Oct. 7, 1958 R. H. WIDMYER 2,855,047

PRODUCING PETROLEUM FROM UNDERGROUND FORMATIONS

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Fig. 2.

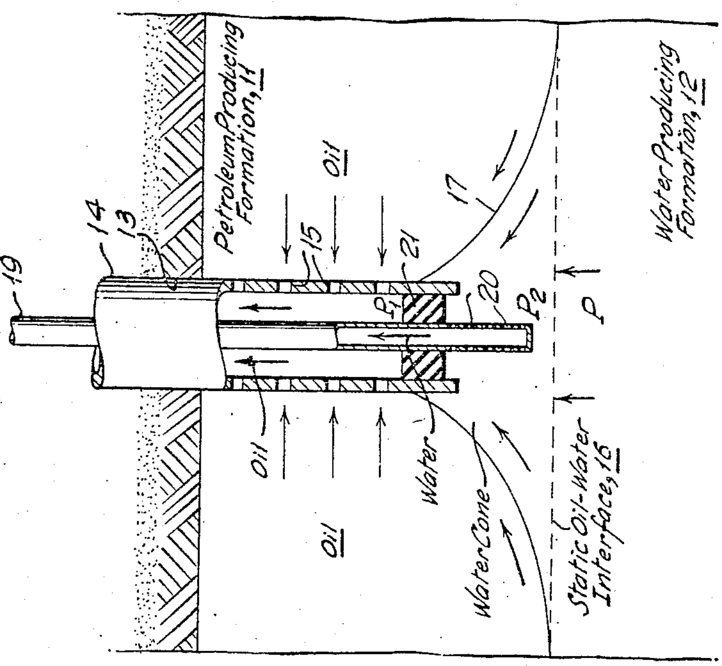

Fig. 1.

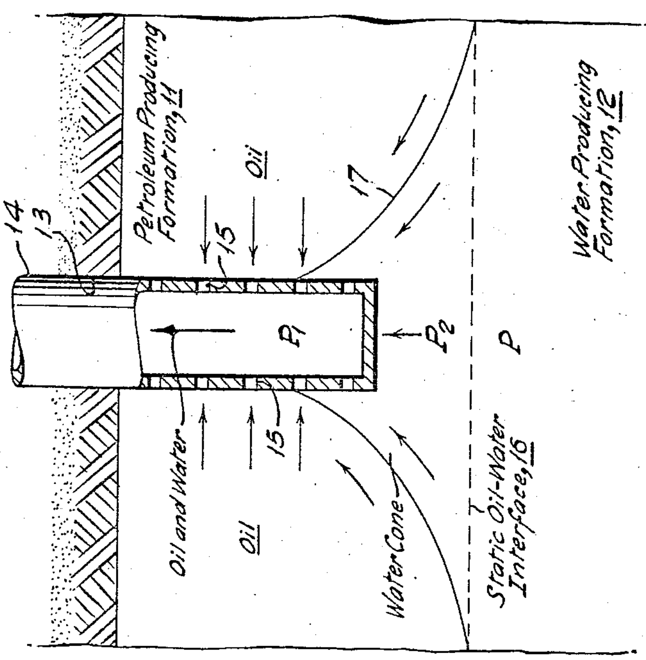

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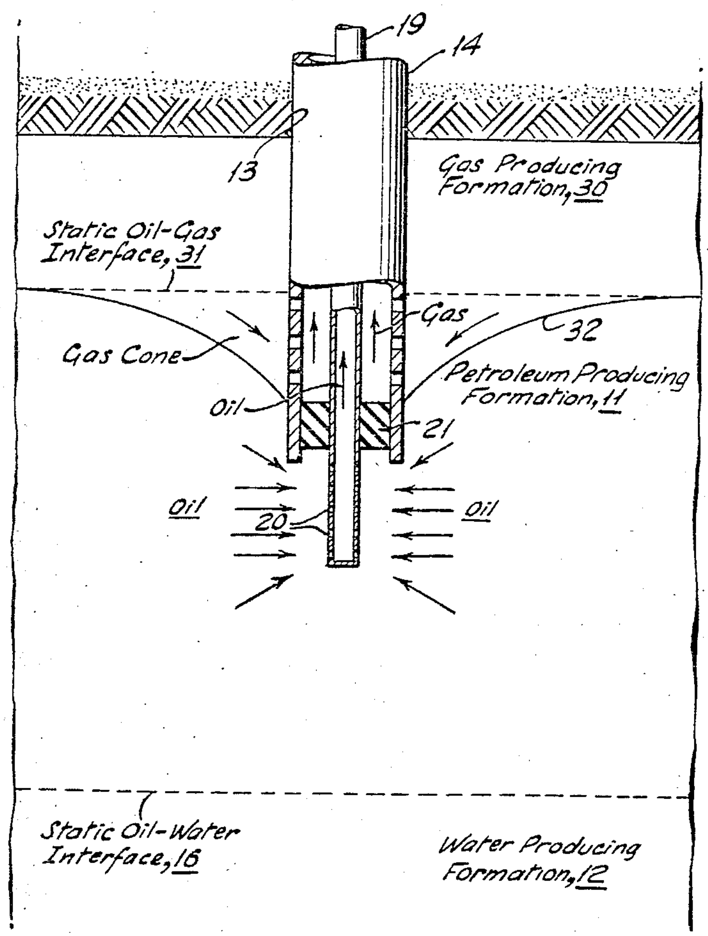
Fig. 3.



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PRODUCING PETROLEUM FROM UNDERGROUND FORMATIONS

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4 Claims. (Cl. 166—42)

This invention relates to the production of petroleum hydrocarbons from a subsurface reservoir. More particularly, this invention relates to the production of petroleum hydrocarbons from a subsurface reservoir which is in contact with and overlays a substantially water-saturated formation, or is in contact with and underlies a gas-producing formation, such as a gas cap. Still more particularly, this invention relates to a method for controlling "coning" which sometimes results during the production of petroleum hydrocarbons from a hydrocarbon-producing formation which overlays a water-saturated, water-producing formation, or which is located adjacent and beneath a gas-producing formation.

Water coning is a term given to the mechanism underlying the entry of bottom waters into producing wells. Petroleum hydrocarbons are often produced from a porous subsurface formation which overlays a water-saturated, water-producing formation. Under static conditions the water, being of greater density than the hydrocarbons, remains beneath and at the bottom of the hydrocarbon-producing formation. At high rates of production of petroleum hydrocarbons the upper boundary or surface (oil-water interface) of the water-saturated formation rises due to the flow of petroleum hydrocarbons into the well bore which extends into the petroleum-producing formation immediately adjacent and above the water-saturated formation. The rise of water into the petroleum-producing formation and into the well bore represents a dynamic effect in which the upward directed pressure gradings associated with the flow of the hydrocarbons into the producing well bore balance the hydrostatic head of the resulting elevated water column.

Various methods have been suggested heretofore to eliminate or to reduce the water coning phenomenon. These methods have included reducing the well penetration into the petroleum-producing formation so that relatively high oil production rates are possible without at the same time experiencing a relatively increased production of water therewith. Another method which has been suggested is to bottom a producing well into a substantially water-impermeable formation. These indicated methods, however, cannot be successfully employed in all instances to eliminate or reduce water coning. Certain underground petroleum-producing formations are only a relatively few feet in thickness. Accordingly, reducing well penetration into such a formation would unduly restrict the recovery of petroleum hydrocarbons therefrom. Other petroleum-producing formations do not have associated therewith an immediately underlying water-impermeable formation or a formation which can conveniently be rendered relatively water-impermeable.

Gas coning is a term given to the mechanism underlying the entry of gaseous hydrocarbons from the gas cap into the underlying normally liquid hydrocarbon-producing formation during the production of normally liquid hydrocarbons therefrom. To a certain extent gas coning is analogous to water coning. Gasiform hydrocarbons, as present in porous underground formations, are generally

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less viscous and more fluent and mobile than liquid hydrocarbons. When liquid petroleum is produced from an underground reservoir which is adjacent and underlies a porous formation containing gasiform hydrocarbons, the gasiform hydrocarbons being less viscous and more fluent than liquid petroleum, move more readily and easily and accordingly penetrate downwardly into the liquid petroleum-producing formation and tend to displace the liquid petroleum during the production of liquid petroleum therefrom. When production of liquid petroleum is commenced near the bottom of an overlaying gas-producing formation, i. e., in the liquid petroleum-producing formation and near the gas-oil interface, it is possible, particularly when a high rate of liquid petroleum is initially employed, that gas from the overlying gas cap eventually will be produced in substantial quantity along with the produced liquid petroleum due to the downward penetration or coning of the gasiform hydrocarbons into the liquid petroleum-producing formation.

Various methods have been proposed to inhibit or prevent gas coning. For example, it has been proposed to render gas impermeable the gas-oil interface between the upper gasiform hydrocarbon-producing formation and the lower liquid hydrocarbon-producing formation by depositing solid material at the interface. This method, however, as well as other proposed methods, cannot be successfully employed in all instances to prevent or inhibit gas coning.

Accordingly, it is an object of this invention to provide an improved method for the recovery of petroleum hydrocarbons from underground reservoirs.

It is another object of this invention to provide an improved method for the recovery of petroleum hydrocarbons from a petroleum hydrocarbon-producing formation which overlays a substantially water-saturated, water-producing formation, or which underlies a gas cap.

It is still another object of this invention to provide a method of controlling and/or reducing water coning as evidenced by the production of a relatively large amount of water together with the produced petroleum hydrocarbons during the production of petroleum hydrocarbons from a well bore extending into a petroleum-producing formation in contact with an underlying water-producing formation.

Still another object of this invention is to provide a method for controlling and/or reducing gas coning as evidenced by the production of a relatively large amount of gasiform hydrocarbons together with produced liquid petroleum during the production of liquid petroleum from a well bore extending into a liquid petroleum-producing formation in contact with an overlying gas-producing formation.

Yet another object of this invention is to provide an improved method of well completion and well production wherein the well bore extends into a liquid petroleum-producing formation which overlays a water-producing formation, or which underlies a gas-producing formation.

In at least one embodiment of the practice of this invention at least one of the foregoing objects will be achieved.

These and other objects of this invention and how they are accomplished will become apparent with reference to the accompanying drawing wherein:

Fig. 1 schematically illustrates the water coning phenomenon; and

Fig. 2 schematically illustrates a method in accordance with this invention for controlling water coning, and

Fig. 3 schematically illustrates another embodiment of the practice of this invention as applied to the control of gas coning.

Referring now to Fig. 1 of the drawing which schematically illustrates the water coning phenomenon, a subsurface gaseous and/or liquid petroleum-producing formation is indicated at **11**. An immediately underlying substantially water-saturated, water-producing formation is indicated at **12**. A well bore **13** extends into the petroleum-producing formation **11** and is bottomed in the petroleum-producing formation **11** near the water-producing formation **12**, above the static oil-water interface indicated by dashed line **16**. Production casing **14** within well bore **13** is provided with perforations **15** within the petroleum-producing formation **11**. Under static conditions (no petroleum production) or at a relatively low rate of production from the petroleum-producing formation **11** the upper surface of the water-producing formation is located at about the position indicated by dashed line **16**, the oil-water interface. However, at relatively high rates of petroleum production, and because of the upward directed pressure gradients associated with the flow of petroleum into perforations **15**, the water table or oil-water interface rises to an extent that it is balanced by these upward directed pressure gradients. As the water table rises, as indicated by solid line **17**, into formation **11**, the zone of production of petroleum hydrocarbons, water is produced by the lowermost perforations **15** of casing **14**, as indicated. At still greater rates of production from formation **11** the water table continues to rise and there results a greater production of water relative to the amount of produced petroleum. Eventually at high rates of production, or at high well draw-down pressures, substantially only water will be produced. The above-described phenomenon is commonly known as water coning.

Referring now to Fig. 2 of the drawing there is schematically illustrated therein a method according to this invention for controlling and/or reducing the zone of water coning. Where applicable, for reasons of clarity and ease of understanding, the same reference numerals have been employed in Fig. 2 as are employed in Fig. 1. As indicated in Fig. 2, well bore **13**, provided with casing **14**, extends into petroleum-producing formation **11** which overlays water-producing formation **12**. In accordance with the practice of this invention water coning which would result at high rates of production of petroleum hydrocarbons from petroleum-producing formation **11** via perforations **15** of casing **14**, as schematically illustrated in Fig. 1, is controlled and/or prevented by separately producing water from within the petroleum-producing formation in the zone which would be subject to water coning.

As indicated in Fig. 2 of the drawing, the practice of this invention to control water coning is as follows. Casing **14** is provided with production tubing **19**. Tubing **19** is provided with perforations **20** at the lower end thereof in petroleum-producing formation **11** and relatively close to the static oil-water interface **16** and in the zone of the petroleum-producing formation which would be subjected to water coning if the well was produced by conventional method such as is illustrated in Fig. 1. An annular packer **21** effectively seals and closes the annulus between casing **14** and tubing **19** intermediate the lowermost perforation **15** of casing **14** and the uppermost perforations **20** of tubing **19**. When production of petroleum is commenced from petroleum-producing formation **11** the resulting produced oil enters perforations **15** of casing **14** and flows upwardly therein for eventual recovery at the surface. The water which rises in the resulting water cone is separately produced via perforations **20** of tubing **19** and is eventually recovered at the surface for disposal or, if desired, for reinjection into the water-producing formation **12** for pressure maintenance purposes.

By producing water through tubing **19** a pressure differential $\Delta P'$ between P_2, the pressure at the location of water production at about the bottom of tubing **19** in the zone of water coning, and P, the pressure at the static oil-water interface **16**, $\Delta P'=P-P_2$, can be maintained substantially greater than the corresponding pressure differential for the same relative positions for the water coning conditions illustrated in Fig. 1 wherein P_1 represents the pressure at the zone of production at about the bottom of casing **14**. From the above it follows that the pressure differential $\Delta P''$ between P_2 and P_1, $\Delta P''=P_2-P_1$, by producing a well according to the method indicated in Fig. 2, can be made considerably less than the corresponding positions in Fig. 1 wherein water coning is experienced in the absence of separate production of water from within the water cone. Accordingly if $\Delta P''$ is made small enough insufficient pressure is available to extend the water cone well up to the petroleum-producing interval or to the lowermost perforation **15** of casing **14**. $\Delta P''$ can be varied dependent upon P_2 which in turn is dependent upon the water production rate from within the water cone.

It is mentioned that it is not necessary to actually flatten the water cone but only to lower the peak of the cone below the oil-producing interval such as is defined by the perforations **15** of casing **14**. Thus P_1 can be maintained for the desired rate of oil production and the water-producing rate via perforations **20** and tubing **19** so that the oil produced via the annulus between casing **14** and tubing **19** is substantially free of water from the water cone can be experimentally determined and in most instances is dependent upon the individual well conditions and the oil-producing rates desired. As basis for the foregoing it is mentioned that the pressure differential ΔP, the pressure differential between P and P_1, $\Delta P=P-P_1$, for both conditions illustrated in Figs. 1 and 2, is substantially the same, the profile of the oil-water interface (cone) and the oil-producing interval of each being different, as indicated in Figs. 1 and 2.

Referring now to Fig. 3 of the drawing which schematically illustrates one embodiment of the practice of this invention as applied to the control of gas coning, there is schematically illustrated a gas-producing formation or gas-cap **30** which overlies an adjacent oil-producing formation **11**, the static oil-gas interface between formations **30** and **11** being indicated by dashed line **31**. Where applicable, for reasons of clarity and ease of understanding, the same reference numerals have been employed in Fig. 3 as are employed in Figs. 1 and 2.

A well bore **13** penetrates gas-producing formation **30** and petroleum-producing formation **11**. Casing **14** is located within well bore **13**, casing **14** being provided with perforations **15** within the petroleum-producing formation **11** relatively close to the static oil-gas interface **31** and in the zone of the petroleum-producing formation **11** which would be subjected to gas coning if produced by conventional methods. A production tubing **19** is located within casing **14**, tubing **19** being provided with perforations **20** at the lower end thereof within the petroleum-producing formation **11**. A packer **21** is provided in the annulus between casing **14** and tubing **19** desirably intermediate the lowermost casing perforation **15** and the uppermost tubing perforation **20**, as indicated. Solid line **32** indicates the outline of a gas cone which penetrates downwardly from gas-producing formation **30** into petroleum-producing formation.

In accordance with the invention as schematically illustrated in Fig. 3, oil and gas are separately produced and gas-coning is simultaneously controlled as follows. Oil is recovered from petroleum-producing formation **11** via perforations **20** and tubing **19**. During the production of oil, gas penetration from gas-producing formation **30** into the petroleum-producing formation **11** in the direction of perforations **20** tends to occur. Gas coning, however, in accordance with this invention, is controlled and inhibited by the separate production of gas from within petroleum-producing formation **11** in the zone thereof most likely to be subjected to gas coning, i. e. within petroleum-producing formation **11** substantially directly beneath oil-gas interface **31** around well bore **13**, by separately producing gas via perforations 15 of casing 14 with the resulting formation of a gas cone as indicated by solid line 32. The gas thus produced via the annulus between casing 14 and tubing 19 is separately recovered at the surface and desirably is reinjected into the gas-producing formation 30 by means of a gas injection well, not shown, so as to maintain gas pressure within the gas-producing formation 30. By operating in the above-indicated manner and by suitably adjusting the production rates of the oil from petroleum-producing formation 11 and the gas from within gas cone 32 it is possible to substantially completely prevent gas coning into perforations 20 and to produce oil substantially free of gas originating from a gas cone.

In view of the foregoing disclosure it is apparent that the method of this invention is applicable not only to so-called gas drive petroleum reservoirs, wherein a gas cap overlays a liquid oil-producing formation, but is also applicable to so-called water-drive reservoirs wherein a petroleum-producing formation overlies a substantially water-saturated, water-producing formation.

The practice of this invention is applicable not only to newly-drilled wells but is also applicable to wells which have already been in operation for some length of time and which are producing a considerable amount of water or gas due to the phenomenon of water coning or gas coning. In accordance with a preferred embodiment of this invention, particularly applicable to previously drilled producing wells which exhibit an unduly large amount of water production or gas production due to water coning or gas coning, respectively, the producing well is shut in for a period of time necessary to approach or establish static equilibrium conditions in the subsurface producing formation. This period of time, depending upon the various circumstances, may be three hours to a month, more or less. After equilibrium conditions have been established or sufficiently closely approached, as evidenced by the development of a static oil-gas interface, as indicated by dashed line 16 of Fig. 2 or dashed line 31 in Fig. 3, the well is produced in accordance with this invention by separately producing water as hereinbefore described with reference to Fig. 2 or by separately producing gas as hereinbefore separately described with respect to Fig. 3.

In accordance with still another embodiment of the practice of this invention as applied to a liquid oil-producing reservoir which overlays a substantially water-saturated, water-producing formation and which immediately underlies a gas-producing formation and wherein production from the liquid petroleum reservoir tends to give rise to a water cone and a gas cone, both water coning and gas coning are controlled in accordance with the practice of this invention by separating producing oil from the liquid petroleum-producing reservoir by means of an oil production tubing, separately producing gas from the upper portion of the liquid petroleum-producing formation adjacent the gas-producing formation in the zone thereof likely to experience gas coning via perforations in a casing extending into said zone, and separately producing water from the lower portion of said liquid petroleum-producing formation in a zone relatively close to the water-producing formation and likely to experience water coning via perforations in a water production tubing, which may be advantageously concentrically positioned within the aforesaid oil production tubing. By operating in the above-indicated manner water coning and gas coning are not only effectively controlled but also separate production of water, oil and gas is possible.

Yet another embodiment of the practice of this invention applicable to water coning and/or gas coning involves substantially continuously producing petroleum from the petroleum-producing formation at a rate which gives rise to coning or the invasion of a coning fluid (water or gas) into the zone of petroleum production and intermittently producing the coning fluid from the petroleum-producing formation in the zone of coning-fluid invasion. Still another embodiment, also applicable to water coning and/or gas coning, involves discontinuing the production of petroleum from the petroleum-producing formation when a substantial or prohibitive amount of coning fluid is produced together with the produced petroleum due to the invasion of coning fluid into the zone of petroleum production within the petroleum-producing formation with the building-up of a water cone or gas cone therein and then producing the coning fluid, water or gas, from the water cone or the gas cone as the case may be.

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

I claim:

1. A method of producing petroleum from a petroleum-producing formation which is penetrated by a well bore, said petroleum-producing formation underlying and in contact with a gas-producing formation and overlying and in contact with a water-producing formation, which comprises producing petroleum from said petroleum-producing formation via said well bore in a zone surrounding said well bore at a rate which gives rise to a gas cone originating from said gas-producing formation and extending downwardly into said petroleum-producing formation in the direction of said zone and which also gives rise to a water cone originating from said water-producing formation and extending upwardly into said petroleum-producing formation in the direction of said zone wherein said petroleum is produced, separately producing gas from said gas cone within said petroleum-producing formation via said well bore and separately producing water from said water cone within said petroleum-producing formation via said well bore.

2. A method in accordance with claim 1 wherein said separately produced gas is returned to said gas-producing formation.

3. A method in accordance with claim 1 wherein said separately produced water is returned to said water-producing formation.

4. A method in accordance with claim 1 wherein said separately produced gas is returned to said gas-producing formation and wherein said separately produced water is returned to said water-producing formation.

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