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PROCESS FOR RECOVERY OF OIL

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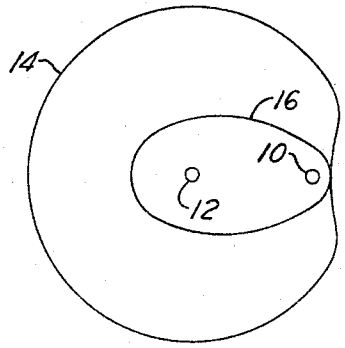


Fig. 1

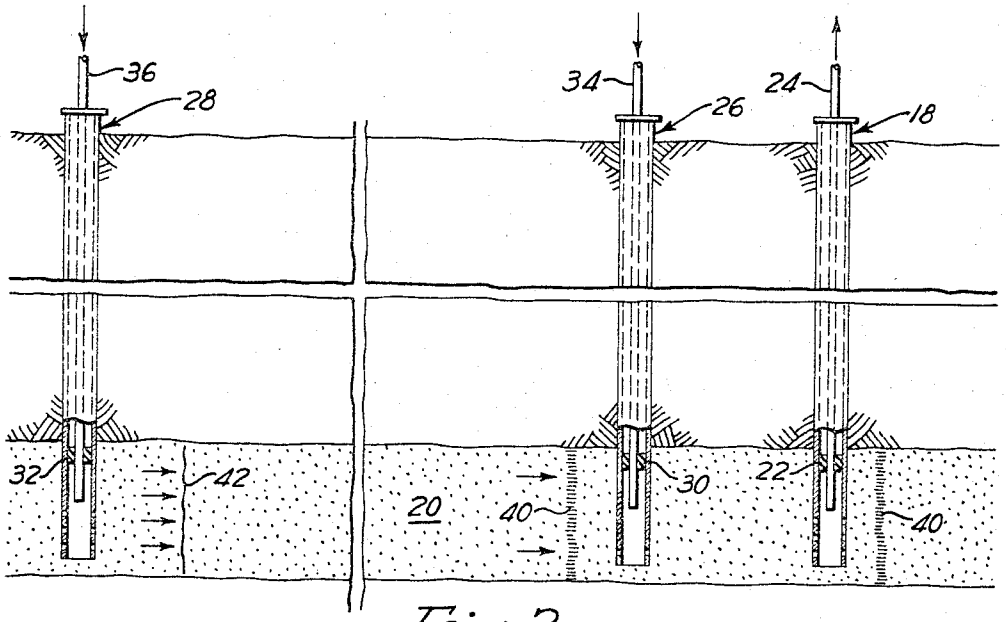


Fig. 2

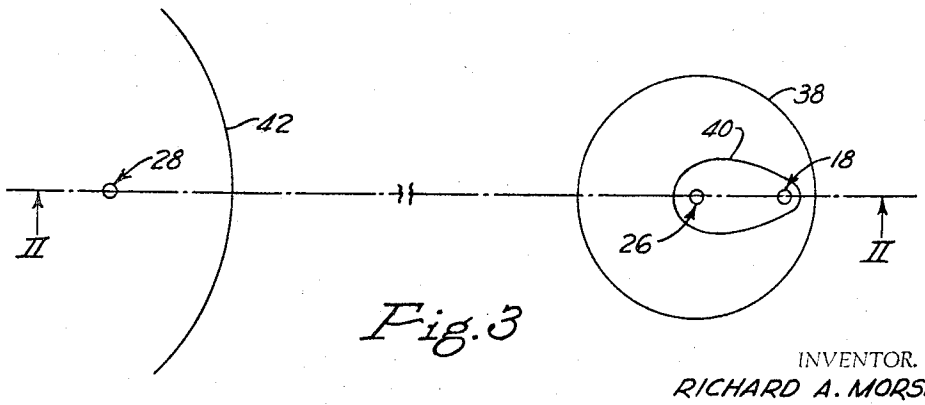


Fig. 3

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PROCESS FOR RECOVERY OF OIL

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This invention relates to the recovery of viscous oils from subsurface oil-bearing formations, and more particularly to a method of stimulating a well for production of such oils.

There are a number of known underground reservoirs containing very large amounts of oil from which there has been little if any production because of the high viscosity of the oil. The high viscosity of the oil frequently does not prevent flow through the underground formation at very low velocities; however, the radial flow pattern into wells makes necessary relatively high velocities adjacent production wells and prevents production of highly viscous oil at profitable rates even though the permeability of the formation may be high.

Attempts have been made to stimulate production from wells penetrating oil-bearing formations containing highly viscous oils by injecting heat from the wells through which oil is to be produced into the surrounding formation to reduce the viscosity of the oil near the well. Frequently, the well is damaged because of excessive temperatures, or other reasons, which cause increased resistance to flow into the well. Moreover, processes for heating the formation surrounding a well from the well through which the oil is to be produced are necessarily of an intermittent nature in which a heating period is followed by a producing period, which in turn must be followed by another heating period if further production is to be obtained. It is apparent that the well will therefore only be on production part of the time.

In-situ combustion of the oil in the formation by the injection of an oxygen-containing gas into the formation at an injection well spaced a substantial distance from the production well has been suggested as a method of recovering highly viscous oils. The injection well in such processes is located approximately at the boundary of the drainage area of the production well. One of the purposes of in-situ combustion processes is to supply heat to the formation by combustion of the oil to raise the temperature of the formation and thereby reduce the viscosity of the oil in the formation.

Two types of in-situ combustion processes have been developed. In the reverse burning process, an oxygen-containing gas is injected into the formation at the injection well and oil in the formation is ignited at the production well. The combustion front travels countercurrently to the flow of oxygen-containing gas, and oil is driven from the region of the combustion front through the heated formation to the combustion well. Although reverse burning processes quickly heat the formation around the production well and thereby reduce the viscosity of the oil flowing into the production well, the process has several disadvantages. A substantial portion of the oil in the reservoir is converted to coke which cannot be recovered. Reverse burning is thermally inefficient; at least partly because the entire formation between the injection well and production well is hot at the end of the process. It is necessary to burn enough oil in the formation to raise the temperature of the entire formation as well as the oil produced.

In the forward burning process, oil in the formation is ignited adjacent the well from which the oxygen-containing gas is injected into the formation and the combustion front moves through the formation toward the production well as the forward burning continues. The temperature gradient ahead of the combustion front is steep; hence, a bank of cold oil must be displaced through the formation ahead of the combustion front. It is apparent that until the combustion front is near the production well nothing has been done to reduce the viscosity of the oil flowing into the production well and the resistance to such flow is extremely high. Frequently, the resistance to flow of the bank of cold oil is high enough to prevent injection of an oxygen-containing gas at rates adequate to maintain combustion of the oil in the reservoir.

The amount of oil present in the reservoir in a forward combustion process between the first heated oil to appear at the production well and the combustion front is small, and no oil is present in the formation behind the combustion front. Once there is a substantial increase in temperature in the production well, for example, to a temperature of 200° or 300° F., injection of air is stopped in the usual forward burning process. Further injection of air merely results in channeling of hot air to the production well. The resultant very high temperatures in the production well causes serious corrosion in that well.

This invention resides in a method of recovering viscous oils from subsurface oil-bearing formations in which a heater well is drilled into the formation a distance in the range of about 50 to 100 feet from a production well, and well within the drainage area of the production well. Heat is injected into the formation at the heater well until the bottom hole temperature of the production well increases. The rate of heat injection at the heater well is then reduced to a rate adapted to maintain the bottom hole temperature at the production well in the range of about 200° to 600° F. and the injection of heat at the heater well is continued at the lower rate while continuing production of oil through the production well.

In the drawings:

FIGURE 1 is a diagrammatic plan view of a production well with a heater well adjacent thereto showing temperature contours at breakthrough of heat into the production well and during subsequent production in accordance with this invention;

FIGURE 2 is a diagrammatic view taken along section line 2—2 in FIGURE 3 of an embodiment of this invention in which heat is injected into the formation at a heater well simultaneously with the injection of a drive fluid into the oil-bearing formation at an injection well located at a distance from the production well substantially greater than the distance between the production well and the heater well; and

FIGURE 3 is a diagrammatic plan view of the embodiment of the invention illustrated in FIGURE 2.

The process of this invention is of particular value in increasing the rate of production of oil from reservoirs containing oil having a viscosity higher than 50 centipoises at normal reservoir temperatures. In some reservoirs, for example at Yorba Linda, California, the oil has a viscosity of 8000 to 9000 centipoises at reservoir temperature. Greatest benefits from the process are obtained when the viscosity of the oil in the reservoir decreases rapidly with an increase in temperature of the oil. Because this invention relies on the flow of oil from the surrounding cold area across the boundary of the heated area, it is no more effective than a normal forward burning process in reservoirs containing oil having a pour point higher than reservoir temperature. Because the advantages of this process increase with the extent to which oil flowing into the formation is heated, and the maximum heating is limited by cracking of the

oil to form coke which becomes serious at temperatures above 600° F., this process is most useful in recovering oil from reservoirs at a temperature below 200° F., and especially from reservoirs at a temperature below 150° F., containing oil having a viscosity less than 10 centipoises at 600° F.

A production well is drilled into the oil-bearing formation and a heater well is drilled into the oil-bearing formation at a distance ranging from 50 to 100 feet from the production well. The distance at which the heater well is drilled from the production well will be determined by the characteristics of the formation; principally the viscosity of the oil and the permeability of the formation. The distance from the production well to the heater well should be such that an increase in bottom hole temperature of the production well should be obtained within no more than two weeks after injection of heat at the heater well commences. Both the production well and the injection well can be completed in a conventional manner. Ordinarily, casing is run and cemented through the oil-bearing formation in each of the wells, and followed by perforation of the casing. It is preferred, especially when the injection of heat is by the injection of air for in-situ combustion, to complete the heater well in a manner to restrict the injection of heat to a narrow zone near the base of the oil zone to avoid channeling across the top of the oil zone.

The heat injected into the oil-bearing formation at the heater well can be derived from any of several sources. When the oil-bearing formation is relatively shallow and at a relatively low pressure, the heat is economically supplied at the heater well by the injection of steam from that well into the oil-bearing formation. Another method of injecting heat into the formation is by burning a fuel in a down-hole burner, which may be of the type described in U.S. Patent No. 2,668,592 of Piros et al., and displacing combustion products from the heater well into the surrounding oil-bearing formation. Another method of injecting heat into the formation is to displace an oxygen-containing gas down the heater well and into the formation, ignite oil in the formation adjacent the heater well, and continue the injection of the oxygen-containing gas whereby the continued combustion of oil liberates heat in the formation. When an oxygen-containing gas is injected into the formation to supply heat by in-situ combustion, the gaseous products of combustion flow to the production well and aid lifting oil through that well to the surface. An advantageous method of supplying heat to the reservoir is to inject a mixture of steam and air; the steam supplies the major portion of the heat and the gaseous combustion products aid in lifting oil in the production well.

Heat is injected into the formation at the heater well at a high rate such that a bottom hole temperature rise will occur at the production well in less than two weeks, and preferably within two or three days after injection of heat is commenced. In reservoirs in which the permeability of the formation is low and the oil has a high viscosity, it may be necessary to fracture the formation from the heater well to the production well before heat can be injected into the formation at the desired high rate. If the injection of heat at the heater well is accomplished by the injection of air to cause in-situ combustion of oil in the oil-bearing formation, the air can be injected at a rate of, for example, 1,000,000 to 5,000,000 std. cu. ft. per day during the initial heating step. During that step, the production well may be shut in whereupon the flow of heat from the heater well will be substantially uniform in all directions from the heater well except for variations caused by variations in the permeability of the formation. The initial step of injecting heat at a high rate into the formation at a heater well also can be performed simultaneously with production of oil from the production well. In that event, the flow of heat from the heater well will proceed substantially uniformly in all directions with variations determined by permeability variations until the outer boundary of the heated zone is close enough to the production well for the reduced pressure surrounding the production well to influence the flow pattern in the subsurface formation.

Referring to FIGURE 1 of the drawings, a production well **10** is illustrated having a heater well **12** spaced 50 to 100 feet from the production well **10**. If the embodiment of the invention illustrated in FIGURE 1, oil is produced at the production well **10** during the initial injection of heat at the heater well **12**; hence, the boundary **14** of the heated zone is flattened near the production well **10**.

Upon an increase in the bottom hole temperature at the production well **10**, the rate of injection of heat into the formation at the heater well is reduced. The reduction in the rate of heat injection can be made by stopping all injection of heat at the heater well until a temperature peak has been reached in the production well, and thereafter injecting heat at the heater well at a rate to maintain a bottom hole temperature in the production well in the range of 200° to 600° F. Another method of obtaining the desired control of bottom hole temperature in the production well is merely to decrease the rate of heat injection and then make whatever further adjustments in the rate of heat injection at the injection well are necessary to obtain the desired bottom hole temperature in the production well. The reduced rate of injection of heat is less than about one-half the initial rate, and in most instances less than one-fourth the initial rate. For example, in a typical application of this invention using in-situ combustion to supply the heat, air is injected into the formation at a heater well spaced fifty feet from a production well at a rate of approximately 2,500,000 std. cu. ft. per day during the initial heating step, and after a temperature rise occurs at the production well, the rate of air injection at the heater well is reduced to approximately 500,000 std. cu. ft. per day.

The rate of injection of heat at the heater well after breakthrough of heat at the production well is controlled to maintain the bottom hole temperature at the production well at a level such that oil in the formation flows readily to the production well. If the viscosity of the oil in the reservoir is only slightly over 50 centipoises at reservoir temperature and the permeability of the formation is relatively high, only slight heating will be necessary to stimulate production from the production well. If a satisfactory rate of production can be obtained at a production well temperature below 150° F., the benefits of this process usually are not sufficient to justify using the process. In reservoirs where this process is most attractive, it will usually be desirable to inject heat at the heater well at a rate such that the temperature of the oil is just below the temperature at which substantial cracking occurs. Usually cracking is not excessive unless the temperature at the production well exceeds 600° F. If air is injected into the formation at a heater well to supply heat by in-situ combustion, it is desirable to reduce the rate of injection of air at the heater well to a rate which results in the appearance of substantially no free oxygen at the production well. A limitation on the minimum rate of injection of heat when the heat is in the form of air for in-situ combustion is that the air must be injected at a rate adequate to maintain high temperature combustion of oil in the reservoir.

It is advantageous in the process of this invention to reduce the bottom hole pressure in the production well and the pressure at which a heating medium is injected at the heater well to as low a level as possible after the temperature rise occurs at the production well. The area around the production well then becomes a pressure sink into which oil from the surrounding formation flows.

After the breakthrough of heat into the production well, there is a tendency for the heating medium injected at the heater well to channel toward the production well. The boundary of the heated zone will then contract to a

position such as is shown in FIGURE 1 by the line **16**. During continued injection of heat at the heater well and continued production of oil from the production well **10**, oil from the surrounding formation flows across the boundary **16** into the heated zone of the formation and is further heated by the heat injected at the heater well **12** as the oil flows to the production well **10**. As indicated in FIGURE 1, the boundary **16** of the heated zone has an area **100** times or more the area of the borehole of production well **10**. Because of the very large area of the boundary **16**, the total flow of cold oil from the surrounding formation into the heated zone is large. The reduced viscosity of the oil within the boundary **16** allows that oil to flow readily to production well **10** and is lifted through that well to the surface.

It is an important advantage of this invention that the breakthrough of heat to the production well and, hence, the increased rate of production occur very quickly after heat injection is begun. Unlike the normal forward burning process in which an oxygen-containing gas is injected at an injection well near the boundary of the production well's drainage area, production of oil continues after the breakthrough of heat to the production well. Control of the rate of heat injection allows control of temperature in the production well and the intervening formation to prevent excessive temperatures which cause the deposition of coke within the formation.

In the embodiment of the invention illustrated in FIGURES 2 and 3 of the drawings, the use of a heater well is combined with the injection of a drive fluid at a remote injection well spaced from the production well the normal distance employed in ordinary secondary recovery operations, i.e., near the boundary of the drainage area of the production well. The drive fluid aids in moving oil from that portion of the oil-bearing formation between the heater well and the injection well into the heated zone between the heater well and the production well. Water drive, gas drive, or in-situ combustion can be used to supply energy to move oil through the formation from the vicinity of the injection well to the heated zone.

Referring to FIGURE 2, a production well, indicated generally by **18**, is drilled through overlying formations into an oil-bearing formation **20** containing a viscous oil. Well **18** is illustrated having a packer **22** set therein and a tubing string **24** run through the packer for the delivery of oil upwardly through the well.

A heater well indicated generally by reference numeral **26** is drilled into formation **20** at a distance approximately 50 to 100 feet from the well **18**. An injection well **28** is drilled into formation **20** at a distance from the production well **18** normal for an injection well in a secondary or pressure maintenance operation. Injection well **28** will ordinarily be at least six times as far from the production well **18** as the heater well; a distance of 300 to 1000 feet between the injection well and production well is normal. The heater well **26** is between the production well **18** and injection well **28**. Although the heater well preferably is substantially on a line connecting those two wells, as shown in FIGURE 3 of the drawings, it is only necessary that it be generally between the wells. The line from the heater well to the production well may make an angle of as much as 90° with the line joining the production and injection wells, but, preferably, makes an angle of 60° or less with such line. Wells **26** and **28** are illustrated with packers **30** and **32**, respectively, set therein and tubing strings **34** and **36** run through the packers. Casing of well **26** is perforated in a narrow zone near the bottom of the oil-bearing formation **20** to minimize channeling across the top of that formation to the production well.

In the operation of the embodiment of the invention illustrated in FIGURES 2 and 3, a drive fluid, which for the purposes of description of the invention is water, is injected through tubing **36** downwardly in well **28** and discharged into the oil-bearing formation **20**. Meanwhile air is injected at a high rate down well **26**, and oil in the formation **20** surrounding well **26** is ignited by, for example, the displacement of a pyrophoric material outwardly into the formation ahead of the air. Injection of the air is continued at the heater well **26** for a period adequate to form a heated zone extending from the heater well **26** beyond the production well **18**. The boundary of the heated zone is indicated by line **38** in FIGURE 3 of the drawings.

After the bottom hole temperature in production well **18** increases, production from production well **18** is commenced and the rate of injection of air at the heater well **26** is reduced to less than one-half the initial rate to control the bottom hole temperature in the production well between 200° and 600° F. The boundary of the heated zone moves inwardly to a position such as indicated by line **40** in FIGURE 3. Injection of air at the heater well **26** is continued at the reduced rate simultaneously with the production of oil through well **18**. Oil is driven through the formation by the drive fluid injected at the injection well **28** ahead of interface **42** between the drive fluid and oil and enters the heated zone around the heater well. Because of its reduced viscosity resulting from the heating, the oil flows readily to the production well **18**.

The injection of heat into a formation containing a viscous oil at a heater well spaced a short distance from a well through which oil is produced from the formation has the effect of greatly extending the effective diameter of the production well. Because of the greatly reduced viscosity of the oil after it enters the heated zone, the resistance to flow through the heated zone of the formation is low. The very large area of the boundary between the heated zone and the surrounding cold formation allows substantial total flow rates into the heated zone even though the oil flowing into the heated zone has an extremely high viscosity. By injecting heat into the formation at a heater well spaced 50 to 100 feet from a production well, the critical area of the formation around the production well can be continuously heated to stimulate production from the reservoir while oil drains from a large area into the heated zone. By maintaining a low pressure in the production well after the temperature rises in that well, and injecting fluids supplying heat at a low rate at the heater well, the entire heated zone becomes a low pressure sink of large area; thereby facilitating flow of cold oil into the heated zone and mixture of the cold oil with hot oil in that zone.

I claim:

1. A method for recovery of oil from an underground oil-bearing formation penetrated by a production well, an injection well spaced from the production well, and a heater well between the production well and injection well and near the production well comprising drilling said heater well within the radius of drainage of the production well at a distance of from about 50 to about 100 feet from the production well, injecting a drive fluid at the injection well to drive oil through the formation toward the production well, injecting heat into the formation at the heater well at a rate sufficient to raise the bottom hole temperature in the production well to a temperature of at least 200° F. within a period of two weeks after commencing injection of heat at the heater well, thereby creating in the formation a zone having a temperature greater than 200° F. around the production well, after break-through of heat at the production well reducing the rate of heat injected at the heater well to maintain a bottom hole temperature in the range of 200° to 600° F. at the production well, and continuing the injection of drive fluid at the injection well and the injection of heat at a reduced rate at the heater well while producing oil from the formation through the production well.

2. A method as set forth in claim **1** in which the oil in the formation has a viscosity exceeding 50 centipoises at the formation temperature.

3. In a process for increasing the production of oil from an oil-bearing formation penetrated by a production well

and a heater well spaced from the production well, the improvement comprising drilling the heater well within the drainage area of the production well at a distance of from about 50 to about 100 feet, injecting heat into the formation at the heater well at a rate sufficient to raise the bottom hole temperature in the production well to at least 200° F. within two weeks after commencing injection of heat at the heater well to form a zone having a temperature greater than 200° F. around the production well, thereafter reducing the rate of injecting heat into the formation at the heater well, producing oil from the production well, and continuing the injection of heat into the formation at the heater well while producing oil at the production well to maintain the temperature in the production well in the range of 200° to 600° F.

4. A process as set forth in claim 3 in which the oil in the oil-bearing formation has a viscosity exceeding 50 centipoises at the formation temperature.

5. In a process for increasing the production of oil from an oil-bearing formation penetrated by a production well, an injection well, and a heater well between said production well and said injection well, the improvement comprising drilling said heater well within the drainage area of the production well at a distance within 50 to 100 feet from the production well, said injection well being at least six times as far away from the production well as is the heater well, injecting heat into said oil-bearing formation at the heater well at an initial rate sufficient to raise the bottom hole temperature in the production well to at least 200° F. within two weeks after commencing the injection of heat at the heater well to form a zone in the formation having a temperature greater than 200° F. around the production well, after heat from the heater well reaches the production well reducing the rate of injecting heat into the formation at the heater well to a rate less than one-half the initial rate to maintain the temperature in the production well in the range of 200° to 600° F. and maintain said heated zone around the production well, and injecting a fluid into the oil-bearing formation at the injection well to drive oil through the formation to said heated zone.

6. A process as set forth in claim 5 in which the injection of heat at the heater well is accomplished by the injection of air to effect in-situ combustion in the formation.

7. A process as set forth in claim 5 in which the pressure in the production well is reduced after heat from the heater well reaches said production well.

8. In a process for increasing production of oil from an oil-bearing formation penetrated by a production well and a heater well, the improvement comprising drilling said heater well within the drainage area of the production well at a distance of from about 50 to about 100 feet from the production well, injecting air into the formation at the heater well, igniting oil in the formation adjacent the heater well and continuing the injection of air into the formation at an initial rate at the heater well sufficient to raise the bottom hole temperature in the production well to at least 200° F. within two weeks after commencing the injection of air in the heater well to form a heated zone in the formation having a temperature greater than 200° F. around the production well, simultaneously with the injection of air at the heater well producing oil at the production well, after an increase in temperature in the production well discontinuing the injection of air at the heater well until the temperature in the production well passes a peak, then injecting air into the formation at the heater well at a rate less than one-half the initial air injection rate controlled to maintain the temperature in the production well in the range of 200° to 600° F.

9. In a process for increasing the production of oil from an oil-bearing formation penetrated by a production well and a heater well, the improvement comprising drilling said heater well within the drainage area of the production well at a distance of from about 50 to about 100 feet from the production well, creating a fracture extending from the heater well to the production well, injecting a heating medium into the oil-bearing formation at the heater well at a rate sufficient to raise the bottom hole temperature in the production well to at least 200° F. within two weeks after commencing injection of the heating medium at the heater well to form in the formation a heated zone having a temperature greater than 200° F. around the production well whereby the temperature in the production well increases, reducing the rate of injecting the heating medium at the heater well to a rate not exceeding one-half the initial rate upon an increase in temperature of the production well, and continuing the injection of the heating medium while producing oil through the production well.

10. A method for recovery of oil from an underground oil-bearing formation penetrated by a production well, an injection well remotely spaced from the production well and a heater well adjacent the production well, said method comprising drilling the heater well within the drainage area of the production well at a distance of from about 50 to about 100 feet from the production well, injecting a drive fluid at the injection well to drive oil through the formation toward the production well, injecting air into the formation at the heater well at a rate of from about one million to about five million standard cubic feet per day, igniting oil in the formation adjacent said heater well and continuing the injection of air thereby creating in the formation around the production well a zone having a temperature greater than the normal formation temperature, after break-through of heat at the production well reducing the rate of air injection at the heater well to maintain a bottom hole temperature in the production well within the range of 200° to 600° F., and continually injecting drive fluid at the injection well and continually injecting air at a reduced rate at the heater well while producing oil from the formation through the production well.

11. A method for recovery of oil from an underground oil-bearing formation penetrated by a production well, an injection well remotely spaced from the production well and a heater well near the production well, said heater well being located a distance of about 50 to 100 feet from the production well, said method comprising injecting a drive fluid at the injection well to drive oil through the formation toward the production well, injecting air into the formation at the heater well, igniting oil in the formation adjacent the heater well, continuing the injection of air into the formation at the heater well at a rate adequate to maintain the temperature of the formation oil at a temperature sufficient to support in situ combustion of that oil and create in the formation around the production well a zone having a temperature greater than the normal formation temperature, simultaneously with the injection of the drive fluid at the injection well and the injection of air at the heater well producing oil at the production well, after an increase in temperature at the production well reducing the rate of air injection at the heater well and controlling said rate of air injection to maintain the bottom hole temperature in the production well within the range of from about 200° to about 600° F.

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