United States Patent

Driscoll

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[54] MULTIPLE PRODUCING INTERVALS TO SUPPRESS CONING

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[52] **U.S. Cl.** **166/314**

[51] **Int. Cl.** **E21b 43/00**, E21b 43/119

[58] **Field of Search** ..... 166/314, 306, 305 R, 268, 308, 166/281, 285

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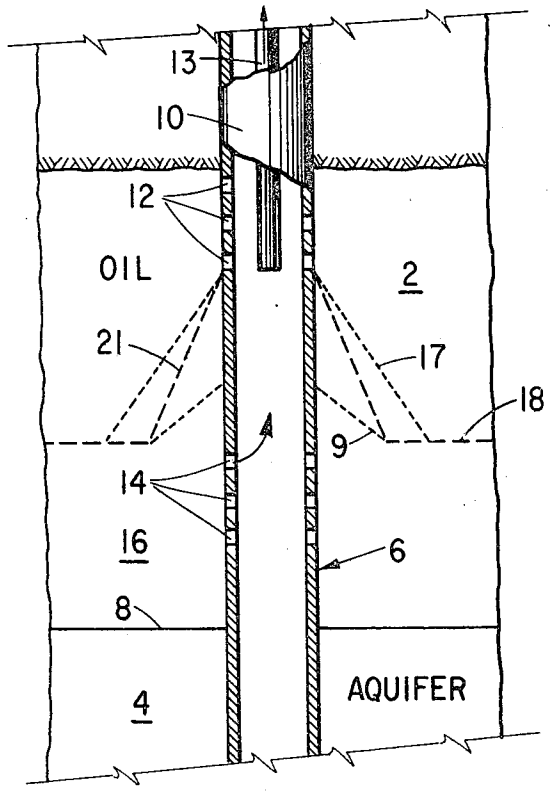
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[57] **ABSTRACT**

In wells subject to water and/or gas coning, hydrocarbons and undesired fluids are produced into the well in commingled form from separate spaced intervals. The well is produced at such a rate that an equal pressure drop —and therefore the same pressure profile for a given distance away from the well —occurs at all producing levels. This permits the oil-producing level to be rate independent provided undesired fluids from the other producing level(s) are produced in the proportion required.

10 Claims, 5 Drawing Figures



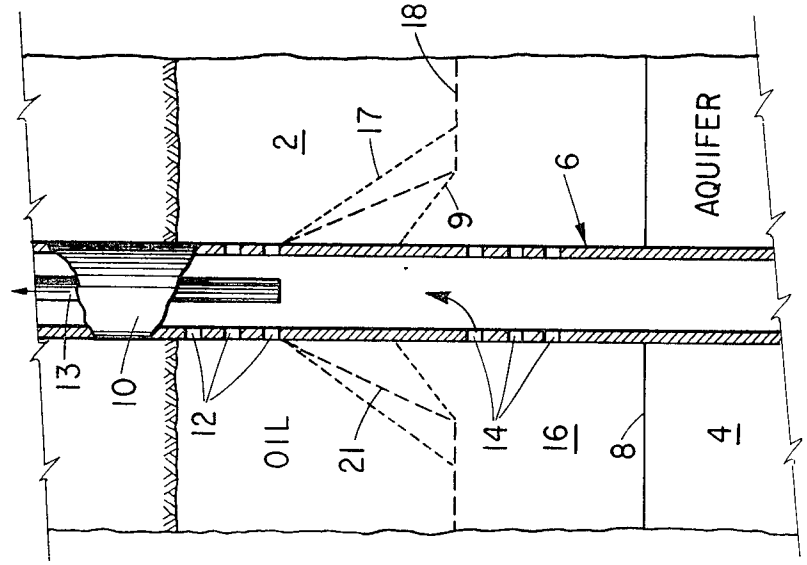


FIG. 2

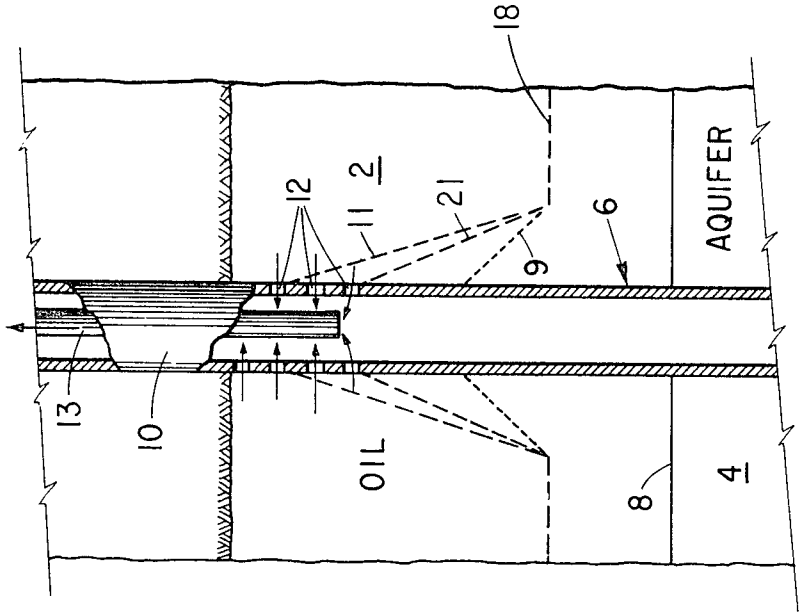


FIG. 1

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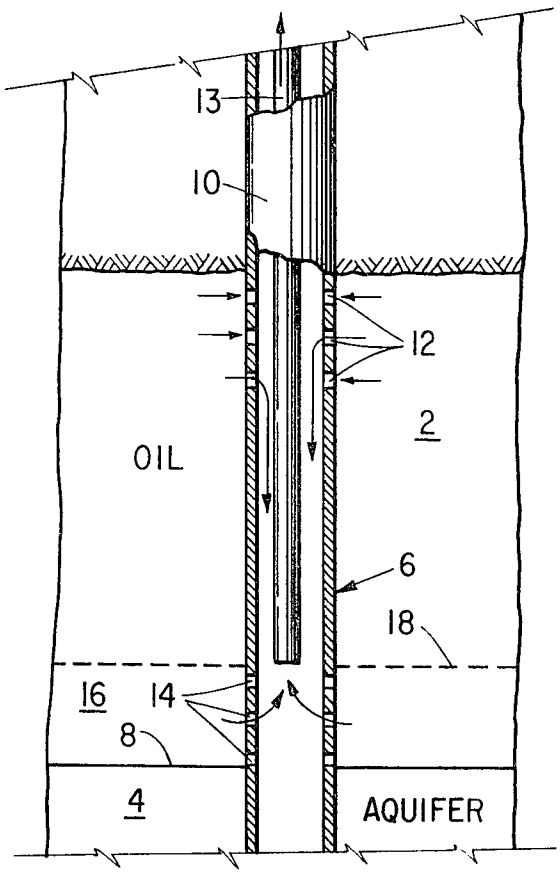


FIG. 3

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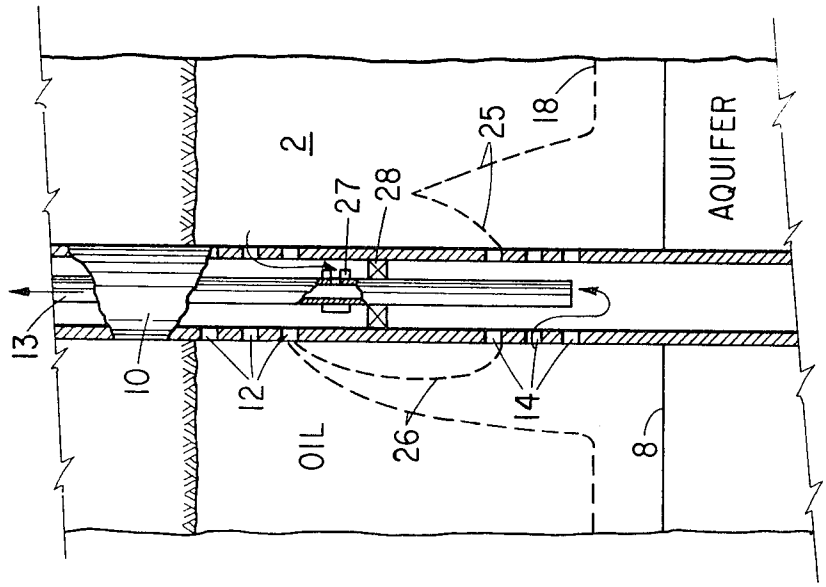


FIG. 5

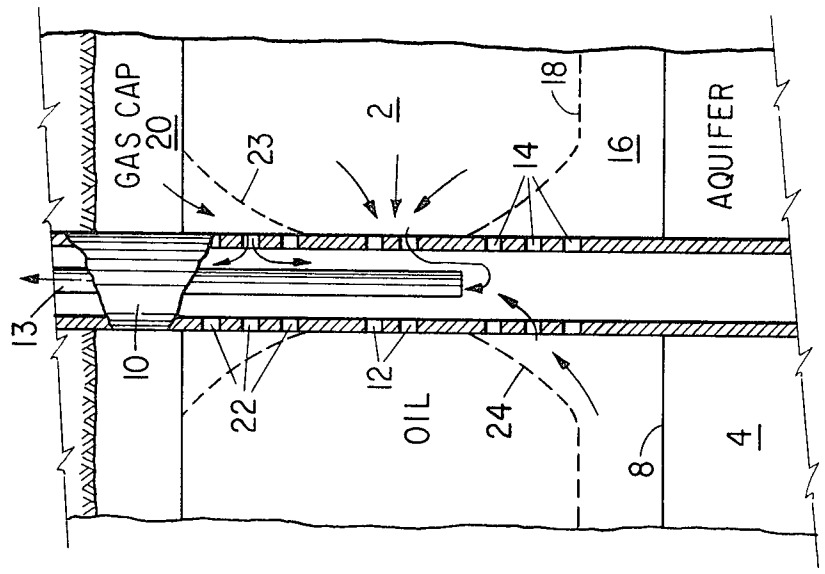


FIG. 4

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MULTIPLE PRODUCING INTERVALS TO SUPPRESS CONING

INTRODUCTION

The present invention relates to an improved technique for the production of hydrocarbon fluids from underground deposits thereof. More particularly, it is concerned with a novel method for the prevention of gas and/or water coning during the production of liquid hydrocarbons and for the prevention of water coning while producing gas.

BACKGROUND OF THE INVENTION

Water coning is a term given to the mechanism underlying the entry of bottom water into producing wells. Petroleum hydrocarbons are often produced from a porous subsurface formation which overlies a water-saturated portion of the same formation. Under static conditions the water, being of greater density than the hydrocarbons, remains beneath and at the bottom of the hydrocarbon-producing formation. With production of petroleum hydrocarbons the upper boundary or surface (oil-water contact) of the water-saturated formation rises due to the pressure drop created by flow of petroleum hydrocarbons into the well bore through a producing interval open to the petroleum-producing formation above the contiguous water-saturated formation. The rise of water into the petroleum-producing formation represents a dynamic effect in which the upward directed pressure gradings resulting from flow of the hydrocarbons into the producing well bore are balanced by the differential hydrostatic head of the resulting elevated water column. At sufficiently high flow rates the differential fluid column head cannot fully offset the dynamic gradient, and thus water is produced along with the oil.

Gas coning is a term given to the mechanism involved in the entry of gaseous hydrocarbons from the gas cap into the underlying liquid hydrocarbon-producing formation during the production of normally liquid hydrocarbons therefrom. To a certain extent gas coning is analogous to water coning. Here the pressure drop due to flow of liquid hydrocarbons tends to be offset by the buoyancy effect of the gas as it is drawn down into the liquid hydrocarbon area. However, again if liquid hydrocarbon rates are high enough to create too much pressure drop, gas will cone into the producing interval and at higher rates tend to completely suppress oil production.

The problem of interference by gas and/or water during the production of petroleum has plagued the industry since its inception and, accordingly, there have been numerous proposals made directed to the solution of this problem. Such procedures have included:

1. Optimum location of a single perforated interval to maximize permitted oil production rate without the downward cone of overlying gas or upward cone of underlying water reaching the perforated interval. It has been shown that the optimum perforated interval under these circumstances consists of a relatively thin producing interval near the top of the oil pay in the case of underlying water with no gas cap, a thin producing interval near the bottom of the oil pay in the case of a gas cap without bottom water, and an intermediate location usually based on differences in relative fluid density in the event both gas and water are present. However, these approaches may not be optimum in the sense of obtaining maximum cumulative oil production with minimum cumulative gas or water production or maximum oil-producing rates to depletion even with large volumes of undesired fluid production when the afterbreakthrough performance history is considered. Also, at withdrawal rates in excess of the critical, a thin set of perforations at the top can actually result in higher water cuts than a top interval of greater penetration for the same level of fieldwide water table rise.

2. Another method to minimize well coning effects has involved the placement of horizontal barriers below the perforated interval in the case of underlying water or near the top of the oil column in the case of overlying gas. These barriers could either be induced horizontal fractures pumped full of cement or other material where horizontal fracturing is feasible, or such barriers may be created by placing impermeable or semi-impermeable time-setting gels in the lower portion or upper portion of the oil pay, depending, respectively, on whether gas or water coning is involved. Where effective, such technique allows higher producing rates without water breakthrough, or will allow production with lower water cuts for limited periods of time.

3. Another approach to this problem has been to reinject higher or lower in the oil pay a portion of the oil produced to minimize the effects of gas or water coning. In this procedure the pressure drop in the immediate vicinity of the well bore is minimized or eliminated between the main producing interval and the offending contact. Thus, it is possible to produce water-free oil at higher rates and/or produce a comparable amount of oil with a lower water cut. The overall flow path is upward, however, and water can still cone around the lower injection perforations at distances removed from the well bore if rates are raised too much above the previous single producing interval critical rate. Thus, the effect is similar to the placement of a cement or equivalent impermeable barrier for a short distance from the well bore.

4. The use of separate flow streams from multiple perforations to control coning is taught in Widmyer U.S. Pat. No. 2,855,047 which employs two or more sets of producing intervals with intervening packets and separate flow streams to suppress coning. In the case of water coning into an oil section, water is separately produced within the petroleum producing formation through either perforations or an open hole producing interval separated by a packer from upper casing perforations or open hole interval. Fluids from both intervals are then produced by separate flow streams to the surface. By regulation of rates the net pressure differential between the two producing levels can be lowered below that at which water reaches the upper perforations and water free, or substantially water free, production obtained from the upper interval with oil-producing rates higher than otherwise possible from the same main producing interval without secondary interval production to minimize or suppress coning effects.

5. Glass et al. U.S. Pat. No. 2,923,356 teaches the use of partial plugging materials to further reduce under some situations amount of undesired separate flow stream production of gas or water to suppress coning. While this method, as well as the one recited immediately above, can suppress coning, they both can be costly to apply, they always require the use of production packers, and frequently may require multiple tubing strings and separate or more expensive artificial lift equipment along with higher operating costs to permit separate flow stream production from two or more sets of perforations. Also, they are not mechanically applicable in some situations owing to (1) multiple completion of the well with other overlying or underlying separate petroleum accumulations and (2) desired production rates cannot be obtained due to greater limitations on lift volumes due to multiple flow streams from a mechanical standpoint.

BRIEF DESCRIPTION OF THE INVENTION

For purposes of this description, the term "critical rate" as used herein is defined as the maximum flow rate of desired fluid production at a given point in time from a single producing interval, or several closely grouped intervals considered as one interval for production of desired fluid, at which under steady state conditions the plane of flowable saturation of the gas cone or water cone will just reach but not enter that producing interval.

It is recognized that, due to capillary pressure effects, the transition from water to hydrocarbon or liquid hydrocarbon to gas is not abrupt even under static conditions but goes from a zone of 100 percent water saturation to one of hydrocarbon with essentially irreducible nonflowable water saturation. A similar effect occurs for gaseous hydrocarbon over oil.

Distance involved may be several to as much as 50 feet or more depending on various rock and fluid parameters such as fluid density differences, formation porosity and permeability, wettability effects, etc. Thus, in those few cases where the main producing interval is in a zone of above irreducible water saturation or gas saturation, it is not always possible to completely eliminate undesired fluid production. However, it can be reduced to a certain minimum. In these situations where a flowable amount of undesired fluid saturation exists under static conditions opposite the main producing interval, any rate of production from the main producing interval(s) would be above the critical rate.

The critical rate often is less than desired or even minimum economic rate or can become so due to fieldlide gas cap expansion or water encroachment due to depletion of the oil reservoir. This general encroachment reduces permitted rates without coning of undesired fluids or even with production of these fluids due to tendency of undesired fluid production through the same interval to suppress desired fluid production.

Briefly the process of my invention solves the problem of objectionable coning restricting oil rates (gas rates in the case of a gas reservoir overlying water) or giving excessive undesired fluid rates for the desired fluid rate by producing well bore commingled fluids from two, three, or more spaced producing intervals. These spaced producing intervals may be perforated intervals at two or more levels in a cemented casing or liner, two or more open hole intervals separated by packers to create intervals of nonflow from the formation into the well bore, or any combination of methods provided by the general art to obtain separate flow of fluids from several levels in a single porous formation into a well bore. Thus, where the problem occurs, I employ an additional producing interval between the main producing interval and the offending contact. The secondary producing interval in the case of water could be lower in the oil-producing interval, in the general fieldwide encroached interval, or below the original oil-water contact. In the case of a secondary perforated interval for suppression of gas coning, it would be above the main oil-producing interval either higher in the oil pay or in the gas cap area itself. Purpose of the secondary producing interval or intervals is to prevent or minimize coning into the main producing interval or intervals. The well is then produced as a single completion with the fluids commingled in the well bore.

Under ideal conditions this will result in essentially equal pressure profiles radially with distance from the well bore at all levels and will prevent water coning above the lower perforation level or gradually eliminate water coning if previously present in the main producing interval. A similar effect occurs with respect to gas coning. Thus, while net production of undesired fluid or fluids may or may not be decreased, I am able to increase oil production rates (gas production rates in the case of gas over water) without requiring separate flow streams to the surface.

Owing to differences in density between well bore fluids and those in the formation outside the casing, it is also possible to further regulate to some extent the relative withdrawal rates where desired without requiring separate flow streams from producing intervals above or below the contacts or in the gas and/or water cone areas. This can be accomplished by either raising or lowering the tubing flow entry point or by allowing gas bleedoff through the annulus as result of phase separation of the commingled fluids. Further regulation, if desired, can be obtained by placing a packer or packers in the single flow string with flow chokes (preferably retrievable and adjustable by wire line) to further regulate the rate of entry of the separate interval production into the commingled stream. Thus, it is unnecessary to separately produce intervals by separate flow streams to the surface as practiced by the prior art to obtain benefits of cone suppression.

It will be appreciated that the process of my invention may in some cases be used to advantage in combination with previously known methods for preventing coning such as injection of an intervening impermeable material, e.g., cement; partially plugging pay intervals producing undesired fluids; and stimulation of the main perforated interval by acidizing, shooting, fracturing, etc., to reduce pressure drop and in turn coning in the immediate well area.

DESCRIPTION OF SPECIFIC EMBODIMENTS

In the case of an oil-bearing formation with underlying water and having a single set of perforations at or near the top of the pay, production is free of water until such time as the pressure at the formation face opposite the base of the perforations has dropped to a level such that the underlying plane of flowable water saturation rises just to the base of the perforations, offsetting the pressure drop at this point by density differences. As previously mentioned, when this happens under steady state conditions, this is considered to be the critical rate. Owing to radial flow, pressure drop is less at distances farther removed from the well bore. Thus, the water cone height is less at distances radially removed from the well bore at the same elevation. In addition, because of quasi-spherical flow the pressure drop in the invaded oil sand at the same radial distance removed from the well bore is normally less at levels above or below the main producing interval after considering differences in head. Similar considerations apply to water coning into a gas pay and gas cap coning into an oil sand.

My invention is further illustrated by reference to the following drawings wherein:

FIG. 1 shows a producing well having an optimum single set of perforations for bottom water coning with production at less than, equal to, or greater than the critical rate.

FIG. 2 illustrates commingled production from a producing well with two producing intervals with the tubing at the base of the upper perforations. This is for conditions in which the producing rate is equal to the critical rate and how, due to production from the lower interval as rates are increased, net pressure differential to cause coning is not increased and, therefore, the cone remains at base of the upper producing interval.

FIG. 3 illustrates commingled production from a producing well in which two sets of perforations are employed, one in the upper portion of the oil pay, and the other set in the water encroached oil pay but near the original oil-water contact (O.W.C.) level, with the inlet end of the production tubing at the level of the current general static water-oil interface.

FIG. 4 shows suppression of gas cap and water coning in a producing well by commingled production from three producing intervals.

FIG. 5 shows suppression of water coning in a producing well by commingled production from two sets of perforations where a packer and wire line retrieval adjustable flow choke are used to further adjust relative pressure drops and relative flow rates for nonideal conditions.

Referring again to FIG. 1, schematically representing the coning phenomenon, 2 indicates an oil-producing formation. Underlying the latter is a contiguous water-producing formation 4. Well bore 6 extends into aquifer or water-producing formation 4 below solid line 8, indicating the level of the original O.W.C. Cemented casing 10 is provided with a single set of perforations 12 within oil-producing formation 2. Under static conditions due to previous oil withdrawals from oil zone 2 and fieldwide water encroachment, the current static oil-water contact is located at about the position indicated by dashed line 18. With a low rate of production the water cone close to the well bore rises only to the level indicated by dashed line 9. However, at greater production rates and because of the increase in upward directed pressure gradients associated with the flow of oil into perforations 12, the water cone rises (dashed line 11) to the extent that it breaks into perforations 12, thereby tending to suppress oil production. As higher production rates are employed, substantially water only is produced. This phenomenon is known as water coning.

The producing rate at which a plane of flowable water saturation will just reach but not enter the single set of perforations 12, as illustrated by dashed line 21, is the critical rate.

FIG. 2 is a schematic presentation of the present invention in practice for controlling water coning. Well bore 6 is provided with cemented casing 10 extending into the aquifer or water zone 4 underlying oil pay 2. In accordance with my invention casing 10 has two sets of perforations, 12 and 14, opposite oil-producing zone 2 and a water-encroached zone 16, respectively. With production through perforations 12 at the critical rate and the flow entry point of tubing 13 at the base of perforations 12, no flow of water occurs through lower perforations 14 since the pressure drop profile at perforations 12 has been offset by density difference due to water cone rise and no pressure gradient exists at the level of perforations 14. The position of the water cone under these circumstances is indicated by dashed line 21. When the production rate is below the critical rate, the position of the current O.W.C. is shown by dotted line 9, essentially no water being produced from perforations 14. This is for the reason that the well bore fluid up to perforations 12, or to some intermediate point, at rates less than the critical rate equilibrate with the water cone average density outside the perforations. Thus, after initial minor disturbances essentially no fluid production occurs through perforations 14 as long as production from perforations 12 is at equal to or less than the critical rate. In the case of bottom water coning into an oil reservoir, locating the fluid entry point into the tubing at or above oil perforations 12 without a packer results in minimizing water encroachment into perforations 12 at a production rate above the critical rate. In this situation the pressure drop at perforations 12 exceeds the density difference resulting from a rise in the water cone as shown by line 17, thus allowing a pressure drop in well bore 6 at perforations 14 causing production of water to commence from this level thus holding the incremental pressure drop at perforations 12 to about the critical rate pressure drop even though total pressure drop and producing rate has been increased from perforations 12 to above the single-perforation critical rate.

FIG. 3 is another embodiment of my invention in which multiple perforations are employed and the commingled production enters the tubing at the level of the current field-wide static O.W.C., shown in dashed line 18. Under ideal conditions only oil is recovered from perforations 12 via tubing 13 at production rates less than or greater than the previously limiting single producing interval critical rate. Flow through perforations 12 travels downwardly to the entry point of tubing 13. Thus the fluid density in the well bore between perforations 12 and the fluid entry point is approximately the same as oil. Consequently, the fluid density is about the same as that of the fluid in formation 2. Under this condition a pressure drop from the face of formation 2 to a radial distance remote from well bore 6 at perforations 12 also is reflected by a substantially identical pressure drop at perforations 14 from the face of water pay zone 16 to distances remote from well bore 6, resulting in commencement of water production via perforations 14 simultaneously with production of oil through perforations 12. Regardless of production rate, however, no water coning occurs at either below or in excess of critical rates since approximately identical pressure drops at perforations 12 and 14 are created in a radial direction. Some water production can be tolerated at less than critical rates. However, as a practical matter the well would generally be operated in excess of critical rates.

FIG. 4 is another embodiment of my invention in which three producing intervals have been employed to suppress both gas and water coning. Oil production comes from perforations 12 with coned water production from perforations 14 located lower in the oil formation and coned gas from perforations 22 near the top of the oil bearing formation 2 and contiguous to gas cap 20. Fluids from all three intervals are commingled in the well bore and produced principally through tubing 13. However, some phase-separated fluids (principally gas) may be produced via the casing annulus. Here the water cone 24 is suppressed or held to about the level of perforations 14 and the downward cone of gas 23 is held to about the level of perforations 22 allowing oil production substantially free of gas cap gas or water to be produced from perforations 12.

FIG. 5 is yet another embodiment of my invention whereby a production packer 28 and a choke assembly 27 in the tubing string is used to change relative withdrawal rates for a water-coning situation while still producing the fluids commingled in the well bore. Casing 10 has been set and cemented through the oil bearing formation 2. With tubing flow entry point at level of perforations 14 and no packer or choke, cone 26 under ideal conditions would have been suppressed to level of perforations 14 regardless of flow rate since radial pressure drops at both levels would be equal. However, due to desired production at much higher than the single producing interval critical rate from perforations 12 and nonequal pressure profiles radially due to variations in relative permeability, permeability, capillary pressure, and saturation plus boundary effects, saturation hysteresis, etc., net pressure drop at level of perforations 12 is greater than that at level 14 by more than the pressure difference between perforations 12 and 14 due to oil and water density difference at some distance from the well bore. This allows cone 26 to enter upper perforations 12.

To adjust for this nonideal condition, production packer 28 has been set and tubing rerun with tubing choke assembly 27 preferably equipped to allow wire line retrieval and running of variable-sized opening flow beans. Use of a small-sized opening flow bean (choke) creates an additional pressure drop due to choking effect and, thus, increases production from perforations 14 relative to perforations 12. This increases pressure drop at perforations 14 at all distances away from the well bore with respect to those at perforations 12, causing water cone to recede from position 26 to 25 making upper perforations 12 water free and increasing allowable oil withdrawal rates from perforations 12.

Depending on amount of decrease in water production from perforations 12 as compared to increased water production from perforations 14, overall water production rate in the commingled well stream at the surface may either be decreased or increased. However, due to the relatively small costs of handling water as compared to the value of the increased oil-producing rate, a considerable economic advantage can be gained. Perforated interval 14 could also have been stimulated by acidizing, fracturing, etc., to increase withdrawals therefrom relative to perforations 12 for a given common well bore pressure and could, therefore, have accomplished essentially the same effect as obtained by choking back on perforations 12.

Obviously, other combinations in addition to those described above are possible without departing from the scope of my invention. For example, if the tubing flow entry point is located somewhat below the base of the upper perforations, very little, if any, water should flow from the lower perforations until the cone height outside the casing had reached the tubing flow entry point. In turn, at high rates the coning is not suppressed much below this point. Also, it will be recognized that it is possible to place the tubing entry point initially above the upper perforations. Thus, even though two sets of perforations exist, substantially water-free production is obtained until such time as production exceeds the critical rate. At this point the tubing can be lowered to the current general oil-water contact level or below the base of the upper perforations, if higher. This in turn essentially results in a higher pressure drop at the lower perforations which would result in added production from the lower interval, tending to suppress the water cone. Gradually the cone outside the well approaches equilibrium, depending on lower perforation location with respect to the general oil-water contact level, the position of the cone could be at various levels. However, in general, it would normally be at or below the higher of these two points. Formation of the second set of perforations could be deferred until required.

The essential features of the process of my invention are that it eliminates the need for separate flow streams from different producing intervals to the surface to suppress coning by commingling of fluids in the well bore. Due to the simpler downhole arrangement in many situations and requirements usually for only a single string of tubing and lift equipment afforded by my invention, it has considerable general application because of lower cost. Also, even if slightly less effective in some situations, my invention is specifically applicable to multiple pay fields or single, completed wells with small size casing where the mechanical dual completion technique of the prior art would be more costly or of lesser benefit due to greater mechanical limitations on fluid withdrawal rates.

I claim:

1. In a method for the production of a hydrocarbon fluid from an underground formation, the latter being penetrated by a well, said hydrocarbon fluid being in contact with at least one undesirable fluid in said formation, said at least one undesirable fluid tending to form a cone and be produced with said hydrocarbon fluid when said well is placed on production, the improvement comprising:

producing into said well at least at the critical rate said hydrocarbon fluid and said at least one undesirable fluid separately from spaced producing intervals in said formation,

commingling the resulting produced fluids in said well, and

withdrawing said fluids from said well in a commingled condition.

2. The method of claim 1 wherein said formation is penetrated by a cased well and said hydrocarbon and at least one undesirable fluid are produced into said well through spaced perforated intervals in said formation.

3. The method of claim 2 wherein three spaced perforated intervals are employed, hydrocarbon fluid being produced from the intermediate of said perforated intervals and gas and water being produced into said well, respectively, from the upper and lowermost of said intervals.

4. The method of claim 1 wherein said at least one undesirable fluid is returned to said formation.

5. The method of claim 1 wherein a fluid impermeable barrier extending radially from said well is placed between said producing intervals.

6. The method of claim 1 in which said well is produced in excess of the critical rate.

7. The method of claim 6 wherein the lower producing interval is located at a level between the current oil-water contact and the original oil-water contact.

8. The method of claim 7 wherein a single production tubing is employed and the fluid entry point thereof is essentially at the level of the current field wide oil-water contact.

9. The method of claim 7 wherein the hydrocarbon fluid is a gas.

10. The method of claim 1 wherein the undesirable fluid is gas and the hydrocarbon fluid is a liquid.

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