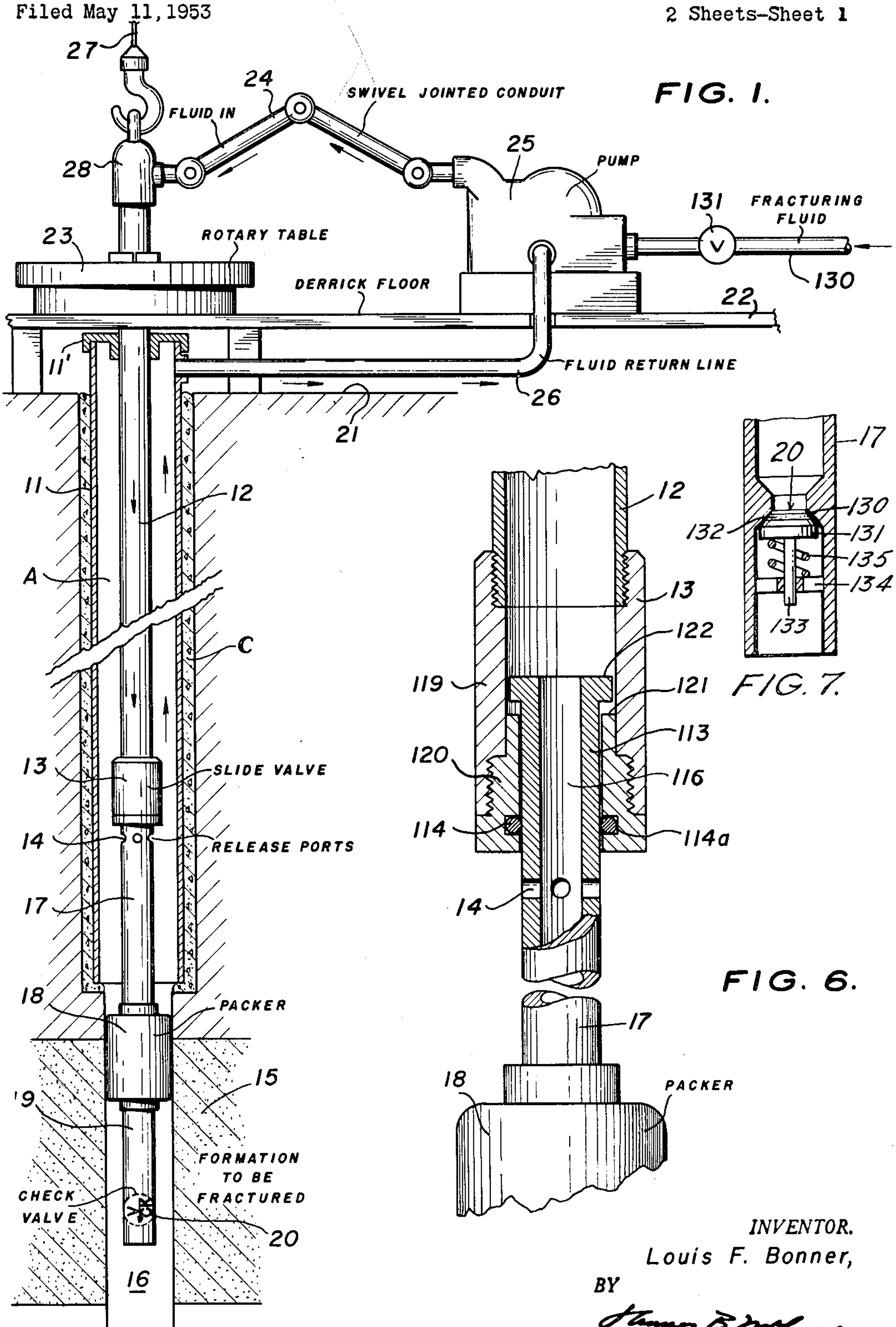

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FIG. 2.

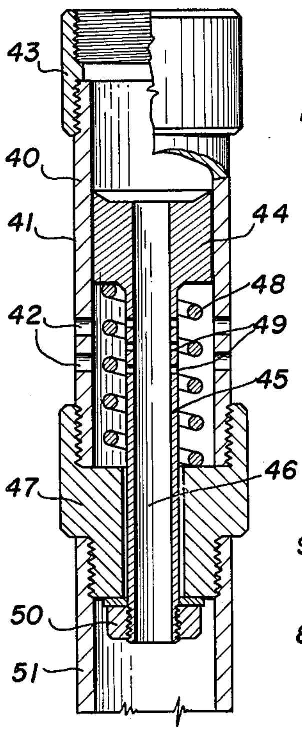


FIG. 4.

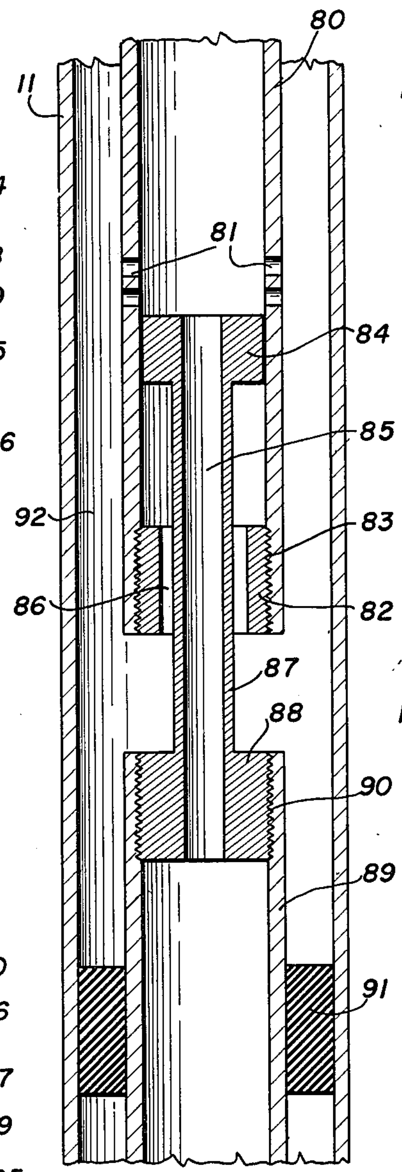
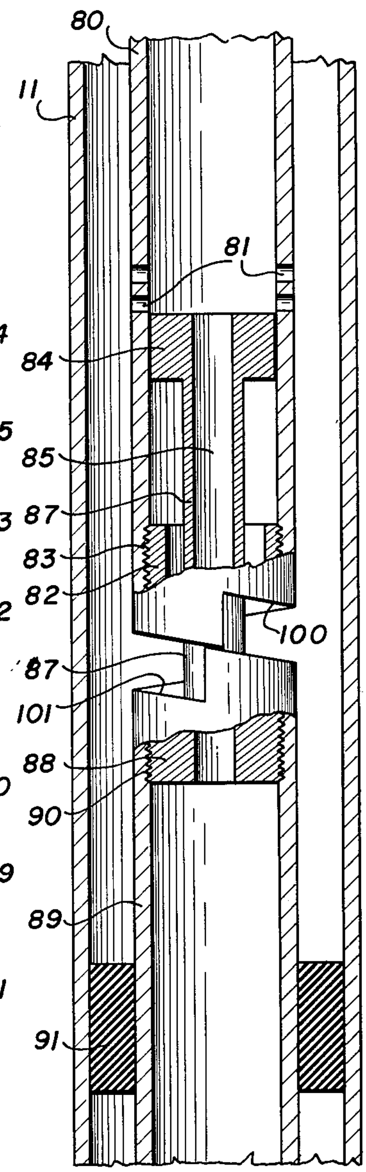


FIG. 5.



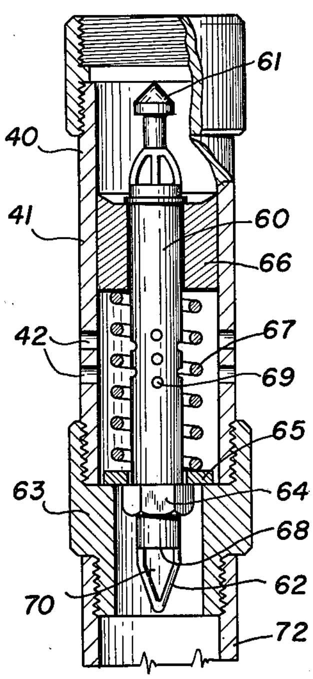


FIG. 3.

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METHOD AND APPARATUS FOR FRACTURING A SUBSURFACE FORMATION

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Application May 11, 1953, Serial No. 354,344

15 Claims. (Cl. 166—42)

The present invention is directed to increasing the permeability of subsurface earth formations. More particularly, the invention is directed to fracturing of subsurface earth formations. In its more specific aspects, the invention is directed to a method for increasing the permeability of a low permeability subsurface earth formation whereby valuable fluids in the low permeability formation may be recovered.

The present invention may be briefly described as a method for increasing the permeability of a low permeability subsurface earth formation in a well bore penetrating said formation which comprises establishing a first path of flow from the earth's surface to the formation. A portion of the well bore penetrating the formation is isolated from upper portions of the well bore. A second path of flow from the earth's surface is established to a point above the isolated portion and thence to the earth's surface. A fracturing liquid is then flowed under pressure down the well bore along the second path of flow. Once the flow has been established, it is suddenly interrupted along the second path of flow, and the flow is directed along the first path of flow into contact with the formation for a period of time sufficient to utilize the energy in the flowing liquid to cause fractures in the formation and increase the permeability thereof. After the fractures have been formed, valuable fluids, such as oil and/or gas and the like, may be produced from the originally low permeability formation which has had its permeability increased.

The invention is also directed to apparatus for fracturing subsurface earth formations which is adapted to be connected to a lower end of a pipe such as a tubing string in a well bore. The apparatus comprises, in combination, a valve which is connected to the lower end of the pipe string, which has at least a port communicating the interior of the valve with an exterior surface of the valve. The valve is provided with means for closing and opening the port. A pipe extension member is connected to the lower end of the valve. The pipe extension member has a check valve arranged in a lower end of the pipe extension member to resist backflow into the apparatus. The pipe extension member carries a packer which is employed to isolate the earth formation from the upper portion of the well bore.

The valve of my apparatus may embody as a closing means a sleeve slidably arranged on the valve which is operated by lowering and raising the pipe string to which the valve and pipe extension member is connected.

The closing means may be a piston having a central bore slidably arranged in the valve to close and open the bore on movement of the pipe either rotatably or vertically.

The closing means may also be a spring-biased piston having a central bore which is operative on flow of fluid through the valve from the earth's surface.

It is further contemplated that the valve employed in my apparatus may be a wire line removable valve of a type operable by fluid flow in which the wire line removable valve embodies ports in the pipe string and a removable member comprising a mandrel having a fishing spear and the like on an upper end and having a spring-biased piston slidably arranged on the mandrel.

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The invention will be further illustrated by reference to the drawing, in which

Fig. 1 shows an arrangement of my apparatus in a well bore;

Fig. 2 is a sectional view of a fluid operated valve suitable for use in my invention;

Fig. 3 is a sectional view embodying a wire line removable fluid valve which may suitably be employed;

Fig. 4 is a sectional view of a slidable valve operable by vertical movement of the pipe string;

Fig. 5 is a sectional view of a slidable valve operable by rotatable movement of the pipe string;

Fig. 6 is a sectional view of a slidable valve as illustrated in Fig. 1; and

Fig. 7 is an enlarged sectional view of the check valve of Fig. 1.

Referring now to the drawing, numeral **11** designates a cased well bore in which is arranged a pipe string **12** provided with a slidable valve **13** having release ports **14**. The casing **11** extends from the earth's surface to a point just above a producing formation **15** which is penetrated by the well bore **16** which has not been cased. The pipe string **12** is provided with an extension member **17** which carries a packer **18** which is set in the upper portion of the producing formation **15**. The lower or open end **19** of the extension member **17** is provided with a check valve **20** to resist backflow into the pipe string **12**. The well bore extends to the earth's surface **21**, and the casing **11** terminates at its upper end below the derrick floor **22** and is closed by cap **11'**, the pipe string **12** being arranged in a rotary table **23**. Connected to the pipe string **12** is a flexible or swivel jointed conduit **24** which connects into a pump **25**, which is in turn connected to the casing **11** by a conduit **26** to allow flow from the annulus A between the outer surface of the pipe string **12** and the inner surface of the casing **11**. The pipe string **12** may be moved vertically by means of a wire line or suitable hoist **27** connected to a hoisting machine, not shown. The wire line **27** is connected to the pipe string **12** by suitable well known connecting devices indicated generally by **28** and, by means of the rotary table **23** which is connected by means not shown to suitable power equipment, the pipe may also be moved rotatably in the pipe casing **11**.

Referring now to Fig. 2, a modification of a valve is disclosed which may be used in lieu of slide valve **13**. The valve of Fig. 2 is indicated generally by the numeral **40** and comprises a pipe section **41** provided with ports **42**. The pipe section **41** may be connected into the pipe string **12** by means of a suitable threaded connecting means **43**.

Arranged in the pipe section **41** embodying the valve of the present invention is a piston member **44** embodying a longitudinal member **45** provided with a central bore **46** which allows flow of fluid from the pipe string through the valve **40**. Arranged in the pipe section **41** is a bumper or suitable member **47** which supports the member **45**. Arranged between the bumper **47** and the piston **44** is a biasing means **48** which suitably may be a helical coil spring. The longitudinal member **45** is provided with ports **49** which allow fluid flow from the central passageway **46** and through the ports **42**. The whole assembly is held together by means of a threaded retaining nut **50** which is threadably engaged with the member **45** and holds it in place against the bumper **47** and serves to restrain the spring **48**. The bumper sub **47** is threaded into a pipe extension member **51** which carries the packer, as illustrated in Fig. 1.

In the apparatus of Fig. 3, identical numerals are employed to designate identical parts as to Fig. 2. Thus the valve is indicated generally as **40**, and a pipe section **41** is provided with ports **42**. In this particular embodiment of my invention, the movable member of the valve is retrievable or may be located by means of a wire line. To this end, a mandrel **60** is provided having a cage and fishing spear **61** on the upper end thereof and having a guide point and a cage **62** on a lower end thereof. The mandrel **60** is positioned by a bumper or restraining means **63**. Arranged above the bumper **63** is an annular plate **65**. Arranged adjacent the upper end of the mandrel **60** is a piston **66** which is slidably arranged on the mandrel **60**. Between the piston **66** and the annular plate **65** is a biasing means **67** which may be a helical coil spring which is held in place by a threaded retaining nut **64**. The biasing means **67** urges the piston **66** upwardly. The mandrel **60** defines a central passageway **68** which allows flow through the pipe section **41** through the openings **69** and outwardly therefrom through the openings **70** in the guide point **62**. The bumper **63** is threaded into a pipe extension member **72** which carries a packer, as illustrated in Fig. 1. The movable member may then be lowered by means of a wire line to the desired point.

In the embodiment of Fig. 4, a casing **11** has arranged therein a pipe **80** which is provided with ports **81**. The lower end of the pipe **80** is provided with an annular sleeve **82** which is threadably connected thereto by mating threads **83**. Slidably arranged in the pipe **80** is a piston member **84** which is provided with a central passageway **85**. The sleeve and the piston member **84** define annular space **86** by way of which fluid may escape. The piston **84** has an extension member **87** which is connected into a plug **88**, which in turn is connected to a pipe extension member **89** by mating threads **90**. The pipe extension member **89** carries a packer **91** to seal off an annulus **92** between the extension member **89** and the pipe **80** with the casing **11**.

Referring now to Fig. 5, identical numerals will designate identical parts as to Fig. 4. It will be seen that a pipe **80** is provided with ports **81**, and arranged in the pipe **80** is a slidable piston **84** having a central passageway **85**. In this modification of my invention, the lower end of the pipe **80** is provided with cam surfaces **100**, and the upper end of the pipe extension member **89** is provided with cam surfaces **101** to correspond with the cam surfaces **100**. The extension member **87** is connected to a plug **88**, which in turn is connected by mating threads **90** to the pipe extension **89**. The pipe extension **89** carries a packer **91** as in Fig. 4.

Referring now to Fig. 6, a pipe tubing **12** has attached to it a slidable sleeve **13**. The slidable sleeve **13** fits over a valve body **113** and is provided with a suitable sealing means such as an O-ring **114** arranged in a recess **114***a*. The valve body **113** is provided with a plurality of ports **14** which allows communication with the central passageway **116** and the interior of pipe tubing **12**. The lower end of the valve body **113** serves as a pipe extension member **17** which carries a packer **18** to allow the lower end of the bore hole to be isolated from an upper end.

The sleeve **112** is constructed of two parts **119** and **120**. Part **119** is attached to the pipe **110**, and part **120** is threadably attached to part **119**. Part **120** is provided with an internal shoulder **121** which serves as a stop for limiting upward movement of sleeve **112**. Valve body **113** has a shoulder **122**, which limits upward travel of sleeve **112** by engagement with stop **121**.

With respect to Fig. 7, the check valve **20** is arranged in the extension member **17** adjacent the lower open end **19** and is comprised of a seating member **130** for seating of the valve member **131** thereon. The valve member **131** is provided with a seal **132** and has a stem or guide member **133** arranged in a spider **134**. The valve member **131** is biased into seating engagement with the seating member **130** by a biasing means, such as a helical coil spring **135**, which normally holds the valve member **131** in closed position. The check valve **20** is opened by a predetermined pressure overcoming or compressing the spring **135**.

The apparatus of my invention is employed in the following manner to obtain production from low permeability producing formations and to increase the permeability thereof.

Referring now to Fig. 1, the casing **11** has been cemented securely in the well bore by means of cement, indicated generally as C. Thereafter the pipe **12** in which is arranged a valve, such as **13**, shown in more detail in Fig. 6, is lowered into the well. The valve has connected to its lower end a pipe **17** which has a check valve arranged adjacent the lower end **19** of the pipe extension **17**. Carried on the pipe **17** is a packer which is set by suitable means well known to the art at a point in or at the top of the formation **15**.

Fracturing fluid is drawn into the pump **25** by means of a conduit **130** controlled by valve **131** from a source not shown which may be a suitable tank. The fracturing fluid is flowed down through the pipe **12** and out through ports **14** since the packer **18** has been set and since the check valve is of the type to restrain flow and to be overcome by a designated pressure. The flow is down the pipe **12** through the ports **14** and up the annulus A, as indicated by the arrows. Thence the fluid returns by conduit **26** and pump **25** and back down the tubing or pipe **12**. After the flow has been established along the path indicated, it is desired to fracture the formation **15**; then slide valve **13** may be manipulated by lowering the pipe **12** such that the sleeve **13**, as in Fig. 6, will cover the ports shown in Figs. 1 and 6 as **14**. This causes the flow to proceed down through the pipe **17** to unseat the check valve **20** and out through the open end **19**. The energy contained in the flowing stream is thus exerted suddenly against the formation **15**, which is sufficient to cause horizontal and/or vertical fractures in the formation **15** to increase the permeability thereof. The pipe string **12** may then be raised to open the ports **14** and to allow flow along the path defined by pipe **12** through ports **14**, annulus A, conduit **26**, pump **25** and conduit **24**. The sequence may be repeated by lowering the pipe **12** such that the sleeve **13** again covers the ports **14** to utilize the energy of the moving column against the formation **15**.

In the apparatus of Fig. 2, the helical coil spring **48** normally urges the piston or plunger **44** upwardly leaving the port **42** open such that fluid passes from the pipe string to which the valve is connected by connecting means **43** through central passageway **46** and thence through ports **49** and **42** to the annulus A. When the velocity of the fluid flowing down the pipe string increases to a predetermined value, the ports **49** have insufficient flow area to allow the fluid to pass without a build-up in pressure. This causes the plunger or piston **44** to move downwardly, overcoming the tension of spring **48**. Thus the plunger or piston **44** then covers the ports **49** and forces the fracturing liquid to pass down the central passageway **46** and thence against the formation **15** described with respect to Fig. 1. The valve **40** remains closed until the flow through check valve **20** drops below a predetermined value. The valve then opens and fluid circulation up the annulus is resumed and the cycle repeated. The time between opening and closing the valve may vary from a fraction of a second to several seconds, say from 0.01 to 20 seconds.

The apparatus of Fig. 3 operates similarly to that of Fig. 2. In this respect, however, the valve may be located by a wire line device connected to the spear **61** such that the device may be lowered to the proper position in the pipe section **41** until it is adjacent the ports **42**. Fluid is then pumped down the pipe connected by connecting means **43** and through the valve **40** until the velocity forces the piston **66** to move downwardly on mandrel **60**, compressing spring **67** and covering the ports **42**. Thus the fluid is forced abruptly through the opening **69** into passageway **68** and thence through opening **70** down into the well bore below the packer and against the formation to be fractured.

The apparatus of Figs. 4 and 5 works in a similar manner. With respect to Fig. 4, the piston member **84** covers the ports **81** by sliding the pipe **80** downwardly, the extension member **87** being only of sufficient length to allow movement of the piston **84** sufficiently to cover ports **81**. This operation may be conducted rapidly to cause a water hammer effect when flow through the ports **81** is interrupted and to cause flow through passageway **85** and thence against the formation, as has been described with respect to Fig. 1.

In the device of Fig. 5, the piston **84** is caused to cover the ports **81** by rotating the pipe **80** with the rotary table **23**. This causes the cam surfaces **100** and **101** to open and close the ports **81** vertically by upward and downward movement of the piston **84**. This sudden opening and closing of the ports allows the flow to be diverted to the central passageway **85** and against the formation **15**, as has been described.

The operation of the device of Fig. 6 has been substantially described with respect to Fig. 1 which employs identical equipment and will not be repeated here in the interest of briefness.

The check valve **20** is opened by a designated pressure compressing the spring **135**; on release of pressure by opening port **14**, the check valve **20** closes by the action of spring **135**.

The present invention utilizes the energy contained in a flowing or pumped stream wherein the flow is suddenly interrupted. In short, I exert a water hammer effect against a low permeability formation such that by means of the energy contained in the stream, I fracture the formation without expenditure of a large amount of pumping energy.

As liquids or fluids suitable for use in fracturing formations having low permeability I may use, in accordance with my invention, oil, water and dilute hydrochoric acid and the like. If acid is used, it may react chemically with the formation to enlarge the fissures thereof while it is being injected into the formation or thereafter. Under some conditions, oil is deemed the most suitable liquid for the purpose, as it does not contaminate oil-bearing rock formations as does water, and its viscosity may be easily controlled as by mixing it with suitable soaps, as is well known to those skilled in the art of making oil base driling fluids. In an oil producing formation, liquid can perhaps be removed easier in an aqueous treating or fracturing fluid. In this respect, see "The Flow of Homogeneous Fluids Through Porous Media" by M. Muskat, copyright 1937, McGraw-Hill Book Company, pages 478–480.

Under some conditions, liquids of very low viscosity may be employed, although it is recognized that if sand or gravel are mixed with the liquid which is forced into the formation by the water hammer effect, the liquid may have a sufficiently high viscosity to suspend the particles of such materials uniformly. Under other conditions, liquid of reasonably high viscosity may be employed, but in no event should the viscosity of the liquid be so high that the formation becomes clogged by the liquid after the formation has been fractured. From the foregoing, it may be seen that I contemplate employing as a fracturing liquid either a hydrocarbon vehicle or an aqueous vehicle. I further contemplate that either the hydrocarbon or aqueous vehicle may contain a propping agent such as sand or gravel, which will serve to maintain the fracture or fissures in the formation in an open condition after the fractures have been formed.

In my invention, after I have fractured the formation by utilizing the apparatus described whereby a water hammer effect is employed, the desirable subsurface fluid in the formation would be allowed to flow under its own pressure from the formation into the well and produced.

It is contemplated and it may be desirable that after the fracturing operation has been conducted, the packers used to isolate the formation may be unseated and retrieved. Packers suitable in the practice of the present invention are well known in the art. A description of a packer which may be employed in my invention may be found on page 2852 of the 1951 Edition of Composite Catalog of Oil Field and Pipe Line Equipment, shown as packer model C–100.

For the present invention to be effective, it is contemplated that the flow of the fracturing fluid will be interrupted only momentarily, a matter of perhaps 0.01 to 20 seconds such that the water hammer effect may be created. It is contemplated that the water hammer effect may be exerted against the formation a plurality of times or only once, as is necessary to increase the permeability of a formation to a desired value. Thereafter the formation may be produced after normal clean out operations well known to the art have been performed. It is intended that this invention will include the steps of increasing the permeability of a producing oil formation and then producing said formation.

The fracturing liquid employed may be insufficient in amount to fill the pipe and the annulus, and it is, therefore, contemplated that a column of mud or water or other liquid may be used to follow the charge of fracturing liquid. Also it is considered that the column of mud or water may be used in the annulus above the packer instead of having the annulus filled with fracturing liquid.

The nature and objects of the present invention having been completely described and illustrated, what I wish to claim as new and useful and to secure by Letters Patent is:

1. A method for increasing the permeability of a low permeability subsurface earth formation in a well bore penetrating said formation which comprises establishing a first path of flow from the earth's surface to said formation, isolating at least a portion of the well bore penetrating said formation from an upper portion of said well bore, establishing a second path of flow from the earth's surface to a point above said isolated portion common with said first path of flow and thence to the earth's surface, pumping a fracturing liquid under pressure down said well bore along said second path of flow, terminating the flow along said second path of flow, and then pumping said fracturing liquid along said first path of flow into contact with said formation whereby the energy of the pumped liquid is exerted against said formation to fracture same and increase the permeability thereof.

2. A method in accordance with claim 1 in which the fracturing liquid is a hydrocarbon vehicle.

3. A method in accordance with claim 1 in which the fracturing liquid is a hydrocarbon vehicle containing a propping agent.

4. A method in accordance with claim 1 in which the fracturing liquid is an aqueous vehicle.

5. A method for producing a desirable subsurface earth fluid from a low permeability subsurface earth formation in a well bore penetrating said formation which comprises establishing a first path of flow from the earth's surface to said formation, isolating at least a portion of the well bore penetrating said formation from the upper portion of said well bore, establishing a second path of flow from the earth's surface to a point above said isolated portion common with said first path of flow and thence to the earth's surface, pumping a fracturing fluid under pressure down said well bore along said second path of flow, terminating the flow along said second path of flow, pumping said fracturing fluid along said first path of flow into contact with said formation for a period of time in the range from 0.01 to 20 seconds whereby the energy of the pumped liquid is utilized to fracture said formation and

increase the permeability thereof, and then recovering the desired earth fluid from said fractured formation.

6. A method in accordance with claim 5 in which the fracturing liquid is a hydrocarbon vehicle.

7. A method in accordance with claim 5 in which the fracturing liquid is a hydrocarbon vehicle containing a propping agent.

8. A method in accordance with claim 5 in which the fracturing liquid is an aqueous vehicle.

9. Apparatus for fracturing a subsurface earth formation which comprises, in combination, a pipe tubing adapted to be arranged in a well bore with its lower end adjacent the formation to be fractured and its upper end extending above the earth's surface, valve means arranged in said tubing adjacent the lower end of the tubing provided with at least one port communicating the interior of the tubing with the exterior of the tubing, means for opening and closing said port, an upwardly biased check valve in the lower end of the tubing normally closing the lower end of the tubing and openable under a designated pressure for flow downwardly through the tubing, a packer carried by said tubing between said valve means and said check valve for isolating said earth formation from the well bore, conduit means flexibly connected to the upper end of said pipe tubing, and pumping means connected to said conduit means for pumping fracturing fluid to said formation while said valve means and said check valve are alternately opened and closed.

10. Apparatus in accordance with claim 9 in which means are provided for moving said pipe tubing to cover and uncover said port while fracturing fluid is being pumped downwardly through said pipe tubing.

11. Apparatus in accordance with claim 9 in which the closing and opening means is a sleeve slidably arranged on said valve to close and open said port by lowering and raising the pipe.

12. Apparatus in accordance with claim 9 in which the closing and opening means is a piston having a central

bore slidably arranged in said valve to close and open said port on movement of the pipe.

13. Apparatus in accordance with claim 9 in which the closing and opening means is a spring biased piston having a central bore slidably arranged in said valve to close and open said port on flow of liquid through the valve.

14. A method for producing a desired subsurface earth fluid from a low permeability subsurface earth formation in a well bore penetrating said formation which comprises establishing a path of flow from the earth's surface to said formation, isolating at least a portion of the well bore penetrating said formation from an upper portion of said well bore, establishing a second path of flow from the earth's surface to a point above said isolated portion common with said first path of flow and thence to the earth's surface, pumping a fracturing fluid under pressure down said well bore along said second path of flow, terminating the flow along said second path of flow, pumping said fracturing fluid along said first path of flow into contact with said formation for a period of time in the range from 0.01 to 20 seconds whereby the energy of the pumped liquid utilized to fracture said formation and increase the permeability thereof, removing fracturing fluid from said formation and said first path of flow, and obtaining the desired earth fluids from said fractured formation.

15. A method in accordance with claim 14 in which the earth fluid is a hydrocarbon.

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