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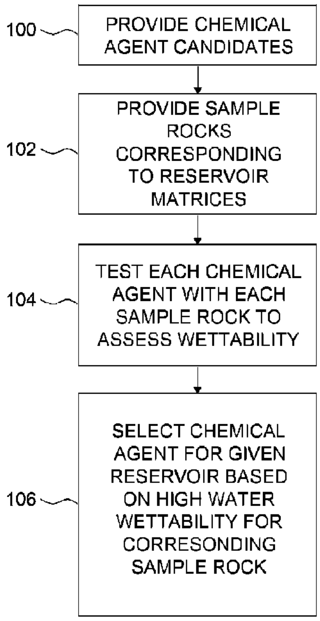
(72) **Inventeur/Inventor:**
GUERRERO, URIEL, CA
(73) **Propriétaire/Owner:**
SUNCOR ENERGY INC., CA
(74) **Agent:** ROBIC

(54) **Titre :** OPERATIONS DE DRAINAGE PAR GRAVITE AU MOYEN DE VAPEUR AVEC INJECTION D'AGENTS MOUILLANTS A L'EAU
(54) **Title:** SAGD OPERATIONS WITH INJECTION OF WATER WETTING AGENTS



(57) **Abrégé/Abstract:**
Steam-Assisted Gravity Drainage (SAGD) operations may involve injection of a water wetting agent selected for increasing the water wettability of the mineral surfaces that define micro-channels of the reservoir matrix. Whereas chemicals have been conventionally selected based on increasing the mobility of the oil phase and reducing the interfacial tension between the oil and the water phases, selection based on water wettability of the micro-channels in the reservoir matrix can facilitate increasing water mobility in the reservoir matrix and, in turn, the bitumen-in-water emulsification process can be improved. Chemical selection methods, hydrocarbon recovery processes including low-pressure SAGD, and various other techniques are described.

50 rue Victoria • Place du Portage 1 • Gatineau, (Québec) K1A 0C9 • www.opic.ic.gc.ca
50 Victoria Street • Place du Portage 1 • Gatineau, Quebec K1A 0C9 • www.cipo.ic.gc.ca

Canada

ABSTRACT

Steam-Assisted Gravity Drainage (SAGD) operations may involve injection of a water wetting agent selected for increasing the water wettability of the mineral surfaces that define micro-channels of the reservoir matrix. Whereas chemicals have been conventionally selected based on increasing the mobility of the oil phase and reducing the interfacial tension between the oil and the water phases, selection based on water wettability of the micro-channels in the reservoir matrix can facilitate increasing water mobility in the reservoir matrix and, in turn, the bitumen-in-water emulsification process can be improved. Chemical selection methods, hydrocarbon recovery processes including low-pressure SAGD, and various other techniques are described.

SAGD OPERATIONS WITH INJECTION OF WATER WETTING AGENTS

TECHNICAL FIELD

The techniques described herein generally relate to the field of in situ bitumen recovery.

BACKGROUND

The injection of chemical compounds into hydrocarbon-bearing reservoirs has been performed in an attempt to enhance some aspects of in situ hydrocarbon recovery. For some in situ hydrocarbon recovery processes, the selection of chemical compounds has largely centered on decreasing the interfacial tension between oil and water phases in the reservoir.

In one type of in situ recovery operation referred to as Steam-Assisted Gravity Drainage (SAGD), a well pair is provided in the reservoir. The well pair includes an injection well and an underlying production well that are vertically spaced apart from each other. Steam is injected via the injection well in order to mobilize the hydrocarbons which drain by gravity toward the production well. SAGD includes a startup phase in order to establish fluid communication between the injection and production wells. The startup phase can include injection of steam or circulation of hot water through one or both of the wells in order to mobilize the bitumen in between the well pair. After startup, SAGD typically then includes a ramp up phase, a normal operational phase, and a wind-down phase.

There are various challenges related to chemical selection and use for in situ hydrocarbons recovery operations such as SAGD.

SUMMARY

In some implementations, there is provided a process for producing bitumen from a bitumen-bearing reservoir, comprising:

> injecting an aqueous emulsification solution comprising a water wetting agent into the bitumen-bearing reservoir, wherein:

the bitumen-bearing reservoir comprises a matrix comprising solid mineral particles and micro-channels, the micro-channels having channel walls defined by mineral surfaces of the mineral particles;

the water wetting agent is selected for increasing the water wettability of the mineral surfaces; and

the aqueous emulsification solution flows through the micro-channels, thereby:

increasing the water wettability of the mineral surfaces;

increasing water mobility in the matrix; and

generating a bitumen-in-water emulsion; and

producing the bitumen-in-water emulsion from the bitumen-bearing reservoir.

In some implementations, the process further includes selecting the water wetting agent comprising:

measuring the ability of a chemical agent candidate to increase the water wettability of sample mineral surfaces corresponding to the mineral surfaces of the micro-channels; and

selecting the chemical agent candidate as the water wetting agent for use in the bitumen-bearing reservoir, if the chemical agent increased the water wettability of the sample mineral surfaces.

In some implementations, the sample mineral surfaces are comparable in chemical composition to the mineral surfaces of the micro-channels of the reservoir.

In some implementations, the sample mineral surfaces are obtained from core samples from the reservoir.

In some implementations, the sample mineral surfaces are synthetic. In some implementations, the synthetic sample mineral surfaces are selected to simulate the chemical composition of the mineral surfaces of the micro-channels of the reservoir.

In some implementations, the process also includes selecting the water wetting agent based solely on the ability of a candidate chemical agent to increase water wettability of mineral surfaces corresponding to the mineral surfaces of the micro-channels.

In some implementations, the chemical agent is selected from a plurality of candidate chemicals based on enabling a maximum water wetting affectivity.

In some implementations, the chemical agent is selected from a plurality of candidate chemicals based on enabling a maximum water wetting affectivity per cost ratio.

In some implementations, there is provided a method of selecting a chemical agent as a water wetting agent for use in SAGD bitumen recovery from a bitumen-bearing reservoir comprising a matrix comprising solid mineral particles and micro-channels, the micro-channels having channel walls defined by mineral surfaces of the mineral particles, the method comprising:

> measuring the ability of a chemical agent candidate to increase the water wettability of sample mineral surfaces corresponding to the mineral surfaces of the micro-channels; and
>
> selecting the chemical agent candidate as the water wetting agent for use in the bitumen-bearing reservoir, if the chemical agent increased the water wettability of the sample mineral surfaces.

In some implementations, the sample mineral surfaces are obtained from core samples from the reservoir.

In some implementations, the sample mineral surfaces are synthetic.

In some implementations, the synthetic sample mineral surfaces are selected to simulate the chemical composition of the mineral surfaces of the micro-channels of the reservoir.

In some implementations, selecting the chemical agent candidate as the water wetting agent is based solely on the ability of the candidate chemical agent to increase water wettability of the sample mineral surfaces.

In some implementations, the chemical agent is selected from a plurality of candidate chemicals based on enabling a maximum water wetting affectivity.

In some implementations, the chemical agent is selected from a plurality of candidate chemicals based on enabling a maximum water wetting affectivity per cost ratio.

In some implementations, there is provided a process for Steam-Assisted Gravity Drainage (SAGD) startup, comprising:

> injecting an aqueous emulsification solution comprising a water wetting agent into at least one of a SAGD injection well and a SAGD production well provided in a bitumen-bearing reservoir, in order to penetrate into an interwell region defined between the SAGD injection well and the SAGD production well, wherein:
>
> > the interwell region of the bitumen-bearing reservoir comprises a matrix comprising solid mineral particles and micro-channels, the micro-channels having channel walls defined by mineral surfaces of the mineral particles;
> >
> > the water wetting agent is selected for increasing the water wettability of the mineral surfaces; and
> >
> > the aqueous emulsification solution flows through the micro-channels, thereby:
> >
> > > increasing the water wettability of the mineral surfaces;
> > >
> > > increasing water mobility in the matrix; and
> > >
> > > generating a bitumen-in-water emulsion; and
>
> producing the bitumen-in-water emulsion from the bitumen-bearing reservoir, thereby removing bitumen from the micro-channels of the interwell region while increasing the water mobility between the SAGD injection well and the SAGD production well.

In some implementations, the aqueous emulsification solution is co-injected with steam.

In some implementations, the aqueous emulsification solution is injected alone in the form of a liquid.

In some implementations, the process further includes pre-heating the aqueous emulsification solution prior to injection.

In some implementations, the injection of the aqueous emulsification solution is performed via the injection well.

In some implementations, the process further includes providing a pressure sink in the production well to promote flow of the aqueous emulsification solution through the interwell region.

In some implementations, the process further includes providing a pressure sink in the production well to promote flow of the aqueous emulsification solution through the interwell region.

In some implementations, the process further includes isolating a section of the interwell region to provide an isolated section, and injecting the aqueous emulsification solution into the isolated section.

In some implementations, the process further includes identifying the section of the interwell region in accordance with permeability.

In some implementations, the process further includes injecting the aqueous emulsification solution in order to increase uniformity of permeability along a length of the interwell region.

In some implementations, there is provided a process for startup of an infill well located in between two adjacent well pairs in a Steam-Assisted Gravity Drainage (SAGD) operation, comprising:

> injecting an aqueous emulsification solution comprising a water wetting agent into the infill well, in order to penetrate into part of a pre-heated region defined between two adjacent well pairs, wherein:
>
> > the pre-heated region comprises a matrix comprising solid mineral particles and micro-channels, the micro-channels having channel walls defined by mineral surfaces of the mineral particles;

the water wetting agent is selected for increasing the water wettability of the mineral surfaces; and

the aqueous emulsification solution flows through the micro-channels, thereby:

increasing the water wettability of the mineral surfaces;

increasing water mobility in the matrix; and

generating a bitumen-in-water emulsion; and

producing the bitumen-in-water emulsion from the bitumen-bearing reservoir via the infill well, thereby removing bitumen from the micro-channels of the pre-heated region.

In some implementations, there is provided a process for startup of an step-out well located laterally spaced away from an adjacent well pair in a Steam-Assisted Gravity Drainage (SAGD) operation, comprising:

injecting an aqueous emulsification solution comprising a water wetting agent into the step-out well, in order to penetrate into part of a pre-heated region defined around the step-out well, wherein:

the pre-heated region comprises a matrix comprising solid mineral particles and micro-channels, the micro-channels having channel walls defined by mineral surfaces of the mineral particles;

the water wetting agent is selected for increasing the water wettability of the mineral surfaces; and

the aqueous emulsification solution flows through the micro-channels, thereby:

increasing the water wettability of the mineral surfaces;

increasing water mobility in the matrix; and

generating a bitumen-in-water emulsion; and producing the bitumen-in-water emulsion via the step-out well, thereby removing bitumen from the micro-channels of the pre-heated region.

In some implementations, there is provided a process for Steam-Assisted Gravity Drainage (SAGD) startup, comprising:

injecting into an interwell region defined between a SAGD injection well and a SAGD production well, a surfactant-generating agent that converts native compounds present in the reservoir into natural surfactants to increase the water wettability of the region of the reservoir; and

injecting a synthetic surfactant into the region to further increase the water wettability of the region of the reservoir;

generating a bitumen-in-water emulsion in the interwell region; and

producing the bitumen-in-water emulsion from the bitumen-bearing reservoir.

In some implementations, the surfactant-generating agent includes an alkali compound. The alkali compound may injected within an aqueous solution. The alkali compound may be co-injected steam.

In some implementations, the process also includes selecting the surfactant-generating agent based solely on generating natural surfactants having the ability to increase water wettability of sample mineral surfaces corresponding to mineral surfaces of micro-channels of the reservoir.

In some implementations, the process also includes selecting the surfactant-generating agent based on enabling a maximum water wetting affectivity of the natural surfactants.

In some implementations, the process also includes selecting the surfactant-generating agent based on enabling a maximum water wetting affectivity per cost ratio of the natural surfactants.

In some implementations, the process also includes selecting the synthetic surfactant based solely on ability to increase water wettability of sample mineral surfaces corresponding to mineral surfaces of micro-channels of the reservoir.

In some implementations, the process also includes selecting the synthetic surfactant based on enabling a maximum water wetting affectivity.

In some implementations, the process also includes selecting the synthetic surfactant based on enabling a maximum water wetting affectivity per cost ratio.

In some implementations, the process also includes injection of the surfactant-generating agent is ceased prior to commencing injection of the synthetic surfactant.

In some implementations, the process is performed during SAGD startup to achieve fluid communication between the SAGD injection well and a SAGD production well.

In some implementations, the process includes not soaking the region after injection of the surfactant-generating agent or after injection of the synthetic surfactant.

In some implementations, injection of the surfactant-generating agent and the synthetic surfactant are each performed continuously through a SAGD injection well. The process may also include producing a bitumen-in-water emulsion via an underlying SAGD production well.

In some implementations, there is provided a process for Steam-Assisted Gravity Drainage (SAGD) startup, comprising:

> injecting via a SAGD injection well an aqueous emulsification solution comprising a water wetting agent, into an interwell region defined between the SAGD injection well and a SAGD production well, to generate a bitumen-in-water emulsion in the interwell region;
>
> producing the bitumen-in-water emulsion via the SAGD production well; and
>
> providing a residence time of the aqueous emulsification solution in the interwell region to promote formation of the bitumen-in-water emulsion while inhibiting formation of a water-in-bitumen emulsion.

It should be noted that one or more features of the processes and methods described or illustrated herein may be used in connection with other processes and methods described herein. For example, the water wetting chemical selection method, and various optional features thereof, may be used in combination with some of the SAGD startup and/or hydrocarbon recovery processes described herein. In addition, certain features that are described herein with respect to SAGD startup operations, may also be adapted and used in normal ramped-up SAGD operations and/or other hydrocarbon recovery methods.

BREIF DESCRIPTION OF THE DRAWINGS

Figs 1a are 1b are cross-sectional view schematics of part of a matrix of a bitumen-bearing reservoir.

Fig 2 is a front cross-sectional view schematic of a well pair.

Fig 3 is a top side perspective view schematic of a well pair with a process flow illustration of pumps, lines and heat exchangers.

Fig 4 is a side cross-sectional view schematic of a well pair.

Fig 5 is a close-up front cross-sectional view schematic of parts of a well pair and a matrix of a bitumen-bearing reservoir.

Fig 6 is a front cross-sectional view schematic of a well pair.

Fig 7 is a front cross-sectional view schematic of a Steam-Assisted Gravity Drainage (SAGD) recovery operation.

Fig 8 is a front cross-sectional view schematic of a SAGD recovery operation.

Figs 9a and 9b are cross-sectional view schematics of part of a micro-channel of a bitumen-bearing reservoir.

Figs 10a to 10b are cross-sectional view schematics of part of a micro-channel of a bitumen-bearing reservoir.

Fig 11 is a schematic of matching candidate chemical agents to sample rocks.

Fig 12 is a process flow diagram.

DETAILED DESCRIPTION

Various techniques are described for enhancing the micro-channel water wettability in a bitumen-bearing reservoir by injecting an aqueous emulsification solution including a water wetting agent selected to increase the water wettability of mineral surfaces that form part of the micro-channels. Enhancing the water wettability facilitates the production of a bitumen-in-water emulsion as the aqueous emulsification solution flows through the micro-channels, removing bitumen from the micro-channels and increasing water mobility in the micro-channels of the reservoir matrix. Aqueous emulsification solutions may be injected in the context of Steam-Assisted Gravity Drainage (SAGD) startup operations, during normal operation of SAGD processes, during SAGD wind-down and/or during other stages of SAGD operations.

Some techniques include the selection of a chemical agent for injection into a bitumen-bearing reservoir for enhancing SAGD operations, based on the chemical agent's water wetting properties for the mineral surfaces of the bitumen-bearing reservoir. The selection may be based on a maximum water wetting affectivity or a maximum ratio of water wetting affectivity per cost of the chemical agent. The "affectivity" may be considered to be the time needed to achieve a certain result; the "water wetting affectivity" may be the time to achieve a given degree of water wetting of the mineral surfaces. The selection of a given chemical agent may also be based on the chemical agent's water wetting properties for particular phases of the SAGD operation, such as startup phase. Thus, one water wetting agent may be selected for maximizing water wetting during startup phase and another water wetting agent may be selected for maximizing water wetting during normal operation phase, for example.

In the context of the present description, "water wettability" refers to the tendency of water to adhere to solid mineral surfaces in the presence of an immiscible hydrocarbon fluid. Water wettability may be defined by the contact angle of water with the solid mineral surface.

Conventional approaches for enhancing in situ recovery operations have treated bitumen-containing reservoirs with the focus of increasing the mobility of the oil phase and reducing the interfacial tension between the oil and the water phases of the produced emulsion. However, by increasing the water wettability of the micro-channels in the reservoir matrix along with injecting an aqueous phase emulsification solution, the water mobility in the reservoir matrix can be increased and, in turn, the bitumen-in-water emulsification process can be improved.

The techniques for enhancing water wettability may be used in a variety of scenarios for in situ recovery operations. For example, some of the techniques may be used for enhancing a SAGD startup operation.

Injection of water wetting agent through micro-channels

Referring to Fig 1a, in some implementations the techniques can be applied to a bitumen-bearing reservoir that includes a matrix 10 including solid mineral particles 12 and micro-channels 14. The micro-channels 14 have channel walls defined by mineral surfaces 16 of the mineral particles 12. The micro-channels 14 are also partially occupied with free water native to the reservoir matrix.

Now referring to Fig 1b, an aqueous emulsification solution 20 including a water wetting agent 22 is injected into the reservoir so as to flow through the micro-channels 14. As the aqueous emulsification solution 20 flows through the micro-channels 14, the water wetting agent 22 contacts the mineral surfaces 16 and enables hydrophilic surface modification, thereby forming hydrophilically modified mineral surfaces 24 effectively increasing the water wettability of the mineral surfaces. The hydrophilically modified mineral surfaces 24 are in contact with adhered surface water 26. The flow of the aqueous emulsification solution 20 also forms a bitumen-in-water emulsion 28 including bitumen droplets and a continuous water phase. The bitumen droplets in the bitumen-in-water emulsion 28 may include bitumen that was present as droplets in the micro-channels 14 as well as bitumen that was previously bound to mineral surfaces under bitumen-wet conditions.

Referring to Figs 9a and 9b, some of the micro-channels 14 may be predominantly water wet at the outset of the process with only some oil-wet areas. The injection of the water wetting agent enables formation of the hydrophilically modified mineral surfaces which promote detachment of bitumen from bitumen-wet surfaces.

Referring to Figs 10a to 10e, some of the micro-channels 14 may be predominantly bitumen-wet at the outset of the process with only some water-wet areas. The injection of the water wetting agent enables formation of the hydrophilically modified mineral surfaces which promotes modified contact angles between the mineral surfaces and the liquid phases (see Figs 10b and 10c), followed by detachment of bitumen from bitumen-wet surfaces (see Figs 10d and 10e).

The matrix of the bitumen-bearing reservoir may have an initial permeability or water mobility facilitating injection of the aqueous emulsification solution. For example, the initial permeability of the matrix may be at least 10 millidarcies (md) to enable initial injection. In some scenarios, the initial permeability of the matrix may be at least 20 md, 50 md, 100 md, or 500 md.

In some implementations, the aqueous emulsification solution is provided as a liquid in a tank at the surface, and is pumped through one or more injection wells of the SAGD operation. The aqueous emulsification solution may be injected alone as a liquid, or co-injected with steam. For example, in SAGD startup implementations, the aqueous emulsification solution may be injected alone, while in ramped-up SAGD operations the aqueous emulsification solution may be injected along with the high temperature steam. The injection pressure may depend on the stage of SAGD. In SAGD startup, the injection pressure may be below the fracture pressure of the reservoir region surrounding the SAGD well pair, while in ramped-up SAGD operations co-injection with steam involves the given steam pressure conditions.

SAGD startup implementations

Referring to Figs 2 to 5, in some implementations, a SAGD well pair may be provided in the reservoir. The SAGD well pair includes an injection well 29 overlying a production well 30 separated by an interwell region 32. SAGD startup may include injecting the aqueous emulsification solution including the water wetting agent into the SAGD injection well 29 and/or the SAGD production well 30 provided in the bitumen-bearing reservoir in order to penetrate into the interwell region 32. The interwell region 32 may include a matrix as described above and illustrated in Figs 1a and 1b. The aqueous emulsification solution forms a bitumen-in-water emulsion, removing bitumen from the channel walls of the micro-channels of the interwell region and increasing water mobility in the interwell region. Various implementations and scenarios may be used for SAGD startup with enhanced water wetting of the micro-channels, as will be further described below.

Targeted injection along length of interwell region

Referring to Figs 3 and 4, in some scenarios the injection of the aqueous emulsification solution may be performed into isolated areas along the length interwell region 32 based on different properties, such as water permeability, along interwell region 32. The interwell region 32 may extend about a kilometer in length and it may have relatively different water permeabilities along its length. The interwell region 32 may include low water permeability zones 34, medium water permeability zones 36 and/or high water permeability zones 38. The water permeabilities can be tested or estimated, and then the chemical injection can be adapted by isolating (e.g., with packers) certain zones having low permeability for early and/or extra chemical injection. Fig 4 illustrates isolating a medium permeability zone 36 with packers 40 in the injection well 29 in order to provide targeted injection of the aqueous emulsification solution into that zone 36, to improve conformance along the well and enhance balanced startup operations.

Staged addition of different chemicals

In some implementations, the process may include initially injecting a first chemical agent (e.g., an alkali compound that can convert in situ acids in the bitumen into native surfactants) followed by injection of a second chemical agent (e.g., a synthetic surfactant) to complete the emulsification cleaning of the interwell region 32. Staged chemical addition may provide the advantage of using native surfactants effectively at the beginning of the process and saving the expense of using large quantities of synthetic surfactants.

In some scenarios, the first chemical agent is a surfactant-generating agent that converts native compounds in the reservoir into natural surfactants to pre-treat the interwell region; and the subsequent chemical agent is a synthetic surfactant with high water wetting affectivity to further enhance the water wetting of the interwell region. Other compounds, such as hydrocarbon solvents or steam, may be injected before and/or after the surfactant-generating agent as well as before and/or after the synthetic surfactant.

In some implementations, the selection of the chemical agent selected for use at each stage is based on water wetting properties of the chemical agents. For example, if the ratio of water wetting affectivity per cost is used to determine the selection of the chemical agent, a lower cost agent that reacts with native acids to form surfactants in situ may be selected as a first agent for the first stage of the SAGD startup, while a higher cost synthetic surfactant may be selected as a second agent for the later stage of the SAGD startup operation. In this way, the overall startup phase may be divided into multiple stages for which different chemical agents are injected in accordance with an optimum water wetting per cost ratio. The SAGD startup phase may be divided into more than two stages.

Injection with pressure sink in production well

Referring to Fig 6, in some implementations the process includes injecting the aqueous emulsification solution through the injection well 29 only and the production well 30 is put on production mode, creating a pressure sink that draws the aqueous emulsification solution through the interwell region and into the production well 30. The pressure sink enabled flow can be facilitated by the water permeability in the interwell region and allows reduced consumption of the injected solution which permeates the area between the well pair rather than outward into other areas of the reservoir where it is not required for SAGD startup. Fig 6 illustrates a chemical-affected region 42 using the pressure sink technique.

In some implementations, various fluids may be injected into the interwell region using the pressure sink technique. The fluids may be aqueous solutions including one or more chemical agents for enhancing SAGD startup in various ways, such as increasing water wettability of the mineral surfaces.

Continuous flow through the interwell region

In some implementations, the aqueous emulsification solution is not permitted to soak within the interwell region but rather is continuously injected via the injection well and produced as a bitumen-in-water emulsion via the production well. The residence time of the aqueous emulsification solution in the interwell region can be selected to promote formation of the bitumen-in-water emulsion while avoiding formation of a water-in-bitumen emulsion.

In some implementations, the water mobility of the interwell region may be pre-determined and the injection conditions, such as pressure and flow rate, may be provided according to the water mobility.

Injection with sufficient temperature for emulsification

Referring to Fig 3, in some implementations, the injection of the aqueous emulsification solution 20 may be performed, while ensuring the temperature of the affected region of the reservoir is sufficient to heat the bitumen to enable increased emulsification. For example, the aqueous emulsification solution 20 may be pre-heated by one or more heat exchangers 44 above ground to produce a pre-heated aqueous emulsification solution 46, which is injected through the injection well 29. The heat exchangers 44 may be fed with steam, hot water, and/or a hot process fluid derived from the SAGD operation for pre-heating the solution 20. The pre-heated aqueous emulsification solution 46 may be at a temperature of at least about 50°C, for example, in order to facilitate emulsification of the bitumen. Sufficient heating lowers the viscosity of the bitumen in contact with the solution flowing through the micro-channels, facilitating bitumen droplets to be adsorbed into the flowing aqueous phase. In some implementations, the temperature may be provided to soften the bitumen and thus facilitate emulsification, while not so high as to mobilize the bitumen such that it would start to flow as a bulk fluid toward the production well 30 and/or promote formation of a water-in-bitumen emulsion. The reservoir temperature may be provided between about 50°C and about 80°C, for example, to increase the bitumen-in-water emulsification. Heating may be performed by pre-heating the injected aqueous emulsification solution, and/or by providing a separate source of heat by injection, circulation or electrical heating methods.

The aqueous emulsification solution may be formulated to have a desired concentration of the water wetting agent, according to the reservoir matrix chemistry, permeability, bitumen saturation, water saturation, operating parameters of the injection, among other factors. In some scenarios, the initial concentration of the water wetting agent is relatively high to promote a more rapid initial increase in water wettability and mobility, and then the concentration is decreased in a gradual or step-wise manner as the injection continues. The aqueous emulsification solution may be injected in accordance with various injection strategies. For example, the aqueous emulsification solution may be injected at an initial injection rate and the beginning of the startup phase, and then modified to a lower or higher injection rate as the startup phase progresses. For example, the process may include a first step using a relatively slow injection rate with a high concentration of water wetting agent, followed by a second step of using a higher injection rate with a lower concentration of water wetting agent. The concentration of the water wetting agent may be dictated on the basis of the cost of the chemicals, and batch injection may be advantageous for injecting different chemicals as the process evolves.

In some scenarios, the flow rate of injection via the SAGD injection well may be coordinated with the pressure sink provided in the SAGD production well. For example, high injection rates may be coordinated with a high pressure sink. At different stages of the startup phase, the injection rate and the pressure sink may also be coordinated so as to be offset; for instance, at the beginning of the startup phase one may provide a relatively high pressure sink and a relatively low injection flow rate, followed by a lower pressure sink and a higher injection flow rate at latter stages of the startup phase. A high initial pressure different between the injection and production wells may be advantageous to overcome lower initial water mobilities in the interwell region, for example, and once the mobility increases then lower pressure differential may be employed to save on pump energy. The injection and the pressure sink may also be provided in a gradually or step-wise increasing manner, a gradually or step-wise decreasing manner and/or a pulsed manner. In some scenarios, the flow of the aqueous emulsification solution may be provided in an alternating or cyclic manner, for instance by reversing the flow between the SAGD injection and production wells. Alternating flow can facilitate cleaning of micro-channels, and can also enable access of the aqueous emulsification solution to new or different micro-channels and retrieval of some of the aqueous emulsification solution that has been trapped in dead-end pores rather than micro-channels.

The amount of injected aqueous emulsification solution can also be provided in accordance with various factors. For example, the volume of injected aqueous emulsification solution may be based on a target volume of the interwell region or part of the interwell region. The volume of the aqueous emulsification solution may be based on water wetting affectivity of the water wetting agent, i.e., lower volumes for higher affectivity.

Infill well and step-out well startup implementations

Referring to Fig 7, in some implementations, the injection of the aqueous emulsification solution 20 may be performed through an infill well 48 and/or a step-out well 50. The infill well 48 may be a single well located in between two adjacent SAGD well pairs that previously operated to form SAGD steam chambers 52 extending upward into the reservoir. The SAGD steam chambers 52 may pre-heat an in-between region 54 located in between the two steam chambers 14 where the infill well 48 is provided. Operation of the infill well 48 may benefit from injecting the aqueous emulsification solution 20 through the infill well 48 into the surrounding pre-heated region 54 to increase water wettability in the region 54. Following injection of the aqueous emulsification solution 20, the infill well 48 may be put on production mode to produce the bitumen-in-water emulsion from the surrounding region. In some scenarios, the injection of the aqueous emulsification solution 20 may be performed once the surrounding region to be water wetted has reached a temperature sufficient to facilitate emulsification and prevent significant mobilization of the bitumen. The infill well may be a single well 48 as illustrated in Fig 7, or part of an infill well pair 56 as illustrated in Fig 8. In the case of the infill well pair 56, the SAGD startup methods described above may be employed.

Similar techniques to those describe above for infill wells may also be employed for step-out wells 50 located in a region 58 of the reservoir adjacent to one of the SAGD steam chambers 14. The step-out well may be a single well 50 as illustrated in Fig 7, or part of a step-out well pair 60 as illustrated in Fig 8. In the case of the step-out well pair 60, the SAGD startup methods described above may be employed.

Selection of water wetting agent

In some scenarios, the water wetting agent may be selected in accordance with certain methodologies. The methods for selecting a chemical agent as a water wetting agent for use in SAGD bitumen recovery may include measuring the ability of a candidate chemical agent to increase the water wettability of sample mineral surfaces corresponding to the mineral surfaces of the micro-channels; and then including or excluding the candidate chemical agent as a potential water wetting agent for use in the bitumen-bearing reservoir depending on the results. If the chemical agent increased the water wettability of the sample mineral surfaces, it may be retained for use in the given reservoir. In some scenarios, the method consists of measuring the ability of candidate chemical agents to increase the water wettability of sample mineral surfaces, without measuring other properties such as the impact on the interfacial tension between oil and water phases.

Conventionally, chemicals have been selected for use in SAGD methods based on reduction in interfacial tension between the oil and the water phases of the produced emulsion. However, the present methods select chemicals based on an increase in wall wettability, which has been found to be a more consistent predictive factor in the success of an injected chemical to improve recovery. The ability of a chemical agent to make the surface of the pore space more hydrophilic and more oleophobic can facilitate bitumen-in-water emulsion formation in situ, and thereby increase production rate. By testing the ability of a candidate chemical to alter the water wettability of mineral walls defining micro-channels and pore space, the improved selection of water wetting agents can result in improved production rates and increased economic performance. It has been observed that an increase in wall wettability is a more consistent predictive factor in the success of an injected chemical to improve recovery.

The step of measuring the water wettability may include determining impacts of the candidate chemical agent on the hydrophilic properties of mineral surfaces and/or on the roughness of mineral surfaces, both of which can affect water wettability. Chemical agents that increase the hydrophilic or oleophobic properties of mineral surfaces may be retained as potential water wetting agents. Chemical agents that maintain or increase the roughness of hydrophilic mineral surfaces may also be retained as potential water wetting agents. The impact of chemical agents on roughness may be tested in the laboratory as an approximation for reservoir behavior.

It is also noted that while the techniques described herein primarily concern generating bitumen-in-water emulsions, some alternative methods may be adapted for reservoirs where production of water-in-oil emulsions are desired, e.g., by selecting an oil wetting chemical to increase the preference of the micro-channels for oil.

In some scenarios, the water wetting agent is selected from a plurality of candidate chemical agents, each having a theoretical or determined oil-water interfacial tension effect, a theoretical or determined water wettability effect, and other physical or chemical properties. The plurality of candidate chemical agents may be subjected to laboratory wettability tests, including water wettability and/or oil wettability tests. The wettability tests may be conducted with respect to sample rock surfaces that correspond to a plurality of different reservoir minerals. For example, the reservoir minerals may include carbonate minerals, silicate minerals and/or clays, including various different sub-types of each. The sample rocks may be obtained from core samples from the given reservoir and/or from other sources in order to imitate certain reservoir minerals. In some scenarios, wettability can be determined using synthetic mineral surfaces and measuring the contact angle or leaching of a fluid from its surface when contacted by the chemical solution. Additionally, wettability tests such as the Amott index test can be done in core samples to determine wettability preference. The plurality of candidate chemical agents may be ranked for applicability to one or more given bitumen-bearing reservoir matrices.

In microfluidic environments, such as those found with the injection of fluids into a reservoir matrix having micro-channels, the wettability of the solid mineral surfaces is the controlling factor in emulsion formation.

Referring to Fig 12, the selection method may include the flowing steps:

> providing chemical agent candidates (step 100);
>
> providing sample rock candidates corresponding to different reservoir matrices (step 102);
>
> testing each chemical agent candidate with each sample rock candidate to assess water wettability (step 104); and
>
> selecting chemical agents for use as water wetting agents for given reservoir matrices based on high (e.g., highest) water wettability for the corresponding sample rock (step 106).

Referring to Fig 11, various chemical agent candidates (I to V) may be tested with various sample rock candidates (A to E) corresponding to different reservoir matrices, and the results may indicate that certain chemical agent candidates are not suitable for any of the reservoir matrices (e.g., II and V) while other chemical agent candidates are suitable for one of the reservoir matrices (e.g., IV) or more of the reservoir matrices (e.g., I and III). While five chemical agent candidates and five sample rock candidates are illustrated in the example of Fig 11, it should be understood that less or more of both sets of candidates may be tested with each other to identify and select suitable water wetting agents for use in corresponding reservoir matrices. In some scenarios, only the candidate with the maximum water wettability properties for the sample rock is selected for use as the water wetting agent in the corresponding reservoir matrix.

The candidate chemical agents may be of various different types. For example, the candidate chemicals may include alkali agents or natural or synthetic surfactants.

In some scenarios, the aqueous emulsification solution may be formulated to further include other chemical agents, which may be selected based on various factors, such as co-surfactant properties (e.g., alcohols), surfactant properties (e.g., reduction of interfacial oil-water tension), pH properties, viscosity properties, etc. Alternatively, the aqueous emulsification solution may consist essentially of water and the water wetting agent. The water in the aqueous emulsification solution may at least partly be derived from SAGD process water, oil sands extraction water, recycled oil sands tailings water, and/or fresh or treated water. Process waters may be pre-treated or selected so as to remove components that could precipitate or otherwise deactivate the water wetting agent.

Low pressure SAGD implementations

In some implementations, the injection of the aqueous emulsification solution is performed in the context of low pressure SAGD. Increased water wettability can lead to increased water mobility and, in turn, requires less pressure to move the bitumen-in-water emulsion through the micro-channels. Low pressure SAGD can be uneconomical in some cases due to the lower production rates, since at lower pressures the steam also has a lower temperature and thus the viscosity of the bitumen tends to be higher. Injecting the water wetting agents can enhance oil/water emulsification leading to lower emulsion viscosity and thus increasing production rates.

Various advantages of some implementations

In some implantations, increasing the water wettability of the micro-channels in the reservoir matrix can accelerate oil production rates, increasing the economic performance. In some scenarios, making the rock surfaces more oleophobic may increase the recovery factor by facilitating the production of oil. Faster production rates, potentially higher recovery, lower steam-to-oil ratios (SOR), lower temperatures for bitumen extraction, and production of bitumen previously believed to be non-economical for SAGD or too difficult to exploit (e.g., in shallow reserves), are also advantages of some implementations of the techniques described herein.

It should also be noted that the treatment of the reservoir matrix with the aqueous emulsification solution may be a first of multiple treatments. Alternatively, the reservoir matrix may have been previously conditioned with an additional pre-treatment method, for example to increase the initial water permeability to a desired level for injection of the aqueous emulsification solution. The treatment of the reservoir matrix with the aqueous emulsification solution may also be the first and only pre-treatment before a given in situ bitumen recovery operation is initiated.

It should also be noted that while various techniques are described herein relating to particular implementations, such as SAGD startup methods and low pressure SAGD, techniques could also be used in other implementations of in situ bitumen recovery methods. Various optional aspects and features of some implementations can thus be combined with one or more other optional aspects and features as illustrated or described herein.

CLAIMS

1. A process for producing bitumen from a bitumen-bearing reservoir, comprising:

   operating a steam-assisted gravity drainage (SAGD) well pair comprising a SAGD injection well and a SAGD production well in the bitumen-bearing reservoir under low-pressure SAGD conditions;

   injecting a water wetting agent into the bitumen-bearing reservoir to increase water wettability of mineral surfaces of solid mineral particles in the bitumen-bearing reservoir, and facilitate flow of bitumen-in-water emulsion through micro-channels defined by the solid mineral particles in the bitumen-bearing reservoir, such that lower pressure is required to displace the bitumen-in-water emulsion through the micro-channels compared to a corresponding process in which no water wetting agent is injected; and

   producing the bitumen-in-water emulsion via the SAGD production well.

2. The process of claim 1, wherein the water wetting agent is injected as part of an aqueous emulsification solution.

3. The process of claim 1 or 2, further comprising selecting the water wetting agent comprising:

   measuring the ability of a chemical agent candidate to increase the water wettability of sample mineral surfaces corresponding to the mineral surfaces of the micro-channels; and

   selecting the chemical agent candidate as the water wetting agent for use in the bitumen-bearing reservoir, if the chemical agent increased the water wettability of the sample mineral surfaces.

4. The process of claim 3, wherein the sample mineral surfaces are comparable in chemical composition to the mineral surfaces of the micro-channels of the reservoir.

5. The process of claim 4, wherein the sample mineral surfaces are obtained from core samples from the reservoir.

6. The process of claim 4, wherein the sample mineral surfaces are synthetic.

7. The process of claim 6, wherein the synthetic sample mineral surfaces are selected to simulate the chemical composition of the mineral surfaces of the micro-channels of the reservoir.

8. The process of any one of claims 3 to 7, further comprising selecting the water wetting agent based solely on the ability of the candidate chemical agent to increase water wettability of mineral surfaces corresponding to the mineral surfaces of the micro-channels.

9. The process of any one of claims 3 to 8, wherein the chemical agent is selected from a plurality of candidate chemicals based on enabling a maximum water wetting affectivity.

10. The process of any one of claims 3 to 9, wherein the chemical agent is selected from a plurality of candidate chemicals based on enabling a maximum water wetting affectivity per cost ratio.

11. The process of any one of claims 1 to 10, wherein the water wetting agent is injected so as to increase oil/water emulsification.

12. The process of any one of claims 1 to 11, wherein the water wetting agent is injected so as to reduce viscosity of the bitumen-in-water emulsion.

13. The process of any one of claims 1 to 12, wherein the water wetting agent is injected so as to increase production rates of the bitumen-in-water emulsion via the SAGD production well.

14. The process of any one of claims 1 to 13, wherein the water wetting agent is co-injected with steam.

15. A method for reducing operating pressure of a steam-assisted gravity drainage (SAGD) well pair located in a bitumen-bearing reservoir, comprising injecting a water wetting agent into the bitumen-bearing reservoir to increase water wettability of mineral surfaces of solid mineral particles in the bitumen-bearing reservoir and thereby

reducing pressure required to induce flow of a bitumen-in-water emulsion through micro-channels defined by the solid mineral particles in the bitumen-bearing reservoir.

16. The method of claim 15, wherein the water wetting agent is injected as part of an aqueous emulsification solution.

17. The method of claim 15 or 16, further comprising selecting the water wetting agent comprising:

    measuring the ability of a chemical agent candidate to increase the water wettability of sample mineral surfaces corresponding to the mineral surfaces of the micro-channels; and

    selecting the chemical agent candidate as the water wetting agent for use in the bitumen-bearing reservoir, if the chemical agent increased the water wettability of the sample mineral surfaces.

18. The method of claim 17, wherein the sample mineral surfaces are comparable in chemical composition to the mineral surfaces of the micro-channels of the reservoir.

19. The method of claim 18, wherein the sample mineral surfaces are obtained from core samples from the reservoir.

20. The method of claim 18, wherein the sample mineral surfaces are synthetic.

21. The method of claim 20, wherein the synthetic sample mineral surfaces are selected to simulate the chemical composition of the mineral surfaces of the micro-channels of the reservoir.

22. The method of any one of claims 17 to 21, further comprising selecting the water wetting agent based solely on the ability of the candidate chemical agent to increase water wettability of mineral surfaces corresponding to the mineral surfaces of the micro-channels.

23. The method of any one of claims 17 to 22, wherein the chemical agent is selected from a plurality of candidate chemicals based on enabling a maximum water wetting affectivity.

24. The method of any one of claims 17 to 23, wherein the chemical agent is selected from a plurality of candidate chemicals based on enabling a maximum water wetting affectivity per cost ratio.

25. The method of any one of claims 15 to 24, wherein the water wetting agent is injected so as to increase oil/water emulsification.

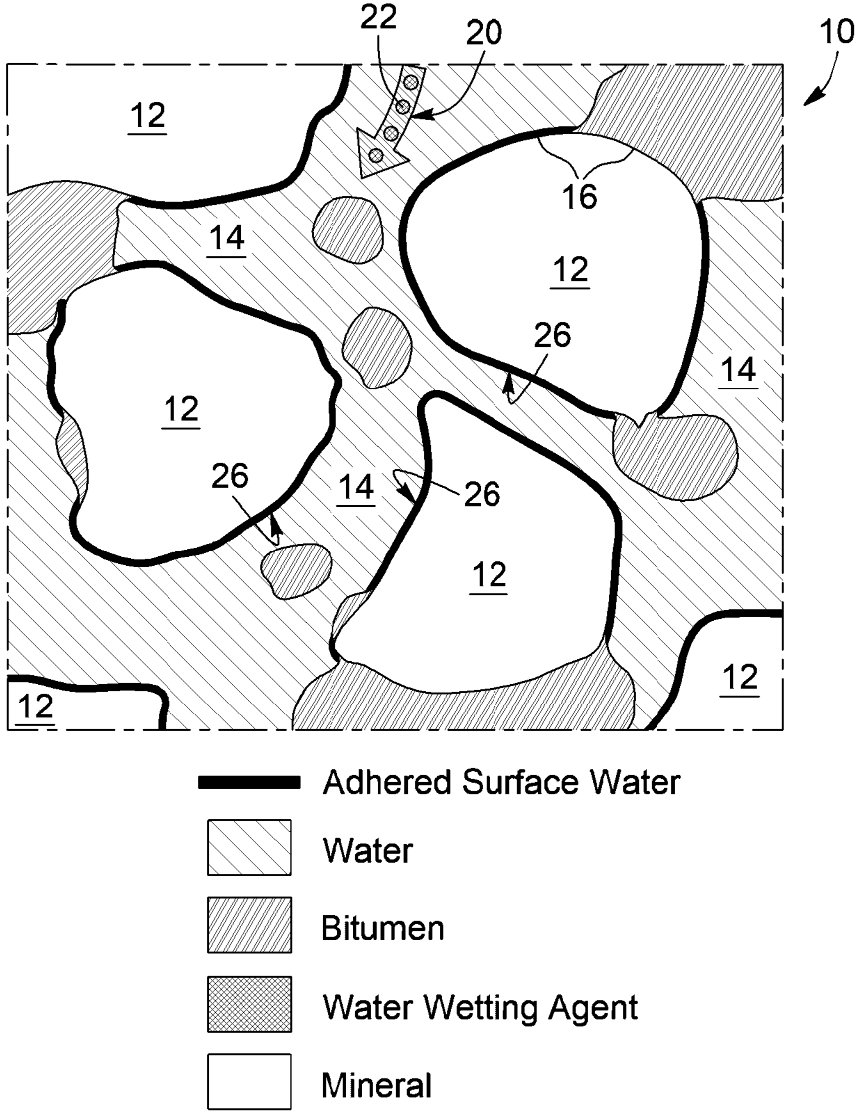
26. The method of any one of claims 15 to 25, wherein the water wetting agent is injected so as to reduce viscosity of the bitumen-in-water emulsion.

27. The method of any one of claims 15 to 26, wherein the water wetting agent is injected so as to increase production rates of the bitumen-in-water emulsion via the SAGD production well.

28. The method of any one of claims 15 to 27 wherein the water wetting agent is co-injected with steam.

29. The method of any one of claims 15 to 28, wherein the bitumen-bearing reservoir comprises a shallow reserve in which the SAGD well pair is located.

FIG. 1a


22
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16
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26
14
26
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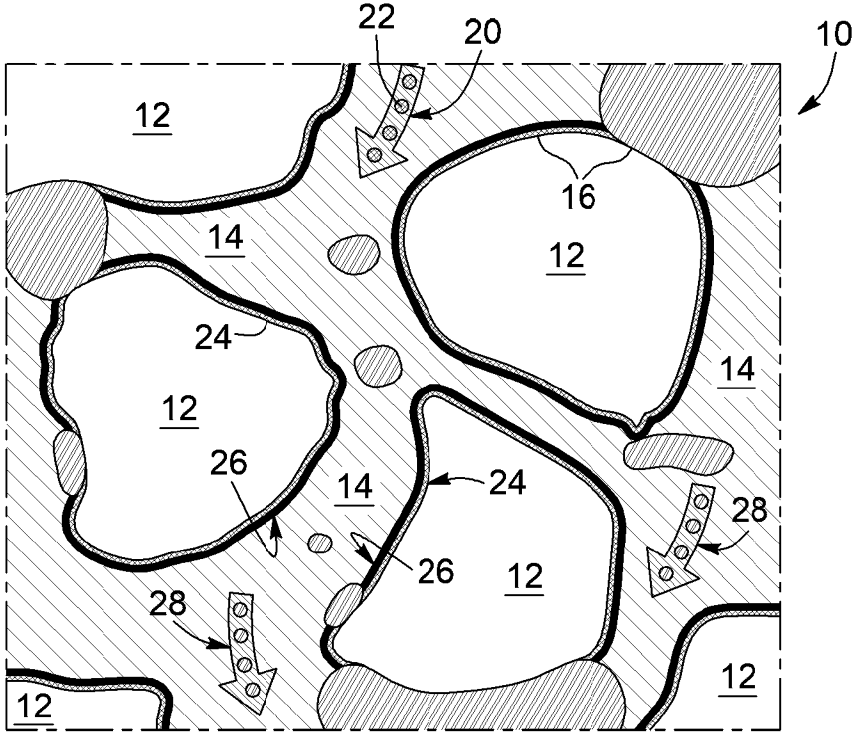
12
12
Adhered Surface Water
Water
Bitumen
Water Wetting Agent
Mineral

FIG. 1b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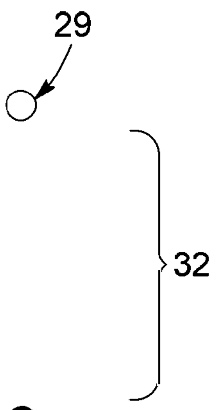


FIG. 2

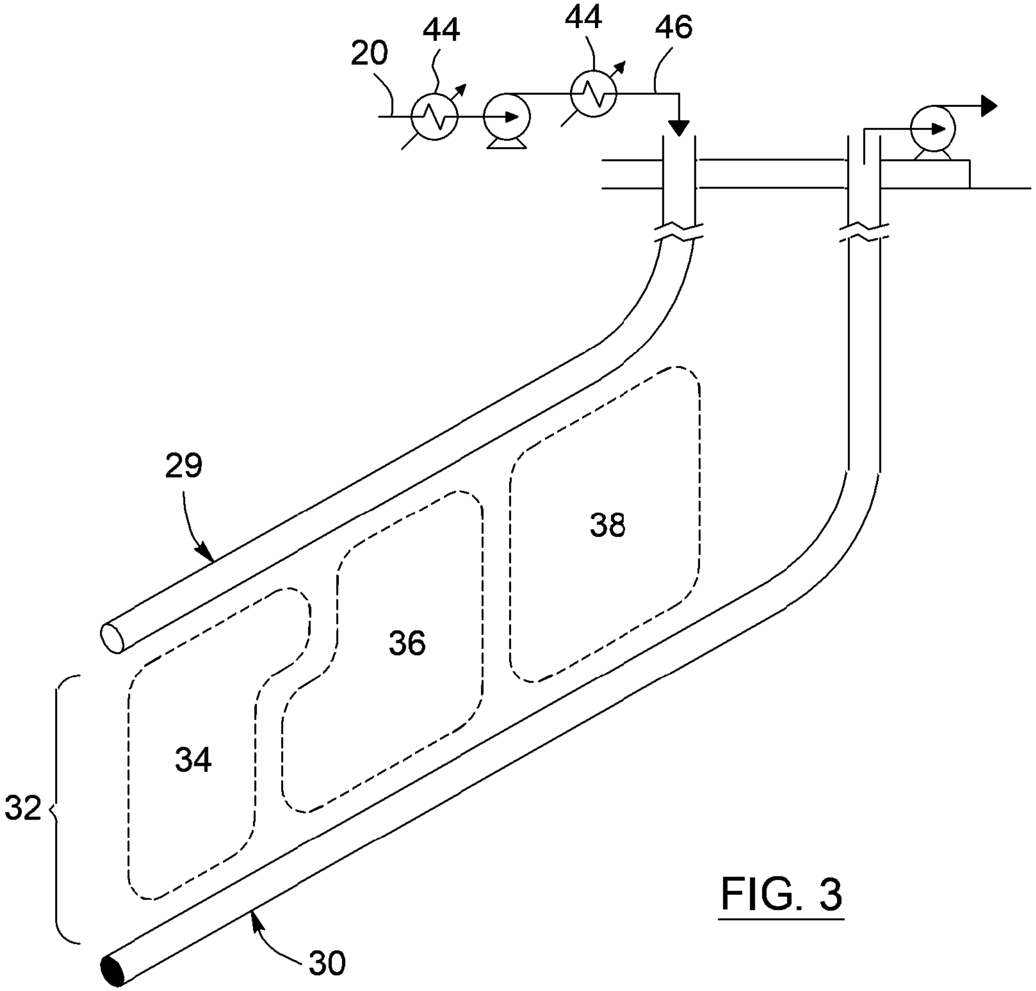


FIG. 3

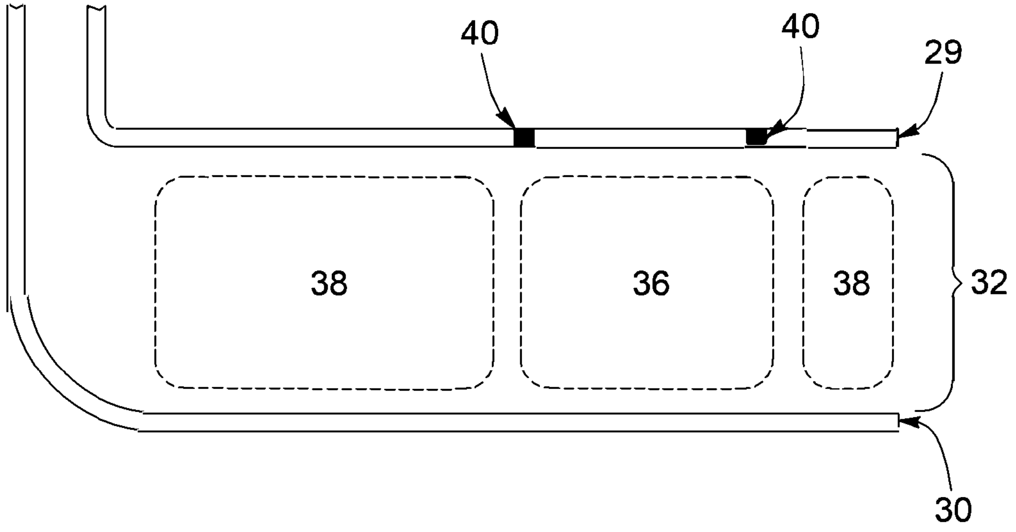


FIG. 4

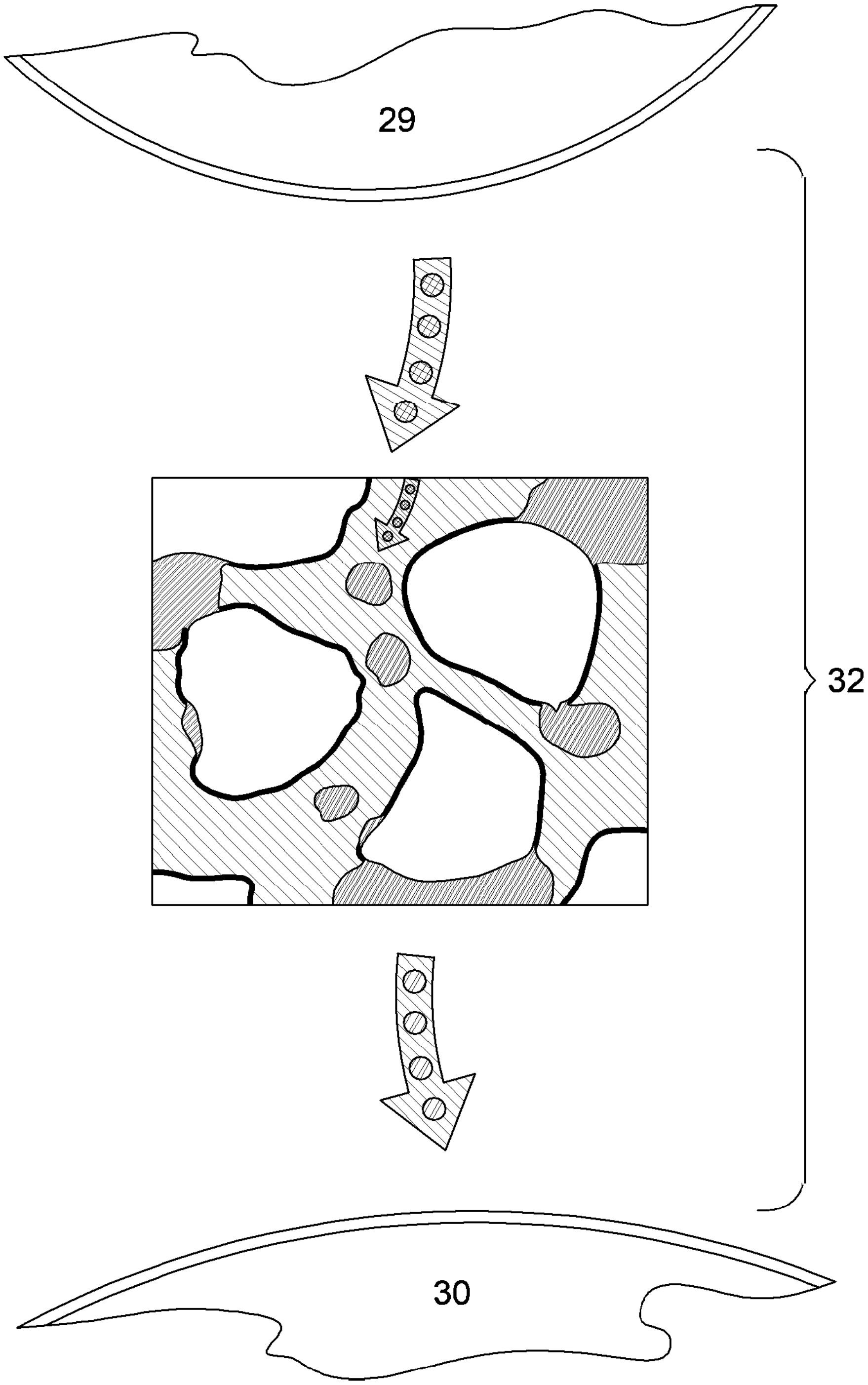


FIG. 5

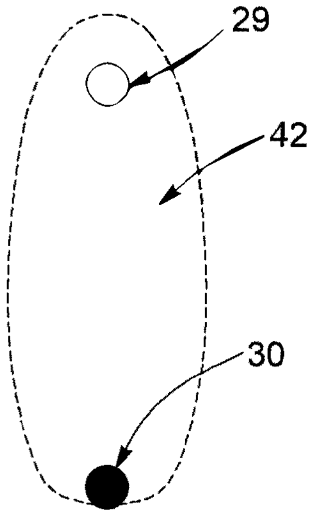


FIG. 6

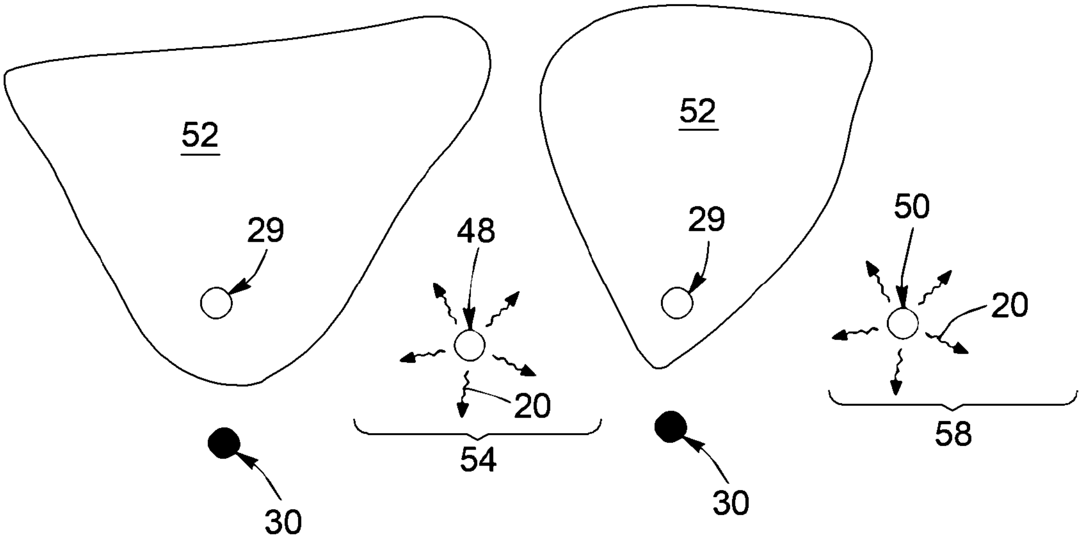


FIG. 7

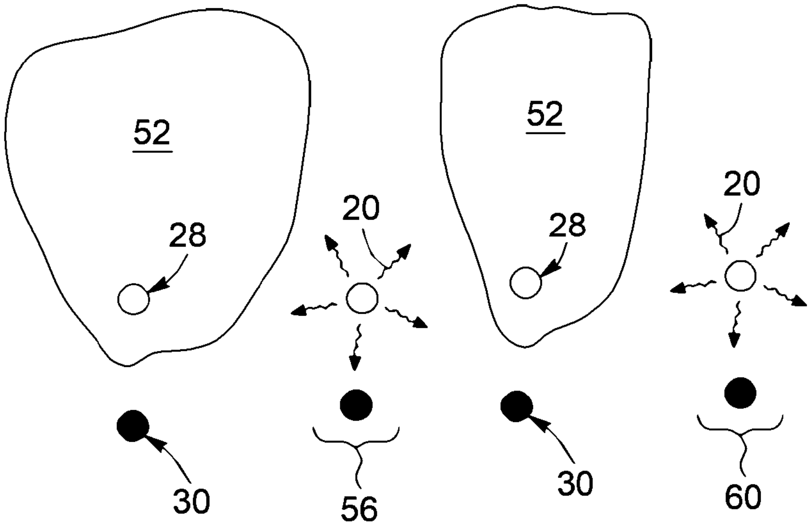


FIG. 8

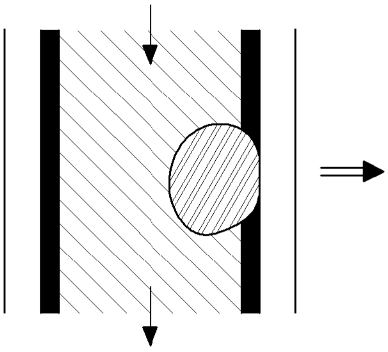


FIG. 9a

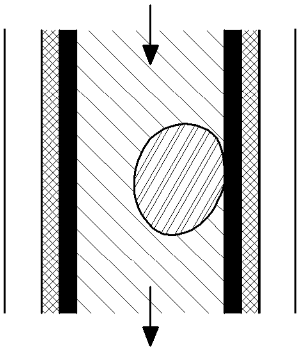


FIG. 9b

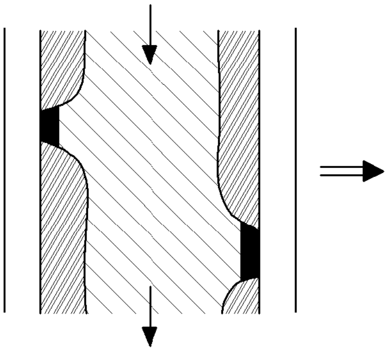


FIG. 10a

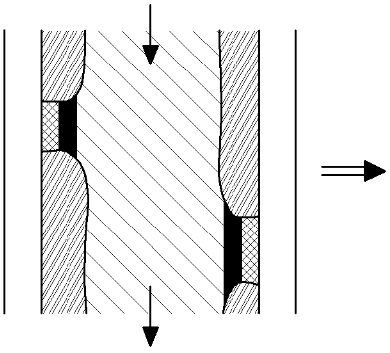


FIG. 10b

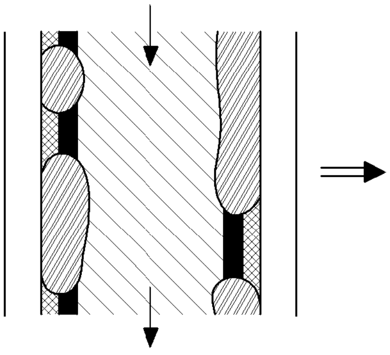


FIG. 10c

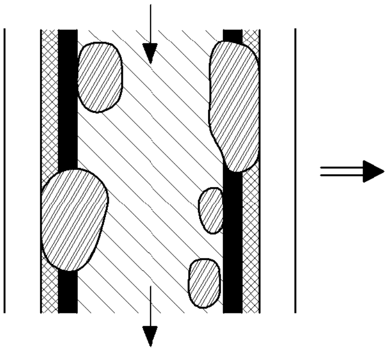


FIG. 10d

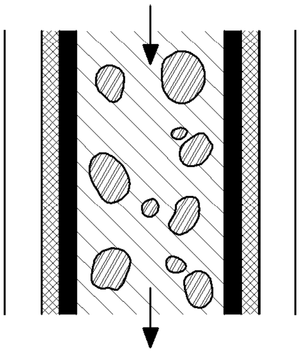


FIG. 10e

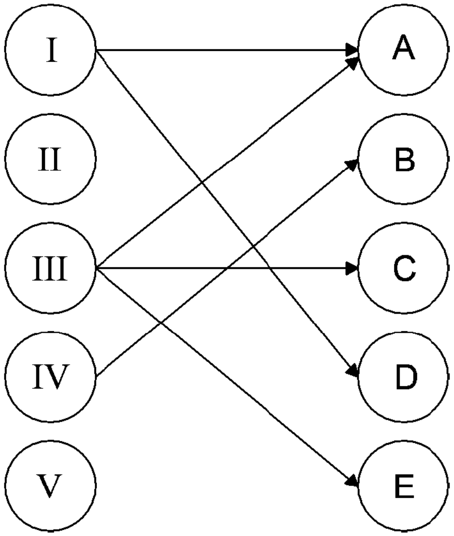
▬ Adhered Surface Water

▧ Water

▨ Bitumen

▩ Water Wetting Agent

☐ Mineral


I
II
III
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V
A
B
C
D
E

FIG. 11

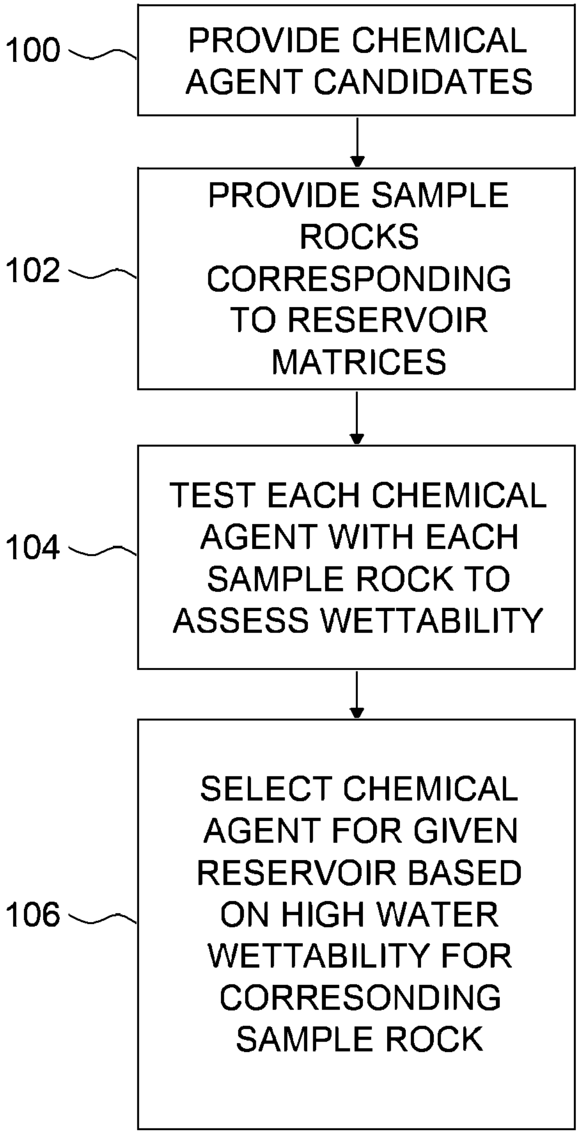
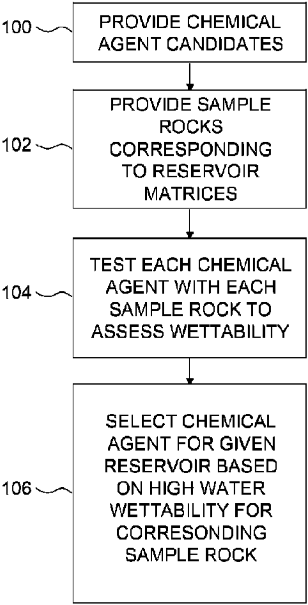

100
PROVIDE CHEMICAL AGENT CANDIDATES
102
PROVIDE SAMPLE ROCKS CORRESPONDING TO RESERVOIR MATRICES
104
TEST EACH CHEMICAL AGENT WITH EACH SAMPLE ROCK TO ASSESS WETTABILITY
106
SELECT CHEMICAL AGENT FOR GIVEN RESERVOIR BASED ON HIGH WATER WETTABILITY FOR CORRESONDING SAMPLE ROCK

FIG. 12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PROVIDE CHEMICAL AGENT CANDIDATES
102
PROVIDE SAMPLE ROCKS CORRESPONDING TO RESERVOIR MATRICES
104
TEST EACH CHEMICAL AGENT WITH EACH SAMPLE ROCK TO ASSESS WETTABILITY
106
SELECT CHEMICAL AGENT FOR GIVEN RESERVOIR BASED ON HIGH WATER WETTABILITY FOR CORRESONDING SAMPLE ROCK