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METHOD OF INCREASING RECOVERY FROM A SUBSURFACE OIL OR CONDENSATE RESERVOIR

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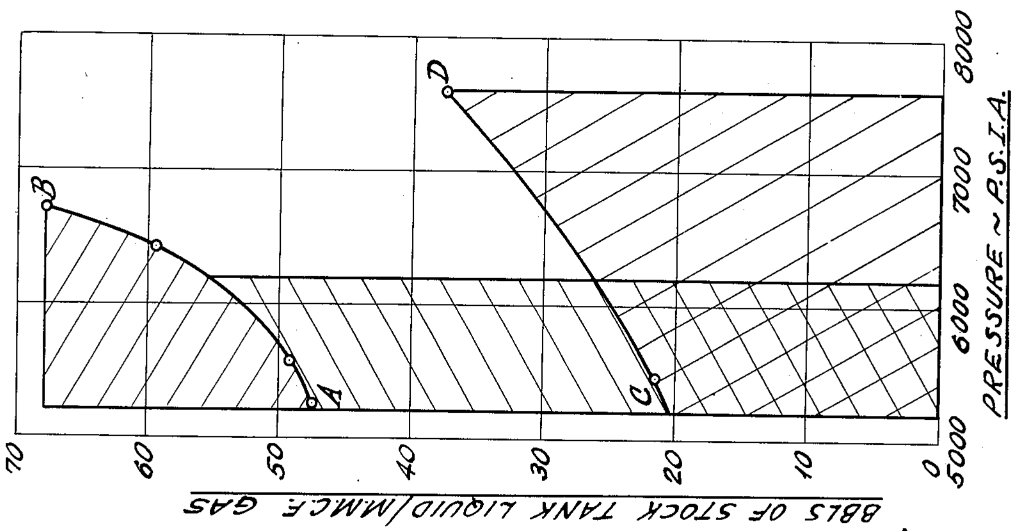

Fig. 2.

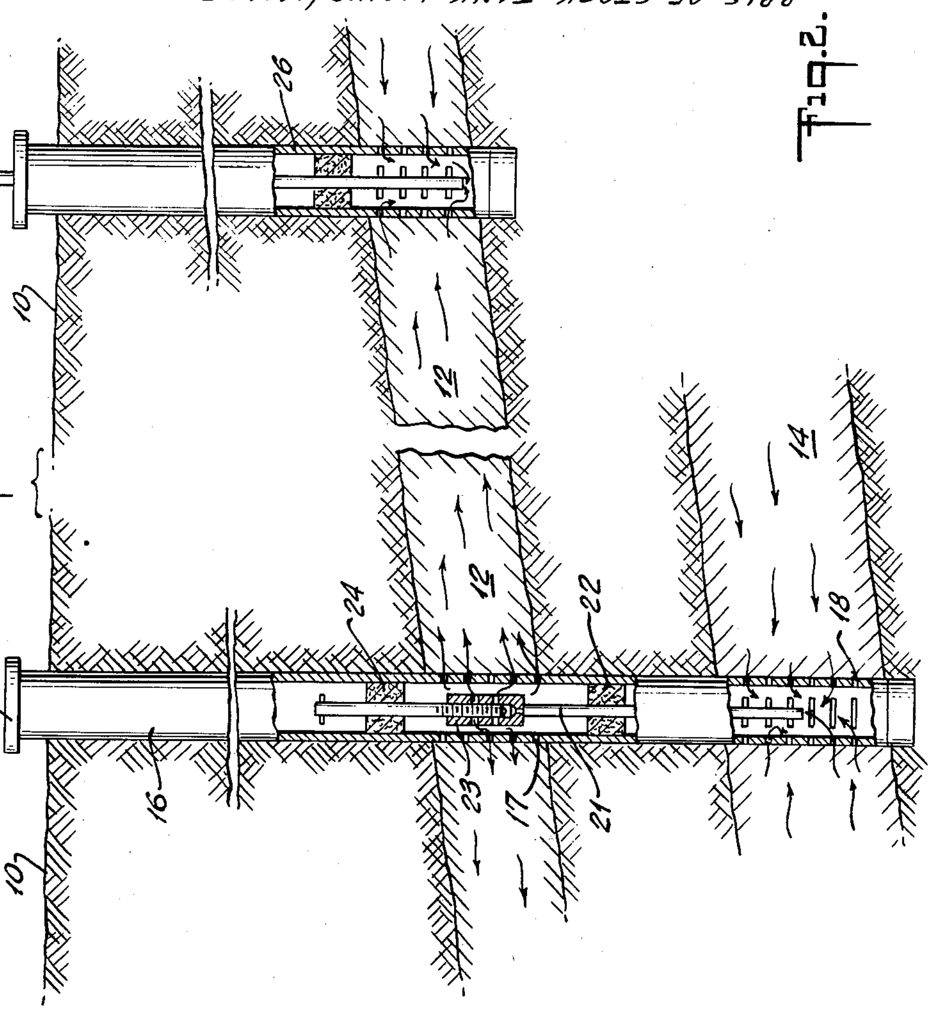

Fig. 1.

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METHOD OF INCREASING RECOVERY FROM A SUBSURFACE OIL OR CONDENSATE RESERVOIR

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1 Claim. (Cl. 166—9)

The present invention relates to production of hydrocarbons from subsurface producing reservoirs and particularly to the maximizing the total overall production of normally liquid phase constituents.

In accordance with the present invention, the contents of a relatively high pressure condensate reservoir are discharged directly into a separate relatively low pressure producing reservoir. The second reservoir is then produced from a point spaced substantially from the point of introduction or injection of the high pressure condensate. Therefore, the contents of both reservoirs are produced from the second reservoir through the production well extending into the second reservoir.

In particular it is contemplated thus directing the contents of a relatively high pressure condensate reservoir into and through a second relatively lower pressure reservoir containing a relatively rich condensate. In other words, the relatively lean high pressure gas condensate reservoir is flowed by subsurface interconnections into a relatively rich but relatively low pressure gas condensate reservoir from which both reservoirs are produced.

A gas condensate reservoir is a subsurface reservoir in which the bulk of the hydrocarbons exist as a retrograde enriched gas subject to condensation upon isothermal pressure decline. Accordingly, the retrograde enriched gas comprises a single phase admixture of normally gaseous hydrocarbons such as methane with enriching constituents comprising a substantial amount of normally liquid hydrocarbons. In the retrograde enriched gas the amount of the enriching fraction of normally liquid hydrocarbons contained therein is far in excess of the amount which could be held by the gas as a vapor in the absence of the retrograde phenomenon. Such a reservoir is produced by withdrawing the retrograde enriched gas to the surface, subjecting it to a reduction in pressure and permitting the constituents to separate into a natural gas fraction and a liquid hydrocarbon condensate fraction.

In accordance with the present invention, it has been found that the relatively lean high pressure retrograde enriched gas entering the second relatively rich condensate reservoir not only increases the pressure thereof, but becomes further enriched by taking up or exchanging normally liquid phase hydrocarbons of the lower pressure condensate reservoir. Moreover, the enrichment which takes place raises the amount of normally liquid hydrocarbons contained in the retrograde enriched phase to a value corresponding to the enrichment characteristic of the relatively rich condensate reservoir at the pressure prevailing. Therefore, the produced condensate from the two reservoirs contains overall a substantially greater amount of liquid hydrocarbons than would be the case where the two condensate reservoirs are separately produced.

For example, the high pressure relatively lean retrograde enriched phase passing into the second or relatively low pressure condensate reservoir picks up or exchange hydrocarbons until it reaches an equilibrium composition corresponding to that of the secondary reservoir. Moreover, since opening up or connecting the two reservoirs results in substantially increasing the pressure of the second reservoir from which production is effected, the total enrichment of the produced condensate is yet further increased. This follows from the fact that, in general, the amount of normally liquid condensate contained in the retrograde enriched gas delivered by a given condensate reservoir increases with the pressure. As the pressure decreases the amount of normally liquid fractions recovered as condensate decreases, that is, the number of barrels of stock tank liquid recovered per MMCF of produced retrograde enriched gas phase becomes progressively less. Conversely, however, with an increase in reservoir pressure the enrichment of the produced phase with normally liquid hydrocarbons is increased, and the recovery of liquid per MMCF of gas becomes greater.

As a result, therefore, normally liquid phase hydrocarbons which may be left in the relatively rich condensate reservoir by virtue of normal pressure decline, are recovered by producing the relatively high pressure and relatively lean fluent from the first reservoir through the second reservoir.

The benefits of this procedure are particularly enhanced by virtue of the fact that the typical condensate reservoir frequently contains, in addition to the retrograde enriched phase which forms the bulk thereof, a separate liquid phase of hydrocarbons referred to as "interstitial" liquid. While the interstitial liquid is usually too small in amount to permit its separate recovery, nevertheless it is obviously available for enrichment of the injected retrograde phase. It therefore diffuses into the high pressure retrograde gas stream injected from the relatively high pressure formation and is recovered as condensate. Accordingly, in addition to recovery of liquid which would normally be condensed in the second or relatively rich condensate reservoir, by normal pressure decline in the course of production, the present invention provides for recovery of interstitial liquid phase hydrocarbons which otherwise form a part of the irrecoverable oil, by which is meant oil remaining in the formation after completion of normal production.

In theoretical explanation of the foregoing discovery it is believed that the increased enrichment of the relatively high pressure and relatively lean phase which occurs in the second reservoir, results from an actual equilibrium exchange of constituents. This is believed surprising in view of the fact that the injected relatively lean, high pressure phase as it is withdrawn from the high pressure condensate reservoir is usually already saturated as regards enrichment with normal liquid hydrocarbons fractions, under the pressure and temperature conditions prevailing therein. Nevertheless, in the second reservoir there is a readjustment of the retrograde enriched gas as above indicated, which results in an enrichment corresponding to that of the second or relatively rich reservoir. This would seem to be accounted for only by the fact that the retrograde enriched gas phase is capable of holding, either in addition to or in lieu of the original enriching phase, an increased amount of the normally liquid hydrocarbon fractions present in the second or relatively rich reservoir.

In any event, the equilibrium composition of the enriched phase not only adjusts itself to that characteristic of the relatively rich reservoir; this equilibrium adjustment significantly occurs at a relatively rapid rate and is completed in any path of underground travel or encountered in the normal practice of subsurface displacement.

As above intimated, the present invention is also applicable to production of liquid oil phase reservoirs. Injection of the relatively high pressure condensate phase of retrograde enriched gas into the liquid hydrocarbon reservoir drives the liquid toward the production well, and also dissolves in the liquid oil to swell its volume and to promote production by solution gas drive. Moreover, at least some of the reservoir liquid diffuses into the retrograde enriched gas phase of the condensate reservoir to effect increased enrichment, as above indicated, so that additional amounts of condensate are produced with the recovered enriched gas.

Most important, however, the enriching fractions contained in the injected gas-condensate sweep gas, to the extent they are absorbed in the liquid oil, swell the volume of the produceable liquid oil and dilute the relatively heavier liquid crude, thereby facilitating its flow to the production wells. This follows from the fact that the enriching fractions contained in the retrograde enriched gas are typically composed of relatively light liquid fractions, for example in the gasoline boiling range, which lower the overall density and viscosity of the liquid crude. As a result the crude flows more freely to the production well.

An operation in accordance with the present invention is illustrated in the accompanying drawing wherein Fig. 1 shows in vertical cross section a high pressure and a low pressure condensate formation provided with means for producing the same in accordance with this invention, and Fig. 2 graphically illustrates the advantages obtainable in the practice of this invention.

In connection with the preferred embodiment of the present invention, reference is made to Fig. 1 of the present drawing illustrating a section thru a geological subsurface formation involving the ground surface **10** and two vertically spaced condensate reservoirs **12** and **14**. The two reservoirs are separate and as is typical, the lower reservoir **14** has a substantially higher original reservoir pressure than the upper one **12**.

For example, the overlying reservoir **12** in its original state contained about 500,000 MMCF condensate (i. e., retrograde enriched gas phase) at 6700 p. s. i. and originally delivered 68 barrels of stock tank liquid/MMCF of gas. The lower condensate reservoir **14** originally contained 430,000 MMCF gas at 7600 p. s. i. and produced 37.4 barrels of stock tank liquid/MMCF.

Fig. 2 herewith represents diagrammatically the contents of the two reservoirs as a function of pressure. For example, the curve AB represents the rate of liquid hydrocarbon production per MMCF of produced gas between the pressures of 6700 and 5200 p. s. i. Curve CD is a similar curve for the production from reservoir **14**.

The reservoir **12** contains 1690 MMCF and the reservoir **14** contains 1200 MMCF of hydrocarbon pore space. On the basis of these engineering facts the total quantity of liquid produceable during the 7600–5200 p. s. i. pressure decline by direct production of reservoir **14**, is represented by the area under the curve CD (neglecting the effect of pore volume). This amounts to approximately 3,940,000 barrels. In the same manner the area under curve AB represents the quantity of liquid recoverable by separate and independent production of reservoir **12**. In a similar way the shaded area above curve AB represents the amount of liquid condensate which remains in the interstices of the porous reservoir **12** as the result of condensation during the pressure decline from 6700 to 5200 p. s. i., as reservoir **12** is produced.

In accordance with the present invention, after the production of the reservoir **12** to a pressure of 5200 p. s. i. connection is made between the two reservoirs **12** and **14** as indicated in Fig. 1. The specific method of interconnecting the reservoirs, forms, per se, no part of the present invention but may be effected, as shown, by perforating a bore hole casing **16** into the reservoir **12** as at **17** and into the reservoir **14** as at **18**. Casing **16** is, of course, capped as at **20** so that there is no pressure loss and the full available pressure energy of reservoir **14** is therefore applied to reservoir **12**. Preferably adjustable valve means is provided to control flow between the reservoirs and to this end pipe **21** extends below a packer **22** set between the two producing formations. Fluid from formation **14** passes upwardly through pipe **21** and is controlled by a throttling valve **23** which may be regulated from the surface by wire line or any other suitable means. For example a tool, not shown, may be lowered on a rod to engage the upper end of valve **23** for rotatable actuation. Packer **24** above the formation **12** seals the casing against the loss of gas thru the casing.

As previously intimated, reservoir **12** is produced by means of a spaced well **26** extending from a surface location into the formation and suitably communicating with the formation **12** at its lower end. Tubing **27** connected to the well head directs the production thereof to stock tank, separators and any other desired recovery means also not shown.

As the reservoir **12** is produced through well **26** its pressure slowly declines to about 5200 p. s. i., at which time, about 47 barrels of stock tank liquid were produced per MMCF of produced gas, as shown by curve AB of Fig. 2. At this time the reservoir **14** is interconnected to reservoir **12** by perforating casing **16** in both reservoirs. The resultant pressure after equalization is approximately 6200 p. s. i. in both reservoirs. At this pressure enrichment of the injected retrograde phase indicated in curve AB takes place by vaporization of the previously condensed liquid in the reservoir **12**. As above disclosed this enrichment results in delivery from well **26** of a condensate production yielding 56 barrels of stock tank liquid per MMCF of gas. Therefore, production is resumed through well **26** at the increased yield of 56 barrels of stock tank liquid/MMCF of gas.

As production continues, pressure gradually declines on both of the sands the yield of stock tank hydrocarbons again follows the pattern represented by curve AB of Fig. 2, the shaded area under curve AB between 6200 and 5200 p. s. i., representing total production attributable to the upper reservoir **12** between these pressure limits after interconnection with reservoir **14**. On the basis of the pore volume of reservoir **12** this production amounts to 4,390,000 barrels of liquid oil. However, due to the interconnection of reservoir **14** the rate of pressure decline is correspondingly less over the same pressure differential, and there is additional production attributable to the increased pore space of the reservoir **14**. The total increase in reservoir volume represented by combining reservoir **14** with reservoir **12** is equal to

$$\frac{1,690+1,200}{1,690}=1.71$$

therefore the total recovery becomes 4,390,000×1.71 which is equal to 7,550,000 barrels.

This compares therefore with only 3,940,000 barrels which would be produced during the pressure decline of the reservoir **14** between its original pressure of 7600 p. s. i. and the pressure of 5200 p. s. i. by ordinary direct production, representing an increased production of 3,610,000 barrels of valuable liquid hydrocarbons.

While the striking results of the foregoing example are based, in part, upon the presence of original interstitial liquid in the sand of reservoir **12**, it is to be noted that in any event the original production of reservoir **12** from its initial pressure of 6700 down to 5200 p. s. i., as previously intimated, necessarily resulted in retrograde condensation to an extent signified by the shaded area above curve AB of Fig. 2. The actual amount of liquid oil deposited by the retrograde condensation during this pressure decline is equal to 1,920,000 barrels. Accordingly, therefore, even in the absence of interstitial liquid, the production of this very material quantity of additional liquid hydrocarbon manifestly represents a valuable advantage.

This increased production, in either case, is particularly advantageous from the standpoint that the increased production is readily predictable by a skilled reservoir engineer on the basis of ordinary engineering data regarding the reservoir. The present invention is particularly applicable to deep fields when the cost of cycling or other methods of secondary recovery are economically prohibitive.

As previously indicated, similar advantages follow from the injection of the contents of the relatively high pressure condensate reservoir to a relatively low pressure liquid oil reservoir. This is particularly true in the case of a reservoir containing oil which is undersaturated with gas at reservoir pressure. In such a case the resulting swelling of the oil volume and the increase of fluidity, due to contact with the enriched condensate phase, materially promote flow to the well bore. Recovery is further facilitated by the fact that the rich condensate phase, having properties as to viscosity and density more closely approaching that of the displaced oil, acts with improved volumetric displacement efficiency. In any event, the total liquid hydrocarbons produced by the methods of the present invention is materially and very surprisingly increased.

In one modification of the present invention the relatively high pressure condensate reservoir may be injected successively into a number of relatively low pressure reservoirs. For example, the contents of the high pressure relatively lean condensate reservoir may first pass through to a lower pressure relatively rich condensate reservoir, as in the above example, and thereafter flow through into a liquid oil reservoir. Production is affected from the liquid oil reservoir at a point spaced from the point of which the condensate gas is injected. Therefore, the first condensate reservoir discharges through the second condensate reservoir and thereafter through the oil reservoir, all of the several sands being produced by a well or wells extending exclusively to the oil reservoir. In this manner each of the sands is produced under conditions of maximum liquid hydrocarbon recovery.

It is important to note, as above indicated, that as a general rule the pressure of a reservoir increases with the subsurface depth of the reservoir. Therefore, it is advisable to derive the pressuring condensate gas from

the lowermost reservoir of the formation. This means that instead of producing a given reservoir, per se, it is advisable to drill thru this reservoir to a lower subsurfacing level to interconnect with a higher pressure condensate source and thereby effect equalization of pressures to produce from the overlying reservoirs at a point spaced substantially from the point of high pressure injection.

Obviously many modifications and variations of the invention, as hereinbefore set forth may be made without departing from the spirit and scope thereof, and therefore only such limitations should be imposed as are indicated in the appended claim.

I claim:

A method for the production of normally liquid hydrocarbons from a plurality of subsurface condensate reservoirs where a low pressure condensate reservoir containing retrograde fluid relatively rich with respect to normally liquid hydrocarbons is located above a high pressure condensate reservoir containing retrograde fluid relatively lean with respect to normally liquid hydrocarbons, which comprises placing said condensate reservoirs in direct fluid communication, directly injecting the high pressure retrograde fluid contents of said high pressure condensate reservoir into said low pressure condensate reservoir and producing said low pressure condensate reservoir at a location removed from the zone at which the contents of said high pressure reservoir are injected thereinto whereby there is recovered from said low pressure reservoir an amount of normally liquid hydrocarbons greater than the total amount separately recoverable from said high pressure and low pressure reservoirs and whereby the fluid so produced from said low pressure reservoir contains an increased amount of normally liquid hydrocarbons with respect to the normally liquid hydrocarbon content of the retrograde fluid originally present in said high pressure reservoir.

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