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THERMAL RECOVERY OF HEAVY CRUDE OIL

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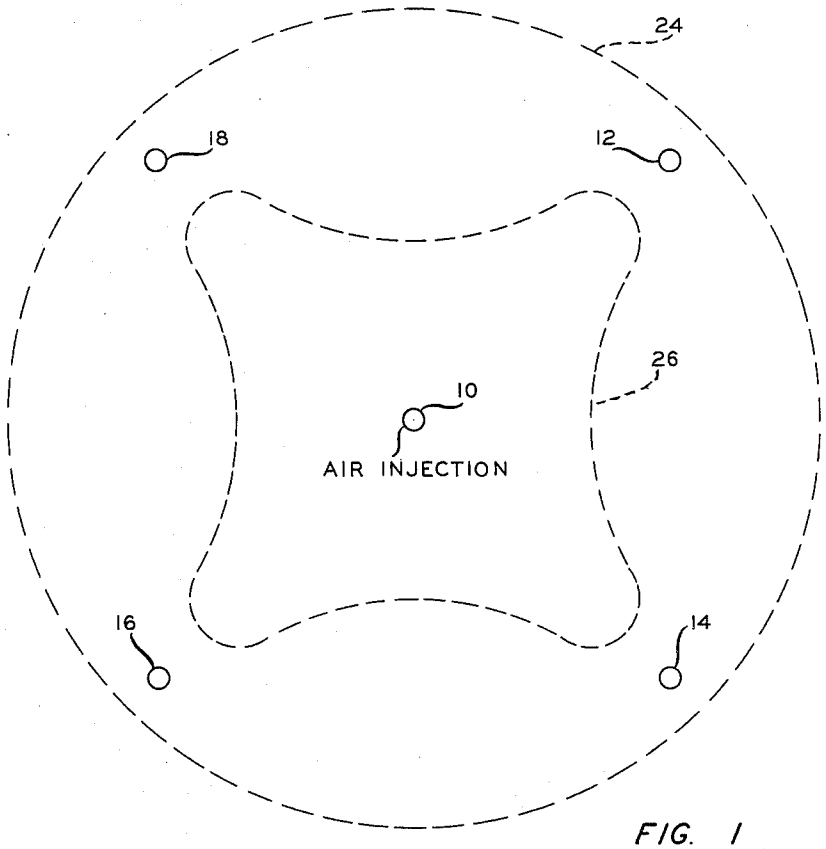


FIG. 1

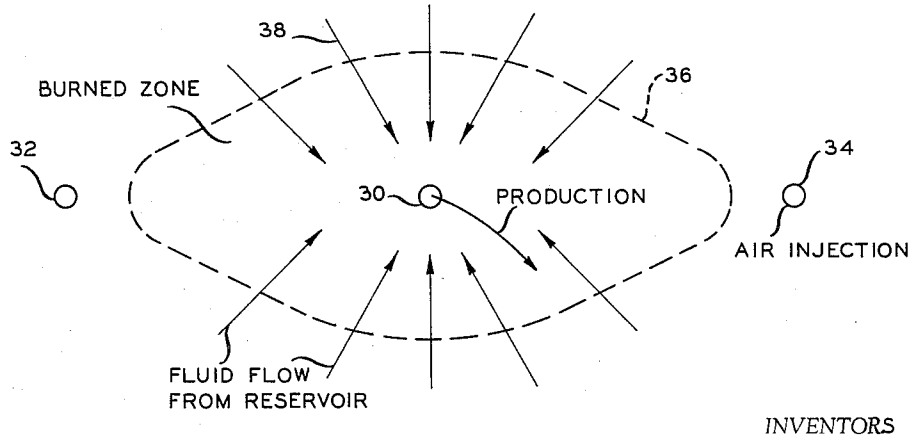


FIG. 2

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THERMAL RECOVERY OF HEAVY CRUDE OIL

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This invention relates to a process for the thermal recovery of heavy crude oil from a subterranean stratum containing such oil.

Because of high oil viscosity many fields containing low API gravity oil yield only a few percent of the oil originally in place when produced by conventional methods. Water flooding and other similar methods are not very effective in producing heavy oils because of the adverse mobility ratios and fingering of the driving fluid. Conventional direct drive underground combustion does not succeed in many cases due to the build-up of a viscous liquid bank which prevents flow of gases thru the producing stratum so that adequate air flow can not be maintained to supply the combustion zone.

This invention is concerned with a novel counterflow combustion procedure for producing highly viscous crude oils found in numerous oil fields in this country and elsewhere.

Accordingly, an object of the invention is to provide an improved process for thermal recovery of heavy crude oil from a subterranean stratum containing the same. A further object is to provide an improved counterflow combustion technique which more effectively produces the crude oil from such a stratum. Other objects of the invention will become apparent to one skilled in the art upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises injecting air thru a first well into a stratum containing heavy crude oil while maintaining one or more offset wells shut-in so as to drive beyond the offset well(s) hydrocarbon oil in the stratum between the wells which oil is mobile under the conditions therein to form a partially evacuated section intermediate the injection well and the offset well(s); thereafter, terminating injection thru the injection well and injecting air thru the offset well(s) and producing thru the original injection well under a backpressure equal to the stratum pressure in the area affected by air injection so as to prevent invasion of displaced oil into the partially evacuated section; after injection thru the offset well(s) has effected an air-oil ratio of at least 30M s.c.f./bbl. (thousand standard cubic feet), igniting the stratum adjacent the original injection well while still under said backpressure to establish a combustion zone therein; continuing injection of air thru the offset well(s) so as to move a counterflow combustion zone toward said offset well(s); after the combustion zone has been moved a substantial portion of the distance to the offset well(s), decreasing the backpressure on the original injection well below stratum pressure in the area affected by air injection so as to allow displaced oil to flow into the combustion zone and the hot burned-over area behind this zone while continuing air injection thru the offset well(s), thereby burning a portion of the invading oil and producing another portion as lighter hydrocarbon material in the original injection well; and recovering the produced hydrocarbons from the original injection well.

Preferably, a conventional pattern of wells is utilized in the process. When utilizing 3 or more in-line wells, injection thru the center well is continued with the outer wells shut-in until the pattern between the wells has been partially evacuated of oil (the mobile portion under reservoir conditions) and when this has been accomplished, injection of air is transferred to the outer wells with backpressure equal to the stratum pressure in the area affected by air injection being maintained on the center well. When the air-oil ratio in the produced fluids in the center well reaches 30M s.c.f./bbl., or a ratio capable of supporting combustion, has been reached, the stratum is ignited around the center well with continuation of air flow from the outer wells so as to move a counterflow combustion zone outwardly from the center well toward the outer wells. Backpressure on the center well is maintained sufficiently high during this period to prevent the invasion of displaced oil into the partially evacuated zone and the combustion zone. At any time after the combustion zone has been moved a substantial portion of the distance to the outer wells such as ⅓ to ⅔ or more thereof, backpressure on the center well is reduced below stratum pressure in the area affected by air injection so as to permit invasion of displaced oil into the combustion zone and the hot burned-over area behind the combustion zone while still injecting air thru the outer wells. This invasion of displaced oil into the hot combustion zone and burned-over area results in cracking of oil and production of the lighter cracked products in the center well, as well as burning of a portion of the invaded oil to produce the heat for cracking. A significant feature of the invention comprises alternately lowering and raising the backpressure on the production well (center well) below and above natural stratum pressure at substantial intervals of time so as to alternatively allow invasion of displaced oil with attendant production thereof thru the production well, and advancement of the combustion zone toward the injection wells. In this manner, there is a substantial heat build-up during the period when backpressure is maintained substantially at stratum pressure in the area affected by air injection and a combustion front is advanced toward the injection wells.

This technique of operation produces far more hydrocarbons from a well pattern than has been produced by any other known method. The process can be continued in a given well pattern until the invasion of hydrocarbons into the hot combustion zone and the hot burned-over area behind the combustion zone, no longer occurs. Continuation of the process eventually results in the arrival of the combustion zone at the injection wells and continuing injection of air thru these wells effects a direct drive process back thru the burned over section of stratum wherein the combustion zone feeds on deposited coke resulting from the counterflow combustion step, and produces additional hydrocarbon material from the stratum.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURE 1 is a plan view of the well pattern for use in the invention and FIGURE 2 is a similar plan view at stratum level of 3 wells in line utilizing the process of the invention.

Referring to FIGURE 1, a 5-spot well pattern is illustrated in which well 10 is surrounded by ring wells 12, 14, 16, and 18.

In operation of the invention utilizing the well pattern of FIGURE 1, air is injected thru well 10 with wells 12–18 shut-in and the injection is continued until oil and other fluids in the stratum mobile under the conditions therein are driven outside of the well pattern as illustrated by ring 24. During this period of injection, pressure on ring wells 12–18 can be reduced or the wells can be opened to temporary flow so as to determine when the mobile fluids have been pushed to an area outside of the well pattern. When it has been determined that the well pattern has been cleared of mobile oil and other fluids, air injection thru ring wells 12–18 is commenced with production of fluids thru well 10 while maintaining a backpressure on well 10 at least as great

but preferably not substantially greater than the natural reservoir pressure tending to force the displaced oil and other fluids back into the well pattern. When the production thru well **10** shows a ratio of air to liquid (oil) of at least 30 and up to 40M s.c.f./bbl., the stratum around well **10** is ignited in conventional manner as with a down-hole heater or a charcoal pack, and continuation of air injection thru the ring wells causes the resulting combustion zone to move outwardly into the pattern from well **10** in a counterflow movement. After the counterflow combustion has continued for an extended period, with production of upgraded hydrocarbons thru well **10** at substantial backpressure at least as great as the stratum pressure in the area affected by air injection, the backpressure on well **10** is reduced substantially below the existing stratum pressure in the operating area so as to allow displaced oil to invade the combustion zone and the hot burned-over rock or sand behind the combustion zone thereby cracking and upgrading the invading oil and producing the upgraded hydrocarbons thru well **10**. During this period of reduced backpressure, injection of air thru the ring wells is continued preferably at the same rate so as to furnish oxygen for combustion in the combustion zone and supply the necessary heat and maintain the necessary temperature for the production of the invading oil.

After an extended period of reduced backpressure operation at well **10**, the backpressure is again increased to prevent further oil invasion from outside the well pattern and continued injection of air thru the ring wells expands the combustion zone and produces additional upgraded hydrocarbons from the in-place oil. Preferably the combustion zone is expanded to the area inside dotted lines **26** or some similar pattern prior to the reduction of backpressure and the invasion of displaced oil into the hot combustion area. The process is continued until the combustion zone actually reaches the ring wells and a direct drive combustion zone is then moved back to the injection well with the coke deposited in the counterflow combustion serving as fuel for the direct drive phase of the process. This direct drive of the combustion front back thru the burned-over area of the well pattern produces additional upgrade hydrocarbons from the stratum.

Referring to FIGURE 2, center well **30** is in line with outer wells **32** and **34**, forming an in-line pattern involving 3 wells. Obviously, additional wells in the line may be operated in the same manner. The combustion pattern is outlined by line **36** and shows the expansion of the burned zone at one stage of counterflow combustion. Well **30** is operated similarly to the operation of well **10** of FIGURE 1 and wells **32** and **34** in the manner of operation of ring wells **12–22**. Arrows **38** illustrate the direction of movement of displaced oil into the burned and burning zones during the period of reduced backpressure on well **30** while injecting air thru wells **32** and **34**.

It is also feasible to perform the process of the invention utilizing a pair of wells by operating one of the wells in the manner of operation of well **30** and the other in the manner of operation of well **32** or **34**. It is also within the scope of the invention to operate 3 parallel lines of wells illustrated by each of wells **32**, **30** and **34** wherein the wells in the inner line are operated the same as well **30** and the wells in the outer lines are operated the same as wells **32** and **34**. The spacing of the wells depends upon the particular stratum to be produced and will vary considerably depending upon the conditions involved. A suggested spacing is in the range of 100 to 500′ between wells in the pattern but spacings outside of this range are within the scope of the invention.

The technique of the invention permits carrying out a counterflow in situ combustion process for recovering heavy oil without movement of the fire zone a great distance from the ignition well by proper control of pressures at the injection and production wells. To illustrate, when utilizing the well pattern of FIGURE 2, reduction of backpressure at well **30** to below stratum pressure in the area affected by air injection may be effected when the combustion front has reached out only one-fourth or one-third the distance to wells **32** and **34**. Invasion of displaced oil then prevents further advance of the front until backpressure at well **30** is raised at least to existing stratum pressure in the area affected by air injection. In this manner a great deal of the displaced oil is upgraded and produced without substantial movement of the front or leading edge of the combustion zone. During this production period, the invading oil passes thru the combustion front and its velocity toward the production well is increased.

Reservoir pressure in strata to which the invention is applicable will vary in the range of 200–2500 p.s.i.g. Injection pressures in the range of 300–3000 p.s.i.g. are used. Generally, the backpressure before the reduction to allow displaced fluids to enter the combustion zone is substantially equal to reservoir pressure in the area of the reservoir affected by air injection. In the reduction step at the production well, the pressure is reduced to the range of about 5 to 500 p.s.i.g. lower than reservoir pressure in the affected area. The actual value to be used is determined by close adjustment to give a constant air-oil ratio which indicates oil movement to the combustion zone at a rate necessary to maintain a stationary combustion front.

The process disclosed herein is more effective with a well pattern such as that illustrated in FIGURE 2 and in the production of parallel lines of in-line wells. In these patterns the invasion of displaced oil into the combustion zone is in greater volume than in a ring pattern including a substantial number of wells in a ring, such as in a 9-spot pattern.

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

We claim:

1. A process for producing fluid hydrocarbons from a subterranean stratum having substantial pressure and containing a viscous crude oil penetrated by three substantially in-line wells which comprises the steps of:

(1) injecting air thru the center well of said wells while maintaining the outer wells closed in so as to drive mobile liquid oil out of a section of stratum intermediate the center well and the outer wells beyond the outer wells;

(2) thereafter, terminating injection of air thru said center well and injecting air thru the outer wells and producing fluids thru said center well while maintaining sufficient backpressure thereon to prevent any substantial return of displaced liquid oil into said section, until the air-liquid ratio in the fluids produced at the center well reaches at least 30M s.c.f. (thousand standard cubic feet) per liquid barrel;

(3) thereafter, igniting the stratum around the center well to form a combustion zone;

(4) continuing injection of air thru said outer wells while maintaining substantial backpressure on said center well so as to move said combustion zone outwardly from said center well toward said outer wells and provide a substantial hot burned over area in said section;

(5) reducing the backpressure at said center well substantially below stratum pressure so as to allow displaced oil to gradually flow into said hot area while continuing air injection thru said outer wells, thereby burning a portion of the invading oil and producing another portion as lighter hydrocarbon material in said center well; and

(6) recovering produced hydrocarbons from said center well.

2. The process of claim 1 wherein the combustion zone is moved toward the outer wells less than half the distance thereto before step (5) is performed.

3. The process of claim 1 including alternately lowering and raising backpressure at said center well below and to stratum pressure in the air injection area following step (5) so as to alternately burn and produce invading oil and in-place oil.

4. The process of claim 1 wherein said outer wells are in a ring of wells surrounding said center well and the other wells in said ring are operated in substantially the same manner as said outer wells.

5. A process for producing fluid hydrocarbons from a subterranean stratum having substantial pressure, containing a viscous crude oil, and being penetrated by first and second wells which comprises the steps of:

(1) injecting air thru said first well into said stratum while maintaining said second well shut-in so as to drive beyond said second well hydrocarbon fluids in said stratum mobile under the conditions therein to form a partially evacuated section intermediate said wells;

(2) thereafter, terminating injection thru said first well and injecting air thru said second well and producing fluids thru said first well under backpressure substantially equal to stratum pressure in the air injection area so as to prevent invasion of displaced fluids into said partially evacuated section;

(3) after step (2) has effected an air-liquid ratio of at least 30M s.c.f./bbl., igniting said stratum adjacent said first well while still under said backpressure to establish a combustion zone;

(4) continuing injection of air in step (2) so as to move said combustion zone countercurrently to air flow toward said second well;

(5) after said combustion zone has been moved a substantial portion of the distance to said second well, decreasing the backpressure on said first well below stratum pressure in the injection area so as to allow displaced hydrocarbon fluids to flow into the combustion zone and the hot burned over area behind said zone and continuing the injection of air as in step (4) so as to burn a portion of the invading hydrocarbon fluids and produce a portion thereof as lighter hydrocarbons; and

(6) recovering produced hydrocarbon fluids from said first well.

6. The process of claim 5 wherein the backpressure is alternately decreased and increased below and above stratum pressure in the air injection area so as to alternately produce principally invading hydrocarbon fluids and in-place hydrocarbon material.

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