

[54] **METHOD FOR ESTABLISHING COMMUNICATION PATH IN VISCOUS PETROLEUM-CONTAINING FORMATIONS INCLUDING TAR SAND DEPOSITS FOR USE IN OIL RECOVERY OPERATIONS**

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[58] Field of Search **166/272, 271, 263**

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[57]

ABSTRACT

Many oil recovery techniques for viscous oil recovery such as recovery of bitumen from tar sand deposits, including steam injection and in situ combustion, require establishment of a high permeability interwell fluid flow path in the formation. The method of the present invention comprises forming an initial entry zone into the formation by means such as noncondensable gas sweep or hydraulic fracturing and propping, or utilizing high permeability streaks naturally occurring within the formation, and expanding the zone by injecting steam and a noncondensable gas into the gas swept zone, propped fracture zone or high permeability streak. The mixture of steam and noncondensable gas is injected into the formation at a pressure in pounds per square inch not exceeding numerically the overburden thickness in feet, and the steam-noncondensable gas-bitumen mixture is produced either from the same or a remotely located well. The operation may be repeated through several cycles in order to enlarge the flow channel. Suitable noncondensable gases include nitrogen, air, carbon dioxide, flue gas, exhaust gas, methane, natural gas, ethane, propane, butane and mixtures thereof. Saturated or supersaturated steam may be used.

13 Claims, 3 Drawing Figures

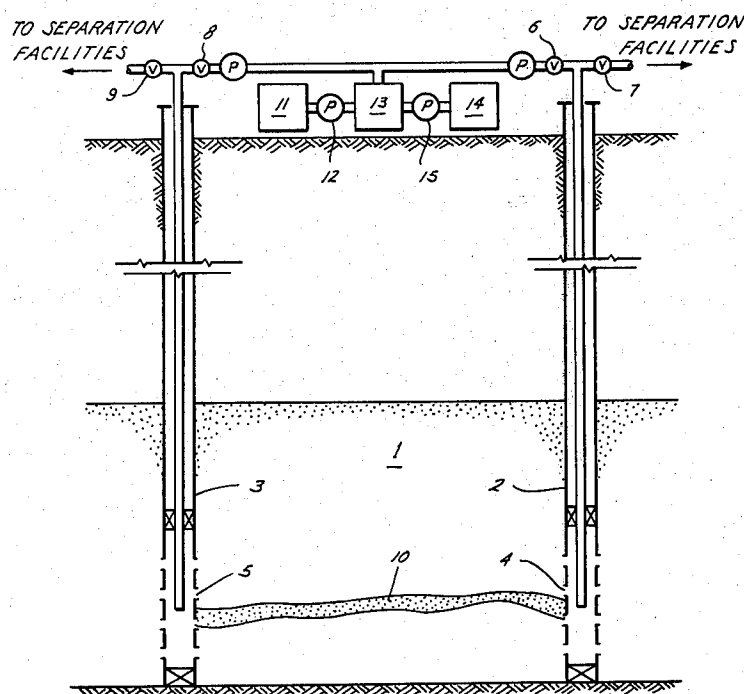
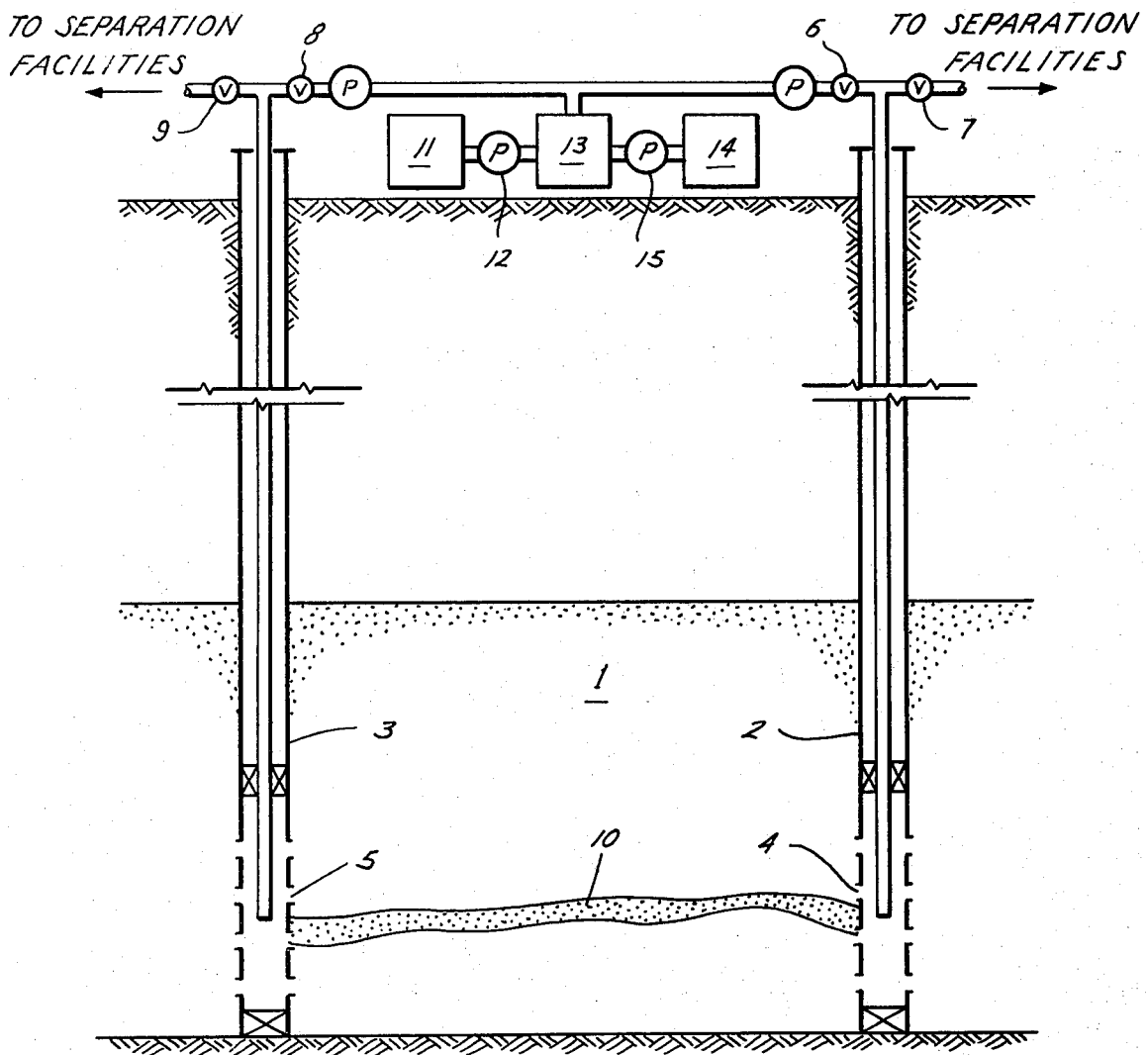
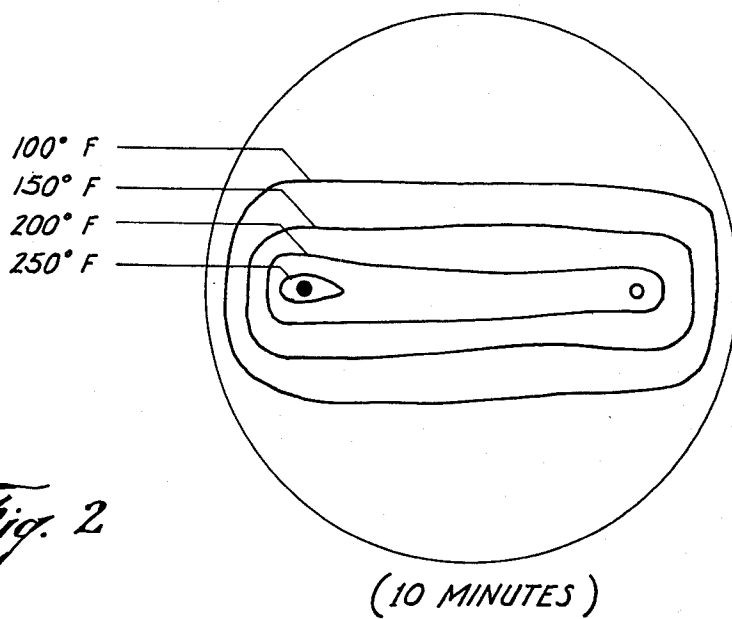
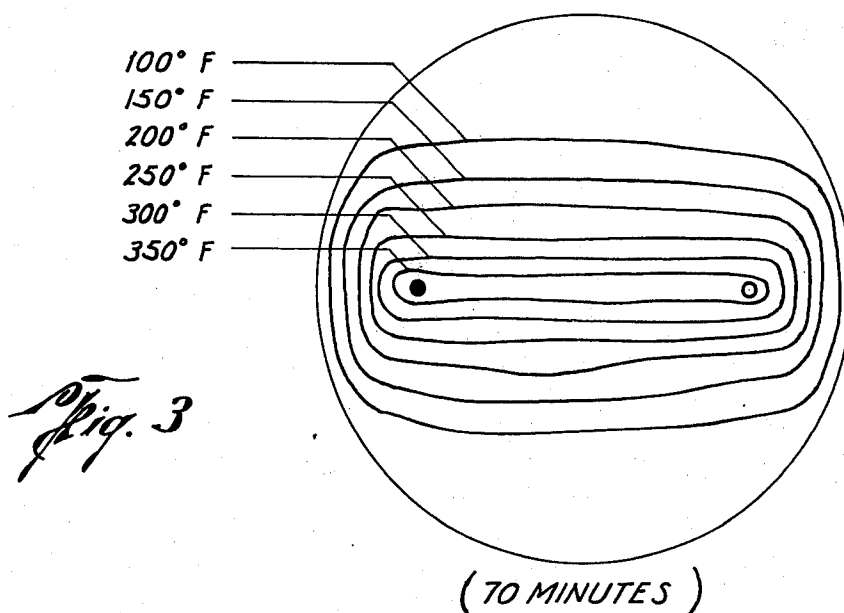


Fig. 1



- INJECTION WELL
- PRODUCTION WELL



METHOD FOR ESTABLISHING COMMUNICATION PATH IN VISCOUS PETROLEUM-CONTAINING FORMATIONS INCLUDING TAR SAND DEPOSITS FOR USE IN OIL RECOVERY OPERATIONS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention pertains to a method for recovering petroleum from viscous petroleum-containing formations including tar sand deposits, and more specifically to a method for establishing a stable interwell communication path in the formation, and to a method for using the communication path in an oil recovery process involving injection of a recovery fluid such as solvent, steam or air for in situ combustion into the communication path.

2. Description of the Prior Art

There are many subterranean, petroleum-containing formations throughout the world from which petroleum cannot be recovered by conventional means because of the high viscosity of the petroleum contained therein. The best known and most extreme example of such viscous petroleum-containing formations are the so-called tar sands or bituminous sand deposits. The largest and most famous such deposit is in the Athabasca area in the northeastern part of the Province of Alberta, Canada, which deposit contains in excess of 700 billion barrels of petroleum. Other extensive tar sand deposits exist in the western United States and in Venezuela, and lesser deposits are located in Europe and Asia.

Tar sands are defined as sand saturated with a highly viscous crude petroleum material not recoverable in its natural state through a well by ordinary production methods. The petroleum or hydrocarbon/materials contained in tar sand deposits are highly bituminous in character, with viscosities ranging in the millions of centipoise at formation temperature and pressure. The tar sand deposits are about 35 percent by volume or 83 percent by weight sand, and the sand is generally a fine grain quartz material. The sand grains are coated with a layer of water, and the void space between the water coated sand grains is filled with bituminous petroleum. Some tar sand deposits have a gas saturation, generally air or methane, although many tar sand deposits contain essentially no gas. The sum of bitumen and water concentrations consistently equals about 17 percent by weight, with the bitumen portion thereof varying from about two percent to about 16 percent. One of the striking differences between tar sand deposits and more conventional petroleum reservoirs is the absence of a consolidated matrix. While the sand grains are in grain-to-grain contact, they are not cemented together. The API gravity of the bitumen ranges from about 6° to about 8°, and the specific gravity at 60° Fahrenheit is from about 1.006 to about 1.027.

Recovery methods for tar sand deposits are classifiable as strip mining or in situ processes. Most of the recovery to date has been by means of strip mining, although strip mining is economically feasible at the present time only in those deposits wherein the ratio of overburden thickness to tar sand deposit thickness is around 1 or less. In situ processes which have been proposed in the prior art include thermal methods such as fire flooding and steam injection, as well as steam-emulsification drive processes.

It has been recognized in the prior art that many of the thermal processes and the steam-emulsification drive process require the establishment of a communication path between one or more injection wells and one or more production wells, through which the recovery fluid may be injected. Many failures to recover appreciable quantities of bitumen from tar sand deposits by in situ recovery processes are related to plugging of the communication path between injection wells and production wells. Plugging can occur in a propped fracture zone as a result of two phenomena. (1) Bitumen heated by the injected fluid to a sufficiently high temperature will flow in the fracture zone for a brief period, but will lose heat and become so viscous that it is essentially immobile after traveling only a short distance from the thermal recovery fluid injection point. (2) When a heated fluid such as steam is injected into a propped fracture communication path between injection and production wells, bitumen above the communication path is heated, softens and flows down into and plugs the propped fracture zone.

In view of the foregoing, it can be seen that there is a substantial, unfulfilled need for a method for establishing a stable communication path between injection wells and production wells within a tar sand deposit, which communication path will not be plugged or otherwise affected during the subsequent injection therein of a thermal recovery fluid.

SUMMARY OF THE INVENTION

I have discovered, and this constitutes my invention, that a stable, permeable communication path may be established between wells drilled into and completed in a subterranean, viscous petroleum-containing formation such as a tar sand deposit according to the process described below. My process requires that there be at least moderate gas permeability or a high permeability streak within the formation, which may be a naturally occurring high permeability streak or one which is formed by means of conventional hydraulic fracturing and propping according to techniques well known in the prior art. My process utilizes simultaneous injection of steam and a noncondensable gas. The steam may be supersaturated or saturated. Gases suitable for use in my invention include carbon dioxide, methane, nitrogen, air, and mixtures thereof.

If the permeability of the formation is sufficient to permit injection of gas from one well to the other through the formation, then gas injection should be the first step in this process. Any noncondensable gas such as nitrogen, air, carbon dioxide, natural gas or methane may be used. If a permeable streak is present, gas may be injected briefly through this permeable streak. Otherwise, hydraulic fracturing and propping are required to open a zone into which steam and noncondensable gas are injected.

Steam and the noncondensable gas may be mixed prior to injection or injected sequentially or separately to mix in the formation. The injection pressure of the steam-noncondensable gas mixture should not exceed a value in pounds per square inch numerically equal to the overburden thickness in feet in order to avoid fracturing the overburden. Steam and noncondensable gas are injected into one well, and flow through the gas swept zone, permeable streak or propped fracture zone to a remotely located well. Flow reversal may be used to insure creation of a uniform thickness communica-

tion path. Recovery of bituminous petroleum by more conventional, high efficiency techniques such as steam emulsification drive, combined thermal-solvent injection, or in situ combustion operations may be undertaken next using the communication path.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 presents an illustrative embodiment of my invention, wherein an injection well and production well are treated to produce the desired stable communication path according to the process of my invention.

FIG. 2 shows the temperature profile of a test cell after 10 minutes of injection during evaluation of the process of my invention.

FIG. 3 shows the temperature profile similar to FIG. 2 but after 70 minutes.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

I. The Process

My invention may best be understood by reference to the attached drawings, which shows in cross-sectional view, a tar sand deposit type of petroleum formation being subjected to one illustrative embodiment of the process of my invention. In the drawing, tar sand formation 1 is penetrated by wells 2 and 3, which are in fluid communication with the tar sand deposit 1 by means of perforations 4 and 5 respectively. Wells 2 and 3 are both equipped on the surface for injection of fluid thereinto or production of fluid from the well. This is accomplished by providing well 2 with valves 6 and 7, and by providing well 3 with valves 8 and 9.

Hydraulic fracturing and propping is performed in the formation via both wells, which gives rise to the creation of a thin, high permeability streak 10 extending at least part way between wells 2 and 3. Even though propping material is injected into the hydraulic fracture, the fracture is not adequate for sustained injection thereinto of steam in the final recovery phase of the operation because of the tendency for heated bitumen to cool and plug the propped fracture of bitumen above the zone to flow down into the fracture zone. Accordingly, valve 7 is closed and valve 6 is opened, and a mixture of steam and noncondensable gas is injected into well 2 through perforation 4 into the propped fracture zone 10. Noncondensable gas is supplied by a compressor or contained under pressure in vessel 11 and pumped therefrom by pump 12 into mixing vessel 13. Steam is supplied from generator 14 by a pump 15. The injection pressure is raised to the desired value and pumps 12 and 15 insure mixing steam and noncondensable gas in the desired ratio. The material being injected into the fracture zone is preferably essentially 100% noncondensable gas initially, with the steam content being increased with time.

The hydraulic fracturing operation may establish an interwell connecting fracture as shown in the figure, or fracture zones may extend into the formation only part way to the other wells. If an interwell fracture cannot be established, steam and noncondensable gas should be injected into each discrete fracture zone via each well. The maximum injection pressure is still limited by the overburden thickness. The preferred method is to inject steam and noncondensable gas up to a pressure in pounds per square inch not greater numerically than the overburden thickness in feet. Injection of fluid should be stopped and pressure should then be held at

the above described level on all wells for a soak period of from 4 to 24 hours. The pressure is then reduced and production of steam, noncondensable gas, steam condensate and bitumen taken from all of the wells. This procedure is repeated until interwell communication is established.

The presence of noncondensable gas in the fracture zone is thought to help avoid formation plugging in several ways. The rate of heating is reduced because the presence of a noncondensable gas with steam reduces the heat transfer rate significantly. The gas pressure is higher in the fracture zone than it would be if steam alone is present, and this higher pressure helps hold softened tar sand material in place above the fracture. Moreover, if hot, liquefied bitumen tends to cool and become immobile as it flows through the propped fracture zone and cools, the presence of noncondensable gas in the zone maintains small flow channels open in the immobile bitumen plug through which hot fluids can flow to heat and relieve the bitumen plugs. The reason for this effect is related to the high mobility ratio of noncondensable gas and viscous liquid bitumen. Such high mobility ratio is normally detrimental to recovery efficiency because the high mobility (low viscosity) gas tends to channel or finger through the viscous petroleum. Channeling in this instance is beneficial, since it facilitates passing the hot steam through the immobile bitumen, resulting in heating and consequent viscosity reduction of the bitumen. When bitumen becomes immobile and plugs a propped fracture zone such as when steam alone is being injected, the portion of the steam vapor near the obstruction cools and eventually condenses, so neither channeling nor heating of the immobile bitumen obstruction results. Injection of additional steam alone is not helpful since it cannot reach the immobile bitumen obstruction, and the only heating effect is by conduction along the long dimension, of the fracture, a very inefficient heat transfer process.

Passage of the mixture of steam and gas through the propped fracture zone results in gradual enlargement of the vertical thickness by continually heating bitumen above and below the zone. The viscosity of bitumen is reduced by heating and flows through the fracture toward the production well 3, carried along by the flowing steam and gas in propped fracture zone 10. Although injection of 100% steam would heat and liquefy bitumen along the faces of the zone more rapidly than steam and noncondensable gas, plugging usually results when pure steam is injected into a fracture.

Since the heating effect is a function of temperature of the fluid flowing in zone 10, and since the fluid cools as it passes through the zone from injection well to production well, the extent of removal of bitumen from the formation adjacent to the zone is greatest near the injection well, decreasing steadily with distance from the point of injection. This results in a non-uniform, wedge shaped communication zone. Although this is not always objectionable, certain recovery processes which may be used give better results if the vertical thickness of the communication path is more nearly uniform. Accordingly, when it is desired to produce a more nearly uniform communication path, the injection-production functions of wells 2 and 3 are reversed, with injection of steam and noncondensable gas being into well 3 and production of steam, steam condensate and liquefied bitumen being taken from well 2, this is accomplished

using an arrangement such as is shown in the attached figure by closing valves 6 and 9 and opening valves 8 and 7 so the mixture of steam and noncondensable gas is introduced into well 3 and passes therefrom into interval 10 via perforations 5. Fluid consisting mainly of steam, noncondensable gas, steam condensate and liquefied bitumen are produced via well 2 through valve 7 to surface located treating facilities.

Whichever injection sequence is being utilized, the fluid produced will be a mixture of steam, water (steam condensate), bitumen and noncondensable gas, which must be treated on the surface to separate water and bitumen. Gravity separation tanks are satisfactory for separating bitumen and water unless a substantially stable emulsion has been formed due to the presence of naturally occurring emulsifiers in the bitumen. Resolution of water-in-oil emulsions must also be accomplished and is easily done by contacting the water-in-oil emulsion with an acid.

Depending on the type of recovery process contemplated in the communication path, from one to four or even more repetitive cycles of the above treatment may be required to convert the propped fracture zone into a satisfactory communication path.

When developing a communication path for an in situ separation process involving steam injection, the transition from the communication path development phase to the in situ recovery phase can occur smoothly. The first fluid injected into the propped fracture zone will ordinarily consist of from 50% to 100% inert gas, the remainder being steam. After production of inert gas is detected at the production well, the steam fraction of the fluid being injected into the production well is increased. The maximum safe rate of increase in steam to noncondensable gas ratio varies from one formation to another because of differences in bitumen composition and content, sand particle size, etc. It is generally preferred to inject essentially 100 percent noncondensable gas initially, and then include gradually increasing quantities of steam with the noncondensable gas.

One may include a small quantity of an alkalinity agent such as caustic (sodium hydroxide or ammonia) in the first portion of steam-noncondensable gas mixture injected to aid in forming of bitumen-in-water emulsion. Emulsion formation makes possible the movement of bitumen which is otherwise immobile. Removal of bitumen from the zone immediately adjacent to the original fracture is necessary in order to expand the fracture into a communication path which will remain open upon injection of thermal fluids during the main recovery portion of the process.

The above cycles are continued through a series of separate steps, simultaneously in each well or alternating from one well to the other, until a satisfactory stable, permeable flow path between well 2 and well 3 is achieved.

The communication path between wells 2 and 3 established according to the above procedure may be utilized for a subsequent in situ recovery process such as steam injection, steam plus emulsifying chemical injection, or numerous other recovery techniques applicable to tar sand deposits which required the establishment of an interwell communication path. Although steam injected into the communication path via well 2 will channel through the communication path, heating of bituminous petroleum contained in the tar sand deposit

will continue along the surfaces exposed to the communication path through which the heated fluid is being injected. Bituminous petroleum along the interface between the tar sand deposit and the communication path will be heated, the viscosity will be reduced, and the material will flow into the communication path. The bituminous petroleum will then flow toward the production well and will be produced along with steam condensate. The recovery process is aided materially by including a small amount of a basic material such as caustic or sodium hydroxide in the steam, which enhances the formation of a low viscosity oil-in-water emulsion. The produced fluid in such a recovery program is an oil-in-water emulsion which has a viscosity only slightly greater than water. Surface equipment for separating bituminous petroleum from the oil-in-water emulsion must be provided.

The communication path established according to the above described procedural steps may also be utilized in the refluxing solvent recovery process described in pending application Ser. No. 357,425, filed May 4, 1973.

II. The Noncondensable Gaseous Constituent

Gases suitable for use in combination with steam in the process of my invention include carbon dioxide, methane, nitrogen and air. Carbon dioxide and methane are preferred gases because of their high solubility in petroleum, although this solubility must be taken into consideration in selecting the ratio of noncondensable gas, to insure that more than the amount which will dissolve in the petroleum is injected, so some gas-phase will remain at formation conditions. Also, crude gases such as flue gas or engine exhaust gas, both rich in carbon dioxide and nitrogen content, may be used. Ethane or propane may also be used. Nitrogen and air are also preferred noncondensable gases because of their widespread availability.

III. Field Example

My invention may be better understood by reference to the following pilot field example, which is offered only as an illustrative embodiment of my invention, and is not intended to be limitative or restrictive thereof.

A tar sand deposit is covered with 300 feet of overburden, and it is determined that the thickness of the tar sand deposit is 75 feet. An injection and a production well are drilled, 100 feet apart, and completed into the full interval of the tar sand deposit. Spinner surveys indicate that there are no intervals of high permeability within this particular segment of the tar sand deposit, and gas permeability of the entire formation is quite low. Hydraulic fracturing must be undertaken in order to establish an injection zone for the process of my invention. Conventional hydraulic fracturing is applied to the formation adjacent to both the injection well and production well, and coarse sand propping material is injected into the fracture to prevent healing thereof after fracture pressure is removed. Gas injectivity tests are performed, and it is determined that communication between wells has been achieved by fracturing.

Pure nitrogen is injected into the fracture zone via the injection well at a pressure of 200 pounds per square inch. After production of nitrogen from the production well is observed, a mixture of 80 percent quality steam and nitrogen is injected into the well. The volume ratio of nitrogen to steam is initially 1 standard cubic feet per pound, with the ratio decreasing gradually to about 0.20 over a 6 day period. Approximately

0.2 percent caustic soda (sodium hydroxide) is added to the steam during the first 10 days of steam injection to aid in forming an emulsion with the bitumen, so that bitumen may be removed more effectively from the zone around the fracture more readily. Caustic soda is not needed after 10 days.

Injection of the nitrogen and steam continues for approximately 1 week, which is sufficient to establish a communication path of sufficient extent that pure steam may be injected without danger of plugging occurring in the communication path as a result of cooling of bitumen or slumping of heated bitumen into the path. As a safety measure, the steam content is increased gradually rather than abruptly, over a 10 day period. Injection of steam is continued as the principal recovery technique, bitumen being produced in the form of an oil-in-water emulsion.

IV. Experimental

In order to establish the operability of the process of my invention, and further to determine the optimum materials and procedures, the following laboratory work was performed. A laboratory cell was utilized in these experiments in order to simulate underground tar sand deposits. The model is a pipe, 15 inches long and 18 inches in diameter. One inch diameter wells, one for injection and one for production, are included, each being positioned three inches from the cell wall and 180° apart. The top of the well is equipped with a piston and sealing rings which impose overburden pressure.

The cell described above was packed with a mined tar sand sample and compressed by pneumatic tamping to a density of 2 gm/cc, followed by application of an overburden pressure of 500 psig for 6 days. A 1/8 inch × 2 inch clean sand path was provided between wells in this sample to simulate a fracture.

Nitrogen gas flow was adjusted to 24 standard cubic feet per hour at a pressure of 300 pounds per square inch into the injection well, through the simulated fracture in the compressed tar sand material and out the production well, and this was continued for several hours. Steam and nitrogen were injected at a pressure of 300 pounds per square inch. The first production of bitumen occurred after only 2 minutes, and the pressure at the model's production well quickly rose to above 250°F. The rapid occurrence of bitumen production and low pressure differential between the injection and production wells are indicative of formation of a communication path between the injection well and production well. Throughout the run, large amounts of "free" bitumen (appearance of pure bitumen but was actually a water-in-oil emulsion) floated on the oil-in-water emulsion in the production receiver. Steam and noncondensable gas were injected at a pressure of 290 to 350 pounds per square inch for 4 5/6 hours, followed by injection of steam only for 2 hours before terminating the run. There was no indication of plugging during the run.

Analysis of data obtained from thermocouples placed in the cell indicated a hot flow path across the tar sand between wells and movement of heat outwards from this path. The temperature profile of FIG. 2 illustrates this result after 10 minutes of steam injection, and FIG. 3 shows the result after 70 minutes of steam injection.

The cell was unpacked in the usual manner and inspected. Major depletion was noted around the injection port and extending toward the production port,

with lesser degree of depletion throughout most of the cell.

While my invention has been described in terms of the number of illustrative embodiments, it should be understood that it is not so limited, since many variations of the process of my invention will be apparent to persons skilled in the related art without departing from the true spirit and scope of my invention. Similarly, while a mechanism has been proposed to explain the benefits resulting from the process of my invention, I do not wish to be restricted to any particular mechanism responsible for the benefits achieved through the use of my process. It is my desire and intention that my invention be limited only by such restrictions and limitations as are imposed in the appended claims.

I claim:

1. In a method of recovering viscous petroleum including bitumen from a subterranean, viscous petroleum-containing formation including a tar sand deposit, said formation being penetrated by at least one injection well and by at least one production well, said recovery method being of the type wherein a fluid is injected into the injection well for the purpose of increasing the mobility of the petroleum contained in the formation, the improvement for creating a permeable, stable, fluid communication path between the injection well and production well which comprises:

- a. fracturing the formation adjacent to at least one of the wells by hydraulic fracturing and injecting into the fractured zone a propping agent to establish a permeable, propped fracture zone extending at least a portion of the way into the tar sand deposit toward the other well;
- b. injecting steam and a gas selected from the group consisting of methane, ethane, propane and butane into the propped fractured zone via the well adjacent thereto at a preselected pressure; and
- c. recovering bitumen, steam and steam condensate from at least one of said wells.

2. A method as recited in claim 1 wherein steam and gas are injected into at least one well and travels through the propped fracture to at least one remotely located well.

3. A method as recited in claim 1 wherein repetitive cycles are performed with injection alternating between the wells.

4. A method as recited in claim 3 wherein repetitive cycles of injecting steam and gas and producing fluids from the same wells are continued until communication between wells is established.

5. A method as recited in claim 1 wherein steam and gas are injected into injection and production wells simultaneously.

6. A method as recited in claim 1 wherein the pressure at which the steam and gas are injected into the formation is equal to a value between the original formation pressure and a value in pounds per square inch numerically equal to the thickness of the overburden in feet.

7. A method as recited in claim 1 wherein the recovery fluid injected into the communication path is steam.

8. A method as recited in claim 1 wherein the recovery fluid injected into the communication path is a mixture of steam and an alkaline material including caustic.

9. In a method of recovering viscous petroleum including bitumen from a viscous petroleum containing formation including a tar sand deposit, the formation being permeable to gas, the formation being penetrated by at least one injection well and by at least one production well, the recovery method being of the type wherein a fluid is injected into the formation to increase the mobility of the petroleum contained in the formation, the improvement for creating a permeable, stable communication path between the injection and production well which comprises:

- a. introducing a first gas which is noncondensable at formation conditions into the formation via the injection well and recovering the gas from the formation via the production well for a preselected period of time to create a gas swept zone in the formation;
- b. introducing a mixture of steam and a second gas which is noncondensable at formation conditions into the gas swept zone; and
- c. recovering bitumen, steam condensate and the noncondensable gas from the production well.

10. A method as recited in claim 9 wherein the first noncondensable gas is selected from the group consisting of nitrogen, carbon dioxide, flue gas, exhaust gas, methane, natural gas, ethane, propane, butane, and mixtures thereof.

11. A method as recited in claim 9 wherein the second noncondensable gas is selected from the group consisting of nitrogen, carbon dioxide, flue gas, exhaust gas, methane, natural gas, ethane, propane, butane,

and mixtures thereof.

12. A method as recited in claim 9 wherein the first noncondensable gas and second noncondensable gas are the same.

13. In a method of recovering viscous petroleum including bitumen from a subterranean, viscous petroleum-containing formation including a tar sand deposit, said formation being penetrated by at least one injection well and by at least one production well, said recovery method being of the type wherein a fluid is injected into the injection well for the purpose of increasing the mobility of the petroleum contained in the formation, the improvement for creating a stable, permeable fluid communication path between the injection well and production well which comprises:

- a. hydraulically fracturing and introducing a propping agent into the formation adjacent the injection well and the production well to form a propped fracture zone adjacent each well extending only part way from that well to the fracture adjacent the other well;
- b. injected steam and a gas selected from the group consisting of methane, ethane, propane and butane into the fracture zone adjacent each well until the injection pressure reaches a predetermined value;
- c. maintaining steam and the gas in each fracture for a predetermined soak period;
- d. reducing the pressure in each well to permit steam, non-condensable gas and viscous petroleum to flow from each propped fracture zone into each well.

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