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METHOD FOR RECOVERING OIL FROM SUBTERRANEAN FORMATIONS

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ABSTRACT OF THE DISCLOSURE

This invention concerns a cyclic process for recovering oil from viscous oil reservoirs, tar sands and oil shale formations. Spaced wells are drilled into the oil-bearing formation and the formation fractured to establish fluid communication between the wells. Recovery operations are conducted along the fracture paths and oil recovered from at least one of the wells. When the formation adjacent the fracture has been substantially denuded of oil, a body of foam is established in the fracture to inhibit further fluid communication between the wells. Thereupon the formation is again fractured to form new fracture paths and recovery operations repeated along these virgin fractures.

This invention relates generally to the recovery of hydrocarbons from subterranean formations wherein, because of the nature of the deposits contained in the formation, ordinary recovery methods will not suffice. In many instances, because of the high viscosity of the oil or because of the nature of the formation itself, it is necessary to repeatedly fracture the formation and conduct recovery operations along and coextensive with the formed fractures in the formation so as to drive the hydrocarbon material from an injection well towards a production well from where it is recovered. Examples of such formations most notably include tar sands and oil shale.

The recovery of heavy viscous oils and the recovery of hydrocarbons from oil shale and tar sands have recently come to the fore with the advent of new production methods which make the recovery of these oils and hydrocarbons economically feasible. As is well known, these oils are in abundance but have, for the most part, been considered as natural resources worthy of little present economic interest. Because the quality of these oils is substantially below the quality of ordinary crude oil, and because of the difficulties in extracting these materials from the earth, any method or process directed to extracting these valuable mineral deposits must of necessity be low in cost.

The formations in which some heavy viscous oils are found, and indeed oil shale and tar sand formations themselves, do not readily permit the utilization of conventional secondary oil recovery methods. The most notable methods of economic worth are generally those depending upon in situ combustion of the hydrocarbons in place in order to economically produce the formation. Generally, these methods also entail the creation of horizontal fractures extending between an injection well and a production well so that the in situ combustion process or other secondary recovery processes may be conducted along these paths in order to extract valuable oil deposits. However, once the formation adjacent the fractures has been depleted of kerogen or hydrocarbons, the formation must again be fractured so that the recovery process may be conducted along virgin fractures. In this manner, much of the hydrocarbon content of a formation may be recovered. However, because of the low margin of economic operation, it is necessary to keep the cost of any given recovery process to a minimum. Heretofore, the depleted fractures have been cemented or sealed off

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from the injection well bore by means of cement, resins and other sealants which prevent either hydrocarbon solvents or the hot gases from an in situ combustion process from invading the therein previously worked faults or fractures. These methods are generally uneconomical and infeasible, considering the low value of the hydrocarbon materials recovered from tar sands, oil shale and the like formations.

Now, in accordance with this invention, an economically feasible method of producing hydrocarbon material has been found which obviates the necessity of using cements, resins, and other sealing materials, wherein these materials have been utilized to plug off or seal initially created fractures along which recovery processes have been conducted. After the formation has been initially fractured and as much of the hydrocarbon content has been extracted along the fractures as is possible, employing any one specific recovery method, a suitable foam is disposed within the depleted fracture at least in that portion of the fracture communicating with and adjacent to the injection well bore. Thereafter, the formation may again be fractured, thereby creating virgin fractures extending from the injection well to the production well upon which and along which subsequent recovery practices may be conducted.

The foam may be disposed in the fractures per se, but, because of inherent difficulties in pumping foam to great depths and under high pressures, it is preferred to inject a liquid slug material or vehicle in which the surfactant or foaming agent is dissolved, and thereafter to inject a sufficient quantity of gas to substantially completely foam the initially injected surfactant solution. In this manner, a tenacious foam is formed which retards the entry of fracturing fluid or other fluids, including gases which may be oxygen-containing, from entering the heretofore depleted fracture. Thus, it can be seen that not only is the quantity of fracturing fluid needed for producing the fractures lowered; but also, the subsequently injected oxygen-containing gases necessary for supporting an in situ combustion process are not lost to areas of the formation which have been heretofore depleted. In other instances, where it is desired to carry out a recovery process employing a hydrocarbon solvent which is injected into the fractured formation and driven from the injection well to the production well, the presence of the foam in the depleted fracture prevents the solvent from entering the depleted fracture, thereby increasing the amount of hydrocarbon material that may be recovered at the production well. Generally, however, the recovery of heavy viscous oil or hydrocarbon material from tar sands or oil shale and kerogen will necessitate the use of in situ combustion wherein a portion of the hydrocarbon material contained within the formation will be ignited, thereby establishing a heat wave which is driven through the formation from the injection well towards the production well along a fracture path.

The object of this invention, therefore, is to provide an oil recovery process suitable for use in oil shale, tar sands, and the like formation wherein fractures or channels are created within the formation extending from the injection well to a production well and wherein recovery processes are conducted along these channels.

The various embodiments of the invention will be best described and more fully appreciated from the following detailed description. However, the only limitations which are to be imparted to the invention disclosed herein are those contained in the appended claims.

When a formation such as a tar sand or oil shale or the like, and even those formations wherein there is contained a heavy viscous oil, is encountered, good production techniques necessitate the establishment of some communication between an injection well and a produc-

tion well penetrating the formation so that recovery processes may be conducted along these paths of communication. The art is well aware of various fracturing techniques which have been heretofore propounded for establishing communication within a formation between an injection well and a production well. Generally, communications between two wells are established by the application of high hydraulic pressures to the formation to be fractured, such as is described in U.S. Patent 2,734,861. It is to be appreciated that in conducting fracturing operations more than one fracture puts the injection well and production well in communication. Ideally, it is desired to cause as many fractures as is possible so that as many individual fractures and formations adjacent the fractures may be stripped of oil as is possible.

Once a series of fractures have been created to put the injection well and production well in communication through the fractured formation, secondary recovery operations are conducted along these paths of communication such as by the use of hydrocarbon solvents, e.g., LPG and benzene so that the hydrocarbon material in and adjacent to the fractures may be extracted therefrom and driven to the production well from whence it is recovered. Other recovery methods are contemplated and indeed are the most practical in dealing with tar sands and oil shale formations, an example of which is an in situ combustion process wherein a portion of the formation's hydrocarbon material is ignited, or alternatively extraneous fuel is provided to the formation, to establish a heat wave in the formation. Thereafter, this heat wave is propagated through the fractures of the formation to heat the oil or hydrocarbon material and extract same from the rock and drive same towards the production well. It is to be noted, however, that only that hydrocarbon material in and around the fracture is recovered from the formation. Therefore, in order to extract as much hydrocarbon material as is possible from any given formation, it is necessary to repeatedly fracture and conduct the recovery operations along the newly formed or virgin fracture paths. Now in accordance with this invention, once a fracture path or communication has been denuded of its hydrocarbon content, a foam is disposed within the depleted fracture so that the subsequent fracturing fluid will not be lost to these large fissures and so that other portions of the formation may be fractured and worked upon.

While the foam per se may be injected into the denuded fracture paths, it is preferred to inject a slug of surfactant or foaming agent-containing solution and to follow this slug with a sufficient amount of gas to substantially completely foam the previously injected surfactant slug, thereby forming foam in at least that portion of the denuded fractures adjacent the injection well. In some instances, it may be desirable to form foam in substantially the entire length of the fracture between injection and production well. However, this method would tend to become costly and in most instances will not be necessary. Once the foam has been disposed in the denuded fracture, the fracturing step may again be repeated thereby forming new fractures in the formation and creating new paths of communication between the injection and production well which may be worked upon in order to extract the hydrocarbon material therefrom and adjacent the fracture.

The term surfactant or foaming agent, as used in the specification and appended claims denotes a surfactant or foaming agent which will have a tendency to generate foam in a subterranean formation in the presence of a liquid and a gas. Because of variations in the foaming characteristics of any one particular foaming agent, the type of strata to be sealed, and the distance in the formation in which a foam is to be generated, it will sometimes be necessary to conduct a few simple laboratory core experiments to determine the amount of surfactant or foaming agent necessary to effectively plug the denuded fractures communicating the injection and production wells. These are tests which are well known in the art

and simply involve taking a core sample from the well bore or from the formation in the general vicinity of the well bore, determining its permeability and porosity, and then calculating the amount of surfactant necessary to effectively plug the pores or interstices of the formation and the fracture which has been previously denuded of oil.

The use of various commercial foaming surfactants or foaming agents is contemplated, the characteristics of which may be determined from available published tables. Oil soluble foaming agents, such as a 1:1 mixture of dicoco dimethyl ammonium chloride and decyl trimethyl ammonium chloride will be satisfactory. An example of a suitable water soluble surfactant or foaming agent is a poly-oxyethylated alkyphenol, such as that known commercially under the tradename "Triton X-100." Other foaming agents or surfactants which may be used in the practice of this invention are:

Trade name:	Chemical name
20 Aerosol C-61 -----	Ethanolated alkylguanidine - amine complex
Aerosol OS -----	Sodium isopropyl naphthalene sulfonate
25 Arquad 2 C -----	Dicocodimethylammonium chloride
Arquad T -----	Tallow trimethylammonium chloride
Duponol EP -----	Fatty alcohol alkylolamine sulfate
Duponol RA -----	Modified ether alcohol sulfate sodium salt
30 Duponol WAQ -----	Sodium lauryl alcohol sulfate
Ethomid HT-60 ----	Condensation product of hydrogenerated tallow amide and ethylene oxide
35 Hyonic FA-75 -----	Modified fatty alkylolamide
Miranol HM Concentrate -----	Ethylene cyclomido 1-lauryl, 2-hydroxy ethylene Na alcoholate methylene Na carboxylate
40 Miranol MM Concentrate -----	Same as Miranol HM except myristyl group is substituted for lauryl group
Nacconal NR -----	Alkylarylsulfonate
45 Ninol AA62 -----	Lauric diethanolamide
Ninol 1001 -----	Fatty acid alkanolamide
Petrowet R -----	Sodium alkylsulfonate
Pluronic L44 -----	Condensation product of ethylene oxide with propylene glycol
50 Product BCO -----	C-cetyl betaine
Renex 650 -----	Polyoxyethylenealkyl aryl ether
Sorbit AC -----	Sodium alkyl naphthalenesulfonate
Sulfanole FAF -----	Sodium salt of fatty alcohols, sulfated
55 Triton AS-30 -----	Sodium lauryl sulfate
Span 20 -----	Sorbitan monolaurate
Span 40 -----	Sorbitan monopalmitate
Span 85 -----	Sorbitan trioleate
Tween 65 -----	Polyoxyethylene sorbitan tristearate
60 Tween 81 -----	Polyoxyethylene sorbitan monooleate
OPE 1 -----	Octylphenoxyethanols
OPE 2 -----	Octylphenoxyethanols
OPE 3 -----	Octylphenoxyethanols
Orvus K -----	Ammonium alkyl sulfate
65 Triton GR-7 -----	Diocetyl sodium sulfosuccinate
Triton B-1956 -----	Modified phthalic glycerol alkyl resin

The surfactant or foaming agent may be injected into the denuded fractures or paths of communication per se if its form permits, or, for ease of handling and for quicker dispersion, it may be incorporated in a liquid vehicle such as water or brine in the case of a predominantly water soluble surfactant and in an oil base vehicle where the surfactant is predominantly oil soluble. The amount

of surfactant incorporated in the vehicle will normally comprise about 0.001 to 10 wt. percent of the vehicle. The amount of surfactant-containing vehicle will normally depend on the type of formation involved and the porosity of the denuded formation adjacent the fracture path and the size of the fracture paths themselves. Ordinarily, the size of the vehicle slug in which a surfactant is incorporated will comprise about 0.001 to 20% of the formation pore volume. By pore volume, it is meant the reservoir pore volume in the area affected by my process. Ordinarily, an amount of vehicle-surfactant solution equivalent to approximately 0.001% of the pore volume will suffice in order to gain the attributes of the various embodiments of the hereindisclosed invention. One means of determining whether or not sufficient plugging of the denuded fracture paths and denuded formation adjacent these paths has occurred will be indicated while injecting the gas necessary to completely substantially foam the surfactant-solution. That is, gas injection will continue to such a point until a rather high back pressure is encountered which will indicate that substantially all of the fracture paths and denuded areas surrounding these paths are sufficiently plugged with foam.

The types of gases subsequently injected to foam the surfactant or surfactant solution are those which are well known in the art and include as nonlimited examples: air, nitrogen, natural gas, flue gas, carbon dioxide, oxygen, etc. The volume of gas should be sufficient to effect substantially complete foaming of the surfactant. Ordinarily, this amount will be about 10 to 1,000 times the volume of foam solution injected, measured under reservoir conditions.

After the surfactant solution has been foamed, thereby plugging the denuded faults or fissures and also the pores of the reservoir surrounding these fracture paths which have been extracted of their hydrocarbon content, the formation may then again be subjected to a fracturing process so that recovery operations may again be conducted along new so-called virgin fracture paths communicating the injection well and production well.

As indicated earlier, various modes of recovery conducted along these fracture paths are contemplated, including solvent extraction using hydrocarbons such as benzene, ethers, LPG, etc., followed by a suitable driving fluid such as water, carbon dioxide, carbonated water, etc. However, because of the great attributes connected with a thermal type recovery, it is preferred to initiate an in situ combustion process within the well bore and inject oxygen-containing gas so as to ignite the hydrocarbon material in at least a portion of the formation in proximity to the fracture communication paths and to burn a small portion of the native hydrocarbons so as to produce a heat wave which may be propagated through the formation along the fracture paths from the injection well to the production well.

Any heretofore disclosed well patterns may be used in practicing this invention as, for instance, the direct line drive process or the conventional five spot, seven spot and nine spot well patterns, as well as other patterns known in the prior art.

As a specific example of this invention, an injection well and a production well are drilled into an oil shale formation spaced approximately 200 ft. apart, the overburden above the oil shale formation is 1,000 feet thick. The wells are completed and the formation is fractured by injecting water into the injection well at a pressure of about 1,000 p.s.i., thereby establishing communication between the injection well and the production well through means of fracture paths. A propane burner is then lowered into the injection well and ignited, and oxygen-containing gas and propane are injected into the well and into the fractured formation at the rate of 1,000 gallons of propane per day at a pressure of about 500 p.s.i. with sufficient oxygen-containing gas to sustain combustion of the propane. This injection of propane and oxygen-containing gas is carried

on for about one week. Thereafter, the propane supply is shut off and oxygen-containing gas alone is injected at a rate of about 70 s.c.f./per minute at a pressure of about 500 p.s.i. which pressure and injection rate is insufficient to lift the overburden. The injection of air propagates a heat wave through the formation from the injection well to the production well, and oil resulting from the cracking of kerogen in the oil shale is produced in the production well until same no longer becomes economically profitable, that is, until a high air-to-oil ratio occurs. Thereafter, a 0.001 pore volume of aqueous solution containing 1 wt. percent of Orvus K surface active agent is injected into the injection well, thereby invading the denuded fracture paths and formation surrounding the fractures. Thereafter, air is injected into the injection well to substantially completely foam the heretofore injected foaming solution. The injection pressure of the foaming gas is about 500 p.s.i. and injection is continued until gas production at the producing well is substantially reduced, indicating that the denuded fractures and formation adjacent the fractures have been substantially plugged with foam. Thereafter, the fracturing, heating, igniting and recovery processes are repeated as above described until further production of the formation becomes uneconomical. The above described process may be repeated cyclically as many times as production of the formation remains economically feasible.

The embodiment of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In a process for recovering oil from a subterranean formation penetrated by at least one injection well and one production well in which the formation is successively fractured to establish fluid communication between the injection well and the production well and subjected to a recovery operation conducted coextensive with the fracture to recover oil from the formation adjacent the fracture until said adjacent formation is substantially depleted of oil whereupon the fracturing and recovery steps are repeated, the improvement which comprises disposing a tenacious foam in the oil depleted fracture prior to initiating subsequent fracturing and recovering steps.

2. A method of recovering oil from oil-bearing tar sands, oil shale and like subterranean formations penetrated by at least one injection well and one production well, which comprises the following sequential steps:

- (a) injecting a fracturing fluid into said injection well at a pressure sufficiently high to form fractures between said injection and production wells;
- (b) conducting an oil recovery operation along said fracture to recover oil from the formation adjacent said fracture and to drive said oil to said production well;
- (c) terminating said oil recovery operation upon the formation adjacent said fracture becoming substantially depleted of oil;
- (d) thereafter disposing foam in the oil-denuded fractures so as to inhibit the flow of subsequently injected fracturing fluid through said oil-denuded fractures;
- (e) repeating steps (a) through (d) in sequence; and simultaneously therewith recovering oil from said production wells.

3. The method in accordance with claim 1 wherein said recovery operations are thermal and an in situ combustion front initiated at said injection well is propagated at least through a portion of said formation towards said production well.

4. The method in accordance with claim 1 wherein said foam is disposed in said hydrocarbon-denuded fracture paths by injecting into said injection well and into said formation a quantity of foaming agent capable of forming a tenacious foam under formation conditions when intimately contacted with a gas, and a sufficient amount of gas is subsequently injected to substantially completely foam said previously injected foaming agent.

5. The method in accordance with claim 4 wherein said foaming agent is injected in the form of an aqueous solu-

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tion containing about 0.001 to 10 wt. percent of foaming agent and said solution is disposed in said formation in an amount of about 0.001 to 0.2 pore volume, and the amount of said gas injected to foam said foaming agent is about 0.001 to 10 pore volumes, measured under reservoir conditions.

6. The method in accordance with claim 4 wherein said gas is selected from the group consisting of air, nitrogen, carbon dioxide and natural gas.

7. The method in accordance with claim 2 wherein said recovery operations comprise the in situ combustion of hydrocarbons in said tar sands and an in situ combustion front is propagated through and along said fractures moving recoverable hydrocarbons to said production well.

8. The method in accordance with claim 7 wherein air is injected to propagate said combustion front.

9. The method in accordance with claim 1 wherein said foam is disposed in said hydrocarbon denuded fractures by injecting into said injection well a quantity of foaming agent, capable of forming a tenacious foam under formation conditions when intimately contacted with gas, and subsequently injecting a sufficient amount of gas to substantially completely foam the previously injected quantity of foaming agent.

10. The method in accordance with claim 9 wherein

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said foaming agent is injected in the form of an aqueous solution containing about 0.001 to 10 wt. percent of said foaming agent and said solution is injected in an amount of about 0.001 to 0.2 pore volume and the amount of said gas injected to foam said foaming agent is about 0.001 to 10 pore volumes, measured under reservoir conditions.

11. The method in accordance with claim 10 wherein said gas injected to foam said foaming agent is air.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

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Donald C. Bond

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 7, line 17, for the claim reference numeral "1" read -- 2 --; column 8, line 3, for "injeted" read -- injected --.

Signed and sealed this 12th day of November 1968.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

EDWARD J. BRENNER

Commissioner of Patents