

May 10, 1960

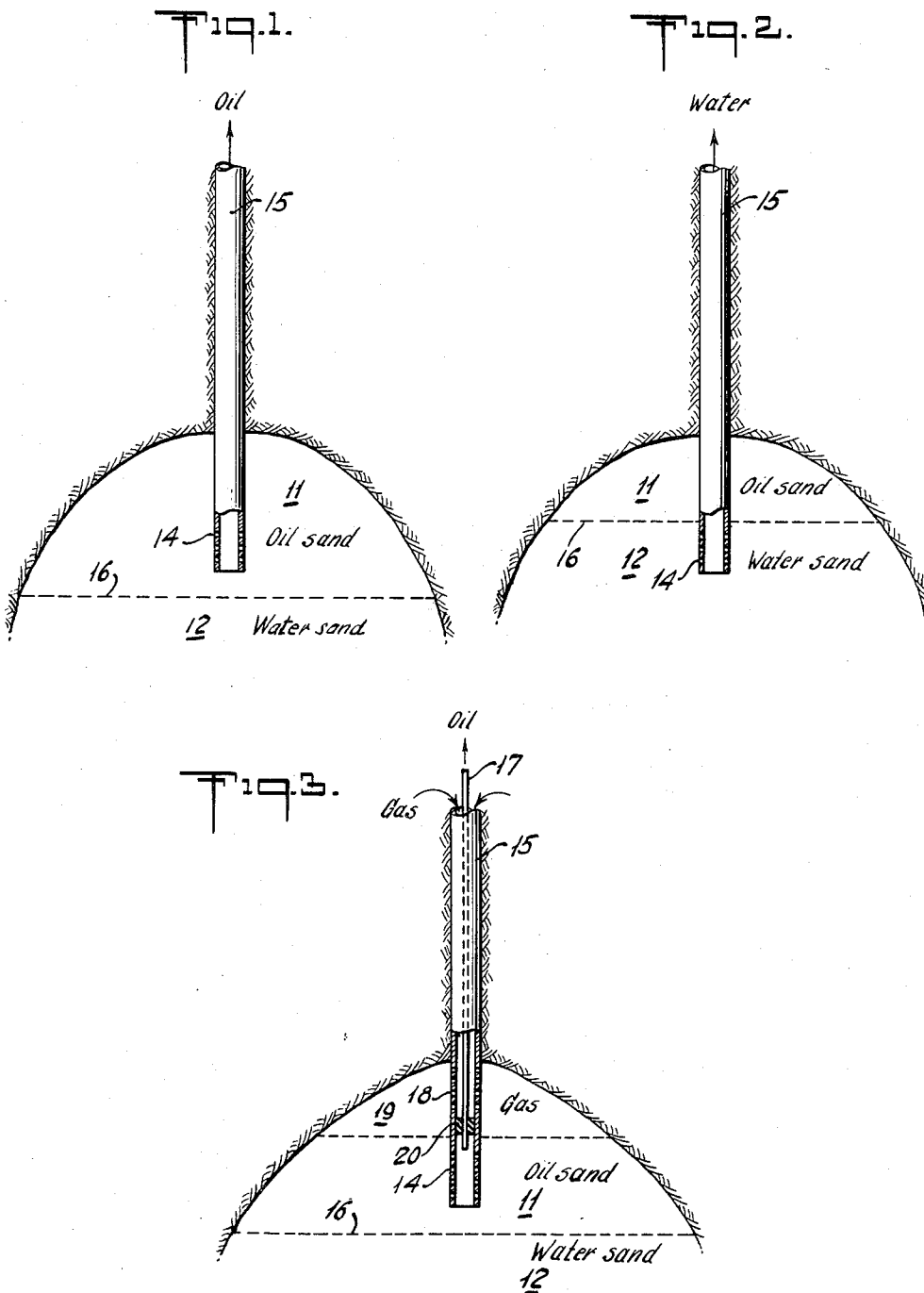
J. C. ALLEN

2,936,030

METHOD OF PRODUCING PETROLEUM FROM A WATER DRIVE RESERVOIR

Filed March 28, 1957

2 Sheets-Sheet 1



May 10, 1960

J. C. ALLEN

2,936,030

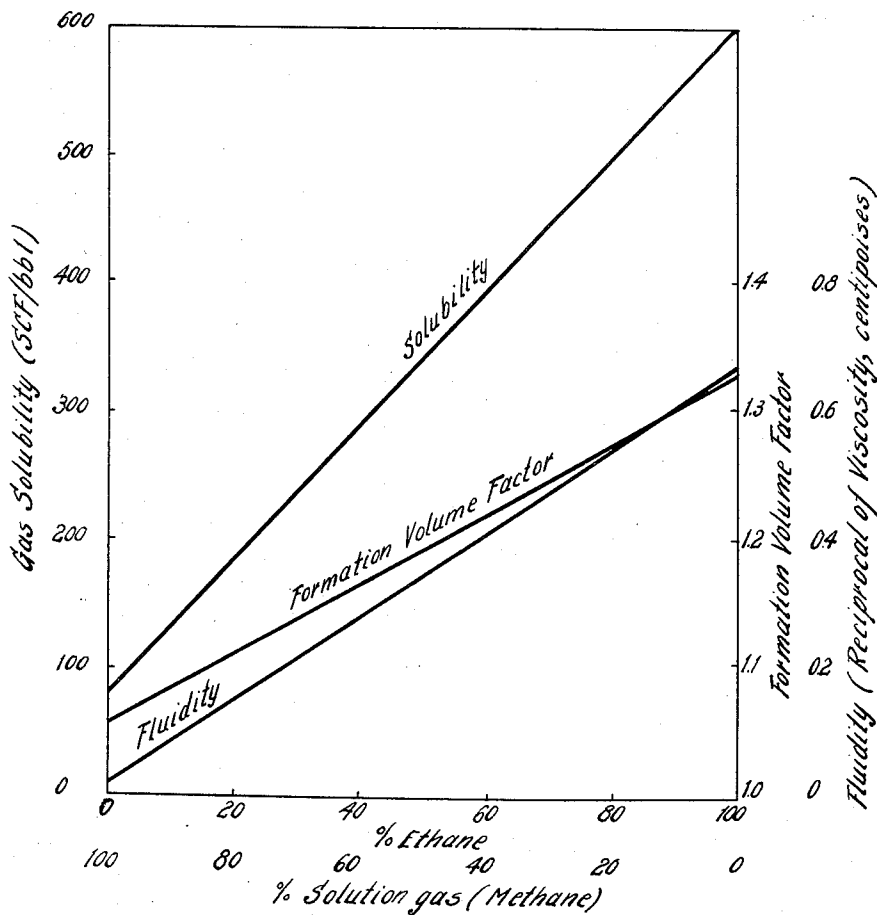
METHOD OF PRODUCING PETROLEUM FROM A WATER DRIVE RESERVOIR

Filed March 28, 1957

2 Sheets-Sheet 2

Fig. 4.

*Solubilities of Methane and Ethane
in a viscous, California crude at 843 psia & 127°F*



1

2,936,030

METHOD OF PRODUCING PETROLEUM FROM A WATER DRIVE RESERVOIRJoseph C. Allen, Bellaire, Tex., assignor to Texaco Inc.,
a corporation of Delaware

Application March 28, 1957, Serial No. 649,193

1 Claim. (Cl. 166—42)

This invention relates to recovery of petroleum from underground reservoirs. More particularly, this invention relates to a method of producing petroleum from an underground petroleum-producing formation or reservoir which is under the influence of an active water drive. In accordance with one embodiment this invention is particularly applicable to the production of liquid petroleum from a petroleum producing reservoir which contains substantially only liquid petroleum (under formation conditions of temperature and pressure) wherein said petroleum producing reservoir is in contact with, overlays and under the influence of an active water-producing formation or aquifer.

In the production of petroleum from underground reservoirs which are under the influence of an active water drive reservoir pressure depletion is generally not a problem, i.e., formation pressure within the petroleum-producing formation remains substantially unchanged as the petroleum-producing formation is depleted. One important difficulty, however, in the production of petroleum from underground formations under the influence of an active water drive, is that all too frequently water invasion from the water-producing formation or aquifer underlying the petroleum-producing formation prematurely occurs with the result that production of petroleum from the petroleum-producing formation because of excessive production of water becomes uneconomic, leaving behind in the reservoir a substantial amount of petroleum. The above-indicated problem more frequently presents itself when the petroleum-producing formation is not provided with a gas cap and is substantially saturated with liquid petroleum, especially viscous liquid petroleum. In the case of production of viscous crudes the relatively high drawdown pressures required to effect movement of the viscous crude into the production well bore are of such magnitude as to give rise frequently to water coning. In other circumstances high permeability stringers or fingers may exist within the petroleum-producing formation with the result that when production of liquid petroleum is attempted water fingers prematurely invade the petroleum-producing formation via the high permeability stringer (high permeability with respect to water) with the result that uneconomic amounts of water are produced and/or the producing sands immediately surrounding the well bore in the zone of production become watered out and severely restricted the flow of liquid petroleum therethrough.

Accordingly it is an object of this invention to provide an improved method for the recovery of petroleum from an underground formation containing the same.

Another object of this invention is to provide a method for increasing the ultimate recovery of petroleum from a petroleum-producing formation which is in contact with and overlays an active water-producing formation or aquifer.

Still another object of this invention is to provide a method of producing a liquid petroleum reservoir which is under the influence of an active water drive.

2

How these and other objects of this invention are accomplished will become apparent in the light of the accompanying disclosure made with reference to the accompanying drawing wherein:

Figs. 1, 2 and 3 are schematic diagrams illustrative of a practice of this invention as applied to a petroleum-producing formation which is positioned above and in contact with an active water-producing formation, and wherein

Fig. 4 graphically illustrates the advantages obtainable and the benefits derivable from a practice of this invention.

In accordance with this invention a petroleum-producing formation, such as an underground formation containing substantially only liquid petroleum under the formation conditions of temperature and pressure, wherein the petroleum-producing formation is in direct contact with, overlays and is under the influence of an active water-producing formation, is produced to recover an increased amount of petroleum therefrom by introducing into the upper portion of the petroleum-producing formation a gas, such as natural gas, to create within the petroleum-producing formation a gas cap. After the creation of an artificial gas cap within the petroleum-producing formation petroleum is produced from said formation in an intermediate portion thereof between said gas cap and the underlying water-producing formation or underlying oil-water interface. From time to time as the petroleum-producing formation is depleted by the production of petroleum therefrom and the oil-water interface tends to rise within the petroleum-producing formation additional gas is introduced into the upper part of the formation to enlarge the artificially created gas cap, thereby tending to displace more petroleum from the upper portion of the formation to the intermediate portion of the formation wherein it is produced and/or at the same time tending to move the oil-water interface downwardly or to maintain the oil-water interface substantially static within the petroleum-producing formation or substantially completely within the underlying water-producing formation. By operating in the above-indicated manner it is possible to substantially completely deplete the underground petroleum-producing formation without the production of unduly large or uneconomic amounts of water. Still further, by operating in the above-indicated manner, such as by creating an artificial downwardly moving gas cap, it is possible to substantially completely produce liquid petroleum from an underground petroleum-producing formation at a certain horizon or zone of production therein and at the same time to overcome or to inhibit water coning or water fingering from the underlying water-producing formation.

Referring now to the accompanying drawing which schematically illustrates a practice in accordance with this invention, Fig. 1 schematically illustrates a petroleum or oil-producing formation 11 which is in contact with and overlays an active aquifer or water-producing formation 12. As petroleum is produced from the petroleum-producing formation 11 via perforations 14 in production casing 15 the oil-water interface 16 tends to rise. Eventually upon continued production, as illustrated in Fig. 2 of the accompanying drawing, the oil-water interface 16 rises to a level such that perforations 14 are substantially beneath the oil-water interface 16 with the result that substantially only water is produced via perforations 14. When this condition is obtained the well is sometimes referred to as "gone to water."

In accordance with the practice of this invention, however, as illustrated in Fig. 3 of the drawing, there is introduced into the upper portion 19 of petroleum-producing formation 11 a suitable gas, such as natural gas, via

3

the annulus between production casing 15 and production tubing 17 and perforations 18, packer 20 being inserted beneath the lowermost perforation 18 and above the uppermost perforation 14 and within the annular space between production casing 15 and production tubing 17. When a sufficient amount of gas is thus introduced, as illustrated in Fig. 3, into the upper portion of petroleum-producing formation 11 there is created within upper portion 19 thereof an artificial gas cap which displaces or otherwise tends to force downwardly petroleum from the upper portion of the petroleum-producing formation toward the intermediate portion thereof in the zone of the formation surrounding perforations 14. At the same time the oil-water interface 16 is displaced to a level substantially below the lowermost perforation 14 so that it is possible to produce petroleum from petroleum-producing formation 11 without concomitant excessive or uneconomic amounts of water.

In accordance with one feature of the practice of this invention as petroleum is produced from petroleum-producing formation 11 gas is injected into the upper portion thereof via perforations 18 so as to maintain the oil-water interface 16 at a level beneath the lowermost perforation 14 within the lower portion of petroleum-producing formation 11 and preferably at least at about the top of water-producing formation 12.

As previously indicated, any gas is suitable in the practice of this invention for injection into the upper portion 19 of the petroleum-producing formation in order to create artificially a gas cap therein. Gases which are suitable in the practice of this invention include natural gas, such as a gas comprised essentially of or containing a major amount of methane, carbon dioxide, air, combustion gases such as a gaseous mixture of carbon dioxide, nitrogen, water and the like, sometimes including carbon monoxide and small amounts of oxygen. Gases particularly useful in the practice of this invention include the normally gaseous hydrocarbons, such as ethane, ethylene, propane, propylene, isobutane, n-butane, isobutylene and the like.

The practice of this invention is particularly useful for the production of relatively viscous crudes, such as crudes having an in place viscosity in the range 25-300,000 Saybolt Universal seconds at 80° F. In the production of liquid petroleum from a petroleum-producing formation, particularly in the production of viscous crudes from a petroleum-producing formation which initially comprised only liquid petroleum it is preferred in accordance with the practice of this invention to employ a normally gaseous hydrocarbon, such as methane, ethane or propane or mixtures thereof as the gas which is injected into the upper portion of the petroleum-producing formation to artificially create a gas cap therein. The use of ethane as the gas is particularly valuable. Still in accordance with the practice of this invention it is desirable to maintain the gas injected into the upper portion of the petroleum-producing formation at a temperature therein above the critical temperature of the injected gas. This is readily accomplished, particularly in those petroleum-producing formations which have a formation temperature greater than the critical temperature of the gas injected therein. In those instances where the formation temperature is below the critical temperature of the gas introduced therein some means must be provided for maintaining the injected gas at a temperature above its critical temperature. This can be done by means of an electric heater and the like or by the continued circulation of hot injected gases through the upper portion of the formation, hot gases being continuously supplied and relatively cool gases being continuously withdrawn from the formation.

Ethane, preferably alone, or in a admixture with methane and/or propane, is the preferred normally gaseous hydrocarbon which is injected into the upper portion of petroleum-producing formation 11 to create arti-

4

ficially a gas cap therein. The advantages of employing ethane in the practice of this invention are apparent in the light of the following tests which involve investigations of normally gaseous hydrocarbons together with changes in the physical properties of a viscous stock tank oil, actually a California San Ardo crude. This particular crude in place contains substantially pure methane dissolved therein. The solubility of methane within this crude under formation conditions of temperature and pressure (127° F. and 843 p.s.i.a.) amounts to about 78 standard cubic feet (s.c.f.) per barrel of crude oil. However, under these same conditions of temperature and pressure this highly viscous crude dissolved about 600 s.c.f. of ethane.

Referring now to accompanying Fig. 4 of the drawing, there is graphically illustrated a comparison of the properties of a viscous crude when saturated with its native solution gas (methane) and the same crude when saturated with ethane, the connecting lines in the graphical illustration have been drawn assuming the applicability of ideal gas and solubility laws.

Considering now a condition, such that there is created within the reservoir by the formation therein of an artificial gas cap having a 50-50 methane-ethane composition, the in place crude being originally saturated with respect to methane. As illustrated in Fig. 4, 340 cubic feet of a gas having the composition 50-50 methane-ethane would be soluble in one barrel of the in place viscous crude. However, since the in place crude originally contained only 78 s.c.f. methane and since only an equivalent amount of ethane would be required to make a 50-50 soluble gas composition, actually only 150 cubic feet of methane should be dissolved. This means, therefore, as Fig. 4 clearly indicates, that the ethane injection actually causes an increase in the solubility of methane in the in place crude. This increase in methane solubility is due to the fact that distribution coefficients or equilibrium "constants" are not true constants but vary with the overall composition of the system.

Fig. 4 also graphically illustrates the marked increase in formation volume factor (swelling) and in place oil fluidity as ethane diffuses into the viscous oil within the formation being treated. The increased swelling and increased fluidity leads to marked increased crude production rates and an increase in ultimate recovery of the in place crude.

In accordance with another practice of this invention it is possible to deplete substantially completely a reservoir of its liquid hydrocarbon content by a combination of operations in accordance with this operation wherein (1) an artificial gas cap is created within the petroleum-producing formation to maintain the oil-water interface at a static low level in the lower portion of the petroleum-producing formation or at least about the top of the water-producing formation so that liquid petroleum can be produced from an intermediate portion of the petroleum-producing formation and (2) by the continued injection, sweeping and removal of the petroleum-producing formation by means of a gas introduced into the upper portion of the petroleum-producing formation to create a gas cap therein so as to vaporize normally liquid petroleum hydrocarbons into the gas cap and eventually recovering the thus vaporized normally liquid petroleum hydrocarbons from the injected sweep gas recovered at the surface. As indicated hereinabove, it is particularly desirable to maintain the injected gas within the petroleum-producing formation at a temperature above the critical temperature of the injected gas or gaseous admixture. This is desirable in order to avoid the condensation of the injected gas within the formation undergoing treatment since it has been observed that better commingling or admixing of the injected gas with the in place crude, particularly when the in place crude is a viscous crude, is obtained when the injected gas is maintained in the vaporous or gaseous state.

5

Although emphasis in this disclosure has been placed upon a one well system wherein the same well bore is employed to effect gas injection and recovery of produced crude containing injected gas dissolved therein, it will be apparent to those skilled in the art in the light of this disclosure that the practice of this invention is readily adaptable to a multiple well system employing at least one injection well and at least one production well, the injection well being employed to introduce a normally gaseous hydrocarbon into the formation containing a viscous crude to be recovered and a production well being employed to recover crude oil and/or the sweep gases containing normally liquid petroleum hydrocarbons vaporized thereinto.

Further, the practice of this invention is suitable as a remedial treatment for a well which has gone to water, i.e., useful for lowering the oil-water interface with the producing formation. This invention may be practiced continuously or intermittently as the operator may desire. Generally before the practice of this invention is applied to a producing formation it is desirable to attain substantially equilibrium conditions within the formation undergoing treatment. Equilibrium conditions can usually be attained within a reasonable period of time by shutting-in the well, i.e., halting production of petroleum therefrom immediately prior to treatment.

As will be apparent to those skilled in the art in the light of the foregoing disclosure many changes, substitutions and alterations are possible without departing from the spirit or scope of this invention.

I claim:

In the production of petroleum via a well bore from an intermediate portion of an underground petroleum-producing formation which contains substantially only liquid petroleum under the formation conditions of temperature and pressure and which is in contact with and underlies an impermeable formation and which is also in contact with, overlays and under the influence of an active water-producing formation wherein petroleum is produced via said well bore from said intermediate portion

6

of said petroleum-producing formation with the result that water from said water-producing formation moves upwardly into the lower portion of said petroleum-producing formation, displaces petroleum therefrom and invades said intermediate portion of said petroleum-producing formation so that eventually substantially only water is produced from said intermediate portion of said petroleum-producing formation the method of increasing the recovery of petroleum from said petroleum-producing formation which comprises, when said water from said water-producing formation has begun to invade said intermediate portion of said petroleum-producing formation wherein said petroleum is produced and while continuously producing petroleum from said intermediate portion of said formation, introducing via said well bore into the upper portion of said petroleum-producing formation a sufficient amount of a gas to create within the upper portion of said petroleum-producing formation as a gas cap between the aforesaid impermeable formation and said intermediate portion of said petroleum-producing formation a zone substantially saturated with said gas and to displace the aforesaid liquid petroleum from the upper portion of said petroleum-producing formation downwardly toward said intermediate portion of said formation and to displace the water which has begun to invade said intermediate portion and said lower portion of said petroleum-producing formation downwardly toward said water-producing formation, said gas cap substantially completely occupying said upper portion of said petroleum-producing formation between said impermeable formation and said intermediate portion of said petroleum-producing formation.

References Cited in the file of this patent

UNITED STATES PATENTS

2,258,614	Kendrick	Oct. 14, 1941
2,788,855	Peterson	Apr. 16, 1957

FOREIGN PATENTS

696,524	Great Britain	Sept. 2, 1953
---------	---------------	---------------