United States Patent

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[72] Inventor **Frederick W. Riehl**
2347 Albion, Denver, Colo. 80207

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[54] **METHOD FOR RECOVERING PETROLEUM**
24 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **166/252,** 166/272, 166/306
[51] **Int. Cl.** **E21b 43/24**
[50] **Field of Search** 166/263, 268, 272, 302, 303, 245, 252

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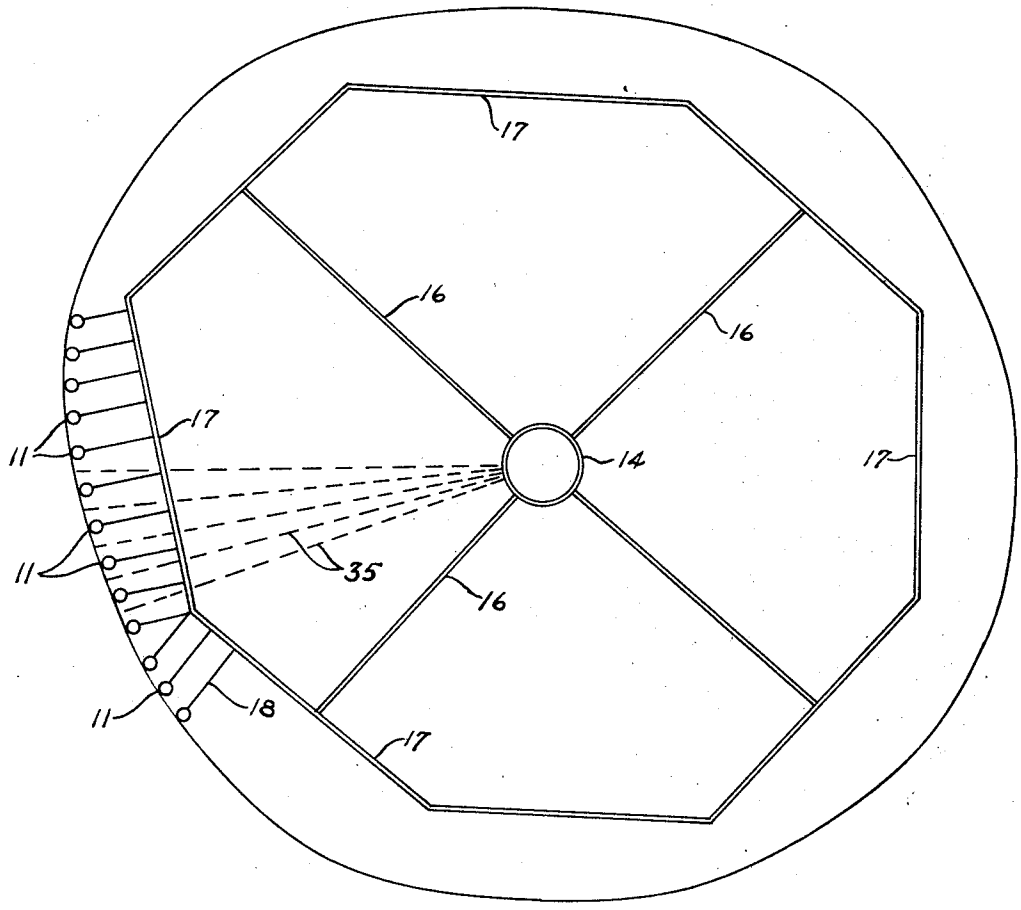
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Primary Examiner—Stephen J. Novosad
Attorney—Mc Grew and Edwards

ABSTRACT: A method for recovering petroleum in the secondary or in the partially depleted primary recovery stages comprises the introduction of high pressure, high temperature superheated steam into the peripheral zone of a dome type formation, the steam being introduced through substantially equally spaced wells about the periphery of the formation. The steam is introduced until the entire formation has been heated to a predetermined temperature range, the viscosity of the petroleum is reduced and the petroleum flows downwardly toward the peripheral or bottom zone of the formation. Steam is introduced continuously to make up losses during the period of production and steam pressure and temperature are maintained until production is complete. The major loss of heat is that resulting from the removal of petroleum from the formation and control of the predetermined temperature range is effected by maintaining a heat balance, steam being added as required to supply all losses during production.



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2 Sheets-Sheet 1

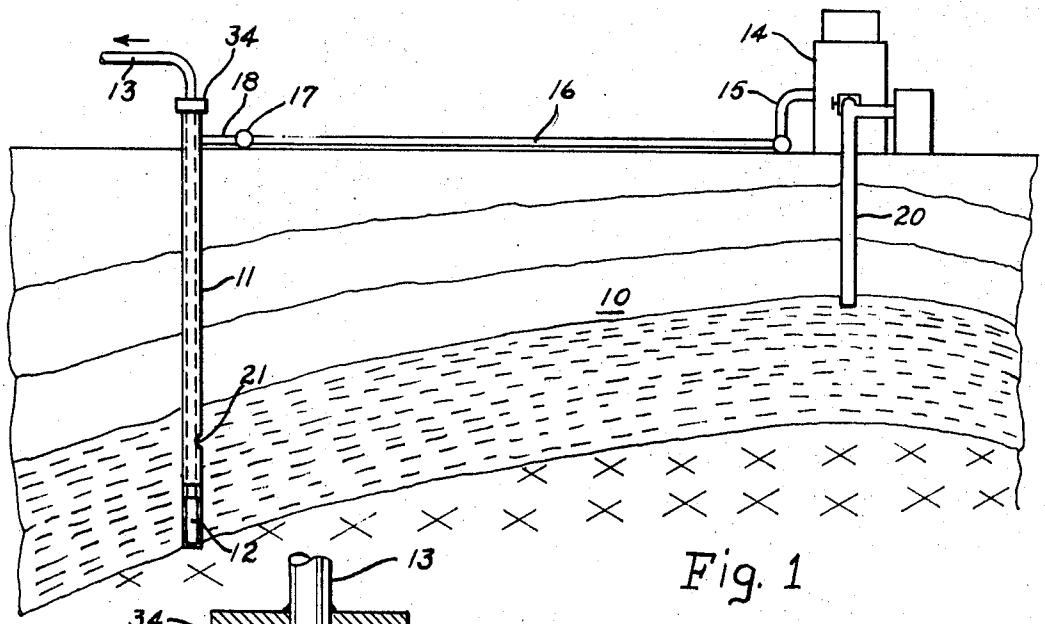


Fig. 1

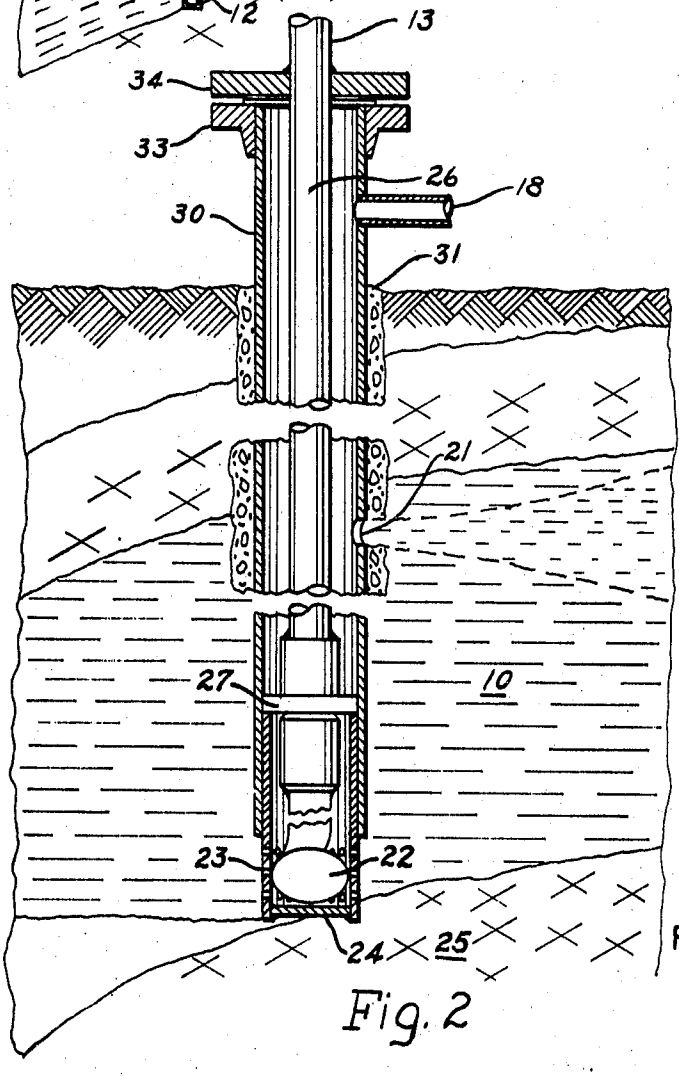


Fig. 2

INVENTOR
FREDERICK W. RIEHL
BY McGrew & Edwards
ATTORNEYS

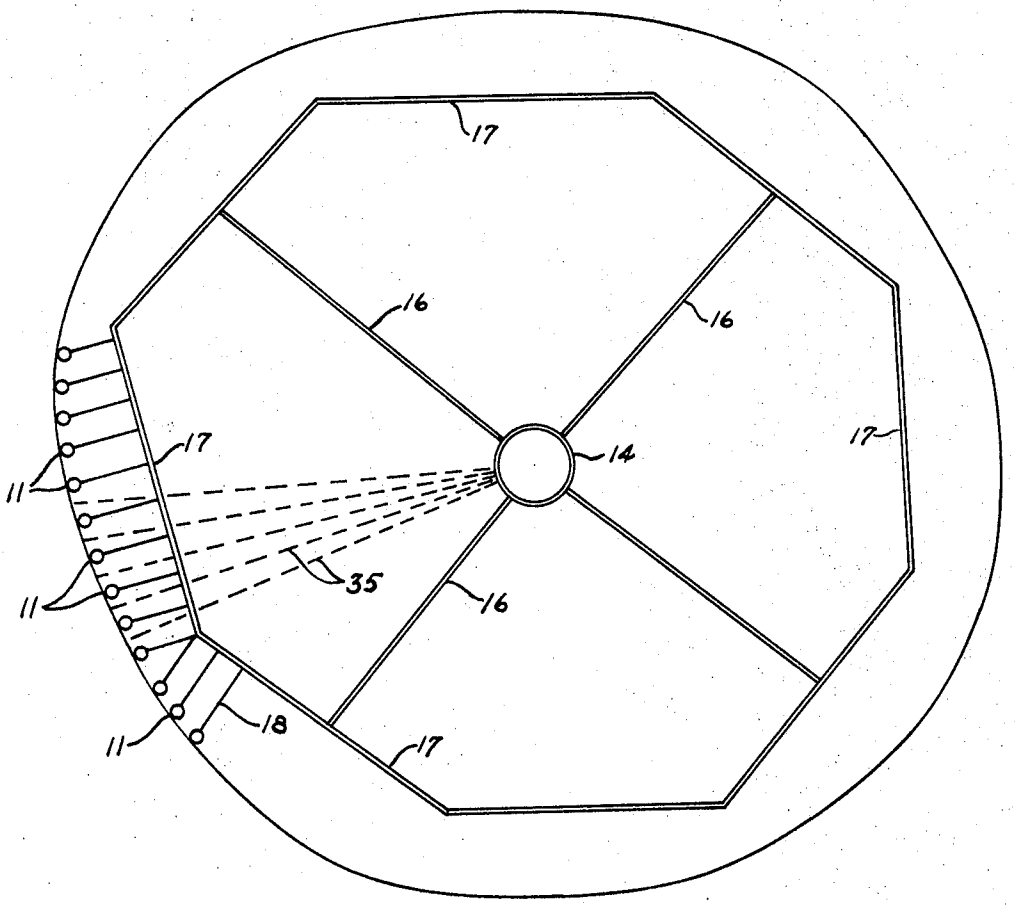


Fig. 3

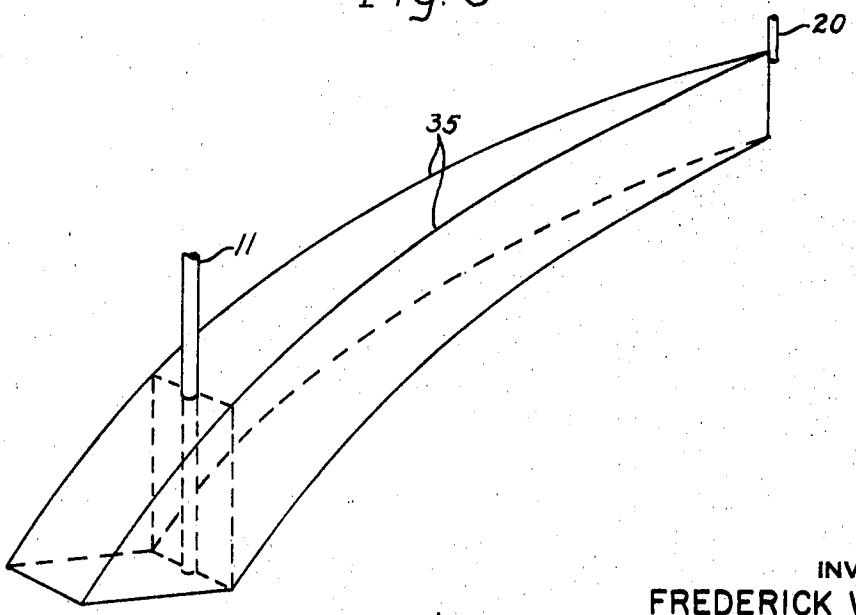


Fig. 4

INVENTOR
FREDERICK W. RIEHL
BY
ATTORNEYS

METHOD FOR RECOVERING PETROLEUM

This invention relates to the recovery of petroleum from dome type reservoir formations and particularly to an improved method of secondary recovery employing superheated stem injected into the formation.

Many secondary oil recovery methods and variations thereof are employed in oil fields particularly after primary recovery methods have removed a substantial portion of the petroleum in the formation. These methods include water flooding with or without additives such as surfactants, the injection of steam which may be superheated steam and combination methods wherein steam and other gases are injected in selected sequences with a view to furthering the production of petroleum from the formation. In these secondary recovery methods as practiced certain wells are selected as injection wells and others as production wells and the fluids introduced into the injection wells are intended to force the petroleum of the formation toward the production wells where it can be produced. Difficulties are encountered in the presently practiced secondary methods of recovery because of the characteristics of the flow of fluids under pressure whereby they flow through the paths of least resistance and tend to bypass some portions of the reservoir formation. Furthermore, by way of example, in water flooding methods very large volumes of water must be circulated and much water is produced with the petroleum released from the formation by the flooding method. It is desirable to provide effective methods for releasing greater quantities of petroleum from the formation and accordingly it is an object of the present invention to provide an improved method of secondary recovery of petroleum for effecting the production of a major portion of the petroleum remaining in the formation after primary production.

It is another object of this invention to provide an improved method of secondary recovery of petroleum utilizing superheated steam and which will facilitate the recovery of greater amounts of petroleum during the secondary stages.

It is another object of this invention to provide an improved method of secondary recovery of petroleum whereby substantially uncontaminated petroleum may be recovered from the reservoir formation.

It is another object of this invention to provide an improved method of secondary recovery of petroleum from dome type reservoir formations.

It is another object of this invention to provide an improved method of secondary recovery of petroleum utilizing superheated steam and whereby the secondary recovery may be accomplished with a greatly reduced number of wells.

Briefly, in carrying out the objects of this invention in one example of the method thereof, cased wells are provided at substantially equal intervals about the periphery of a dome type formation and a high capacity high temperature high pressure boiler is provided at the surface neat the center of the formation or field and a distribution system is provided whereby high pressure high temperature steam can be supplied to all of the peripheral wells. A central well is provided near the boiler which extends into the upper portion of the dome formation and is used for testing purposes to determine the the progress of steam through the formation and also to remove gas from the formation which may be employed for boiler fuel. The peripheral wells are provided with pumps which have intakes near the bottom of the formation and production tubing arranged within the casing extends from the pumps to the surface for producing the fluids from the reservoir. Injector orifices are provided in the wells one orifice at each well and located in the upper portion of the reservoir formation penetrated by the casing. The method of this invention forces the steam to travel radially to the oil field centerline through voids and particularly through the voids in the formation left by primary recovery and the oil flows from the center to the periphery radially. Since steam supply and oil delivery is at the same location in the oil field this assists in the heating of the oil for preconditioning a second time for greater oil flow rates. Steam is introduced at high pressure and high temperature, the supply of steam to the wells being effected in groups

of wells which are supplied with the steam for a substantial period of time before additional wells are supplied with steam, finally all the wells are supplied with steam and this supply is continued until the entire formation reaches predetermined temperature conditions. The viscosity of the petroleum of the formation is reduced by heating and the petroleum flows downwardly toward the peripheral zone where it can be produced by operation of the pumps. During production of the petroleum a heat balance is maintained, the steam being supplied at a rate sufficient to make up all losses particularly the losses due to the heat removed with the produced petroleum fluid. The pressure of the steam in the reservoir facilitates the production of petroleum by aiding the pumping action and the petroleum as produced is maintained at relatively high temperatures by its passage through the production tubing within the casing wherein the steam is flowing downwardly into the well. Furthermore, the lower viscosity of the petroleum facilitates the pumping thereof.

The features of novelty which characterize this invention are pointed out with particularity in the claims annexed to and forming part of this specification. The invention itself, however, both as to its organization and method of procedure, together with further objects and advantages thereof, will best be understood upon reference to the following description taken in connection with the accompanying drawings in which:

FIG. 1 is a diagrammatic sectional view through a dome-type reservoir formation arranged for the practice of the method of this invention;

FIG. 2 is an enlarged view similar to FIG. 1 showing a portion of the reservoir and the casing and pump arrangement;

FIG. 3 is a diagrammatic plan view of a dome-type reservoir formation arranged for the practice of the method of this invention; and

FIG. 4 is a diagrammatic perspective view of a segment of the formation of FIGS. 1 and 3 illustrating the steam injection zone from one of the wells thereof.

FIG. 1 illustrates diagrammatically the section of a dome-shaped oil reservoir **10** having a cased well **11** extending into the reservoir **10** and provided with a production tubing therein for receiving oil from a pump **12** and discharging it through a line **13**, high pressure high temperature steam is supplied to the well from a boiler **14** arranged at the surface above the geographical center of the dome. Steam is delivered by the boiler through a steam outlet connection **15** and a long high pressure steam line **16** to a manifold **17** from which it is delivered to the interior of the casing **11** through a connection **18**, the vent well **20** is provided at the center of the formation and extends into the uppermost portion of the formation for the removal of gaseous constituents of the well fluids and for providing a location for testing the advance of the steam through the formation in a manner to be described.

A boiler **14** is of a high temperature high pressure type capable of delivering very large quantities of superheated steam and to utilize one hundred percent makeup water for this purpose. A boiler of this type suitable for the practice of the method of this invention is disclosed in my U.S. Pat. No. 3,338,219 issued Aug. 29, 1967. During the operation of the secondary recovery method of this invention high pressure high temperature steam is discharged in a jet into the formation through an orifice **21** in the casing of the well **11** which discharges the jet in the upper portion of the formation.

As shown in FIG. 2, a pump **22** for producing oil from the petroleum collected at the periphery of the formation is arranged within a perforated cylinder or screen **23** which is fitted into the bottom of the casing and may be positioned in the casing after the casing has been set in the well and cored for screen acceptance. The screen **23** has a closed bottom indicated at **24** and rests on the impervious formation structure indicated at **25** and which underlies the reservoir **10**. The pump is lowered on the production tubing indicated at **26** and an annular flange or ring **27** secured to the pump structure rests on the top of the screen **23**. The annular ring **27** with a

suitable filler seal (not shown) provides an effective seal between the portions of the casing above and below the ring **27**.

The casing indicated at **30** is cemented in the drilled well in the usual manner, as indicated at **31**. The casing extends above ground as indicated at FIG. **2** and is provided with a flange cap comprising a lower flange **33** securely welded to the top of the casing and a closure flange **34** which is securely bolted to the flange **33**, the production tubing **26** is securely sealed to the flange **34** by welding and the production outlet **13** comprises an extension of the production tubing **26**. The steam delivered through the connection **18** enters the space between the casing **30** and the production tubing **26** and flows downwardly between the casing and tubing and thence outwardly through the orifice **21**. The steam delivered by the boiler **14** is at a temperature and a pressure sufficiently high that the steam entering the well **11** is high pressure high temperature steam which, by way of example, may be at a pressure of the order of 1,000 lbs. per square inch gauge and at a temperature of the order of 800° F. The steam delivered through the orifice **21** is thus high pressure high temperature steam which produces a high energy jet extending into the formation **10**. The formation **10** is commonly a packed or consolidated sand which contains the petroleum fluids in the spaces between the particles of sand. The effect of the discharge of the high energy steam jet into this structure is to produce a passageway extending outwardly toward the center of the formation as indicated in FIGS. **1** and **2**. Here it is assumed that the formation has a total porosity of say 20 percent and 10 percent voids due to the removal of petroleum from the well during primary production. It is the porous and void characteristic of the sand that enables the steam to force its passageway into the formation and this passageway will be continued and expanded for a substantial distance whereupon a zone of substantial area is provided for the further penetration of steam into the formation.

When a dome-type formation is to be produced by this method, wells are drilled about the periphery of the formation at substantially equal distances from one another as indicated in FIG. **3** which is a diagrammatic plan view of the formation shown in FIG. **1**. In the illustration a steam distributing system has been provided which comprises four long distributing high pressure steam pipes **16** the outer ends of which are connected by manifolds **17** thus providing steam loops extending between each pair of the distributing pipes **16**. Each of the wells is of the same construction as that illustrated for the well **11** in FIG. **1**. It is assumed further that the formation is essentially tight and that any existing wells in the formation have been sealed off. When the boiler is in operation and steam is ready for delivery to the reservoir it is first delivered to a plurality of adjacent wells in each of the four illustrated loops of steam distributing systems. The valves to the respective wells being open so that steam is delivered through the connections **18** to the selected wells in each group. After the steam has been delivered for a substantial period of time, say at least **24** hours, additional wells are added to the steam supply system, these wells preferably being wells adjacent to those already supplied with steam. By delivering the steam to selected groups in this manner, it is possible to maintain an adequate flow of steam to the selected wells without having to increase the capacity of the boiler unduly, it being understood that the rate of delivery of the steam to each of the segments to which steam is delivered by respective wells will be high in the initial period of operation of the steam injection. This procedure is continued until steam is being delivered to all of the wells about the periphery of the formation. It is continued further until the entire void containing structure of the formation has been heated to a predetermined temperature and it is thereafter maintained at a pressure and temperature sufficient to keep the entire formation at the predetermined temperature and pressure during production of petroleum therefrom. Dotted lines **35** in FIG. **3** indicate the sides of pie-shaped sections of the reservoir which are heated by delivery of steam from respective wells **11**, each pie-shaped section may be of the general configuration indicated in the perspective view FIG. **4** which shows the well **11** penetrating the lower end of the pie-shaped section and the vent well **20** extending upwardly from the tip of the section. When adjacent wells are receiving steam from the boiler in the manner indicated the steam progresses inwardly toward the center of the formation and the effect of the adjacent supplies of steam is to confine the steam flow for each of the wells generally to the pie-shaped section such as indicated in FIG. **4**. Thus, each well is supplied with steam at a rate sufficient to heat a respective pie-shaped section of the complete reservoir.

As the temperature and pressure rise throughout the reservoir the petroleum therein is heated and the viscosity thereof lowered; the liquid then will flow downwardly toward the periphery of the reservoir and collect about the lowermost portion so that it may be produced by operation of the pumps in the wells **11**. The steam will then fill and heat the portions of the formation from which the oil has flowed. During this operation the temperature of the sand in the formation is increased and the particles of sand become radiating bodies and apply heat throughout the formation into the fluids therein. Highly volatile fluids which move upwardly as gases or vapors may be removed through the vent pipe **20** and may be employed as boiler fuel for the boiler **14**. Vent pipe **20** serves the further purpose of allowing temperature indicating instruments to be lowered therein to detect the approach of the steam toward the center of the reservoir and thereafter to determine the temperature at the center of the reservoir and the progress of steam throughout the entire formation.

After the steam injection procedure has been continued for a sufficient period of time, the entire liquid free portion of the reservoir is raised to a temperature and a pressure substantially the same as those of the stem injected into the peripheral areas of the reservoir. When the petroleum liquid has collected to a sufficient depth about the pumps **12**, they may be started and the production of petroleum continued as long as the level of the petroleum in the peripheral area about each pump remains sufficiently high. The pumps preferably are provided with level detecting mechanisms such as a float mechanism or an electrical mechanism having contacts in the zone of the level to be maintained and such that current flows between the contacts when liquid is present. The details and structural arrangement of such controls have not been illustrated as they are not necessary to an understanding of the present invention.

It will be understood that as soon as petroleum is produced through the production lines of the wells **11** it will carry with it substantial amounts of heat from the reservoir, this heat is made up by the further injection of steam throughout the period of production. An efficient system is maintained by controlling the introduction of the steam so that a heat balance is maintained between the heat lost through production and other losses and the heat added through the additional steam. This provides a highly economical arrangement for maintaining the reservoir formation at the required temperature and pressure until all petroleum which can flow from the reservoir has been produced.

The heating of the petroleum in the reservoir lowers its viscosity and enables it to flow readily toward the lowermost portions of the reservoir, these being the portions about the periphery where the pumps are located. When the pumps are in operation the pressure of the steam as maintained within the reservoir also facilitates the operation of the pumps by providing pressures tending to force oil into the pumps and out of the reservoir. It will be observed that the petroleum is heated in the reservoir and further it is maintained heated while it is being pumped and as it passes upward through the production tubing **26** is heated further by the absorption of heat from the steam proceeding in the counter flow downwardly through the casing **26** about the production tubing.

The effect of the operation of this method is to produce the petroleum from the reservoir in a shorter time than has been possible heretofore. In addition, the method of this invention requires fewer wells since no wells are required within the interior of the formation. Furthermore, all of the wells are injection wells as well as production wells and additional economy is realized by maintaining the petroleum at a relatively high temperature throughout the time it is being produced so that it reaches the surface at a relatively high temperature.

During the injection of the superheated steam into the formation as described above water present in the formation sand is evaporated and no water is present in the formation during the production period; thus the petroleum produced from the reservoir is free of water and when the operation has been stabilized it is unnecessary to produce water with the petroleum in order to effect secondary recovery in accordance with this method. The maintenance of high temperature and high pressure of the superheated system within the reservoir is made possible by the impervious nature of the geological formations on either side of the reservoir formation; these formations are relatively good insulators so that they do not conduct substantial amounts of heat away from the reservoir during production and further, since these formations are impervious, they make it possible to maintain the required pressures. These pressures may be of the same order as the pressures originally present in the reservoir formation prior to primary production, and water which may have entered the bottom of the reservoir because of the loss of pressure during primary production is forced downwardly and out of the reservoir.

As an indication of the boiler capacities and reservoir conditions to be maintained during the practice of the method above-described, and, by way of example rather than by way of limitation, a field of general configuration indicated in FIG. 3 and of a 10,000 acre area will be provided with approximately 200 wells about the periphery thereof. These wells are spaced from one another a distance of the order of 420 feet. The boiler 14 will be designed to have a capacity sufficient to supply steam at a rate of 100,000 lbs. per hour. The steam would be delivered to the distributing pipe **16** at a pressure of say 1,500 lbs. per square inch gauge and injected into the formation at a pressure of the order of 1,000 lbs. per square inch gauge, about 500 lbs. per square inch gauge being lost in the transportation of the steam from the boiler to the oil formation. When The temperature of the steam will be of the order of 800° F. When production is started and oil is pumped from the reservoir, heat is removed with the oil; as the oil flows toward the pumps the further absorption of heat by the oil results in a lowering of the temperature of the steam in a gradient toward the center of the formation. During production the mean temperature difference of the reservoir will average about 240° F. This mean temperature difference is maintained by supplying the steam at about 1,000 pounds per square inch gauge and about 800° F. so that a heat balance is obtained—the heat added making up for the heat removed with the oil and other heat losses.

It will be understood that the temperature and pressure of the steam is to be selected depending upon the characteristics of each reservoir formation and of the petroleum fluids contained therein. The mean temperature difference resulting from maintaining a heat balance will also vary from one reservoir to another. Throughout the recovery operation the sand will be maintained at a relatively high temperature and thus the sand particles will act as radiant bodies. Therefore, this method may be considered to be a radiant heat method of secondary oil recovery.

I claim:

1. The method of producing petroleum from a dome-type reservoir which comprises injecting superheated steam at high temperature and pressure in a multiplicity of jets directed from the periphery of the formation toward the central zone of the formation, the jets being located at substantially evenly spaced positions about the periphery, continuing the injection until the entire formation attains a high temperature above the saturation temperature of the steam, thereby lowering the viscosity of petroleum therein, and while continuing the injection of steam, producing the petroleum from the peripheral zone of the formation.

2. The method of producing petroleum from a dome-type reservoir as set forth in claim 1 including maintaining a heat balance between the steam admitted to the formation and the heat removed therefrom with the produced petroleum, whereby substantially the entire void containing structure of the reservoir formation is continuously maintained filled with superheated steam.

3. The method of producing petroleum from a dome-type reservoir formation which comprises providing cased wells extending into the periphery of the formation at substantially equal intervals about the periphery and extending down into a zone adjacent the bottom of the reservoir,

providing a pump for each well adjacent the bottom of the formation and a production tubing for delivering petroleum from the pump to the surface,

producing superheated steam at high temperature and high pressure,

providing a discharge outlet in the wall of the casing of each well in the part of each respective casing which lies within the formation and directing the outlets toward the central zone of the formation; and

delivering the high temperature steam through the casings of the wells and through the outlets into the formation and continuing the introduction of steam to heat the formation until the entire formation has been heated to a temperature substantially above the dew point of water vapor, and thereby conditioning the petroleum liquids to low viscosity for free flow toward the bottom of the reservoir.

4. The method of producing petroleum from a dome-type reservoir as set forth in claim 3 wherein said discharge outlets are provided in the upper portion of the parts of the casings lying with in the formation.

5. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 3 including the step of generating said superheated steam in large quantities at pressures of the order of at least 1,000 lbs. per square inch gauge and at temperatures of the order of 800° F.

6. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 3 wherein said formation comprises an oil bearing sand, and wherein said superheated steam is admitted to said formation at temperatures sufficiently high to heat the particles of sand of the formation sufficiently that they constitute heat radiating bodies.

7. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 3 including the step of utilizing the heat of the steam flowing through each of the casings of the wells for heating liquid petroleum delivered by the pump through the production tubing.

8. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 3 wherein the superheated steam is delivered continuously at temperatures sufficiently high for preventing the condensation of water vapor in the formation.

9. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 3 including the step of maintaining the pressure and temperature of the steam introduced into the formation sufficiently high to vaporize water present in the formation and to force water present at the periphery of the formation back down through the formation out of the portions of the formation containing petroleum.

10. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 3 wherein the delivery of steam through the wells is initiated in groups of said wells spaced at substantially equal intervals about the periphery of the formation and after substantial heating of the formation adjacent the first groups of wells is extended to other wells until the steam is supplied to all of said wells.

11. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 10 wherein the steam is supplied to the wells of each group for a period of the order of one day before the supply of steam is started to the wells of the other groups.

12. The method of producing petroleum from a dome-type reservoir as set forth in claim 3 including locating the respective production tubing within the casing of each well.

13. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 3 including the positioning of a steam generating means on the surface near the center of the reservoir for producing said superheated steam.

14. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 13 including the steps of distributing said superheated steam from the generating means radially to a plurality of positions near the edge of the field and providing a respective branch steam distributing line to each of the wells.

15. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 14 including the step of connecting the radial supply positions to provide steam loops and connecting the branch steam lines in groups to respective ones of the loops.

16. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 13 wherein the steam generating means operates on 100 percent makeup water and wherein no water is returned to the steam generating means from the formation.

17. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 3 including the step of utilizing the pressure of the steam for facilitating the removal of petroleum from the wells during operation of the pumps.

18. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 3 including the step of injecting steam through said openings in jets toward the central zone of the formation and at high velocity whereby the energy of the steam bores a passageway for a substantial distance into the formation.

19. The method of producing petroleum producing petroleum from a dome-type reservoir formation as set forth in claim 3 including the heating of the entire formation to a temperature of the order of that of the steam discharged into the formation.

20. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 19 including maintaining throughout the operation of the pumps to produce petroleum a heat balance between the heat input of the injected steam and the heat output with the produced petroleum and losses of heat elsewhere from the formation.

21. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 3 including the providing of a well bore centrally of the formation and extending to the top portion of the dome structure, utilizing the bore for access to the formation to test the progress of the injection steam into the central zone of the formation and for extracting volatile petroleum.

22. The method of producing petroleum from a dome-type reservoir formation as set forth in claim 3 including the step of introducing the steam into three of more of adjacent ones of said wells whereby the steam from each well having adjacent wells on both sides extends generally radially toward the center of the reservoir through a generally pie-shaped segment of the formation and liquid petroleum flows generally radially toward the wells.

23. The method of recovering petroleum from a dome-type reservoir formation which comprises:

providing cased wells extending into the periphery of the formation at substantially equal intervals about the periphery and extending down into a zone adjacent the bottom of the reservoir,

providing pumps for removing liquid from each well adjacent the bottom of the formation and a production tubing for delivering petroleum from the pump to the surface,

producing superheated steam at high temperature and high pressure,

providing a discharge outlet in the wall of the casing of each well and directing each outlet toward the central zone of the formation,

delivering the high temperature high pressure superheated steam through the casing of the wells and through the outlets into the formation in high velocity jets directed from the periphery toward the center of the formation,

providing a test well extending into the formation in the central zone thereof and entering the formation in the upper portion of the dome for removing gaseous fluids from the formation,

testing gases removed from the formation to determine the progress of the heating of the formation by the superheated steam and controlling admission of steam to the peripheral zone of the formation in accordance with the condition of the gaseous fluids removed from the test well,

continuing the introduction of steam to heat the formation and fill and maintain filled substantially the entire void containing structure of the formation with steam at temperatures substantially above the dew point of water vapor in the formation,

while continuing the introduction of superheated steam allowing the petroleum liquids in the formation heated by the steam for flow by gravity into the peripheral zone of the formation to form a reservoir of liquid,

at the end of a period sufficiently long to assure the presence of superheated steam throughout the void containing structure of the formation operating the pumps to remove liquid petroleum through the production tubing,

stopping the operation of each pump whenever the level of petroleum adjacent the respective pump reaches a predetermined minimum and starting the pump again when the adjacent level of petroleum has been increased to a predetermined height; and

continuing the operation of the pumps in accordance with the levels of the liquid petroleum in the periphery of the formation and continuing the admission of superheated steam to maintain the void structure including newly produced voids filled therewith until substantially all of the petroleum in the formation has been removed.

24. The method of claim 23 including the step of maintaining throughout the period of production of petroleum from the formation a full heat balance whereby the heat lost and that removed with the produced petroleum is made up by the continued introduction of superheated steam and the void structure of the formation including newly produced voids is maintained filled with superheated steam.