HEAVY OIL RECOVERY

Filed Oct. 26, 1953 2 Sheets-Sheet 1

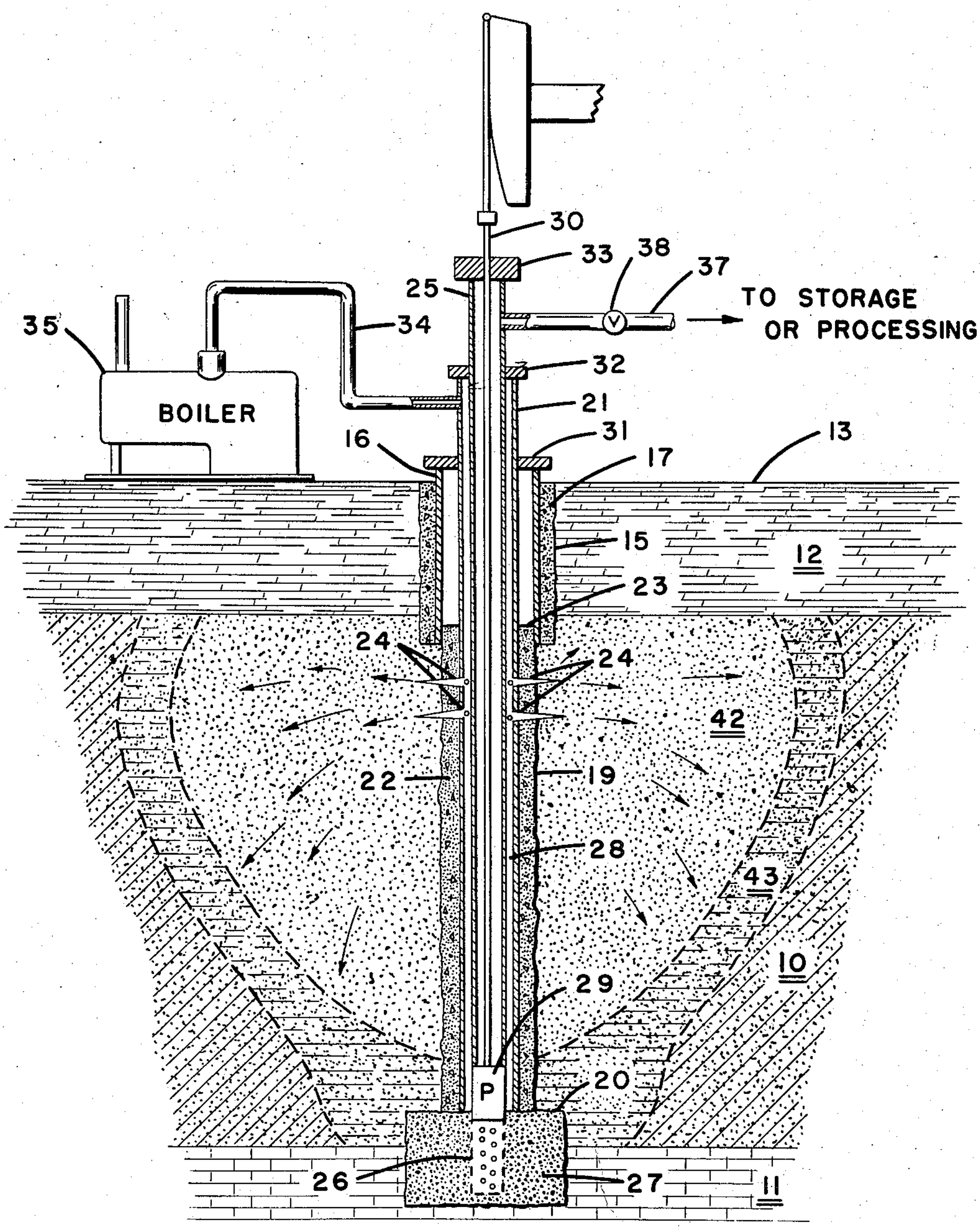

FIG. 1

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April 14, 1959 R. A. MORSE ET AL 2,881,838
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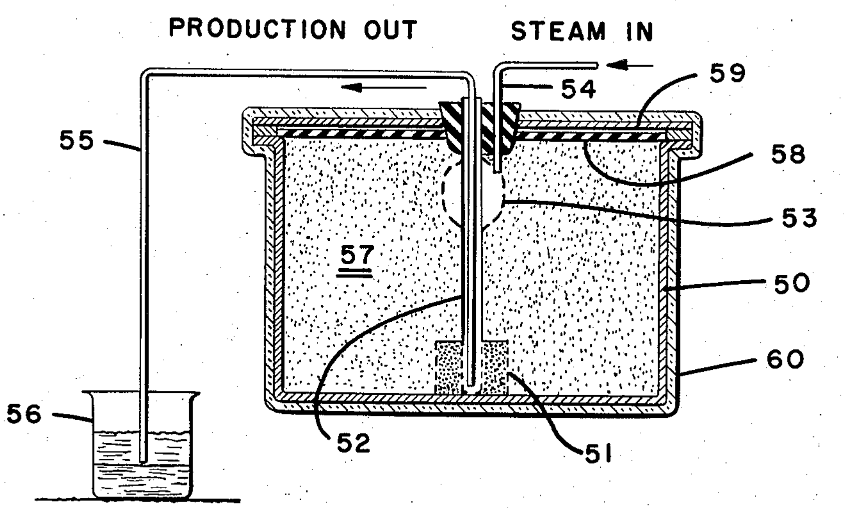

FIG. 2

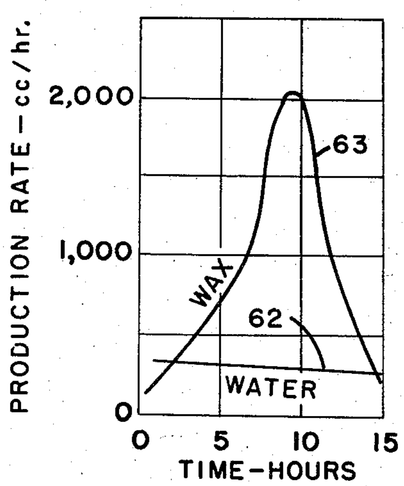

FIG. 3

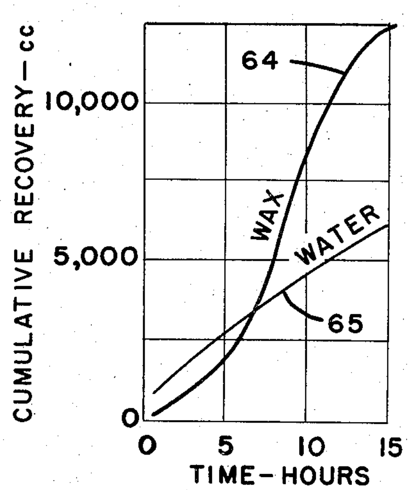

FIG. 4

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HEAVY OIL RECOVERY

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This invention relates to oil recovery and is directed particularly to the recovery of heavy oils or bitumens from the underground strata in which they occur. Specifically it is directed, but not limited, to the in-place treatment and recovery of solid or semisolid hydrocarbons or bitumens, the most notable example of which is the bitumen in the Alberta bituminous sand outcropping along the Athabaska River in Canada.

By even the most conservative estimates the Athabaska tar sands, as they are commonly known, represent a fuel reserve of tremendous magnitude. Many schemes have been proposed, and from time to time experimental or commercial efforts have been made, to recover these bitumens on a basis competitive with the production of crude oil from wells. None of these proposals or efforts has as yet achieved any substantial degree of success. A great many of them have involved the mining and treating of the sand to cause release of the bitumens, in spite of general recognition that recovery from the sands in place without mining and subsequent disposal of waste is much to be preferred.

It is believed that a major difficulty with the in-place treatment and recovery methods heretofore proposed arises from the fact that the bitumens of these bituminous sands generally differ from ordinary crude oils in that the bitumen is too viscous or too nearly a solid to be made to flow like oil, by the application of a driving-fluid pressure thereto, except after the bitumen has been melted or its viscosity sufficiently reduced by heating.

Heat cannot ordinarily be generated in or propagated through such a sand body except by the flow of heated fluids therethrough. When the bitumen is heated, however, to give it the necessary fluidity, any subsequent movement away from the supply of heat results in the bitumen again becoming highly viscous and substantially ceasing to flow, with the further result that whatever permeability may have existed initially is completely plugged off. Thus, an initial melting and flow under pressure quickly form an impermeable barrier against further flow of a heat-carrying fluid into or through the deposit.

In view of the foregoing it is accordingly a primary object of our invention to provide a novel and improved process and apparatus for the in-place treatment and recovery of heavy oils or bitumens which are characterized by being substantially solids or too viscous to flow readily at reservoir conditions. Other and more specific objects of the invention may be summarized as to provide an improved process for heavy-oil recovery in which: (1) externally supplied heat is utilized with high efficiency; (2) the hydrocarbons are recovered in a form which simplifies subsequent processing; (3) problems of mining and waste disposal as well as providing bulk solid processing equipment are avoided; and (4) once-melted bitumens or oils are positively prevented from again solidifying in place in the sand or well equipment during the process of recovery. Other and further objects, uses and advantages of the invention will become apparent as the description proceeds.

Stated briefly, the foregoing and other objects are accomplished by an arrangement of equipment and method of operating it by which the hydrocarbons in the formation and the heat-supplying medium are maintained in contact with each other at all times during movement of the hydrocarbon from its place of occurrence until it reaches the ground surface ready for further utilization. Preferably, a well is first drilled through the producing stratum, and it is then equipped for injecting steam into the upper part of the stratum to induce flow of the hydrocarbon by gravity drainage into the bottom of the well, from which level the liquids are withdrawn to the ground surface. The point of heat input and the path of travel of the fluid to the place where it is recovered are thus arranged both to make use of the forces of gravity drainage and to maintain the liquefied material and the heat-supplying steam in thermal contact from the time the material is first contacted by the steam to reduce its viscosity and/or to produce melting until the time when the material reaches the ground surface.

This will be better understood by reference to the accompanying drawings forming a part of this application, illustrating a preferred embodiment of the invention and a test model of the invention with the results obtained therefrom. In these drawings:

Figure 1 is a vertical cross-section view through a portion of earth strata which include a bituminous sand stratum, showing mostly diagrammatically a preferred embodiment of the invention in operation in said stratum;

Figure 2 is a cross-section view of an experimental apparatus utilized for testing the principle of operation of the invention; and

Figures 3 and 4 are graphs of the test results obtained utilizing the model apparatus of Figure 2.

Referring now to these drawings in detail, and particularly to Figure 1 which shows a vertical cross section of a portion of the earth, a sand stratum **10** containing a solid or semisolid oil or bitumen lies between a lower stratum **11** and one or more overlying strata **12** forming an overburden extending to the ground surface **13**. For carrying out the invention, a bore hole **15** of substantial diameter is first drilled through the overburden **12** to the top of sand stratum **10**, and a surface casing **16** is cemented in place in hole **15** by cement **17**. Thereafter a hole **19**, of somewhat reduced diameter compared to bore hole **15**, is drilled through the major part of sand stratum **10**, terminating at the level **20** where a casing **21** is set and cemented in place by a column of cement **22** which extends from the level **20** to a level **23** just above the lower end of casing **16**. This seals the air space between these two casing strings against the entrance of fluids, so that this space is effective as thermal insulation.

Thereafter, by drilling and underreaming, the hole is deepened and enlarged at least to the bottom of stratum **10** and preferably a short distance into lower stratum **11**. Before installing additional well equipment, casing **21** and cement **22** are first perforated at level **24** preferably just below the top of stratum **10**, and then a tubing **25**, provided with a screen **26** at its lower end, is lowered to the well bottom. Thereafter, by introducing suitably graded granular material down annulus 28 from surface **13**, a gravel pack **27** is formed around screen **26** in a manner well known in the art. Preferably, but not necessarily in every well installation, a pump **29** operated by a sucker rod **30** may be inserted in tubing **25**.

At surface **13** suitable sealing means **31**, **32**, and **33** close off the top ends of casing **16**, casing **21**, and tubing **25**, respectively. From the upper end of casing **21** a pipe **34** extends to a steam boiler or generator **35**, by which means steam can be injected down annulus **28** to the well bottom, or through perforations **24** into stratum **10**, or both. From the top of tubing **25** a pipe **37** controlled by a valve 38 extends to storage or processing facilities (not shown) for the heavy oil or hydrocarbon.

In operation, after the equipment thus far described is in place, steam is injected down through the annulus 28 where it heats the casing 21 and tubing 25 substantially throughout their entire lengths. Steam condensate and any other liquids collecting in the well bottom are withdrawn through tubing 25, preferably at about the same rate as they collect there but without lowering the liquid level below the inlet to pump 29 so as to allow the bypassing of steam directly into the tubing 25.

Heat flows by conduction from casing 21 through the cement sheath 22 to the face of stratum 10, which was exposed in the drilling of well bore 19. Melting of the bitumen or heavy oil then occurs over this entire stratum face with the result that flow downwardly by gravity drainage begins and continues all the way to the pump inlet, thus establishing an initial gravity-drainage flow path.

At first, flow of steam through the openings 24 is substantially prevented by the plugging action of initially melted bitumen which flows and resolidifies in the stratum 10 around these openings, as was mentioned above. As soon as gravity drainage over the formation face through the initiated flow path begins to expose unheated oil or bitumen in the upper portion of the stratum 10, however, steam in increasing amounts passes out through the perforations 24 where it contacts the bitumen in stratum 10. There the heat content of the steam is utilized by cooling and condensation to raise the temperature of the hydrocarbon and the sand containing it until melting of the hydrocarbon occurs. Thereafter the melted hydrocarbon and any free connate water, along with the water condensed from the input steam, move downwardly under gravity flow to the gravel pack 27 where they enter the screen 26 and are removed from the well by pump 29. Continued flow of heat by conduction through the casing 21 and cement sheath 22, as needed, insures that the fluid hydrocarbon immediately outside the casing 21 and cement 22 does not re-solidify and cease downward flow under gravity on its way down to the screen 26. The continuous presence of steam in annulus 28 also insures that liquids inside tubing 25 remain hot all the time they are being lifted to ground surface 13.

As the injection of steam continues and the liquefied hydrocarbon and condensed and connate water flow downwardly and are removed, a new face is constantly being exposed in the stratum 10 where the input steam can condense and give up its content of heat to produce melting of the hydrocarbon.

This is the condition illustrated in Figure 1 where the steam moves generally outward in a radial direction from perforations 24, as suggested by the arrows, through the hot and substantially dry sand body 42 from which substantially all liquid materials have been removed by gravity flow, to the melting face or zone 43, from which the water and melted hydrocarbon move slowly downwardly and inwardly toward the screen 26. An important feature apparent here is that, from the time the hydrocarbon is first melted until it leaves the top of tubing 25 through the pipe line 37, the liquids are in thermal contact with either the steam of the dry zone 42 or that in the annulus 28 forming a jacket for the tubing 25. Cooling and resulting solidification of the hydrocarbon are thus positively prevented.

Another feature of substantial importance, differentiating this process from those in which hot water is utilized to carry the input heat, resides in the fact that input steam here flows to the place where it condenses to water and thus shrinks in volume. Thus, as the greatest amount of condensation and heat transfer occurs on the upper portion of the melting face 43, the major portion of steam flow is in a horizontal direction from the perforations 24 to the melting face 43. Hot water, on the other hand, tends to flow directly from the point of input to the point of output without inducing any appreciable lateral transfer of heat, since the water and the hydrocarbon found in bituminous sands are of very nearly the same specific gravity. Thus, in this process, full advantage is taken of the density contrast between the steam and the liquids.

The process of steam injection and withdrawal of melted hydrocarbon and water of condensation are continued in this manner, with the melting zone 43 moving progressively radially farther away from the well 19, either until such time as the angle of inclination of the melting zone 43 from the horizontal becomes so small that the rate of flow to the screen 26 is uneconomic, or until the rate of loss of heat to the overburden 12 becomes too large. Since the latter is substantially the only place where heat is lost from the system in appreciable amounts, aside from that carried by the liquids emerging from the tubing 25, a very high thermal efficiency is possible if the overburden 12 is sufficiently impermeable and has a low thermal conductivity.

Due to the plugging action of the bitumen or oil as it softens with increasing temperature, the melting face 43 acts as an impermeable barrier or container wall around the drained zone 42, preventing the pressure of the steam inside this zone from acting on the unheated volume of the stratum 10 outside of the melting face 43. Accordingly, the steam pressure within the drained zone 42 depends upon how fast steam is supplied to it through the annulus 28 and perforations 24, in relation to how fast condensation occurs at the zone boundaries.

It is always assumed that the withdrawal rate of liquids from the well bottom through the tubing 25 is sufficient to keep the liquid level around the well bore close to but not at the pump inlet. Otherwise, too low a level permits bypassing of steam directly into the tubing 25, while too high a liquid level slows down the gravity drainage of the liquids toward the well bore by backing up the accumulating liquids into the formation.

The steam pressure within drained zone 42, which is exactly the same as within the annulus 28, except for a minor pressure drop due to the flow through the perforations 24 and the porous drained zone 42, will be either higher or lower than the bottom-hole pressure of the liquids within the tubing 25. If lower, then pump 29 must be operated to raise these liquids to the ground surface. If higher, on the other hand, then the pressure of the steam is able to force these liquids up the tubing, and pump 29 may be dispensed with. The liquid production rate is then regulated by adjustment of the valve 38 at surface 13 to hold any back pressure desired on the sand stratum 10, in addition to the static bottom-hole pressure. By this means, temperatures substantially above the 212° F. level of atmospheric-pressure steam can be achieved for further reducing the viscosity and increasing the fluidity of the hydrocarbon. In fact, where the overburden thickness is great enough and heat loss is not too great, it is preferred to maintain the steam pressure in the stratum 10 at 65 or more pounds per square inch absolute, corresponding to operating temperatures of about 300° F. and above.

It is not strictly necessary that the perforations 24 be located at or near the top of stratum 10, since, if they are lower down, the only result will be that melted hydrocarbons from those portions of the stratum 10 above the steam inlet ports will pass downwardly through the dry zone 42 on their way to the screen 26. It is desirable, however, that the perforations 24 be located above the screen 26 by a substantial distance, and preferably they should be near the top of stratum 10 when it is homogeneous in nature, with a minimum of inter-bedding of low-permeability materials. This steam port location results in less interference between the horizontally moving steam and the downwardly flowing liquids and favors the desired horizontal heat transfer by steam flow. This aids in propagating of the melting front 43 for substantial maximum horizontal distances, as it is at the top of the stratum 10, where the vertical fluid flow is least, that the greatest permeability to steam occurs.

This method of heavy-oil recovery has been tested by apparatus such as that shown in Figure 2. In the center of a cylindrical vessel 50 was placed a screen cup 51 containing 30-mesh sand surrounding a vertical perforated pipe 52. Surrounding the upper unperforated portion of pipe 52 was a perforated steam chamber 53 having a steam inlet tube 54 connected to a steam generator, not shown. From the cup 51 a siphon tube 55 for removal of the produced liquids extended up through the pipe 52 and down to a collection and measuring vessel 56 located outside of and lower than the vessel 50.

Vessel 50 was filled with river sand 57 impregnated with paraffin wax having a melting point of about 128° F. which was allowed to solidify in place in the vessel 50, the top being closed and sealed by a layer of rubber cement 58 and the lid 59 of the vessel. A layer 60 of thermal insulation material was placed around the entire vessel 50 and lid 59.

Steam was then introduced simultaneously through the inlet tube 54 into the chamber 53 and into the pipe 52. After melting of the wax adjacent pipe 52 occurred, as was indicated by production through the tube 55, steam was thereafter admitted to the sand body 57 only through the tube 54 and perforated chamber 53. Wax and water separated into two layers in the collecting vessel 56 for measurement.

The results of this test, with most of the non-significant variations averaged out, are shown graphically in Figure 3. The water-production rate throughout the period of the test was nearly constant, as is shown by the curve 62. The wax production rate, on the other hand, as shown by curve 63, rose somewhat slowly at first and then more rapidly to a high maximum, after which it declined rapidly substantially to zero. It was apparent that this decline was due to the fact that substantially all of the available wax was produced and was not because of plugging of the sand 57 or any other failure of the production process.

The graph of Figure 4 presents the results of Figure 3 in the form of cumulative amounts of wax and water recovered, as functions of time, shown respectively as curves 64 and 65. It is believed of particular significance that the final water-wax ratio was only about 0.5, indicating that this method of supplying heat and its utilization by condensation are quite efficient. Although it is realized that the ratio of water to hydrocarbon may in an actual case in an earth stratum be higher than 0.5, it is believed that, even with the larger heat losses of somewhat elevated steam pressures and temperatures, it would still be substantially less than 2.0, as compared with a water-totar ratio of the order of 10 to 1 for a hot-water recovery process. Hydrocarbons are thus recovered with a minimum of admixed water, consequently simplifying the further processing and separation of the water and hydrocarbon to a high degree.

While our invention has thus been described with reference to the foregoing specific details, it is to be understood that further modifications will now be apparent to those skilled in the art. The invention therefore should not be considered as limited to the specific details set forth, but its scope is properly to be ascertained by reference to the appended claims.

We claim:

1. The method of recovering, from an underground stratum in which it occurs, heavy oil which is substantially non-flowable under reservoir conditions by the application of driving-fluid pressure thereto, which method comprises the steps of drilling a well from the ground surface at least to a depth near the lower boundary of said stratum, initially introducing steam into substantially the full length of said well between the stratum boundaries to heat substantially the entire stratum face exposed in the drilling of said well, whereby the viscosity of the oil at said face is reduced and it flows downwardly by gravity drainage toward the bottom of said well to expose for heating by said steam the unheated oil in said stratum behind said face, and whereby an initial gravity-flow path is established along said face substantially from the upper to the lower stratum boundary, withdrawing from near the bottom of said well the liquids which flow thereto by gravity drainage and which include the condensate from said steam, continuing the injection of steam into said well bore and thence into said stratum at a level substantially above said well bottom, which steam flows outwardly from said well through said stratum to contact and heat the unheated oil therein which is continuously being exposed by said gravity-drainage flow of heated oil and to maintain the temperature of said heated oil throughout substantially its entire gravity-flow path, whereby an oil-heating and drainage face propagates laterally through said stratum away from said well, the rate of said steam injection being adjusted to maintain the steam pressure within said well and the drained portion of said stratum at a steady value where the temperature and pressure are effective to assist the flow and lifting of the oil, and continuing the withdrawal of liquids from near said well bottom at a rate correlated with said steam injection rate to avoid either substantial bypassing of uncondensed steam into the stream of liquids being withdrawn or substantial backing up of liquids into said stratum.

2. The method according to claim 1 in which said steam injection step comprises injecting steam into said stratum near the top of said stratum.

3. The method according to claim 1 in which said steam injection rate is adjusted to maintain a steam pressure within said stratum greater than the bottom-hole pressure exerted by a column of the liquids to be withdrawn of a length equal to the depth of said well.

4. The method according to claim 1 in which said steam injection rate is adjusted to maintain the steam pressure within said stratum at at least 65 pounds per square inch absolute, whereby the temperature to which said oil is heated and at which it is maintained during recovery is at least about 300° F.

5. The method of recovering, from an underground stratum in which it occurs, heavy oil which is substantially non-flowable under reservoir conditions by the application of driving-fluid pressure thereto, which method comprises the steps of drilling a well from the ground surface to a depth near the bottom of said stratum, establishing in said well a first flow channel extending between the ground surface and the face of said stratum exposed in said well at a substantial distance above the bottom thereof, establishing in said well a second flow channel separate from said first channel extending between the ground surface and a point near the bottom of said well, there being an initial gravity-flow path from where said first channel ends at the face of said stratum through said stratum to the end of said second channel at said well bottom, injecting steam through said first channel into said stratum to heat and reduce the viscosity of the oil in said stratum so that it flows by gravity drainage along said gravity-flow path to said well bottom, whereby the unheated oil of said stratum is continuously being exposed to said steam to be heated thereby and the zone of oil heating, viscosity reduction, and gravity drainage propagates through said stratum radially outwardly from said well, and withdrawing through said second channel the liquids which flow to the bottom of said well by gravity drainage at substantially the rate they collect there.

6. The method according to claim 5 in which said steam-injecting step maintains said gravity-flow path and said second flow channel in thermal contact with said steam throughout substantially their entire lengths.

7. The method of recovering, from an underground stratum in which it occurs, heavy oil which is substan-

tially non-flowable under reservoir conditions by the application of driving-fluid pressure thereto, which method comprises the steps of drilling a well from the ground surface to a depth near the lower boundary of said stratum, setting in said well a casing extending substantially to said lower stratum boundary, said casing having perforations opening into said stratum near the top thereof, placing within said casing a tubing extending to at least substantially the same depth as said casing, introducing steam from the ground surface into the annular space between said tubing and casing to heat said tubing and casing by condensation within said space and to heat the face of said stratum surrounding said casing by heat conduction from said casing, whereby an initial oil-viscosity reduction occurs over substantially the entire stratum face and heated oil flows by gravity drainage down said face outside said casing to the bottom of said tubing, thereby establishing an initial gravity-drainage flow path outside said casing from said perforations to said tubing bottom and exposing unheated oil in said stratum behind said face to contact with steam passing through said perforations, withdrawing liquids comprising steam condensate and oil from the bottom of said well through said tubing, continuing the injection of steam into said annular space and through said perforations into said stratum to heat the unheated oil therein continuously being exposed by the gravity drainage of heated oil and thus to propagate a zone of oil heating, viscosity reduction, and the gravity drainage through said stratum radially outwardly from said well, the rate of said steam injection being adjusted to maintain the steam pressure within said annular space and the drained portion of said stratum at a steady value where the temperature and pressure are effective to assist the flow and lifting of the oil, and continuing said step of withdrawing liquids through said tubing at a rate correlated to said steam injection rate to avoid either substantial bypassing of steam into said tubing or substantial backing up of liquids into said stratum.

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