April 27, 1965 H. W. PARKER 3,180,414

PRODUCTION OF HYDROCARBONS BY FRACTURING AND FLUID DRIVE

Filed May 27, 1961

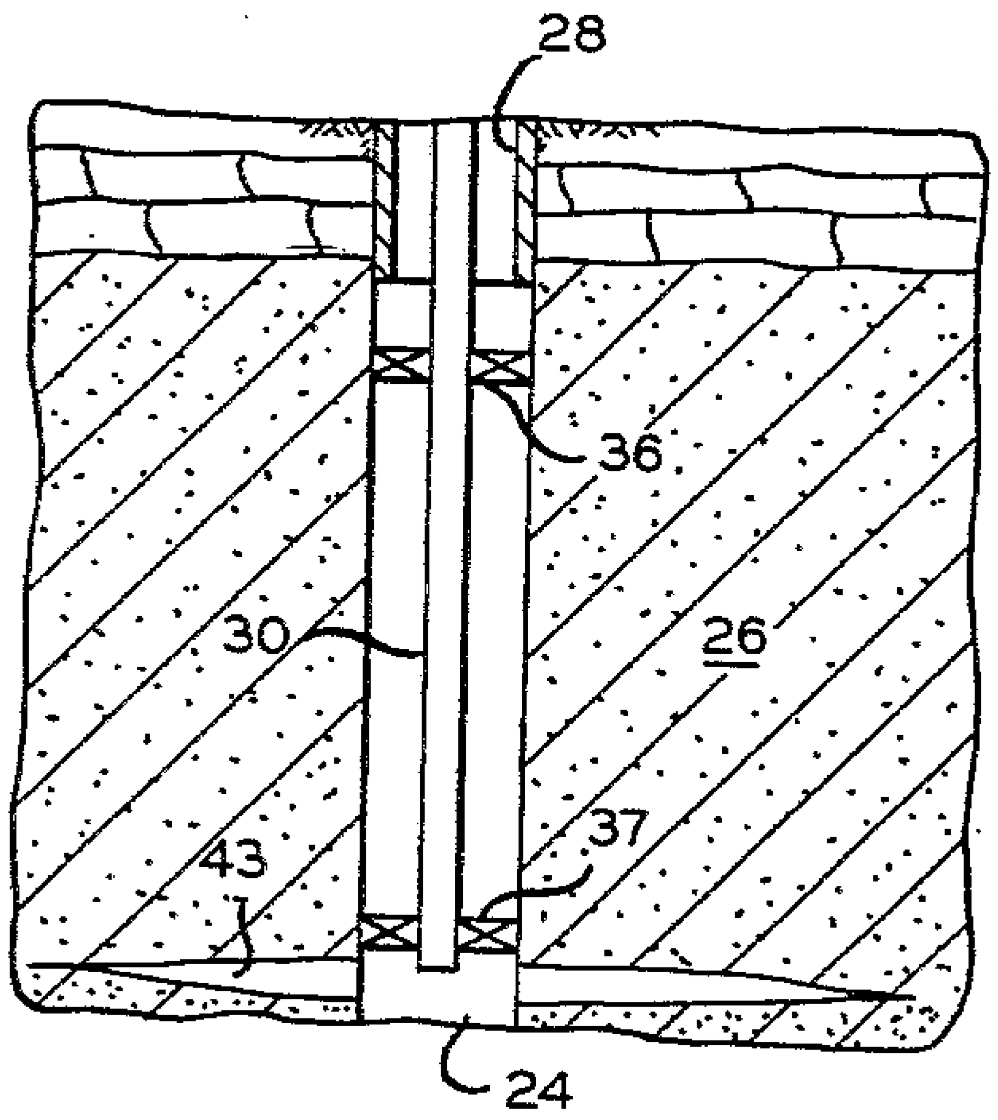

FIG. 5

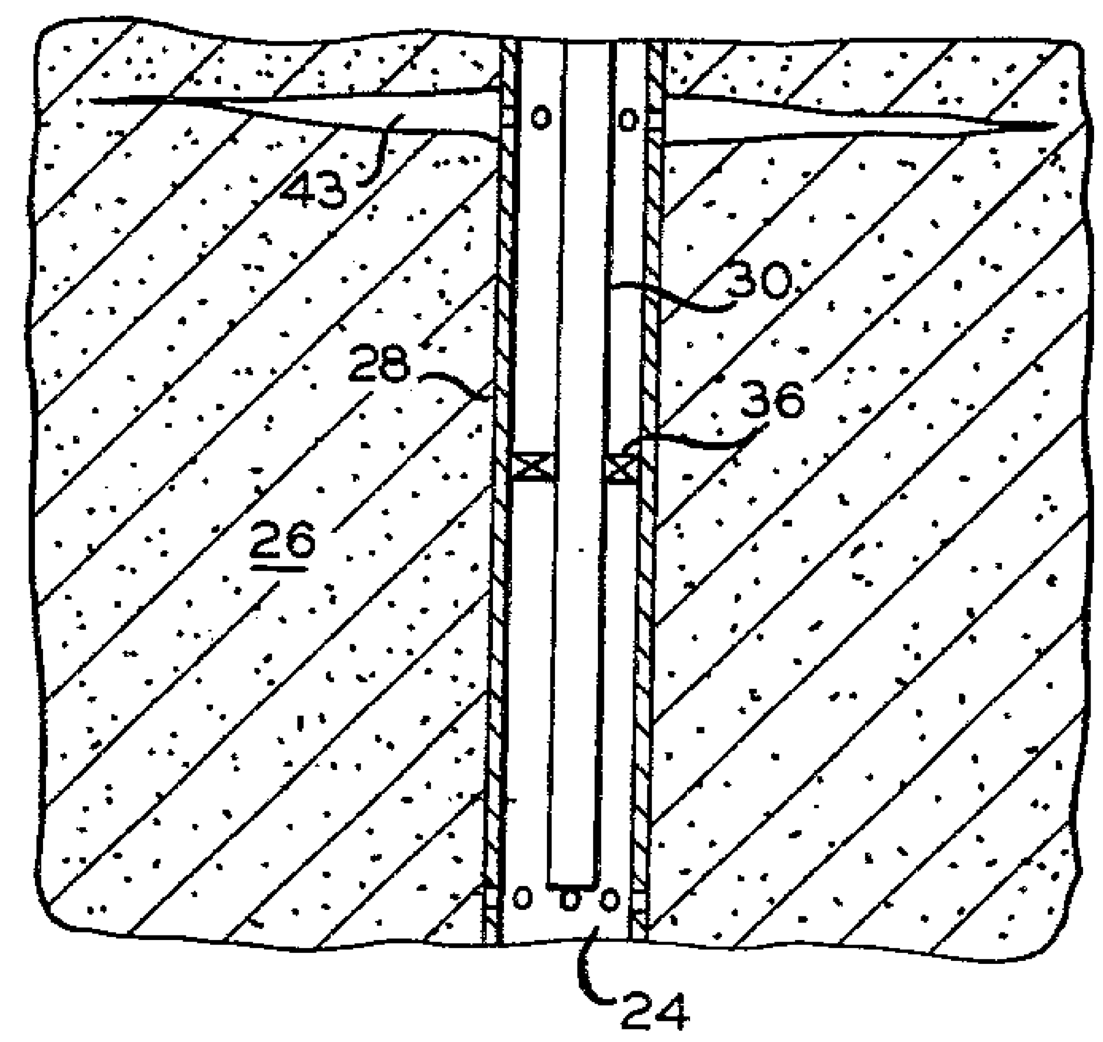

FIG. 4

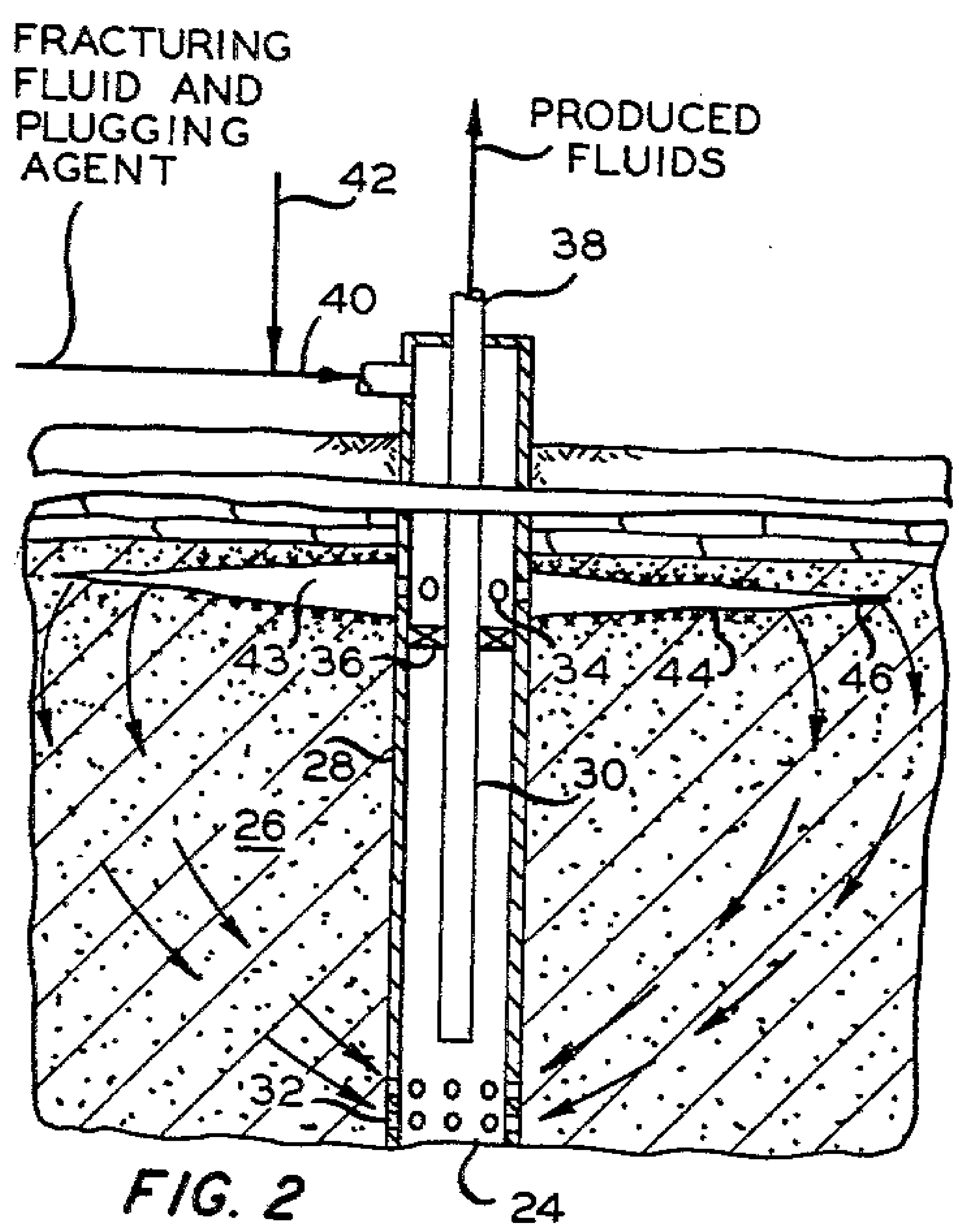

FIG. 2

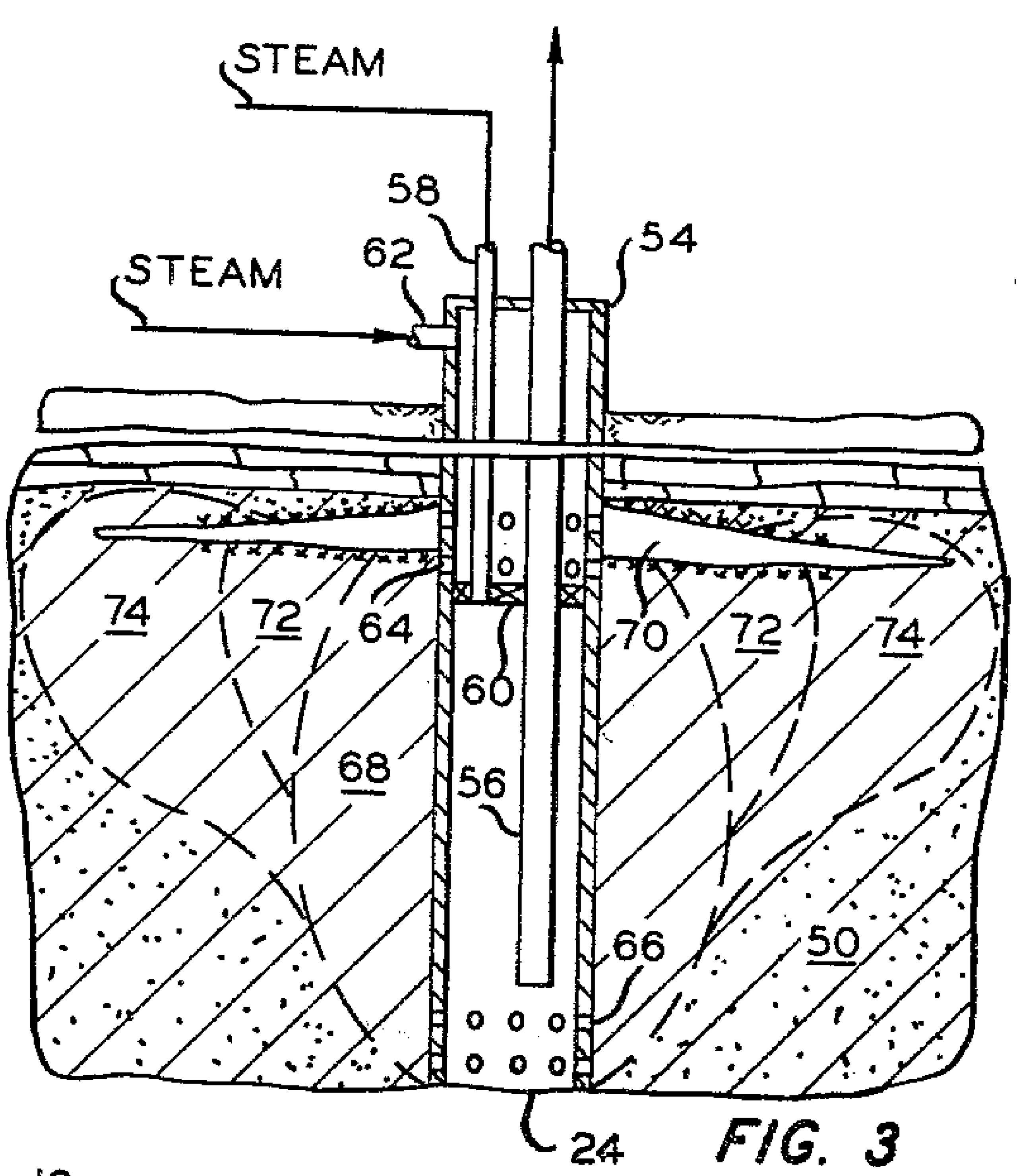

FIG. 3

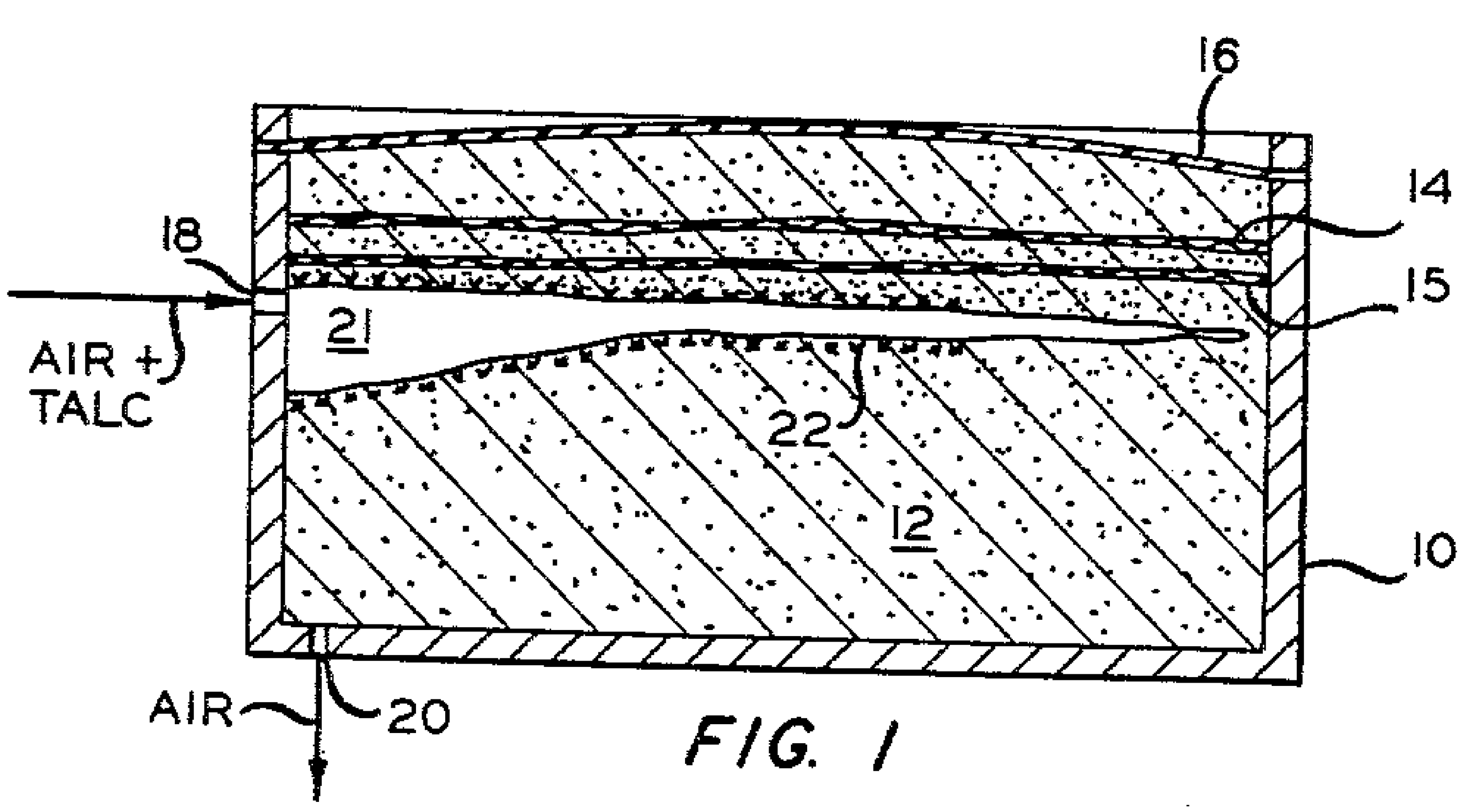

FIG. 1

INVENTOR.
H. W. PARKER

BY Hudson & Young

ATTORNEYS

United States Patent Office 3,180,414
Patented Apr. 27, 1965

3,180,414

PRODUCTION OF HYDROCARBONS BY FRACTURING AND FLUID DRIVE

Harry W. Parker, Bartlesville, Okla., assignor to Phillips Petroleum Company, a corporation of Delaware

Filed Mar. 27, 1961, Ser. No. 98,351
18 Claims. (Cl. 166—29)

This invention relates to a method of fracturing a permeable section of a subterranean stratum containing hydrocarbon material and to the production of hydrocarbons from such a stratum utilizing said method of fracturing.

The production of hydrocarbons from a carbonaceous stratum by the single well method is advantageous in that it requires less equipment and would be more economical if production could be made to reach out into the production zone to appreciable depths. However, this type of production has been limited to a small annular zone around the well, particularly in impermeable strata such as shale and heavy tar sand. The usual technique comprises heating the borehole within the stratum with steam or other hot gas, or with electrical or gas-fired heaters whereby the heavy hydrocarbon material in the wall of the well is rendered less viscous and produced thru tubing extending to the bottom of the well. This leaves a permeable zone in the well wall from which the hydrocarbon has been retorted. The production may be extended farther into the stratum by inserting a packer in the well between the tubing and the wall of the well intermediate the top and bottom of the stratum and then forcing steam or other hot fluid into the stratum on one side of the packer and driving produced hydrocarbons into the well on the opposite side of the packer. This technique soon reaches a limit in production because the hot fluid bypasses the deeper section of the stratum beyond the permeable zone.

In producing from a single well in a permeable stratum, the problem is similar, it being difficult to reach into the stratum to any substantial depth with the heating fluid.

Accordingly, it is an object of the invention to provide an improved method of fracturing a section of permeable subterranean stratum which facilitates improved production of hydrocarbons from the stratum. Another object is to provide an improved process for producing hydrocarbons thru a single well penetrating a carbonaceous stratum. A further object is to facilitate the production of hydrocarbons from both permeable and impermeable strata using a one-well technique and the fracturing method of the invention. Other objects of the invention will become apparent upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises fracturing a permeable section of a carbonaceous stratum by applying fluid pressure on a selected restricted area of a well wall until the stratum is fractured radially outwardly on a plane generally perpendicular to the well axis, injecting powdered material as a plugging agent with the injected fluid while maintaining flow of the fluid thru the permeable zone around a packer into the well bore and out one of the tubing and the annulus between the tubing and the well wall so that the plugging agent progressively plugs the porous wall of the fracture from the well wall outwardly into the stratum, and thereafter terminating the injection of plugging agent while continuing the injection of fracturing fluid so that the fracture is extended deeper into the stratum. This technique is applicable to a permeable stratum and to a permeable zone surrounding a well in an otherwise impermeable tar sand or shale stratum.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURE 1 is a longitudinal cross section

of a laboratory simulation of a permeable sand stratum; FIGURE 2 is a vertical section thru a well in a permeable tar sand illustrating one form of the invention; FIGURE 3 is a similar vertical cross section thru a well penetrating an impermeable tar sand illustrating a second embodiment of the invention; and FIGURES 4 and 5 are similar vertical cross sections thru single wells illustrating other embodiments of the invention.

Referring to FIGURE 1, a Lucite box 10, 12 inches long, 7½ inches high, and ¼ inch wide or thick was filled with Ottawa sand 12 of 20 to 40 mesh. Two thin layers of glass wool 1/32 to 1/16" in thickness were packed in the sand and are designated 14 and 15. A rubber tube or diaphragm 16 was anchored at the ends in the box and stretched tight on top of the sand so as to fit the sides of the box tightly. The glass wool layers serve to simulate a consolidated overburden found in field application. Air was injected at a rate of 0.5 s.c.f.m. thru opening 18 in one end of the box. Talc was added intermittently to the air stream and the sand pack was tapped lightly. Tapping the apparatus had the effect of extending the fracture, thereby reducing the injection pressure required from about 20 to 10 p.s.i.g. This was desirable in order to avoid imposing higher injection pressure on the plastic apparatus. In field operations, however, injection pressure can readily be increased until fracturing occurs, normally. Air was allowed to egress thru opening 20 in the bottom of the box.

The arrangement shown simulates injecting thru a borehole wall at 18 and producing the injected gas thru the borehole wall at a lower level as at 20, the intervening wall being impermeable or blocked off by means of a packer. The fracture 21 was observed visually thru the Lucite box with the powdered material 22 coating the walls of the fracture except at its extreme inner end. Thus it can be seen that the dust or powder injected with the air forms a coating on the fracture walls or plugs the pores therein so that pressure builds up in the fracture and extends the same deeper into the sand, since this is the only escape for the gas.

Referring to FIGURE 2, a borehole or well 24 penetrates a permeable stratum 26 and is cased to the bottom of the stratum by casing 28. A tubing string 30 extends thru the well head to the lower section of the stratum. Casing 28 is perforated near the bottom by holes 32 and near the top of the stratum by holes 34. A packer 36 is set just below perforations 34 to close off the well annulus. A line 38 connects with tubing 30 for recovery of produced fluids and a line 40 connects with casing 28 at the well head for injection of fracturing fluid, plugging agent, and heating fluid. Powdered plugging agent is introduced to line 40 thru line 42.

In operation with the apparatus shown in FIGURE 2, any suitable fracturing fluid such as air, steam, oil, water or a mixture thereof is injected thru line 40 into the well annulus so that it enters the stratum thru perforations 34 by building up fracturing pressure on the stratum opposite perforations 34 until a fracture 43 is produced extending horizontally into the stratum. At this point, leakage of fluid thru the stratum to perforations 32 reduces the pressure in the fracture to below fracturing level. Powdered plugging agent, such as talc, is introduced into the fluid being injected whereby it deposits on the wall of the fracture progressively from the casing outwardly into the stratum so as to block or greatly diminish flow of the injected fluid into the stratum along the fracture. Pressure again builds up to the required fracturing pressure and the fracture is then extended deeper into the stratum at which time the injected fluid can again escape from the fracture thru the stratum back to perforations 32 in sufficient volume to reduce the pressure in the fracture to less than fracturing pressure. Of course, pressure could be built up at this point to further extend the fracture by increasing the injection rate sufficiently. However, this would defeat the method of the invention whereby the walls of the fracture are rendered impermeable out to a section of the stratum remote from the well. Instead, powdered plugging agent is again injected so as to plug the walls of the fracture so that the pressure again builds up, with about the same injection rate, to extend the fracture deeper into the stratum. The step of periodically injecting powdered plugging agent while injecting gas or other fracturing fluid has the effect of extending the fracture farther into the formation from the well, rendering the walls of the fracture impermeable so that the flow of gas into the stratum is limited to the most remote or tip section of the fracture walls and back to the well thru the perforations on the opposite side of the packer from the fracture.

When the fracture is extended into the stratum to the desired depth and the same comprises a plugged wall section 44 and a permeable wall section 46, hot fluid is injected thru line 40 and the well annulus into the fracture so that this hot fluid passes into the stratum thru section 46 of the fracture and back to the well thru perforations 32. In this manner the hot fluid heats the intervening stratum and lowers the viscosity of hydrocarbon material therein so as to flush or transport the same into the well for which it is produced thru tubing 30 and line 38 by conventional means.

The hot fluid is preferably steam, but it may comprise hot water and steam, hot air, hot combustion gas, or other hot fluid. The temperature of the hot fluid is preferably in the range of 250–500° F.

When utilizing hot air, combustion of the hydrocarbon material in the stratum may be initiated so that a combustion front is driven thru the stratum, thereby producing hydrocarbon material from the hot stratum.

Further production can be effected from the section of stratum intermediate the produced section and the well adjacent the plugged wall section of the fracture by pulling tubing 30 and perforating casing 28 at various levels intermediate packer 36 and perforations 32, and plugging perforations 32 so that the injected hot fluid must pass back to the well thru the newly formed perforations after rerunning tubing 30 and resetting packer 36.

Another method which may be utilized to continue the production comprises plugging the fracture walls, as shown, with a water soluble inorganic salt or with sugar and dissolving this plugging agent, after producing thru wall section 46, by injecting water thru perforations 34 and flushing the dissolved material into the most permeable section of the stratum adjacent permeable wall 46. This has a tendency to decrease the permeability of the wall section 46 and adjacent stratum while unplugging wall section 44 so that production of the stratum lying below wall section 44 may be readily effected by hot fluid injection.

It is also feasible to plug the walls of the fracture with a combustible material such as sugar, powdered wood, etc. and burn out the plugging agent with hot air after producing the section of stratum intermediate wall section 46 and perforations 32.

The fracturing technique described herein is effective in extending the fracture to remote areas of the stratum as far as 1500 to 2000 feet, thereby greatly increasing the producible area around a single well.

Referring to FIGURE 3, an impermeable tar sand 50 is penetrated by a well 24 which is cased by casing 54 to the bottom of the stratum. Well tubing 56 extends thru the well head to a low section of the stratum. A steam injection conduit 58 also extends thru the well head and thru a packer 60 between the tubing and casing. Another steam injection line 62 connects with casing 54. The casing is perforated adjacent the upper portion of the stratum at 64 and peforations 66 are provided adjacent the bottom of the stratum.

In operating with the arrangement shown in FIGURE 3, steam is injected thru line 58 so as to heat the stratum adjacent casing 54 and cause fluidized hydrocarbons to flow into the bottom of the well thru perforations 66. As heating is continued and the adjacent stratum becomes permeable, steam is also injected thru line 62 so that it eventually enters perforations 64 and the contiguous stratum, thereby flushing additional hydrocarbon material into the bottom of the well. When this method of production has been continued until the ratio of steam to hydrocarbon being produced thru tubing 56 reaches a maximum value of 4,000 to 5,000 pounds of steam per barrel of oil and an egg shaped zone illustrated as 68 has been produced, the injection of steam thru line 58 is terminated and a fracturing fluid, which may be steam, is injected thru line 62 and perforations 64 at a rate sufficient to build up fracturing pressure to create fracture 70. After creation of fracture 70, injection of steam or other hot fluid thru perforations 64 is resumed or continued so as to produce additional hydrocarbon material from the stratum adjacent the fracture. When the production of hydrocarbons, as measured by the ratio of steam to hydrocarbon, reaches the maximum limit, powdered plugging agent is injected into the fracture as described hereinbefore so as to plug the walls of the fracture a portion of the distance out to the leading edge thereof and, particularly, as far as the permeable wall extends. In other words, the wall of fracture 70 extending out as far as the boundary of zone 68 is plugged. Control of this is readily effected by observing the injection pressure at a given rate of injection and terminating the injection of plugging agent when the pressure rises rather sharply. During this time the wall of the fracture adjacent the section 72 is impermeable and, therefore, no gas is passing thru this section so that the wall of the fracture adjacent the same does not receive plugging agent. When the pressure rises sharply and introduction of plugging agent is terminated, continued injection sends the fracture deeper into the stratum and the hot fracturing fluid (steam, hot air, etc.) transmits heat to section 72 and gradually flushes hydrocarbon from this section beginning at the thin secton nearest the well or zone 68 and progressively moves outwardly to the thicker section. When section 72 has been produced, the step of plugging and fracturing is repeated so as to produce a section 74 deeper in the stratum.

The lowermost section of the stratum may be produced in a similar manner by fracturing thru perforations 66 and injecting hot fluid and plugging agent alternately in the same manner as is practiced in fracture 70.

In the foregoing embodiments of the invention, the casing is extended thru the stratum to be produced. FIGURE 4 illustrates another arrangement wherein the casing 28 extends thru the stratum 26 and packer 36 is set on tubing 30 midway of the stratum.

FIGURE 5 illustrates an arrangement of tubing 30 and a pair of packers 36 and 37 which are set against the wall of the borehole and directly on the formation, casing 28 extending only to the upper boundary of stratum 26. By fracturing stratum 26 with fracturing fluid injected thru tubing 30 to produce fracture 43, the produced fluids are forced into the well above packer 36. It is also feasible to fracture the stratum, with this arrangement, by injecting fracturing fluid thru the annulus and into the stratum above packer 36 so that production is effected by driving the produced hydrocarbons into the well below packer 37 and out the tubing.

Plugging agents include any powdered materials such as talc, clay, inorganic salts, starch, sugar, powdered wood, etc.

To make the injected layer of plugging agent more stable and less permeable it is feasible to inject a powdered material which melts at the normal operating temperature of the process by means of temporarily reducing the temperature of the injected gas stream. This low melting point material then melts and wets the plugging agent thereby consolidating it and rendering it less permeable. Mixtures of common inorganic salts such as calcium chloride and sodium chloride having a melting point of 930 F. and a mixture of sodium chloride and magnesium chloride having a melting of about 800 F. may be utilized. A single salt such as zinc chloride with a melting point of 500 F. may be employed. Any material which melts at reasonably elevated temperatures and is stable at shale retorting temperatures is operable. Sugar or any similar material which melts and then carbonizes can be utilized alone or as means of consolidating the powdered plugging agent.

Another plugging agent comprises calcium oxide which can be contacted with carbon dioxide after the layer is formed on the wall of the fracture so as to convert the oxide to carbonate with an approximate 20 percent increase in volume. This increase in volume has an added plugging effect in the pores of the stratum.

Certain modifications of the invention will become apparent to those skilled in the art and the illustrative details disclosed are not to be construed as imposing unnecessary limitations on the invention.

I claim:

1. A process for producing hydrocarbons from a permeable subterranean carbonaceous stratum penetrated by a well containing a tubing string leading from the bottom of said well thru the well head and forming an annulus with the wall of said well, there being a packer on said tubing string closing said annulus at a selected level in said stratum which comprises injecting a fracturing fluid into a level of said stratum adjacent said selected level thru one of said annulus and said tubing string to fracture said stratum radially at said level; continuing the injection of fracturing fluid at less than fracturing pressure and producing the injected fluid thru the permeable stratum and the other of said annulus and tubing string; while said fluid is being injected into said fracture, dispersing therein a powdered plugging agent which remains solid in said fluid so as to plug the walls of said fracture without filling the fracture; thereafter continuing the injection of said fluid, free of said plugging agent, so as to build up fracturing pressure and extend said fracture farther into said stratum from said well, thereby forming unplugged permeable fracture walls deep in the stratum and providing a fluid flow path back to said well thru the permeable stratum; thereafter passing hot driving fluid thru the permeable stratum between the permeable walls of said fracture and the wall of said well at a level spaced from said fracture so as to drive hydrocarbons therefrom; and recovering resulting production thru one of said tubing string and said annulus.

2. The process of claim 1 wherein said fracture is efrected at an upper level of said stratum by setting a packer between said tubing string and the wall of said well just below said level and injecting said fluid thru said annulus.

3. The process of claim 1 wherein said hot fluid comprises steam.

4. The process of claim 1 wherein said hot fluid comprises water.

5. The process of claim 1 wherein said hot fluid comprises gas.

6. A process for producing hydrocarbons from an impermeable carbonaceous stratum penetrated by a well containing a tubing string leading from the bottom of said well thru the well head and forming an annulus with the wall of said well, which comprises heating said stratum around said well so as to retort hydrocarbons therefrom and form an annular permeable zone in said stratum around said well; setting a packer adjacent one end of said zone between said tubing string and said wall; horizontally fracturing said stratum intermediate said packer and said end of said zone; injecting hot fluid into said fracture so as to retort additional hydrocarbons from the stratum adjacent said one end of said zone; recovering said hydrocarbons from said well thru one of said tubing

and said annulus; thereafter, while said well is open to production, injecting fracturing fluid containing a dispersion of powdered plugging agent into said fracture to plug the walls of said fracture progressively toward the leading edge thereof; terminating injection of said agent before plugging of the entire fracture walls is effected; resuming the injection of hot fluid into said fracture so as to produce additional hydrocarbons; thereafter injecting fracturing fluid into said fracture so as to extend the fracture farther into said stratum; and thereafter repeating the step of injecting hot fluid to produce additional hydrocarbons from said stratum.

7. The process of claim 6 wherein said hot fluid is steam.

8. The process of claim 6 wherein said hot fluid is hot water.

9. The process of claim 6 wherein said hot fluid is hot air.

10. The process of claim 6 wherein superheated steam is injected as said fracturing fluid and as said hot fluid.

11. The process of claim 6 wherein air is injected as said fracturing fluid and as said hot fluid.

12. The process of claim 6 using superheated steam as fracturing fluid and hot fluid and talc as plugging agent.

13. A process for fracturing a permeable section of a subterranean stratum around a borehole penetrating same comprising providing a tubing string extending into said stratum from ground level having a packer thereon sealing the annulus between said tubing string and the wall of said borehole at a selected level of said stratum; applying fluid fracturing pressure on the wall of said borehole adjacent said selected level so as to effect a fracture extending radially from said borehole; flowing fracturing fluid into said fracture and thru said permeable section back to said borehole on the opposite side of said packer from said fracture; thereafter introducing powdered material into said fluid which remains solid in said fluid as a plugging agent so as to cause plugging in the fracture walls without filling the fracture, pressure build-up in said fracture, and extension of the fracture deeper into said stratum; and terminating introduction of said material into said fracture before fracturing ceases so that the walls of said fracture adjacent the more remote boundaries thereof from said borehole are unplugged, thereby providing a selective path for injected fluids into said stratum thru said more remote boundaries.

14. A process for fracturing a permeable section of subterranean stratum around a borehole penetrating same comprising the steps of:

(1) providing a tubing string extending into said stratum from ground level having a packer thereon sealing the annulus between said tubing string and the wall of said borehole at a selected level of said stratum;

(2) applying gas pressure in the wall of said borehole adjacent said selected level with a substantially inert gas so as to effect a fracture extending radially from said borehole;

(3) continuing the application of said gas pressure to said fracture so as to force gas into said formation thru the fracture walls;

(4) dispersing a dry powdered solid in the gas passing into said fracture so as to plug the fracture walls without filling the fracture; and

(5) thereafter continuing the pressure of solids-free substantially inert gas in said fracture as in step 3 so as to extend same deeper into said stratum and provide unplugged fracture surfaces remote from said borehole.

15. The process of claim 14 wherein said gas is air.

16. The process of claim 15 wherein said last solid comprises essentially a mineral insoluble in oil.

17. The process of claim 14 wherein said gas is air and said solid is talc.

18. The process of claim 14 including the step of:

(6) thereafter, injecting a hot driving fluid into said fracture and into said stratum thru the unplugged walls thereof remote from said well to drive hydrocarbons into said well;

(7) and producing said hydrocarbons thru said well.

References Cited in the file of this patent

UNITED STATES PATENTS

1,816,260	Lee	July 28, 1931
2,818,118	Dixon	Dec. 31, 1957
2,819,761	Popham	Jan. 14, 1958
3,044,550	Eilers	July 17, 1962
3,046,222	Phansalker et al.	July 24, 1962
3,050,119	Fast et al.	Aug. 21, 1962

FOREIGN PATENTS

791	Great Britain	Mar. 15, 1872

Disclaimer

3,180,414.—*Harry W. Parker*, Bartlesville, Okla. PRODUCTION OF HYDROCARBONS BY FRACTURING AND FLUID DRIVE. Patent dated Apr. 27, 1965. Disclaimer filed Apr. 1, 1965, by the inventor; the assignee *Phillips Petroleum Company* concurring.

Hereby enters this disclaimer to all of the claims of said patent.

[*Official Gazette July 6, 1965.*]