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[54] **STAIR-STEP THERMAL RECOVERY OF OIL**

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[51] **Int. Cl.** **E21b 43/24**

[58] **Field of Search**.....166/269, 272, 274, 252

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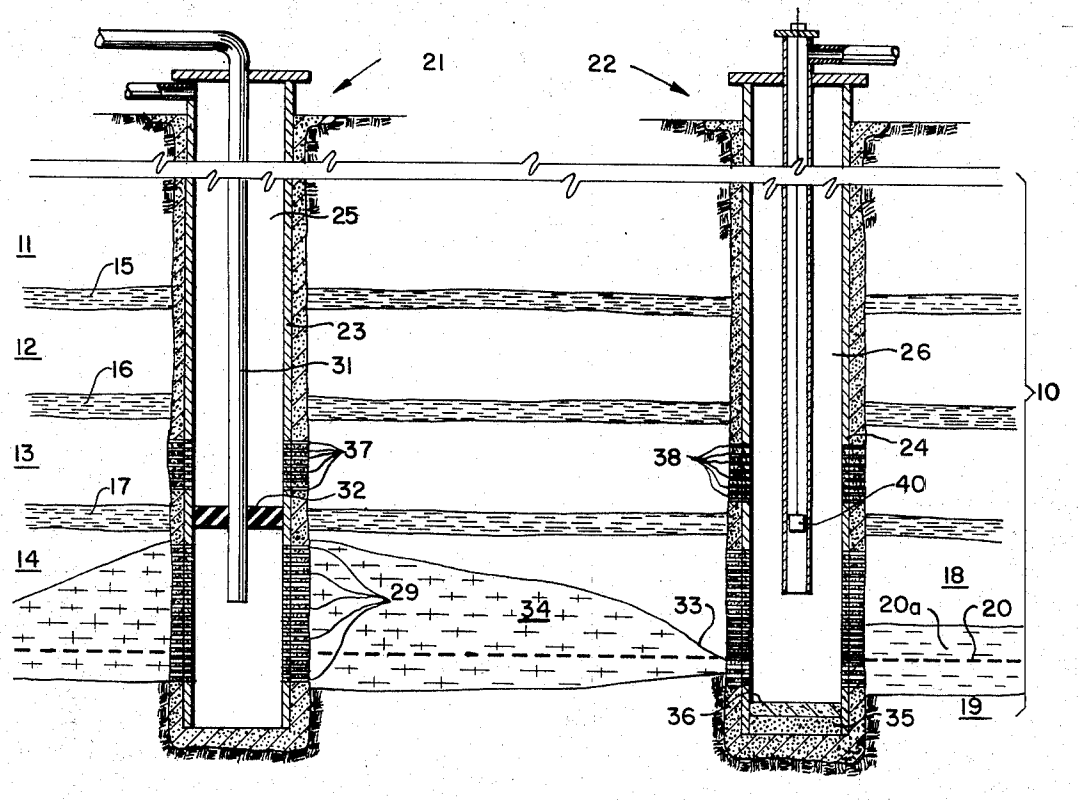
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[57] **ABSTRACT**

A method for producing a viscous oil from a reservoir having a number of permeable oil saturated layers separated by impermeable barriers through which heat may be conducted. According to the method, a water zone and a zone of saturation transition between a water zone and an overlying oil zone of a first formation are used as conduits for carrying heat into the formation. This heat is employed to reduce the viscosity of oil in the formation thus improving the injectivity of the formation and facilitating the initiation of a steam flood therein. Hear from this stream flood is conducted, through an adjoining impermeable barrier and into an adjacent formation which is then steam flooded.

2 Claims, 2 Drawing Figures



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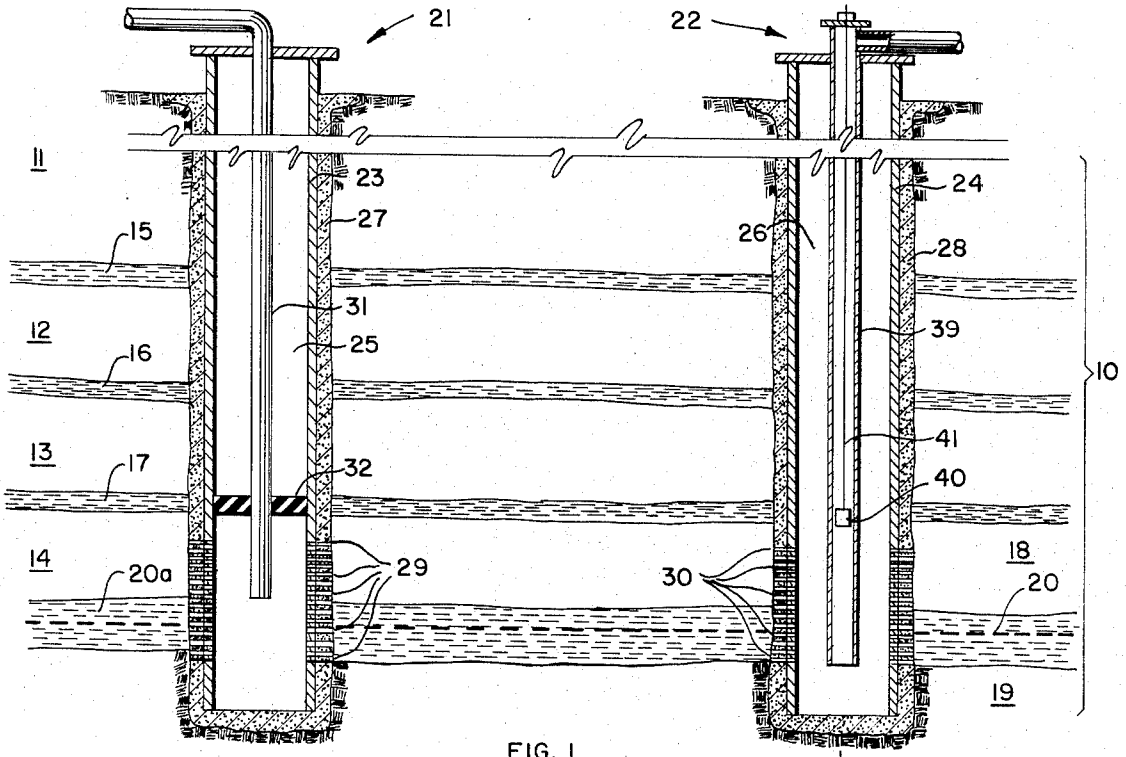


FIG. 1

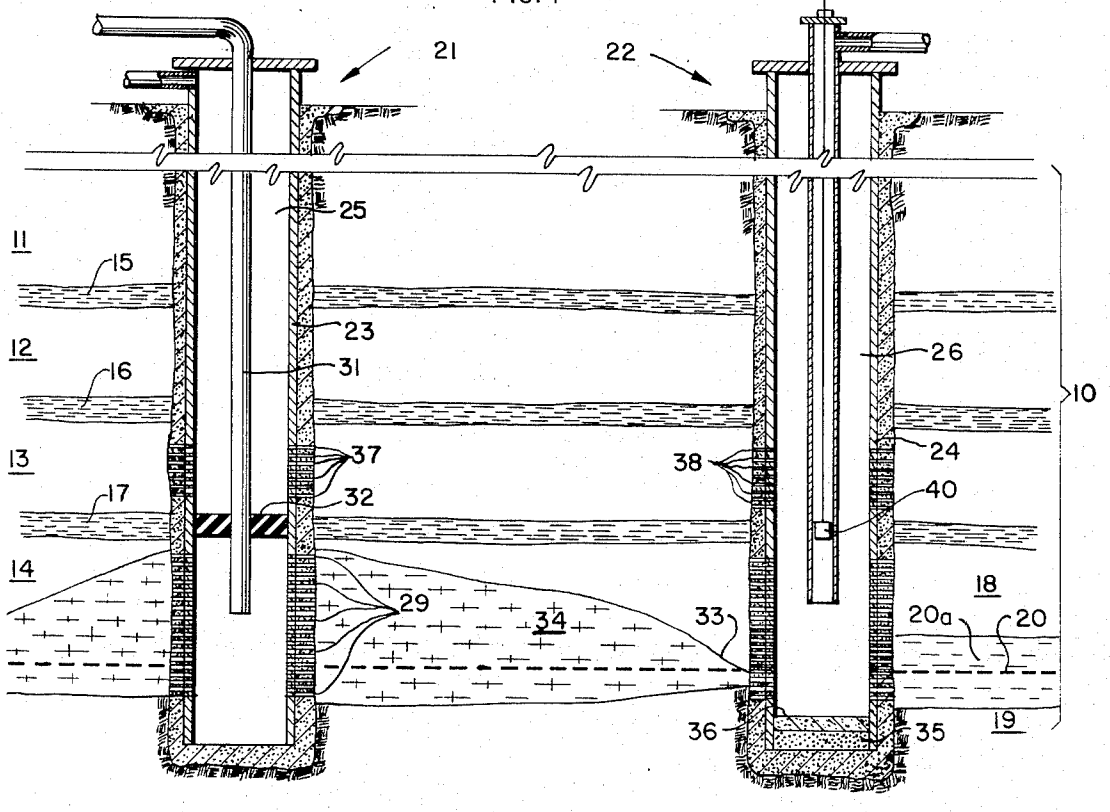


FIG. 2

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STAIR-STEP THERMAL RECOVERY OF OIL

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a method for producing hydrocarbons from a subsurface reservoir. More particularly, this invention relates to a method for treating an oil-bearing reservoir with steam and/or hot water to increase the recovery of hydrocarbons therefrom.

2. Description of the Prior Art

In many areas of the world, reservoirs of low A.P.I. gravity crude oil exist which are difficult to produce because the high viscosity of such low gravity oils makes them substantially immobile within the reservoir. It is well known that the viscosity of most crude petroleum is temperature dependent and that the viscosity of the oil in a given reservoir may be decreased by a factor often on the order of 50 to 1,000 times by an increase in the temperature of that oil above the reservoir temperature on the order of 100° F. To this end, a number of methods for heating oil in a petroleum reservoir have been successfully employed. Among these is the injection of steam and/or hot water into the reservoir to heat the oil, thereby lowering its viscosity, and to drive the heated oil to a producing well.

Some oil reservoirs which contain viscous crudes are composed of a number of layers or formations of sandstone or other permeable oil-bearing rocks separated by relatively thin impermeable barriers through which heat may be conducted such as layers of shale. It has been suggested that heat may be provided by conduction to one of two adjacent oil-bearing layers of such a reservoir by carrying out a conventional steam flood in the other of the adjacent layers. However, in some layered reservoirs, the oil in each of the oil-bearing layers may be so viscous and immobile at the naturally occurring reservoir temperature that it is difficult or impossible to initiate a steam and/or hot water flood in any of the layers by injecting a hot aqueous fluid solely into a predominately oil-saturated zone.

It has also been suggested that an oil-bearing layer may be warmed by heat conducted from a steam flood of an adjacent water sand. However, in some cases it may be economically impractical to heat an adjacent oil-bearing layer by steam flooding a water-saturated layer because it may take a substantial preheat period before significant amounts of oil are produced from the adjacent oil zone.

SUMMARY OF THE INVENTION

It is not uncommon for at least one oil-bearing sand in a reservoir having a number of oil-bearing layers separated by impermeable barriers to include at least one oil-bearing layer which has a predominately water-saturated interval or zone near the bottom of that layer.

The present invention provides a method for producing oil from a viscous oil containing reservoir having a number of oil-bearing layers or formations separated by impermeable barriers through which heat may be conducted and having at least one layer or formation (the "first treated formation") which includes an upper zone predominately saturated with viscous oil, a lower zone predominately saturated with water, and a zone of saturation transition between the upper and lower zones in which oil saturation decreases and water saturation increases with increasing depth. According to the present invention, the transition zone and the water zone of the oil-bearing formation are used as conduits for carrying a heated fluid into the formation. Heat from this fluid is employed to reduce the viscosity of at least some oil in the upper and transition zones. The heated oil is then driven to a producing well, or is then entrained in the fluid passing through the water zone and the transition zone and carried to a producing well. Heat from this thermal treatment of the first treated formation is conducted through the adjoining impermeable barrier to an adjacent oil-bearing formation thereby reducing the viscosity and increasing the mobility of oil in that layer. This conductively heated formation may then be treated according to a hot water and/or steam flood recovery process.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a diagrammatic view partially in cross-section of a layered, subterranean, viscous oil-containing reservoir traversed by two wells suitably equipped for the practice of this invention.

FIG. 2 is a vertical sectional view of the reservoir at a time after it has been treated according to the teachings of this invention.

DESCRIPTION OF A PREFERRED EMBODIMENT

Referring to FIg. 1, we see a subsurface oil reservoir **10**, which encompasses a number of porous, permeable viscous oil-containing formations or intervals **11–14** separated by a number of impermeable layers or barriers **15–17** preferably less than 50 feet thick. The permeable formations **11–14** may, for example, be composed of sandstone while the impermeable layers **15–17** may be composed of shale or other impervious rock capable of conducting heat. The lowermost sand formation **14** has an upper zone **18** predominately saturated with a viscous crude oil and a lower zone **19** predominately saturated with water. The zones **18** and **19** meet at an oil-water contact **20**. Adjacent the oil-water contact **20** may be a zone **20*a*** of saturation transition in which the oil saturation decreases and the water saturation increases with increasing depth. Within at least some of this saturation transition zone **20*a***, the relative permeability to both oil and water is great enough so that oil and water may be expected to flow simultaneously through the zone **20*a*** if the fluids have viscosities of similar magnitude. However, because the viscosity of the viscous oil in the formation **14** is much greater at the naturally occuring reservoir temperature than the viscosity of the water in the formation **14** at that temperature, the oil in the saturation transition zone **20*a*** is substantially immobile when at that temperature whereas at least a portion of the water in this zone **20*a*** is mobile.

To recover oil from the reservoir **10** according to the method of this invention, at least a first well **21** and a second well **22** are extended into the oil reservoir **10**. Each of the wells **21** and **22** at least partially transverses the predominately water-saturated lower zone **19** of permeable formation **14**. The wells **21** and **22** may be completed in a conventional manner, as for example, by extending tubular casings **23** and **24** into well bores **25** and **26** of the wells **21** and **22** and fixing the casings **23** and **24** in place with cement **27** and **28**. The wells **21**

and 22 may then be opened into fluid communication with preferably at least a portion of each of the zones 18, 19 and 20*a* of the formation 14 by any method in the art such as perforating the casings 23 and 24 and the surrounding cement 27 and 28 with perforations such as those indicated by numerals 29 and 30. The intervals of the well bores 25 and 26 which are provided with perforations 29 and 30 preferably extend at least 2 feet above and below the oil-water contact 20, the location of which may be determined by methods well known in the art, such as electric logging, as may the respective locations of the zones 18, 19 and 20*a*.

A flow path for injecting fluid into formation 14 through the first well 21 may be provided as by extending a string of tubing 31 into the well 21 to location in the borehole 25 adjacent the formation 14. A packer 32 may be set in the annulus between the tubing 31 and the casing 23 above the perforations 29 which open the borehole 25 into fluid communication with the formation 14 to pack off the perforate portion of the borehole 25. The second well 22 may be equipped in any conventional manner, as with a string of tubing 39 and a pump means 40 driven by a rod means 41, to produce fluid which flows into that well 22 from the formation 14 through the perforations 30.

The formation 14 may first be preheated by injecting hot water or low-grade steam (about 5 percent quality) down the first well 21, through the perforations 29, and into the formation 14, and producing fluid from the formation 14 through the second well 22. Because the water in the predominately water-saturated lower zone 19 and the transition zone 20*a* has a greater mobility than the viscous oil in the predominately oil-saturated zone 18, the water in the zones 19 and 20*a* will move to the second well 22 relatively rapidly compared to the rate of fluid movement in zone 18.

As the water moves toward the well it is at the same time replaced by hot injected fluid which moves through the zones 19 and 20*a* heating oil in the zone 20*a* and conductively preheating oil in the oil-saturated zone 18. As the oil in the transition zone 20*a* adjacent the oil-water contact 20 is heated, it becomes more mobile. At least some of the heated mobile oil in the transition zone 20*a* is entrained in the moving stream of hot injected fluid and is moved along therewith to the producing well 22 where the oil is produced along with the water in which it is entrained. Thus, oil production from the saturation transition zone 20*a* may begin during the preheat period before a substantial portion of the oil in the upper zone 18 is significantly more mobile than it is at the naturally occurring reservoir temperature.

Preferably, after hot water injection into the formation 14 is commenced, the producing well 22 is at least from time to time checked as by measuring the temperature of the produced fluids to determine whether or not heat communication is established between the injection well 21 and the producing well 22. The injectivity of fluid into well 21 may also be measured for indication of communication. Preferably after heat communication between the injection well 21 and producing well 22 is established, the injection of hot water or low grade steam is stopped and relatively high grade steam (preferably of at least 75 percent quality) is then injected into the formation 14 through the established paths of communication in zones 19 and 20*a* and through the predominately oil-saturated zone 18 making the oil in this zone 18 even more mobile.

According to a second embodiment of this invention, such relatively high grade steam may be injected down the first well 21 and into the formation 14 as a preheating fluid without first injecting hot water or low grade steam into the formation 10. This fluid initially moves into the water-saturated lower zone 19 and the transition zone 20*a* as described above to preheat oil in the upper zone 18. Preheating with this higher quality steam has the advantage of transfering more heat (the heat of vaporization of the steam) to the formation 14 per unit mass of fluid injected than hot water preheating. However, because steam is less dense than water, the contribution to bottom hole pressure in the well 21 of the column of fluid in the tubing 31 is less when steam is used as the preheat fluid. Therefore, for a given injection pressure at the top of the tubing string 31, the mass flow rate of injected preheat fluid may be lower if the preheat fluid is steam instead of hot water.

Whether the preheat fluid is hot water or steam, after the preheat period, the lower zone 19 of the formation 14 may be at least partially resaturated with heated, more mobile oil by continuing to inject steam into the formation 14. This steam forms a front 33 (FIG. 2) which may rise as it advances through the formation 14 toward the producing well 22 forming a predominately steam saturated zone 34 such as that illustrated. At the front 33, the advancing steam heats oil and drives it toward the producing well 22. Simultaneously, at least some of heated oil from above the steam zone 34 may drain down into the steam zone 34 where it may be entrained in and carried with the steam advancing toward the producing well 22. At least some heated oil may drain from the steam zone 34 into the lower zone 19 resaturating this zone with oil. As oil saturation in the zone 19 increases, oil may be entrained in and carried with the injected fluid moving through this zone to the well 22.

Because the steam, at least initially, moves into the formation 14 more rapidly through the predominately water-saturated lower zone 19 than through the viscous oil-saturated upper zone 18, it is to be expected that the steam front 33 first breaks through into the producing well 22 from the lower zone 19. The occurrence of steam breakthrough may be determined in a well-known manner such as by observing the temperature of the produced fluids. When steam breakthrough occurs into the producing well 22 the steam influx into the well may be shut off at least in part by plugging back the lower portions of the perforated interval of the borehole 26 of the well 22 by any method known in the art such as, for example, filling the borehole with a gravel 35 and covering the gravel with a cement cap 36. From time to time, as the steam zone 34 rises through the formation 14 and steam again breaks through into the well 22 more of the perforated interval of the producing well 22 may be plugged back.

During the period of hot fluid injection into the first heated productive formation 14, heat may be transferred by conduction through the adjoining shale barrier 17 and into the adjacent viscous oil-bearing formation 13. This heat reduces the viscosity of the oil in formation 13 thus increasing the mobility and injectivity

of that interval. Preferably, after it has been determined (as by temperature surveys, mathematical analysis or other methods well known in the art) that the injectivity of the formation **13** has been increased to a selected desirable value, the wells **21** and **22** may be opened into fluid communication with the formation **13** as by perforating the casings **23** and **24** with perforations **37** and **38** (if this has not been previously done). A separate confined path for fluid flow into the formation **13** may be provided in the injection well **21** as by installing previously referred to packer **32** in the annulus between the tubing **31** and the casing **23** at a location in the well bore **25** which is between the perforations **37** and **29** which open into formations **13** and **14**, respectively. This provides for the simultaneous injection of separate columns of heated fluid down the tubing **31** and into formation **14** and down the annulus between the tubing **31** and the casing **23** and into the formation **13**.

Preheated viscous oil may then be driven from formation **13** by injecting hot water and/or steam into this formation through the first well **21** while producing fluid from the formation through the producing well **22**. As hot fluid moves through formation **13**, heat is lost by conduction through shale barrier **16** to adjacent formation **12**. This heat reduces the viscosity of the oil in formation **12** thus increasing the injectivity of that formation and facilitating the initiation of a thermal flood therein. Thus, the reservoir **10** may be produced by a stair-step method which begins by injecting heat into the predominately water-saturated zone **18** and the transition zone **20*a*** of formation **14** and leads to the thermal flooding of adjacent formations **13**, **12** and **11**, respectively. It should be understood that while in the embodiment of the invention heretofore discussed only formations above the first treated formation **14** were treated, it is within the concept of this invention to preheat and subsequently thermally flood adjacent formations below the first treated formation **14**.

In summary, the present invention provides a process for the recovery of oil from a subsurface oil-bearing reservoir which includes at least a first and a second productive formation which are adjacent but separated by a substantially impermeable barrier through which heat may be conducted and wherein the first productive formation has three zones — an upper zone predominately saturated with a viscous relatively immobile oil, a lower zone predominately saturated with water and a saturation transition zone wherein oil saturation decreases and water saturation increases with increasing depth. An embodiment of the method comprises the steps of: extending at least a first well and a second well to each at least partially traverse the first and second productive formations; opening the wells into fluid communication with the upper zone, the lower zone, and the transition zone of the first productive formation; preheating the oil in the upper zone of the first productive formation by injecting hot water into the first productive formation through the first well whereby the hot water moves into the transition zone and into the predominately water-saturated lower zone establishing a path of heat communication and carrying heat into the first productive formation which heats oil in the transition zone and which conductively heats at least some of the oil in the upper zone; entraining in the hot water moving through the transition zone of the first productive formation at least a portion of the heated oil in the transition zone, and producing said entrained oil through said second well along with said water.

After the preheat step, one may drive oil to the second well and conductively preheat the adjacent second productive formation by continuously injecting steam simultaneously into the upper, lower, and transition zones of the first productive formation through a single flow path in the first well while producing fluid substantially simultaneously from the upper, lower, and transition zones of the first formation through a single flow path in the second well.

Thereafter, one may open the first well and the second well into fluid communication with the adjacent second productive formation, provide a separate confined path for fluid flow into the adjacent second productive formation through the first well, and drive oil from the adjacent second productive formation by injecting a heated fluid into the second productive formation through the separate confined path for fluid flow in the first well while continuing to inject steam into the first productive formation. This oil may be produced from the second productive formation through the second well. As fluid is produced, one may determine when steam breakthrough into the second well from the first productive formation occurs. After the steam breakthrough occurs, the steam influx into the second well may be at least partially shut off by plugging back at least some of that portion of the second well which is open into fluid communication with the first productive formation.

We claim as our invention:

1. In a process for the recovery of oil from a subsurface oil-bearing reservoir which includes at least two productive formations, a first productive formation having three zones — an upper zone predominately saturated with a viscous relatively immobile oil, a lower zone predominately saturated with water, and a saturation transition zone where in oil saturation decreases and water saturation increases with increasing depth — and an adjacent second productive formation separated therefrom by a substantially impermeable barrier through which heat may be conducted, the method comprising the steps of:

extending at least a first well and a second well to each at least partially traverse said first and second productive formations;

determining the location in said first formation of said first zone, second zone and transition zone;

opening said first well and said second well into fluid communication with the upper zone, the lower zone, and the transition zone of said first productive formation;

preheating at least some of the oil in the upper zone and heating at least some of the oil in said transition zone of said first productive formation by injecting a hot fluid into said first productive interval through said first well whereby said hot fluid moves into said transition zone and said predominately water-saturated lower zone carrying heat into said first productive formation which conductively preheats said upper zone;

entraining in hot fluid moving through said transition zone of said first productive formation at least a portion of said preheated oil in the transition zone;

producing said entrained oil through said second well along with said fluid;

after said preheat step, driving oil to said second well and conductively preheating said adjacent second productive formation by continuously injecting steam simultaneously into the upper, lower, and transition zones of said first productive formation through a single flow path in said first well; and

producing fluid from said upper, lower, and transition zones of said first formation through a single flow path in said second well;

whereby said steam injected into said transition zone and said lower zone moves toward said second well and rises carrying heat into said first productive formation further heating the oil in said upper zone and entraining at least some heated oil draining from said upper zone into said transition zone and said lower zone, whereby said steam injected into said upper zone further heats the preheated oil in said upper zone and drives said oil in said upper zone to the second well, and whereby the adjacent second productive formation is preheated by heat conducted from said first productive formation through said impermeable barrier;

opening said first well and said second well into fluid communication with said adjacent second productive formation;

providing a separate confined path for fluid flow into said adjacent second productive formation through said first well;

driving oil from said adjacent second productive formation by injecting a heated fluid into said second productive formation through said separate confined path for fluid flow in said first well while continuing to inject steam into said first productive formation;

producing oil from said second productive formation through said second well;

determining when steam breakthrough into said second well from said first productive formation occurs; and

when said steam breakthrough occurs, plugging back at least some of that portion of said second well open into fluid communication with said first productive formation to shut off at least some of said steam breakthrough.

2. The method of claim 1 wherein said fluid is hot water.

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