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3,279,538
OIL RECOVERY
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This invention relates to the recovery of oil from subterranean bituminous or tar sand formations, and especially from the tar sands which are found in Alberta, Canada. The invention, more particularly, pertains to an efficient, economical and commercially feasible method of in situ separation and recovery of high yields of oil from tar sands.

As is well known, there are various places throughout the world which have large deposits of tar sands. Usually the oil in these tar sands has a density approaching or even greater than that of water. The most extensive and best known deposits of this type are in the Athabasca 20 district, Alberta, Canada. These Athabasca tar sands extend for many miles and occur in thicknesses varying up to more than 200 feet. Although in some places these tar sand formations are disposed practically on the surface, generally they are located under an overburden 25 which ranges in thickness from a few feet to as much as 100 or more feet in depth. These tar sands constitute one of the largest presently known petroleum deposits. The oil content of these sands ranges between about 10 percent and about 20 percent by weight, although sands 30 having lesser or greater amounts of concentrations of oil are not unusual. The sands also generally contain small amounts of water, e.g., in the range of from about 1 percent to about 5 percent by weight.

The oil present in and recoverable from these tar sands is usually a rather viscous material ranging in specific gravity from somewhat below 1.00 to about 1.04 or somewhat greater. Since this tarry material recoverable from the aforementioned tar sands does not generally command a high price, particularly when in its crude 40 state, the separation and recovery of the oil from these tar sands must involve a minimum of expenditure in order to be economically attractive for commercial practice.

It has recently been found that oil may be economically and effectively recovered from tar sands and like formations by a process which involves fracturing the tar sand formation between at least two spaced wells drilled thereinto, passing a dilute aqueous alkaline solution through the formation adjacent to said fractures, thereby subjecting the tar sands to leaching and emulsifying actions by said solution, and then conveying steam through said tar sand formation to heat the oil and force the emulsion formed by the action of the aqueous alkaline solution towards an output or production well from which the emulsion may then be recovered for subsequent separation and recovery of the hydrocarbon therefrom.

More specifically stated, in accordance to the aforementioned, recently discovered process, hydrocarbons can be recovered from tar sands by fracturing the tar sand 60 formation between at least two spaced wells drilled thereinto, said fracturing being preferably effected by use of an aqueous alkaline solution as the fracturing fluid, passing a dilute aqueous alkaline solution containing between about 0.0025 weight percent and about 1 weight percent (preferably between about 0.05 wt. percent and about 0.2 wt. percent) of an alkali metal hydroxide, such as

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sodium hydroxide, through the fractures and the adjacent tar sand formation, thereby subjecting the tar sands to a leaching action and to emulsification of the thus leached tarry material or oil, conveying steam through said tar sand formation to heat the tarry material and to force the emulsion thus formed towards an output or production well, alternately repeating the injections of the aqueous alkaline solution and of steam, thereby causing the emulsion to be forced to the production well, and recovering the emulsion therefrom, e.g., by gas lift.

It has now been found that when tarry materials or oils are recovered from tar sand formations by the process outlined above, that periodically the tar sand formation surrounding or adjacent to the production well or wells apparently becomes plugged with tar, thus causing a decline and even a complete stoppage in the flow of the oil-containing fluid to and into said production well or wells.

It is an object of the present invention to avoid the above and other defects, and to provide an economical process whereby high yields of oily material may be recovered from tar sands without the necessity of mining these sands, or otherwise handling large masses thereof, and without the necessity of using high concentrations of costly chemicals for the in situ removal of the tarry material or oil from said tar sands. It is still a further object of the present invention to provide a process wherein the aforementioned steps of fracturing and alternate injection of dilute alkaline (caustic solution and of steam through one or more injection wells, may be used, and wherein the yield of the desired tarry material or oil may be maintained for long periods of time without plugging of the formation being treated.

It has now been discovered that the above and other objects may be attained, in accordance with the process of the present invention, by employing the aforementioned process involving the use of dilute aqueous alkaline solutions and of steam, in combination with the periodic injection of a relatively small slug of the dilute aqueous alkaline solution into the formation through the production well or wells. More specifically stated, the invention comprises the process of recovering tarry materials from tar sand formations by fracturing said formation between at least two spaced wells drilled thereinto (one of which is an injection well and the other a production well) passing a dilute aqueous alkaline solution (i.e., an aqueous solution containing between about 0.0025 wt. percent and about 1 wt. percent of an alkali metal hydroxide) through the injection well and into the formation, thereby subjecting the tar sands therein to leaching (of the oil therefrom) and to emulsifying of said oil by said solution, conveying steam into the formation through said injection well, and periodically introducing a relatively small slug of the aforementioned dilute aqueous alkaline solution (which may preferably be preheated) through the production well and into the surrounding formation to increase its permeability and thus maintain and increase the flow of oil-containing fluid through the formation and into the production well, from which said fluid may be recovered to the surface, e.g., by gas-lift, for the purpose of separating the oil or tarry liquid there-

In one of its more specific embodiments, the present invention comprises a process for recovering hydrocarbons (which term is used as an equivalent of tarry materials or oils separable from tar sands), by

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(a) fracturing the tar sand formations between at least two wells drilled thereinto (one of said wells being an injection well while the other is a production well),

- (b) passing a dilute aqueous alkaline solution containing between about 0.0025 wt. percent and about 1 wt. percent (and preferably between about 0.05 wt. percent and about 0.2 wt, percent) of an alkali metal hydroxide, e.g., sodium hydroxide, down the injection well and through the tar sand formation adjacent to the fractures, thereby subjecting the tar sands to a leaching action and the leached tarry material to emulsification.
- (c) conveying steam through said tar sand formation to heat it and to force the emulsion toward production well,
- (d) periodically alternating the last two steps, and
- (e) periodically injecting through the production well into the surrounding formation a relatively small slug of a heated dilute aqueous alkaline solution having the above-defined concentration of an alkali metal hydroxide.

The amounts and temperatures of the slugs of the dilute aqueous alkaline solution (which may be sodium, potassium and/or lithium hydroxide) injected through the production well or wells, may vary within relatively wide limits. This is also true of the frequency of these injections of slugs. In part, these variables will depend on a number of conditions, e.g., temperature of the aqueous solution as well as of the steam injected into the formation through the injection well or wells, the thickness of the tar-containing sand, the distances between the wells. Also, any one of the above variables is affected by one or more of the other of these variables. Without any intention of being limited, it may be stated that these slugs may vary in amount from one to 10 barrels, to 50 barrels or even higher, e.g., 100 barrels in quantity. quency of injections may vary from once every 12 hours to as much as once every month or so. As to the temperature, this may vary from as low as 60° F. to higher than 150° F. or even 200° F., although in some cases it may be desirable to employ higher temperatures, e.g., 300° F.

In general, in order to introduce the slug or slugs of the dilute aqueous alkaline solution through the production well, the latter is closed in and the solution is then 45 pumped through appropriate tubing disposed in the well. As previously indicated, the solution is forced into the formation by any known means and is allowed to remain in said formation for a suitable or desirable period of time, which may vary from several hours to several days, 50 or even longer. Thereafter, the production well is opened up, and recovery of the fluid (which contains the tarry materials) is then re-initiated, e.g., by gas-lift, pumping, or any other well known method or means.

As indicated above, one of the first steps in recovering 55 hydrocarbons or tarry materials from tar sands is to drill a plurality of wells, some of which are to be used as injection wells while others as production wells. Usually, the wells are drilled through the overburden and into tar sand proper, and to a certain depth within the sand forma- 60 tion itself. One of the ways is to provide a so-called fivespot system in which four wells are drilled at spaced intervals to form a square or rectangle, while a single well is drilled substantially in the center of said rectangular The wells are usually drilled to substantially the 65 same depth and preferably cased with tubing having slots or other openings in the lower parts thereof to permit communication between the well interior and the formation from which the tar is to be leached. In some instances the four corner wells are used as injection wells 70 while the center well is the production or oil recovery well; however, the converse system may be used, in which case the center well is the injection well, the oil being recovered from any one or more of the four corner wells.

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Once the wells are drilled, the tar sand formation is fractured so as to provide fractures or fissures extending preferably substantially horizontally through the formation between the wells or at least through a substantial portion of the distances therebetween. The fractures are preferably located near or substantially near the bottom of the drilled wells. Although any system fracturing well known to the art may be employed, it is preferable to use as the fracturing medium an aqueous alkaline solution, and particularly the same solution as that used in the next step for the leaching out of the tarry materials from the tar sands. This dilute alkaline solution, as will be described below, usually contains between about 0.0025 weight percent and about 1 weight percent of an alkaline metal hydroxide, such as sodium hydroxide, and is preferably substantially free from any free polyvalent metal ions. If the tar sand formation is fractured between the wells with steam or substantially pure water, it is necessary (when one does not use a propping agent) to continue the subsequent operations at pressures greater than the weight of the earth above the fracture at least until one has actually removed the tarry material from the fractured zone or zones. On the other hand if an aqueous alkaline solution is employed both for the fracturing and for the subsequent leaching, it is not necessary to continue this latter operation at pressures above that necessary to support the earth because the presence of the alkaline solution prevents or inhibits the tarry materials from re-sealing the formation.

Although the aqueous alkaline solution used for the fracturing operation may be heated prior to injection into and passage through the well used for the introduction of the fracturing fluid, satisfactory results can and have been obtained by employing the alkaline solution at ambient temperatures.

When the formation between the injection well or wells and the production well or wells has been fractured, injection of the dilute aqueous alkaline solution may be continued to leach out the hydrocarbons from the tar 40 sand so that passages for the fluids conveyed will be maintained between the injection and the production wells. The oily or tarry materials present in and around the fractures are emulsified by the passing of the dilute aqueous alkaline solution. It was pointed out above that the aqueous solution should have a low concentration of the alkaline metal hydroxide present. As such alkaline metal hydroxides, one may use sodium, potassium and/or lithium hydroxide, although preferably sodium hydroxide is to be used. Also, the aqueous solution should be substantially free from free or unsequestered polyvalent metal ions such as alkali earth metal ions. The optimum alkali metal hydroxide concentration in the aqueous solution appears to be between about 0.05 weight percent and about 0.2 weight percent although the concentration may be as low as 0.0025 weight percent and about 1 weight percent. The solution may be used at ambient temperatures although it is frequently desired and sometimes even preferred to preheat the solution to temperatures as high as 200° F. to 300° F. or thereabouts. The passage of this solution (injected into the formation through the injection wells) leaches out the tarry material from the tar sand and forms an oil-inwater emulsion which may be readily forced through the formation to one or more of the production wells. For further details of this step, reference is made to the Canadian Patent No. 639,050 which described and claims the leaching of oil from tar sands in situ by using aqueous solutions free from polyvalent metal ions but containing up to about 1 weight percent of a watersoluble alkali metal hydroxide.

70 The temperature of the treating dilute aqueous alkaline solution (introduced into the formation through the injection well or wells) may vary within wide limits. Although no special heating is necssary, it is generally preferred, particularly in the case of the treatment of 75 Athabasca tar sands containing extremely viscous, oily

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or tarrry materials, that the temperature of the aqueous alkaline solution, or at least that portion of it which is injected after the fracturing step has been accomplished, should not be much below about 60° F., this because the leaching and emulsification results can be obtained by using the aforesaid aqueous alkaline solutions at temperatures as high as 150 F. or higher, e.g., up to about 300° F. The use of elevated temperatures generally enhances the activity of the alkali metal hydroxide solution.

The quantity of aqueous alkaline solution to be injected through the input well or wells can likewise vary within wide limits and at least in part depends on the amount and temperature of the steam introduced. As a general rule, the recoverable yields of oil from the tar sands are enhanced by increasing the overall quantity of the aqueous alkaline solution. This total quantity may be divided into several increments or slugs which can be introduced alternatively to steam slugs mentioned above. In general, other conditions being equal, increasing the total volume of aqueous alkaline solution used will increase the percent of the oil recovered by as much as 15–20% or more.

As mentioned the slugs or increments of aqueous alkaline solution, injected through the input well or wells, may be alternated with injections of slugs of steam which is generally introduced into the formation through the same well or wells employed for the introduction of the alkaline solution. The steam thus introduced flows through the fissures from the injection well or wells toward the production well. Under these conditions, the temperature of the reservoir will rise relatively rapidly as the heat flows from the fissure to the surrounding oilbearing strata by diffusion. Thus, relatively rapid transfer of heat both to the reservoir (i.e., the tar sand formation) and to the aqueous alkaline solution and therefore the emulsion formed can be achieved.

It is generally not desirable that live steam in any substantial amounts reach the producing well, this because it is usually desirable that the latent heat or heat of condensation of the injected steam be utilized to heat the tar sands, the aqueous alkaline solution and the emulsion formed between it and the leached out tarry or hydrocarbon materials. As the steam condenses in the fissures, the reservoir will be heated by diffusion and the hydrocarbons 45 as well as the emulsion formed will begin to move under steam and water drive toward the producing well. Although the temperature of the steam may vary within relatively wide limits, excellent results have been obtained when the injection temperature at the wellhead is about 50 350° F. Under such conditions the temperature at the bottom of the injection well will be about 315-325° F. and at the recovery or production well-about 250° F.

When steam is introduced to heat the formation, small amounts of caustic may be added thereto in order that, when said steam or any portion thereof condenses, it will be in the form of a dilute aqueous alkaline solution, this solution being then capable of emulsifying the tar or hydrocarbon.

As a general rule, in accordance with the process of the 60 present invention, the injections of dilute aqueous alkaline solution and of steam are alternated until flow of emulsion from the producing well or wells is attained. At such time one may stop the use of the aqueous alkaline solution and merely proceed with steam drive.

As specific example of the present invention, a plurality of wells was drilled into a tar sand formation which was overlaid by a 30-foot overburden. The wells were approximately 200 feet deep and were cased with pipe having their lower portions slotted so as to provide communication between the interior of the well and the surrounding formation. The wells were drilled according to the so-called five-spot system wherein four wells were located at the corners of a rectangle and were used as the production wells while the fifth well drilled in the middle of 75

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said rectangle was used as the injection well. In accordance with the process of the present invention, a cold aqueous alkaline solution containing about 0.1 weight percent of sodium hydroxide is injected through the injection wells at a pressure of about 500 pounds per square inch and at a rate of about 60 to about 100 barrels per hour until fracturing occurs. Thereafter an aqueous alkaline solution having the same concentration of sodium hydroxide is injected through the injection well for one day, this injection being interspersed with the injection of steam at a rate of about 1,500 pounds per hour for about six days. These introductions of slugs of aqueous alkaline solution and of steam are continued until an emulsion containing 20 percent of oil appears in the producing well, 15 at which time steam drive is continued to force the emulsion to the producing well from which it is recovered by ordinary means. At intervals of about a week, small slugs of the above-mentioned dilute aqueous alkaline solution (containing about 0.1 wt. percent of sodium hydrox-20 ide) are introduced in amounts of from about 20 barrels to about 35 barrels each through the production well, these slugs being at a temperature of about 100° F. These treatments result in a marked increase in the flow of the emulsion to the production or recovery well. Thus, in one instance, the injection of a single 20-barrel slug of the injection of a single 20-barrel slug of the solution increased the flow of tarry of tarry material by about 50 percent, while the injection of a second slug of about 35 barrels, after an interval of one week, further increased the yield by about another 100 percent.

I claim as my invention:

1. The process of recovering oil from a subterranean tar sand formation penetrated by at least one input well and at least one production well, which process comprises the steps of introducing through said input well a dilute aqueous alkaline solution containing between about 0.0025 wt. percent and 1 wt. percent of an alkali metal hydroxide at least a portion of said alkaline solution being positioned adjacent the tar sand formation surrounding said input well under sufficient pressure to create fractures extending through said formation between said wells, continuing the introduction of said dilute aqueous alkaline solution to cause it to flow through the fractures, to extract the oil from the sands and to produce in the formation an oil-in-water emulsion, producing said oil-in-water emulsion from said production well, interrupting periodically said injection of the alkaline solution, periodically interrupting said recovery of said emulsion from said production well while periodically injecting through said production well and into the tar sand formation a slug of aqueous alkaline solution containing between about 0.0025 wt. percent and 1 wt. percent of an alkali metal hydroxide, said slug of said alkaline solution aiding in opening up the tar sand formation adjacent to the output well thereby aiding the flow of the oil-containing emulsion to said output well from which it is recovered and the oil is separated.

- 2. The process according to claim 1 wherein said last named aqueous alkaline solution contains from 0.05 wt. percent to 1 wt. percent of sodium hydroxide at a temperature of between 50° F. and 250° F.
- 3. The process according to claim 2 wherein the last-mentioned slugs of the aqueous sodium hydroxide solution are injected into the formation in quantities of between about 10 barrels and about 100 barrels, at intervals of between about 12 hours and 30 days apart.
- 4. The process according to claim 1 wherein the last-mentioned aqueous alkaline solution slug is at a temperature of between about 50° F. and about 250° F., said slug thus aiding in the heating of the formation around the production well and increasing the permeability of the said formation.
- at the corners of a rectangle and were used as the production wells while the fifth well drilled in the middle of 75 mentioned aqueous alkaline solution is introduced into

the formation through the production well in an amount of between about 10 barrels and about 100 barrels.

6. The process of recovering oil from a subterranean tar sand formation penetrated by at least two spaced wells of substantially similar depths, one of which wells is an injection well while the other is a production well, which process comprises the steps of introducing through the injection well a dilute aqueous alkaline solution containing between about 0.0025 wt. percent and 1 wt. percent of an alkali metal hydroxide, fracturing said tar 10 sand formation by applying a pressure on said aqueous alkaline solution, and therefore on the tar sand formation surrounding said injection well, to create fractures extending substantially horizontally through said formation between said wells, said pressure being applied at a 15 ing said interruption, thereby aiding the flow of the emullevel such that at least some of said fractures are located near the bottom of said injection and production wells, continuing the introduction of said dilute aqueous alkaline solution to cause it to flow through the fractures, to extract the oil from the sand and to produce in the forma- 20 tion an oil-in-water emulsion, producing said oil-in-water emulsion from said production well, interrupting periodically said injection of the alkaline solution, periodically interrupting said recovery of said emulsion from said production well, injecting steam through the injection 25 well during said interruption, thereby aiding the flow of the emulsion through the formation to the production well, and periodically injecting through said production well and into the tar sand formation a slug of heated aqueous alkaline solution containing between about 0.0025 30 wt. percent and 1 wt. percent of sodium hydroxide, fracsaid slug of said alkaline solution aiding in opening up the tar sand formation adjacent to the output well, thereby aiding the flow of the oil-containing emulsion to said output well from which it is recovered and the oil is sepa- 35 rated.

7. The process of recovering oil from a subterranean tar sand formation penetrated by at least one input well and at least one production well, which process comprises the steps of introducing through said input well a dilute 40 aqueous alkaline solution containing between about 0.05 wt. percent and 1 wt. percent of sodium hydroxide, frac-

turing said tar sand formation by applying a pressure on said aqueous sodium hydroxide solution, and therefore on the formation surrounding said input well, sufficient to hydraulically fracture said tar sand formation to create fractures extending substantially horizontally through said formation between said wells, continuing the introduc-tion of said dilute aqueous sodium hydroxide solution to cause it to flow through the fractures, to extract the oil from the sands and to produce in the formation, an oilin-water emulsion producing said oil-in-water emulsion from said production well, interrupting periodically said injection of the sodium hydroxide solution, periodically interrupting said recovery of said emulsion from said production well, injecting steam through the input well dursion through the formation to the production well, and periodically injecting through said production well and into the tar sand formation a slug of heated aqueous alkaline containing between about 0.05 wt. percent and 1 wt. percent of sodium hydroxide, said slug of said alkaline solution aiding in opening up the tar sand formation ad-

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jacent to the output well thereby aiding the flow of the

oil-containing emulsion to said output well from which it

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is recovered and the oil is separated.

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