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(54) Title: SYSTEM AND PROCESS FOR RECOVERING BITUMEN FROM OIL SANDS

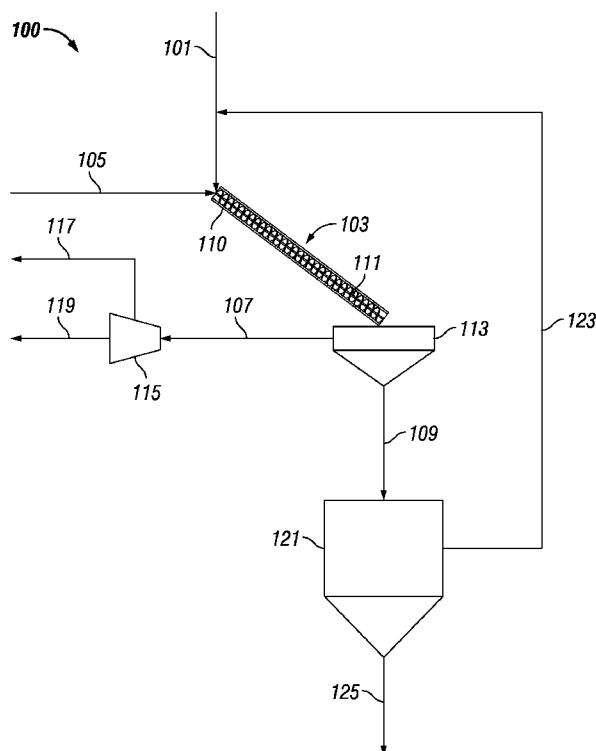


FIG. 1

(57) Abstract: A system and a process for recovering bitumen from oil sands are provided. The system includes a bitumen solvent comprised of at least 75 mol% dimethyl sulfide that is first contact miscible with bitumen, an oil sands material comprised of bitumen, and a contacting apparatus configured to receive the bitumen solvent and the oil sands material and to contact and mix the bitumen solvent and oil sands material to form a bitumen-containing extract and a bitumen-depleted oil sands material. The process includes the steps of providing the oil sands material; contacting the oil sands material with the solvent comprised of at least 75 mol% dimethyl sulfide to form the bitumen-containing extract and the bitumen-depleted oil sands material; and separating the bitumen-containing extract from the bitumen-depleted oil sands material.



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SYSTEM AND PROCESS FOR RECOVERING BITUMEN FROM OIL SANDS

Field of the Invention

5 The present invention relates to a system and a process for recovering bitumen from oil sands.

Background of the Invention

10 Some of the world's largest deposits of oil are located in oil sands formations. Oil sands are comprised of a matrix of loosely consolidated or unconsolidated inorganic solid particulate materials such as sand and clay permeated with oil and water. The oil present in a large proportion of oil sands is viscous bitumen or heavy oil typically having an API gravity of 15 or less.

15 Bitumen present in oil sands located within 100 meters of the earth's surface is typically recovered and produced by surface mining the oil sands and then extracting the bitumen from the mined oil sands ore. The oil sands are mined by digging the oil sands from the earth, then transporting the unearthed oil sands ore to a bitumen extraction facility. Bitumen is extracted from the oil sands ore in the extraction facility by crushing the oil sands ore into particulates, mixing the crushed oil sands with an extractant, capturing the bitumen in the extractant, and separating the resulting bitumen-containing extract from the inorganic
20 solid particulates of the oil sand.

The most common method of extracting bitumen from mined oil sands ore involves separating the bitumen from inorganic solid particulate material in the oil sands using hot water containing an alkali as the extractant. Hot water, caustic soda, and the mined oil sands ore are mixed into a slurry, and the bitumen is allowed to float to the surface of the slurry
25 where it forms a froth. The bitumen froth is then separated from the inorganic solid particulate material. Clean oil is produced from the separated bitumen froth by treating the froth to remove water and mineral fines. Water is separated and recovered from the spent inorganic solid particulate material from which the bitumen froth is separated, and is recycled for reuse as an extractant.

30 Water management, however, has become a significant problem resulting from the use of water as an oil sands extractant. Water separated from the bulk of the spent inorganic solid particulate oil sand materials contains substantial quantities of mineral fines that are not

separated from the water with the bulk of the inorganic particulates. These fines are suspended in the water, and are not easily separated from the water by conventional mechanical solid/liquid separation techniques such as filtration and centrifugation. Therefore, the mineral fines are separated from the water by placing the water containing the mineral fines in tailings ponds to allow the mineral fines to settle out from the water. Such tailings ponds are undesirable, and have become a significant environmental issue.

Other oil sands extraction processes have been developed utilizing an organic solvent containing one or more organic compounds as an extractant. The solvent and oil sands extraction conditions, e.g. temperature and pressure, may be selected to dissolve and extract non-asphaltenic hydrocarbons from the oil sands either with or without a portion of asphaltenic hydrocarbons. One solvent extraction process provides for extracting crushed oil sands ore with heptanes, separating coarse sand from the solvent and extracted bitumen by hydrocyclones, centrifuges, and/or belt filters, then separating mineral fines from the solvent/bitumen mixture by adding pentane to the extraction mixture to induce pentane deasphalting in which C₅ insoluble asphaltenes are flocculated from the heptane/bitumen extraction mixture to capture the fines and separating the flocculated asphaltenes containing the captured fines from the extraction mixture. (*See, A Solvent Extraction Process for Tar Sand*, R. Graham, J. Helstrom, and R. Mehlberg, 1987 Eastern Oil Shale Symposium, Commonwealth of Kentucky, Kentucky Energy Cabinet, pp. 93-99 (1987)). The non-asphaltenic hydrocarbons may then be recovered from the extraction mixture. The recovered hydrocarbons account for approximately 73 wt.% of the bitumen.

WO2011/021092 describes a process of separating bitumen from an oil sands material by contacting the oil sands material with at least one aliphatic hydrocarbon solvent selected from pentane, hexanes, heptanes, and any mixture thereof to form a mass, agglomerating at least a portion of fines and coarse inorganic material, and separating the agglomerated inorganic material and coarse inorganic material to leave a slurry of organic material and non-agglomerated fines. The aliphatic solvent is selected to dissolve non-asphaltenic bitumen material while inhibiting the complete dissolution of asphaltenic material into the solvent, where the non-dissolved asphaltenic material may be used to help agglomerate the fines. After removal of the coarse inorganic material and the agglomerated asphaltenes and fines, the organic material in the slurry may be separated from the non-agglomerated fines by 1) dissolving asphaltenes in the slurry using heat and pressure to reduce the viscosity of the

solution, separating the non-agglomerated fines (e.g. by centrifugation) from the reduced viscosity solution, subsequently re-dispersing the insoluble asphaltenes in the slurry, and then separating a bitumen liquor from dispersed, non-dissolved asphaltenes; or 2) separating the non-dissolved asphaltenes and fines associated therewith from the slurry to form a bitumen liquor, where the separated asphaltenes may be separated from the separated fines by heating and separation of the fines from the asphaltenes (e.g. by centrifuge). The products of the process are a bitumen liquor from which asphaltenes and inorganic materials have been removed and asphaltenes as separate product streams.

US Patent Application Publication No. 2010/0130386 describes a process of extracting bitumen from oil sands with a solvent that increases the rate of recovery of bitumen from the oil sands relative to conventional hydrocarbon solvents such as pentane using a solvent formed of a combination of components, where the solvent has a Hansen hydrogen bonding parameter of 0.3 to 1.7. The combination of components includes a polar component that comprises a compound comprising a non-terminal carbonyl group and a non-polar component that comprises a compound that is a substantially aliphatic substantially non-halogenated alkane. The polar component of the solvent increases the rate of penetration of the solvent into the oil sands, while the non-polar component dissolves non-asphaltenic hydrocarbons in the oil sands. The polar solvent also likely dissolves a portion of the asphaltenic hydrocarbons in the oil sands, so the overall hydrocarbon recovery from the oil sands is increased relative to non-polar aliphatic hydrocarbon solvents (approximately 86 wt.% bitumen recovery).

These solvent extraction processes sacrifice hydrocarbon yield to avoid difficulties in separating the extracted bitumen from inorganic material fines. Asphaltenes are at least partially excluded from solvent extraction processes because 1) the preferred solvents, particularly non-polar aliphatic hydrocarbon solvents such as pentane, hexanes, and heptanes, are not effective to solvate all asphaltenes; and 2) asphaltenes may be flocculated to capture inorganic material fines so that the asphaltenes and fines may be removed from the extracted bitumen together. Loss of asphaltenes is considered acceptable in some processes since asphaltenes require cracking and hydrotreatment to provide more valuable lower molecular weight hydrocarbons.

The loss of asphaltenic hydrocarbons, however, is a significant hydrocarbon yield loss. In refining processes, at least 50% of asphaltenes can be converted to high value lower

molecular weight hydrocarbons. In a solvent extraction process recovering only 73 wt.% of bitumen from an oil sands ore, such as processes excluding asphaltenes from the recovery by flocculation of the asphaltenes with a C₅, C₆, or C₇ solvent, up to 15 wt.% of recoverable hydrocarbons that can be converted to high value low molecular weight hydrocarbons may be excluded from recovery.

Aromatic solvents such as toluene and *o*-xylene are known to be highly effective as solvents for extracting all hydrocarbon components from oil sands ores. Use of such aromatic solvents in an oil sands solvent extraction process, however, is impractical due to the expense of the solvents and the inefficiency of solvent separation and recovery from the spent oil sands material due to the relatively high boiling point of such solvents.

It is desirable to provide an oil sands solvent extraction process and system effective to provide improved hydrocarbon recovery in which inorganic solid particulate materials, including mineral fines, may be easily removed from a bitumen solvent extract in the absence of tailings ponds, and in which solvent separation and recovery from spent oil sands material is improved relative to aromatic solvents.

Summary of the Invention

In one aspect, the present invention is directed to a process for separating bitumen from oil sands comprising: providing an oil sands material comprising bitumen and inorganic solid particulate matter; contacting the oil sands material with a solvent comprising at least 75 wt.% dimethyl sulfide or 75 mol% dimethyl sulfide to form an extract comprising the solvent and bitumen extracted from the oil sands and to form a bitumen-depleted oil sands material; and separating the extract from the bitumen-depleted oil sands material.

In another aspect, the present invention is directed to a system comprising a bitumen solvent that is first contact miscible with bitumen, the solvent comprising at least 75 wt.% or 75 mol% dimethyl sulfide; an oil sands material comprising bitumen and inorganic solid particulate matter; and a contacting apparatus configured to receive the bitumen solvent and the oil sands material and to contact the bitumen solvent and the oil sands material to form a bitumen-containing extract and a bitumen-depleted oil sands material.

Brief Description of the Drawings

Figure 1 illustrates a system in accordance with the present invention that may be utilized to effect a process in accordance with the present invention.

Figure 2 illustrates another system in accordance with the present invention that may be
5 utilized to effect a process in accordance with the present invention.

Figure 3 illustrates a further system in accordance with the present invention that may be utilized to effect a process in accordance with the present invention.

Figure 4 is a graph showing petroleum recovery from oil sands at 30°C using various solvents.

Figure 5 is a graph showing petroleum recovery from oil sands at 10°C using various solvents.

10 Figure 6 is a graph showing the viscosity reducing effect of increasing concentrations of dimethyl sulfide on a West African Waxy crude oil.

Figure 7 is a graph showing the viscosity reducing effect of increasing concentrations of dimethyl sulfide on a Middle Eastern Asphaltic crude oil.

15 Figure 8 is a graph showing the viscosity reducing effect of increasing concentrations of dimethyl sulfide on a Canadian Asphaltic crude oil.

Detailed Description of the Invention

The present invention is directed to a system and a process for separating bitumen from a bitumen-containing oil sands material. The system and the process utilize a solvent
20 comprising at least 75 wt.% dimethyl sulfide or 75 mol% (hereafter the “bitumen solvent”) to extract bitumen from a bitumen-containing oil sands material. Unlike most organic solvents used to extract bitumen from oil sands, the bitumen solvent is effective to solvate substantially all hydrocarbons from the oil sands material including substantially all asphaltenes, aromatics, resins, and saturates, including paraffins. As a result, the process of the present invention is
25 effective to increase hydrocarbon recovery yield from oil sands relative to conventional oil sands solvent extractions. Furthermore, the bitumen solvent of the system and process of the present invention may have a very low dynamic viscosity, for example less than 0.3 mPa s (cP) at 25°C, that enables the removal of inorganic solid particulate fines from a mixture of the bitumen solvent and bitumen by mechanical separation or a rapid settling separation,
30 eliminating the need for a tailings pond to separate the fines. The bitumen solvent of the system and process of the present invention may also have a low boiling point, for example at most 45°C at 0.101 MPa, enabling separation and recovery of the solvent from bitumen-

depleted oil sands with less energy than higher boiling bitumen extraction solvents. The bitumen solvent of the system and process of the present invention also has very low toxicity, rendering use of the solvent in a large scale commercial system and process attractive.

Referring now to Figures 1, 2, and 3, systems 100, 200, and 300 in accordance with the present invention are shown that may be utilized for conducting a process in accordance with the present invention. The systems 200 and 300 depicted in Figures 2 and 3, respectively, may be similar in some respects to the system 100 depicted in Figure 1. Accordingly, certain components of the systems 200 and 300 may be understood with reference to the component numerals in Figure 1, where like numerals are used to indicate like components.

Referring to Figures 1, 2, and 3, a bitumen solvent 101 and a bitumen-containing oil sands material 105 are provided to a contacting apparatus 103 that is configured to receive and mix the bitumen solvent and the oil sands material to form an extract containing substantially all of the bitumen and a bitumen-depleted oil sands material.

The bitumen solvent 101 provided for use in the method or system of the present invention is comprised of at least 75 wt.% or 75 mol% dimethyl sulfide. The bitumen solvent may be comprised of at least 80 wt.%, or at least 85 wt.%, or at least 90 wt.%, or at least 95 wt.%, or at least 97 wt.%, or at least 99 wt.% dimethyl sulfide. The bitumen solvent may be comprised of at least 80 mol%, or at least 85 mol%, or at least 90 mol%, or at least 95 mol%, or at least 97 mol%, or at least 99 mol% dimethyl sulfide. The bitumen solvent may consist essentially of dimethyl sulfide, or may consist of dimethyl sulfide.

The bitumen solvent 101 provided for use in the method or system of the present invention may be comprised of one or more co-solvents that form a mixture with the dimethyl sulfide in the bitumen solvent. The one or more co-solvents are preferably miscible with dimethyl sulfide. The one or more co-solvents may be selected from the group consisting of *o*-xylene, toluene, carbon disulfide, dichloromethane, trichloromethane, C₃-C₈ aliphatic and aromatic hydrocarbons, natural gas condensates, hydrogen sulfide, diesel, kerosene, dimethyl ether, and mixtures thereof. In an embodiment of the system and process of the present invention, water is absent from the bitumen solvent and the bitumen solvent is free of water.

The bitumen solvent may be primarily in liquid phase, where at least 75 wt.%, or at least 90 wt.%, or at least 95 wt.% or at least 75 mol%, or at least 90 mol%, or at least 95

mol% of the bitumen solvent may be in liquid phase. Preferably, substantially all of the bitumen solvent is in liquid phase.

The bitumen solvent 101 provided for use in the method or system of the present invention is first contact miscible with bitumen, heavy oils, and liquid phase petroleum compositions, preferably any liquid phase petroleum composition. The bitumen solvent may be first contact miscible with crude oils having an API gravity of 15 or less, including bitumen. The bitumen solvent may be first contact miscible with a hydrocarbon composition, for example a liquid phase crude oil, that comprises at least 25 wt.%, or at least 30 wt.%, or at least 35 wt.%, or at least 40 wt.% hydrocarbons that have a boiling point of at least 538°C (1000°F) as determined by ASTM Method D5307. The bitumen solvent may be first contact miscible with liquid phase residue and liquid phase asphaltenes in a hydrocarbonaceous composition, for example, in bitumen. The bitumen solvent may be first contact miscible with a hydrocarbon composition that comprises less than 25 wt.%, or less than 20 wt.%, or less than 15 wt.%, or less than 10 wt.%, or less than 5 wt.% of hydrocarbons having a boiling point of at least 538°C (1000°F) as determined by ASTM Method D5307. The bitumen solvent may be first contact miscible with C₃ to C₈ aliphatic and aromatic hydrocarbons containing less than 5 wt.% oxygen, less than 10 wt.% sulfur, and less than 5 wt.% nitrogen.

The bitumen solvent 101 may be first contact miscible with hydrocarbon compositions, for example a crude oil or liquid phase petroleum, over a wide range of viscosities. The bitumen solvent may be first contact miscible with a hydrocarbon composition having a low or moderately low viscosity. The bitumen solvent may be first contact miscible with a hydrocarbon composition, for example a liquid phase petroleum, having a dynamic viscosity of at most 1000 mPa s (1000 cP), or at most 500 mPa s (500 cP), or at most 100 mPa s (100 cP) at 25°C. The bitumen solvent may also be first contact miscible with a hydrocarbon composition having a moderately high or a high viscosity. The bitumen solvent may be first contact miscible with a hydrocarbon composition, for example a liquid phase petroleum, having a dynamic viscosity of at least 1000 mPa s (1000 cP), or at least 5000 mPa s (5000 cP), or at least 10000 mPa s (10000 cP), or at least 50000 mPa s (50000 cP), or at least 100000 mPa s (100000 cP), or at least 500000 mPa s (500000 cP) at 25°C. The bitumen solvent may be first contact miscible with hydrocarbon composition, for example a liquid phase petroleum, having a dynamic viscosity of from 1 mPa s (1 cP) to 5000000 mPa s (5000000 cP), or from 100 mPa s (100 cP) to 1000000 mPa s (1000000 cP),

or from 500 mPa s (500 cP) to 500000 mPa s (500000 cP), or from 1000 mPa s (1000 cP) to 100000 mPa s (100000 cP) at 25°C.

The bitumen solvent provided for use in the method or system of the present invention may have a low viscosity. The bitumen solvent may be a fluid having a dynamic viscosity of
5 at most 0.35 mPa s (0.35 cP), or at most 0.3 mPa s (0.3 cP), or at most 0.285 mPa s (0.285 cP) at a temperature of 25°C. The low viscosity of the bitumen solvent may enable removal of inorganic solid material fines from a mixture of the solvent and bitumen by mechanical separation or by settling in a relatively short period of time.

The bitumen solvent 101 provided for use in the method or system of the present
10 invention preferably has a relatively low density. The bitumen solvent may have a density of at most 0.9 g/cm³, or at most 0.85 g/cm³.

The bitumen solvent 101 provided for use in the method or system of the present invention may have a relatively high cohesive energy density. The bitumen solvent provided for use in the method or system of the present invention may have a cohesive energy density
15 of from 300 MPa to 410 MPa, or from 320 MPa to 400 MPa .

The bitumen solvent 101 provided for use in the method or system of the present invention preferably is relatively non-toxic or is non-toxic. The bitumen solvent may have an aquatic toxicity of LC₅₀ (rainbow trout) greater than 200 mg/l at 96 hours. The bitumen solvent may have an acute oral toxicity of LD₅₀ (mouse and rat) of from 535 mg/kg to 3700
20 mg/kg, an acute dermal toxicity of LD₅₀ (rabbit) of greater 5000 mg/kg, and an acute inhalation toxicity of LC₅₀ (rat) of at least 40250 ppm at 4 hours.

The oil sands material 105 provided for use in the process or system of the present invention is comprised of bitumen and grains of inorganic solid particulate material. The oil sands material may be comprised of 1 wt.% to 25 wt.% of bitumen. “Bitumen” as used herein
25 may refer to a heavy oil or an extra heavy oil having an API Gravity of at most 15 as determined by ASTM Method D287. The inorganic solid particulate material of the oil sands material may be comprised of inorganic minerals selected from the group consisting of sand, silt, fines, clay, and mixtures thereof. The oil sands material may also comprise water. The oil sands material may be water-wet, where at least a majority of the inorganic solid particulate
30 material of the oil sands material is coated with a layer of water with the bitumen being located in the void space around the wetted inorganic solid particulate material grains. Alternatively, the oil sands material may be oil-wet, where at least a majority of the inorganic

solid particulate material of oil sands material is coated with bitumen. In some embodiments, the bitumen may comprise between about 1 wt.% and about 16 wt.% of the oil sands material; sand and clay may comprise between about 80 wt.% and about 85 wt.% of the oil sands material; and the water may comprise between about 1 wt.% and about 16 wt.% of the oil sands material.

The oil sands material 105 may be formed of unconsolidated or loosely consolidated inorganic material particles so that the oil sands material may be easily extracted with the bitumen solvent. Unconsolidated oil sands material may have a tensile strength of 0 Pa. The inorganic solid particles may have an average diameter of from 10 μm to 5 mm, where particles having an average diameter of from 10 μm to 43.99 μm are fines and particles having an average diameter of from 44 μm to 5 mm are medium and coarse inorganic particles.

The oil sands material 105 may be provided by mining the oil sands material from a formation containing oil sands. A formation containing oil sands from which the oil sands material may be mined may be located from the surface of the earth to 100 meters below the surface of the earth, or to 60 meters below the surface of the earth. The formation containing oil sands may be an oil sands formation, an oil shale formation, an oil-bearing diatomite formation, or a tar-saturated sandstone formation. The formation containing oil sands may comprise the oil sands material located beneath an overburden. The oil sands material may be mined from a formation containing oil sands by digging the oil sands material out of the formation and collecting the oil sands material recovered from the formation.

Mined oil sands material containing substantial quantities of consolidated solid material having a particle size greater than 5 mm may be crushed, milled, or pulverized to break consolidated portions of the oil sands material into unconsolidated solid particulates prior to being provided to the contacting apparatus 103 for contact and mixing with the bitumen solvent 101 to enhance the ease of extraction of bitumen from the oil sands material. Preferably, the mined oil sands material is crushed, milled, or pulverized sufficiently to render the oil sands material into unconsolidated solid particulates without forming excessive quantities of inorganic material fines. The mined oil sands material may be crushed, milled, or pulverized to provide an oil sands material having an average particle diameter of from 10 μm to 5 mm, where at most 15 wt.% of the crushed, milled, or pulverized oil sands material may have an average particle diameter of less than 44 μm .

The contacting apparatus 103 is configured to receive the bitumen solvent 101 and the oil sands material 105 and to contact and mix the solvent and oil sands material to form a bitumen-containing extract 107 and a bitumen-depleted oil sands material 109. Referring now to Figure 1, the contacting apparatus may be a slanted pipe or trough 110 having a solids transport screw 111 extending therethrough. The bitumen solvent 101 and the oil sands material 105 may be introduced into an upper portion of the pipe or trough 110 and move downward through the pipe or trough co-currently, where the oil sands material may be carried down the pipe or trough 110 on the flights of the solids transport screw 111 by rotating the screw. The solids transport screw 111 may be positioned in the pipe or trough 110 with the screw flights extending to within 5 centimeters, or to within 1 centimeter, of the inner surface of the pipe or trough to inhibit the oil sands material from passing straight through the pipe or trough outside the diameter of the screw. The screw flights may be pitched to maximize contact of the oil sands material with the bitumen solvent as the oil sands material and solvent proceed through the contacting apparatus. The screw flights may also have corrugations therein to promote the lifting of the oil sands material by the screw to ensure thorough mixing of the oil sands material with the bitumen solvent.

Alternatively, referring now to Figure 2, the contacting apparatus 103 may be a slanted pipe or trough 210 having a solids transport screw 211 extending therethrough where the oil sands material 105 may be introduced into a lower portion of the pipe or trough 210 and the bitumen solvent 101 may be introduced into an upper portion of the pipe or trough. The solids transport screw 211 may be positioned in the pipe or trough to carry the oil sands material 105 upwards through the pipe or trough 210 on the flights of the screw by rotating the screw. The bitumen solvent 101 may flow downwards through the pipe or trough 210 and contact the oil sands material 105 in the pipe or trough in a counter-current flow. The solids transport screw 211 may be positioned in the pipe or trough 210 with the screw flights extending to within 5 centimeters, or to within 1 centimeter, of the inner surface of the pipe or trough to inhibit the oil sands material from falling as it is carried upward through the pipe by the screw. The screw flights of the screw 211 may have small perforations therein to permit the bitumen solvent to pass through the flights after contacting the oil sands material, where the perforations are configured to inhibit the oil sands material from falling through the perforations. The screw flights of the screw 211 may be pitched to maximize contact of the oil sands material with the solvent as the oil sands material and solvent proceed through the

contacting apparatus. The screw flights of the screw 211 may also have corrugations therein to promote the lifting of the oil sands material by the screw.

In an alternative embodiment of the contacting apparatus 103 utilized as shown in Figures 1 and 2, the pipe 110 or 210 may have helical flights extending from the interior wall of the pipe radially inward to the center of the pipe rather than having a transport screw 111 or 211 extending through the pipe 110 or 210, respectively. In this embodiment, the oil sands material is carried through the pipe on the helical flights by rotating the pipe 110 or 210, and the contacting apparatus may have a mechanism for rotating the pipe having the helical flights. Bitumen solvent 101 may be contacted with the oil sands material 105 co-currently as shown in Figure 1, or counter-currently as shown in Figure 2, as the oil sands material is transported through the pipe 110 or 210 on the helical flights within the pipe.

Alternatively, referring now to Figure 3, the contacting apparatus 103 may be a conventional mixer-settler apparatus having a mixing tank 310 and an adjoining settling tank 311. The mixing tank 310 may be configured to receive the oil sands material 105 and the bitumen solvent 101 therein. The oil sands material 105 and the bitumen solvent 101 may be provided to the mixing tank 310, and may be contacted and mixed together in the mixing tank. The mixing tank may have an impeller 313 for stirring and mixing the oil sands material and the bitumen solvent. After mixing, at least a portion of the mixed oil sands material 105 and the bitumen solvent 101 may be provided from the mixing tank 310 to the settling tank 311, which may be configured to receive the mixture of oil sands material and the bitumen solvent from the mixing tank. The settling tank 311 may be configured to enable the liquid bitumen-containing extract portion of the mixture 107 and the solid bitumen-depleted oil sands material portion 109 of the mixture to separate, for example by gravity.

Referring again to Figures 1, 2, and 3, the bitumen solvent 101 may be provided to the contacting apparatus 103 in an amount effective to solvate a substantial portion, preferably at least 90 wt.%, or at least 95 wt.%, or at least 99 wt.% of the bitumen in the oil sands material 105 provided to the contacting apparatus upon contact and mixing with the oil sands material. The bitumen solvent 101 may be contacted with the oil sands material 105 in a weight ratio of solvent to oil sands material of at least 1:1, or at least 2:1, up to 10:1, or up to 5:1, or from 1:1 to 10:1, or from 2:1 to 5:1. Preferably the bitumen solvent and the oil sand material are contacted and mixed in the absence of water other than water present in the oil sands material—the contacting and mixing may be conducted free of additional water.

The oil sands material 105 provided for contact with the bitumen solvent 101 in the contacting apparatus 103 may be comprised of bitumen having a relatively high dynamic viscosity, and the bitumen solvent 101 provided for contact with the oil sands material may have a relatively low dynamic viscosity, such that the step of contacting the oil sands material and the bitumen solvent forms a bitumen-containing extract having a relatively low dynamic viscosity. The oil sands material 105 provided for contact with the bitumen solvent 101 may be comprised of bitumen having a dynamic viscosity at 20°C of at least 5000 mPa s (cP), or at least 50,000 mPa s (cP), or at least 100,000 mPa s (cP), or at least 500,000 mPa s (cP). The bitumen solvent 101 provided for contact with the oil sands material 105 may have a dynamic viscosity at 20°C of at most 0.35 mPa s (cP), or at most 0.3 mPa s (cP), or at most 0.285 mPa s (cP). The bitumen-containing extract 107 formed by contacting and mixing the oil sands material 105 and the bitumen solvent 101 may have a dynamic viscosity at 20°C of at most 500 mPa s (cP), or at most 100 mPa s (cP). The bitumen-containing extract may be relatively easily separated from the bitumen-depleted oil sands material due to the relatively low viscosity of the bitumen-containing extract.

After contacting and mixing the bitumen solvent 101 and the oil sands material 105 to form the bitumen-containing extract 107 and the bitumen-depleted oil sands material 109, the bitumen-containing extract and the bitumen-depleted oil sands material may be separated. In some embodiments of the system and the process of the present invention, separation of the bitumen-containing extract 107 from the bitumen-depleted oil sands material 109 may be effected by removing the extract and the bitumen-depleted oil sands material from the contacting apparatus 103. Referring to Figure 2, the bitumen-containing extract 107 may be separated from the bitumen-depleted oil sands material 109 as the extract exits the bottom portion of the pipe or trough 210 of the contacting apparatus 103 in a counter-current flow relative to the oil sands material. The bitumen-depleted oil sands material 109 may be separated from the bitumen-containing extract as the bitumen-depleted oil sands material exits the top portion of the pipe or trough 210 of the contacting apparatus 103. Alternatively, referring to Figure 3, the bitumen-depleted oil sands material may settle gravitationally into a bottom portion of the settling tank 311 of the contacting apparatus, and the bitumen-containing extract 107 may be removed from a top portion of the settling tank after the bitumen-depleted oil sands material has settled into the bottom portion of the settling tank to separate the bitumen-containing extract from the bitumen-depleted oil sands material. The

bitumen-depleted oil sands material 109 may be removed from the bottom portion of the settling tank to separate the bitumen-depleted oil sands material from the bitumen-containing extract 107.

In other embodiments of the system and process of the present invention, separation of the bitumen-containing extract 107 and the bitumen-depleted oil sands material 109 may be effected after the extract and the bitumen-depleted oil sands material have been removed from the contacting apparatus 103. Referring now to Figure 1, in some embodiments of the system of the present invention, the system may comprise a clarifier 113 operatively fluidly connected to the contacting apparatus 103 to receive a mixture of the bitumen-containing extract and the bitumen-depleted oil sands material from the contacting apparatus and configured to separate the bitumen-containing extract 107 and the bitumen-depleted oil sands material 109. After the bitumen solvent 101 and the oil sands material 105 have been contacted and mixed in the contacting apparatus 103 to produce the bitumen-containing extract and the bitumen-depleted oil sands material, the extract and the bitumen-depleted oil sands material may be provided from the contacting apparatus to the clarifier 113. The bitumen-depleted oil sands material may gravitationally settle to the bottom portion of the clarifier, and the bitumen-containing extract 107 may be separated from the bitumen-depleted oil sands material by removing the extract from the top portion of the clarifier after settling of the bitumen-depleted oil sands material. After settling, the bitumen-depleted oil sands material 109 may be removed from the bottom portion of the clarifier to separate the bitumen-depleted oil sands material from the bitumen-containing extract.

In a preferred embodiment of the process of the present invention, separation of the bitumen-containing extract and the bitumen-depleted oil sands material may be effected in the absence of water other than water contained in the oil sands material—free of additional water—since the presence of significant quantities of water in the separation step may inhibit the separation of inorganic particulate fines from the bitumen-containing extract.

Referring again to Figures 1, 2, and 3, the separated bitumen-depleted oil sands material 109 may contain residual bitumen solvent therein, which may be recovered from the bitumen-depleted oil sands material. The bitumen-depleted oil sands material 109 may be provided to a solvent stripper 121 to recover the residual solvent from the bitumen-depleted oil sands material. The temperature and the pressure in the solvent stripper may be controlled to strip the residual solvent from the bitumen-depleted oil sands material. For example, if the

bitumen solvent is formed of 100 wt.% or 100 mol% dimethyl sulfide, the temperature of the solvent stripper may be controlled to be 50°C and the pressure of the stripper may be controlled to be 0.101 MPa to strip the dimethyl sulfide residual solvent from the bitumen-depleted oil sands material. One advantage of the process of the present invention is that relatively little energy is required to strip the residual bitumen solvent from the bitumen-depleted oil sands material relative to other bitumen solvents that are effective to solvate substantially all of the asphaltenes from an oil sands material—such as toluene and *o*-xylene—due to the relatively low boiling point of the bitumen solvent used in the process of the present invention.

The residual bitumen solvent 123 stripped from the bitumen-depleted oil sands material may be recycled for reuse to extract bitumen from fresh oil sands material 105 by introducing the residual bitumen solvent into the contacting apparatus 103. The stripped bitumen-depleted oil sands material 125 may be returned to its originating site after mining at the originating site is complete, thereby reclaiming the originating site.

The bitumen-containing extract 107 may contain relatively small quantities of inorganic material fines after separation of the extract from the bitumen-depleted oil sands material 109. These inorganic material fines 117 may be separated from the bitumen-containing extract in a fines separation unit 115. The fines separation unit 115 may be any conventional mechanical or physical solid/liquid separator. For example, the fines separation unit 115 may be a centrifuge or a filter configured to separate solid particles having the size of the fines in the bitumen-containing extract from a liquid, for example, the filter may be an ultrafiltration unit. The separation unit 115 may also be a settling tank wherein the fines gravitationally settle to the bottom of the tank for separation from the bitumen-containing extract, preferably within a period of at most 1 hour, or at most 2 hours, or at most 12 hours, or at most 1 day due to the low viscosity of the bitumen-containing extract. The inorganic material fines 117 may be separated from the bitumen-containing extract in the fines separation unit 115 to produce a substantially particulate-free bitumen-containing extract 119.

Alternatively, substantially all of the inorganic solid particulate material, including the inorganic material fines, may be separated from the bitumen-containing extract 107 upon separation of the bitumen-depleted oil sands material 109 from the bitumen-containing extract 107 due to the low viscosity of the bitumen-containing extract, particularly if the bitumen-containing extract is separated from the bitumen-depleted oil sands material 109 in a clarifier.

In the process of the present invention, the bitumen-containing extract 107 separated from the bitumen-depleted oil sands material 109 may contain at most 500 parts per million (“ppm”) by weight, or at most 400 ppm by weight, or at most 250 ppm by weight, or at most 100 ppm by weight, or at most 50 ppm by weight of inorganic solid particulate matter. In such cases, the system of the present invention may require no fines separation unit 115; and the process of the present invention may require no separate step of separating inorganic material fines from the bitumen-containing extract 107 after separation of the bitumen-containing extract from the bitumen-depleted oil sands material 109.

The substantially particulate-free bitumen-containing extract 119 may be comprised of bitumen and the bitumen solvent. The bitumen-containing extract 119 may contain at least 90 wt.%, or at least 95 wt.%, or at least 97 wt.% of the bitumen contained in the oil sands material 105. More particularly, the bitumen containing extract 119 may contain substantially all of the asphaltenes initially contained in the oil sands material 105, for example, the bitumen-containing extract 119 may contain at least 80 wt.%, or at least 90 wt.%, or at least 95 wt.% of the asphaltenes initially contained in the oil sands material 105, including both C_7 asphaltenes and C_5 asphaltenes. The bitumen-containing extract 119 may contain at least 90 wt.%, or at least 95 wt.%, or at least 97 wt.% of the C_7 asphaltenes initially present in the oil sands material 105 and may contain at least 80 wt.%, or at least 90 wt.%, or at least 95 wt.% of the C_5 asphaltenes initially contained in the oil sands material 105.

The bitumen-containing extract 119 may be transported to an oil processing facility such as a refinery, *e.g.* in an oil pipeline, for refining the bitumen into oil products. The bitumen solvent contained in the bitumen-containing extract may be utilized as a diluent for ease of transport of the bitumen contained in the bitumen-containing extract 119. The bitumen solvent may be stripped from the bitumen-containing extract 119 at the oil processing facility and returned for further use as the bitumen solvent 101 introduced into the contacting apparatus 103 to capture further bitumen from an oil sands material 105.

To facilitate a better understanding of the present invention, the following examples of certain aspects of some embodiments are given. In no way should the following examples be read to limit, or define, the scope of the invention.

EXAMPLE 1

The quality of dimethyl sulfide as an oil recovery agent based on the miscibility of dimethyl sulfide with a crude oil relative to other compounds was evaluated. The miscibility of dimethyl sulfide, ethyl acetate, *o*-xylene, carbon disulfide, chloroform, dichloromethane, tetrahydrofuran, and pentane solvents with mined oil sands was measured by extracting the oil sands with the solvents at 10°C and at 30°C to determine the fraction of hydrocarbons extracted from the oil sands by the solvents. The bitumen content of the mined oil sands was measured at about 11.5 wt.% as an average of bitumen extraction yield values for solvents known to effectively extract substantially all of bitumen from oil sands—in particular chloroform, dichloromethane, *o*-xylene, tetrahydrofuran, and carbon disulfide. One oil sands sample per solvent per extraction temperature was prepared for extraction, where the solvents used for extraction of the oil sands samples were dimethyl sulfide, ethyl acetate, *o*-xylene, carbon disulfide, chloroform, dichloromethane, tetrahydrofuran, and pentane. Each oil sands sample was weighed and placed in a cellulose extraction thimble that was placed on a porous polyethylene support disk in a jacketed glass cylinder with a drip rate control valve. Each oil sands sample was then extracted with a selected solvent at a selected temperature (10°C or 30°C) in a cyclic contact and drain experiment, where the contact time ranged from 15 to 60 minutes. Fresh contacting solvent was applied and the cyclic extraction repeated until the fluid drained from the apparatus became pale brown in color.

The extracted fluids were stripped of solvent using a rotary evaporator and thereafter vacuum dried to remove residual solvent. The recovered bitumen samples all had residual solvent present in the range of from 3 wt.% to 7 wt.%. The residual solids and extraction thimble were air dried, weighed, and then vacuum dried. Essentially no weight loss was observed upon vacuum drying the residual solids, indicating that the solids did not retain either extraction solvent or easily mobilized water. Collectively, the weight of the solid or sample and thimble recovered after extraction plus the quantity of bitumen recovered after extraction divided by the weight of the initial oil sands sample plus the thimble provide the mass closure for the extractions. The calculated percent mass closure of the samples was slightly high because the recovered bitumen values were not corrected for the 3 wt.% to 7 wt.% residual solvent. The extraction experiment results are summarized in Table 1.

Table 1 Summary of Extraction Experiments of Bituminous Oil Sands with Various Fluids						
Extraction Fluid	Temperature, C	Input Solids weight, g	Output Solids weight, g	Weight Change, g	Recovered Bitumen, g	Experimental Weight Closure, %
Carbon Disulfide	30	151.1	134.74	16.4	16.43	100.0
Carbon Disulfide	10	151.4	134.62	16.8	16.62	99.9
Chloroform	30	153.7	134.3	19.4	18.62	99.5
Chloroform	10	156.2	137.5	18.7	17.85	99.5
Dichloromethane	30	155.8	138.18	17.7	16.30	99.1
Dichloromethane	10	155.2	136.33	18.9	17.66	99.2
o-Xylene	30	156.1	136.58	19.5	17.37	98.6
o-Xylene	10	154.0	136.66	17.3	17.36	100.0
Tetrahydrofuran	30	154.7	136.73	18.0	17.67	99.8
Tetrahydrofuran	10	154.7	136.98	17.7	16.72	99.4
Ethyl Acetate	30	153.5	135.81	17.7	11.46	96.0
Ethyl Acetate	10	155.7	144.51	11.2	10.32	99.4
Pentane	30	154.0	139.11	14.9	13.49	99.1
Pentane	10	152.7	138.65	14.1	13.03	99.3
Dimethyl Sulfide	30	154.2	137.52	16.7	16.29	99.7
Dimethyl Sulfide	10	151.7	134.77	16.9	16.55	99.7

Figure 4 provides a graph plotting the weight percent yield of extracted bitumen as a function of the extraction fluid at 30°C applied with a correction factor for residual extraction fluid in the recovered bitumen, and Figure 5 provides a similar graph for extraction at 10°C without a correction factor. Figures 4 and 5 and Table 1 show that dimethyl sulfide is comparable for recovering bitumen from an oil sand material with the best known fluids for recovering bitumen from an oil sand material—o-xylene, chloroform, carbon disulfide, dichloromethane, and tetrahydrofuran—and is significantly better than pentane and ethyl acetate.

The bitumen samples extracted at 30°C from each oil sands sample were evaluated by SARA analysis to determine the saturates, aromatics, resins, and asphaltenes composition of the bitumen samples extracted by each solvent. The results are shown in Table 2.

Table 2 SARA Analysis of Extracted Bitumen Samples as a Function of Extraction Fluid				
	Oil Composition Normalized Weight Percent			
Extraction Fluid	Saturates	Aromatics	Resins	Asphaltenes
Ethyl Acetate	21.30	53.72	22.92	2.05
Pentane	22.74	54.16	22.74	0.36
Dichloromethane	15.79	44.77	24.98	14.45
Dimethyl Sulfide	15.49	47.07	24.25	13.19
Carbon Disulfide	18.77	41.89	25.49	13.85
o-Xylene	17.37	46.39	22.28	13.96
Tetrahydrofuran	16.11	45.24	24.38	14.27
Chloroform	15.64	43.56	25.94	14.86

The SARA analysis showed that pentane and ethyl acetate were much less effective for extraction of asphaltenes from oil sands than are the known highly effective bitumen extraction fluids dichloromethane, carbon disulfide, o-xylene, tetrahydrofuran, and chloroform. The SARA analysis also showed that dimethyl sulfide has excellent miscibility properties for even the most difficult hydrocarbons—asphaltenes.

The data showed that dimethyl sulfide is generally as good as the recognized very good bitumen extraction fluids for recovery of bitumen from oil sands, and is highly compatible with saturates, aromatics, resins, and asphaltenes.

EXAMPLE 2

The quality of dimethyl sulfide as an oil recovery agent based on the crude oil viscosity lowering properties of dimethyl sulfide was evaluated. Three crude oils having widely disparate viscosity characteristics—an African Waxy crude, a Middle Eastern asphaltic crude, and a Canadian asphaltenic crude—were blended with dimethyl sulfide. A control sample of each crude was prepared containing no dimethyl sulfide, and samples of each crude were prepared and blended with dimethyl sulfide to prepare crude samples containing increasing concentrations of dimethyl sulfide. Each sample of each of the crudes was heated to 60°C to dissolve any waxes therein and to permit weighing of a homogeneous liquid, weighed, allowed to cool overnight, then blended with a selected quantity of dimethyl sulfide. The samples of the crude/dimethyl sulfide blend were then heated to 60°C and mixed to ensure homogeneous blending of the dimethyl sulfide in the samples. Absolute (dynamic)

viscosity measurements of each of the samples were taken using rheometer and closed cup sensor assembly. Viscosity measurements of each of the samples of the West African waxy crude and the Middle Eastern asphaltic crude were taken at 20°C, 40°C, 60°C, 80°C, and then again at 20°C after cooling from 80°C, where the second measurement at 20°C is taken to

- 5 measure the viscosity without the presence of waxes since wax formation occurs slowly enough to permit viscosity measurement at 20°C without the presence of wax. Viscosity measurements of each of the samples of the Canadian asphaltenic crude were taken at 5°C, 10°C, 20°C, 40°C, 60°C, 80°C, The measured viscosities for each of the crudes are shown in Tables 3, 4, and 5 below.

Table 3 Viscosity (mPa s) of West African Waxy Crude vs. Temperature at Various levels of Dimethyl Sulfide Diluent					
DMS, wt.%	20°C	40°C	60°C	80°C	20°C
0.00	128.8	34.94	15.84	9.59	114.4
1.21	125.8	30.94	14.66	8.92	100.1
2.48	122.3	30.53	13.66	8.44	89.23
5.03	78.37	20.24	10.45	6.55	55.21
7.60	60.92	17.08	9.29	6.09	40.89
9.95	44.70	13.03	7.58	5.04	30.61
15.13	23.96	8.32	4.97	3.38	17.64
19.30	15.26	6.25	4.05	2.92	12.06

10

Table 4 Viscosity (mPa s) of Middle Eastern Asphaltic Crude vs. Temperature at Various levels of Dimethyl Sulfide Diluent					
DMS, wt.%	20°C	40°C	60°C	80°C	20°C
0.00	2936.3	502.6	143.6	56.6	2922.7
1.3	1733.8	334.5	106.7	44.6	1624.8
2.6	1026.6	219.9	76.5	34.3	881.1
5.3	496.5	134.2	52.2	25.5	503.5
7.6	288.0	89.4	37.4	19.3	290.0
10.1	150.0	52.4	24.5	13.5	150.5
15.2	59.4	25.2	13.6	8.2	60.7
20.1	29.9	14.8	8.7	5.7	31.0

Table 5 Viscosity (mPa s) of Topped Canadian asphaltenic Crude vs. Temperature at Various levels of Dimethyl Sulfide Diluent						
DMS, wt.%	5 °C	10 °C	20 °C	40 °C	60 °C	80 °C
0.00			579804	28340	3403	732
1.43			212525	14721	2209	538
2.07			134880	10523	1747	427
4.87			28720	3235	985	328
8.01			5799	982	275	106
9.80			2760	571	173	73
14.81	1794	1155	548	159	64	32
19.78			188	69	33	19
29.88	113	81	51	22	13	8
39.61	23	20	14	8	6	4

Figures 6, 7, and 8 show plots of Log[Log(Viscosity)] v. Log[Temperature K] derived from the measured viscosities in Tables 3, 4, and 5, respectively, illustrating the effect of increasing concentrations of dimethyl sulfide in lowering the viscosity of the crude samples.

The measured viscosities and the plots show that dimethyl sulfide is effective for significantly lowering the viscosity of a crude oil over a wide range of initial crude oil viscosities.

The present invention is well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular embodiments disclosed above are illustrative only, as the present invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. While systems and methods are described in terms of “comprising,” “containing,” or “including” various components or steps, the compositions and methods can also “consist essentially of” or “consist of” the various components and steps. Whenever a numerical range with a lower limit and an upper limit is disclosed, any number and any included range falling within the range is specifically disclosed. In particular, every range of values (of the form, “from a to b,” or, equivalently, “from a-b”) disclosed herein is to be understood to set forth every number and range

encompassed within the broader range of values. Whenever a numerical range having a specific lower limit only, a specific upper limit only, or a specific upper limit and a specific lower limit is disclosed, the range also includes any numerical value “about” the specified lower limit and/or the specified upper limit. Also, the terms in the claims have their plain,
5 ordinary meaning unless otherwise explicitly and clearly defined by the patentee. Moreover, the indefinite articles “a” or “an”, as used in the claims, are defined herein to mean one or more than one of the element that it introduces.

CLAIMS

1. A process for separating bitumen from oil sands, comprising:
providing an oil sands material comprising bitumen and inorganic solid particulate
5 matter;
contacting the oil sands material with a solvent comprising at least 75 mol% dimethyl
sulfide to form an extract comprising the solvent and bitumen extracted from the oil sands
material and to form a bitumen-depleted oil sands material;
separating the extract from the bitumen-depleted oil sands material.
10
2. The process of claim 1 wherein the solvent is first contact miscible with bitumen.
3. The process of claim 1 or claim 2 wherein the extract separated from the bitumen-
depleted oil sands material comprises at most 500 parts per million by weight of inorganic
15 solid particulate matter.
4. The process of claim 1 or any of claims 2-3 wherein the contacting and separating are
conducted free of any water other than water contained in the oil sands material.
- 20 5. The process of claim 1 or any of claims 2-4 wherein solvent is contacted with the oil
sands material in a weight ratio of solvent to oil sands material of at least 1:1, or at least 2:1,
up to 10:1, or up to 5:1, or from 1:1 to 10:1, or from 2:1 to 5:1.
6. The process of claim 1 or any of claims 2-5 wherein the solvent has a density of at
25 most 0.9 g/cm³, or at most 0.85 g/cm³ at 25°C and 0.101 MPa.
7. The process of claim 1 or any of claims 2-6 wherein the solvent has a dynamic
viscosity at 20°C of at most 0.3 mPa s (cP), or at most 0.285 mPa s (cP).
- 30 8. The process of claim 7 wherein the step of providing an oil sands material comprises
providing an oil sands material comprised of bitumen having a viscosity at 20°C of at least
5000 mPa s (cP), or at least 50,000 mPa s (cP), or at least 100,000 mPa s (cP), or at least

500,000 mPa s (cP); and wherein the step of contacting the oil sands material and the solvent forms an extract having a dynamic viscosity at 20°C of at most 500 mPa s (cP), or at most 100 mPa s (cP).

5 9. The process of claim 1 or any of claims 2-8 wherein the solvent has a boiling point of at most 45°C at 0.101 MPa.

10. The process of claim 1 or any of claims 2-9 further comprising the step of separating residual solvent from the separated bitumen-depleted oil sands material and recovering the
10 residual solvent therefrom.

11. The process of claim 10 wherein the step of contacting the oil sands material with a solvent comprises contacting the oil sands material with residual solvent recovered from the bitumen-depleted oil sands material.

15

12. The process of claim 1 or any of claims 2-11 wherein the solvent is comprised of at least 90 mol%, or at least 95 mol%, or at least 98 mol%, or 100 mol% dimethyl sulfide.

13. The process of claim 1 or any of claims 2-12 further comprising the step of separating
20 at least a portion of the solvent from the extract to produce bitumen.

14. The process of claim 13 further comprising the steps of:
prior to separating at least a portion of the solvent from the extract, transporting the extract to an oil processing facility; and
25 subsequent to separating at least a portion of the solvent from the extract, contacting the separated portion of the solvent with an oil sands material to form a bitumen-containing extract and a bitumen-depleted oil sands material.

15. The process of claim 13 further comprising the step of refining the bitumen from
30 which at least a portion of the solvent has been removed.

16. The process of claim 1 or any of claims 2-15 wherein the oil sands material is provided by mining the oil sands material.

17. The process of claim 16 further comprising the step of crushing, milling, or pulverizing the mined oil sands material prior to contacting the oil sands material with the solvent.

18. The process of claim 1 or any of claims 2-17 wherein the oil sands material has a tensile strength of 0 Pa.

19. A system comprising:

a bitumen solvent that is first contact miscible with bitumen, the solvent comprising at least 75 mol% dimethyl sulfide;

an oil sands material comprising bitumen and inorganic solid particulate matter;

a contacting apparatus configured to receive the bitumen solvent and the oil sands material and to contact and mix the bitumen solvent and the oil sands material to form a bitumen-containing extract and a bitumen-depleted oil sands material.

20. The system of claim 19, further comprising a clarifier operatively coupled to the contacting apparatus to receive the bitumen-containing extract and the bitumen-depleted oil sands material from the contacting vessel and configured to separate the bitumen-containing extract from the bitumen-depleted oil sands material.

21. The system of claim 19 wherein the contacting apparatus is further configured to separate the bitumen-containing extract from the bitumen-depleted oil sands material.

22. The system of claim 21 further comprising a fines separator configured to separate solid particles having a particle diameter of less than 44 μm from the bitumen-containing extract.

23. The system of claim 19 or any of claims 20-22 further comprising a solvent recovery apparatus operatively coupled to the contacting apparatus to receive the bitumen-depleted oil

sands material, wherein the bitumen-depleted oil sands material comprises a portion of the bitumen solvent, and wherein the solvent recovery apparatus is configured to separate at least portion of the bitumen solvent from the bitumen-depleted oil sands material.

- 5 24. The system of claim 23 wherein the solvent recovery apparatus is operatively fluidly coupled to the contacting apparatus to provide the portion of the bitumen solvent separated from the bitumen-depleted oil sands material to the contacting apparatus.

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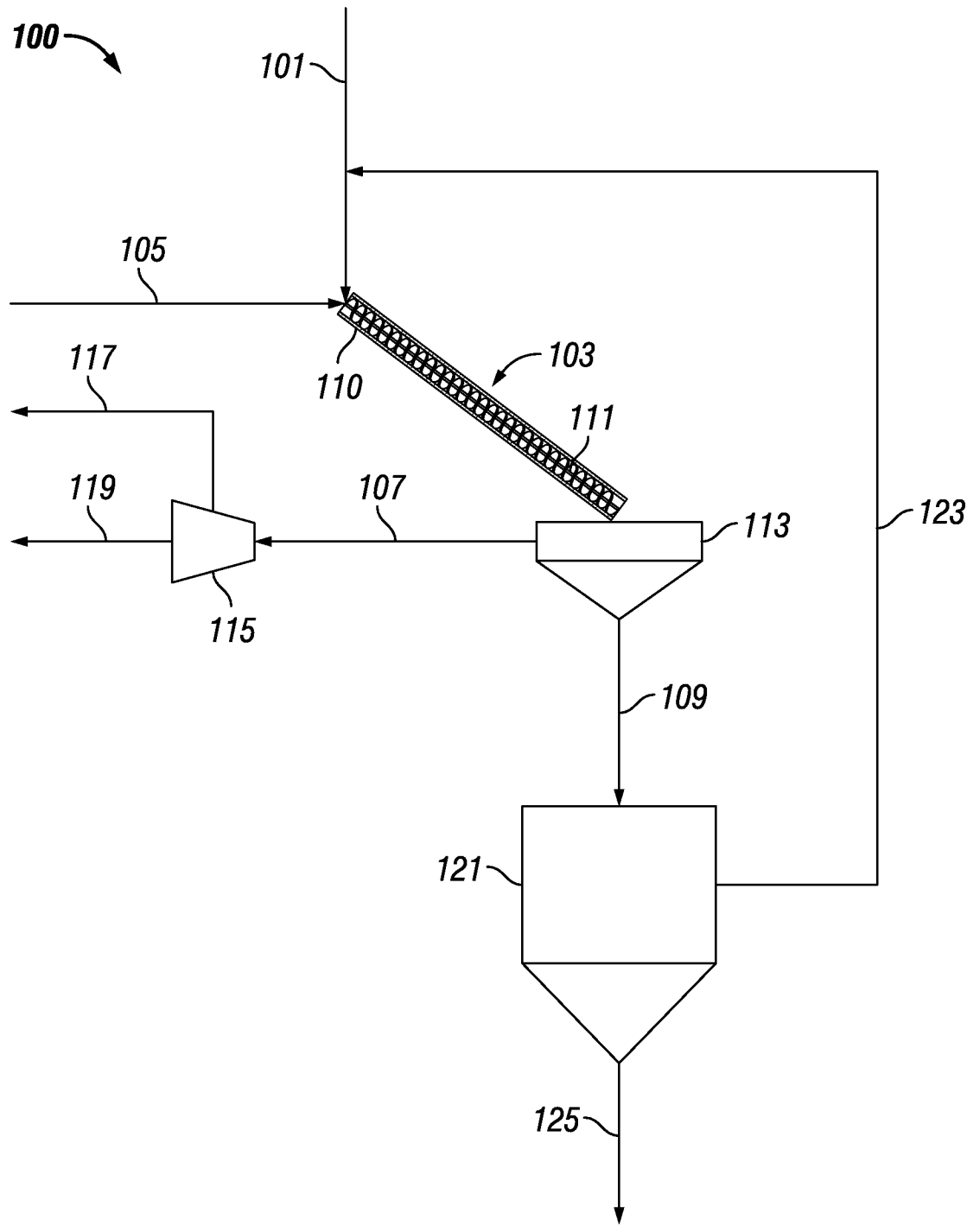


FIG. 1

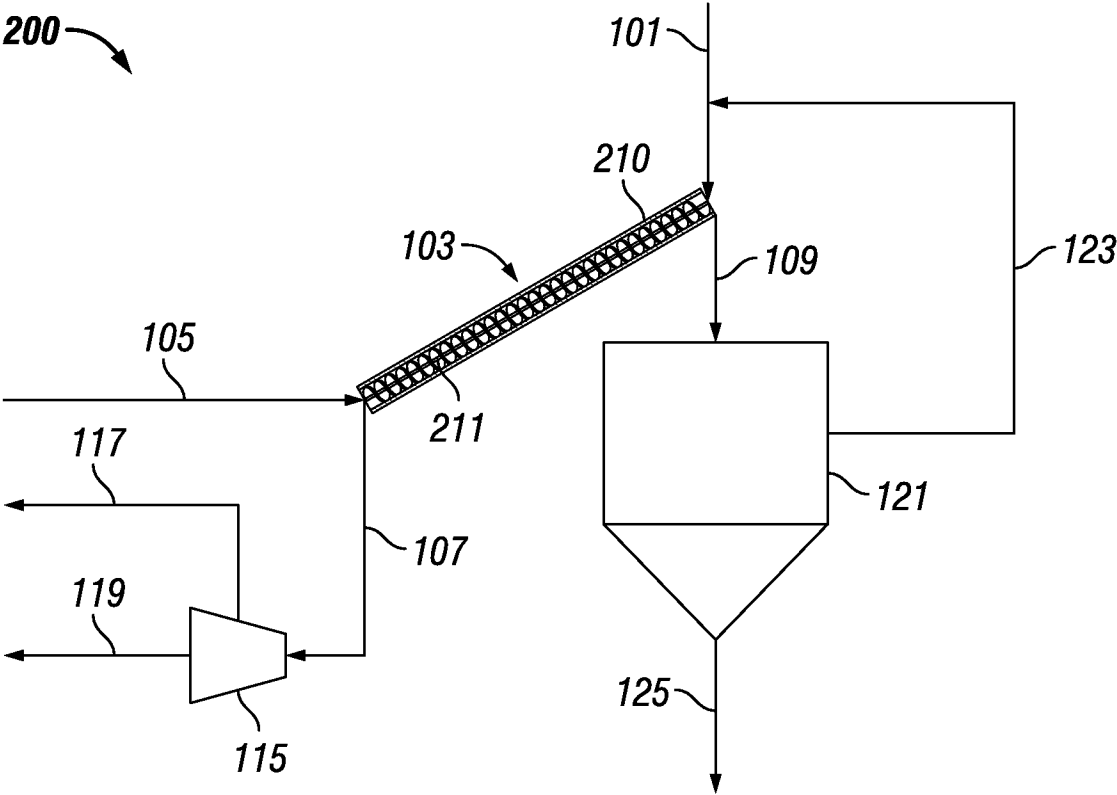


FIG. 2

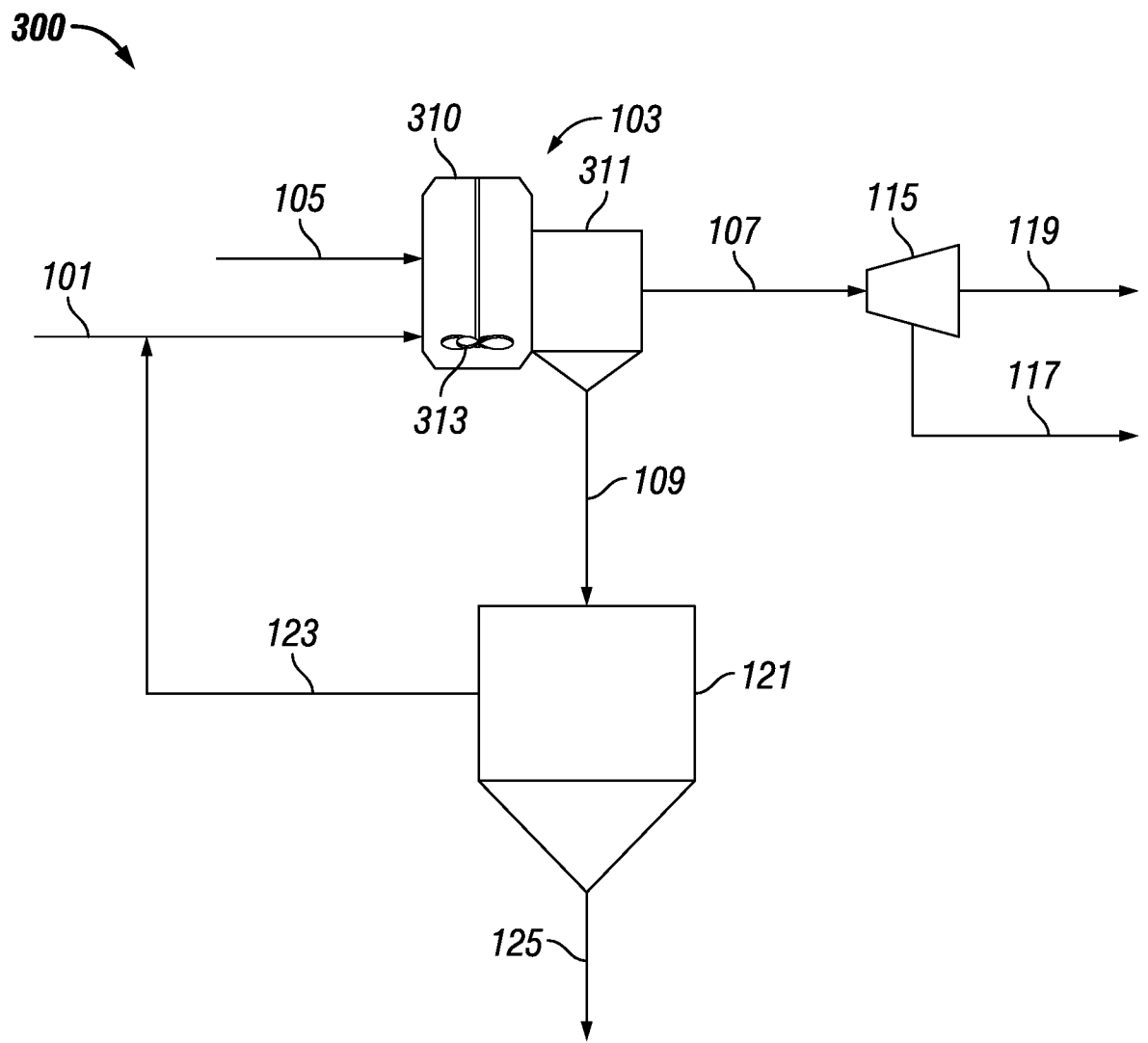


FIG. 3

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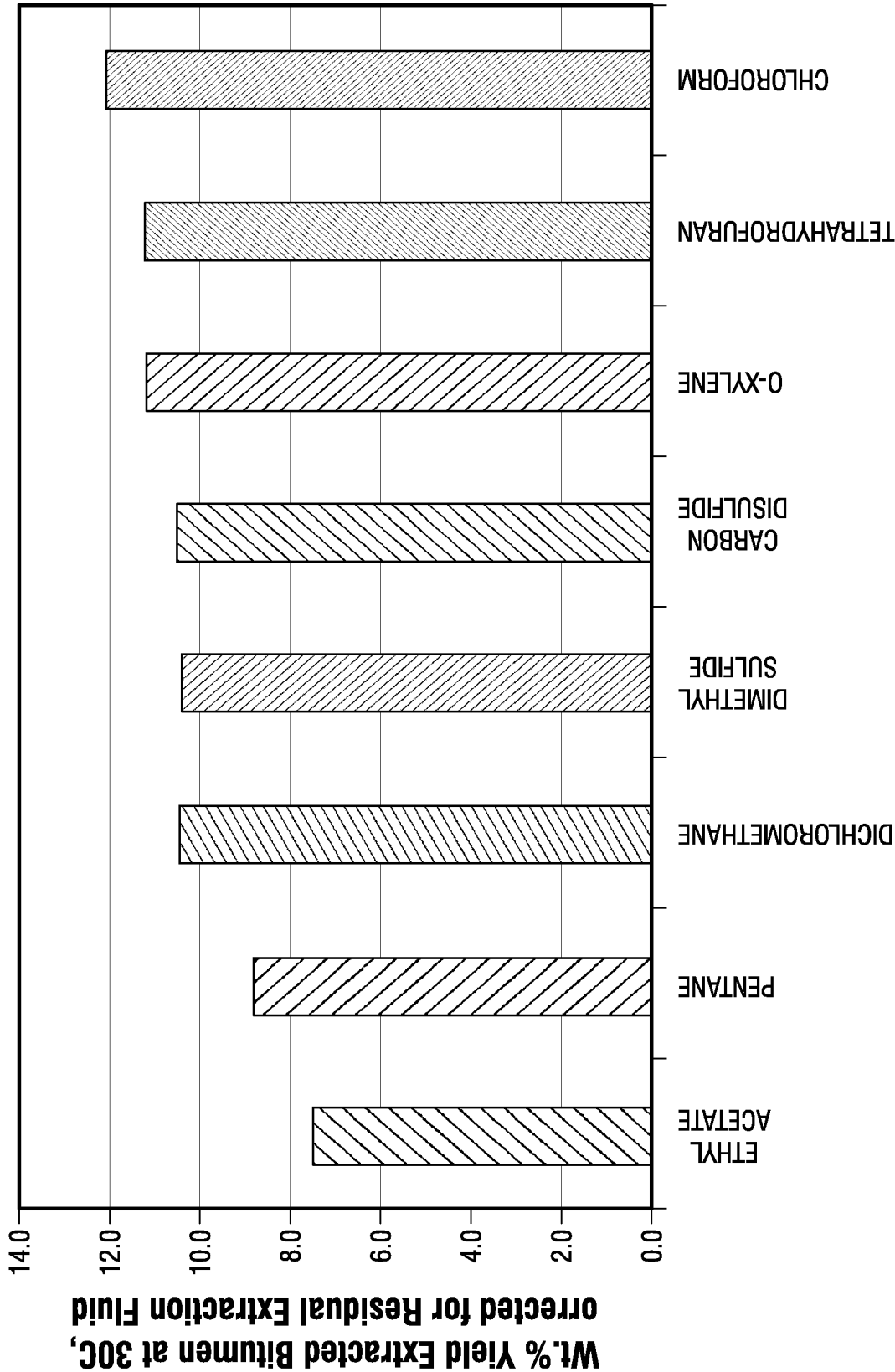


FIG. 4

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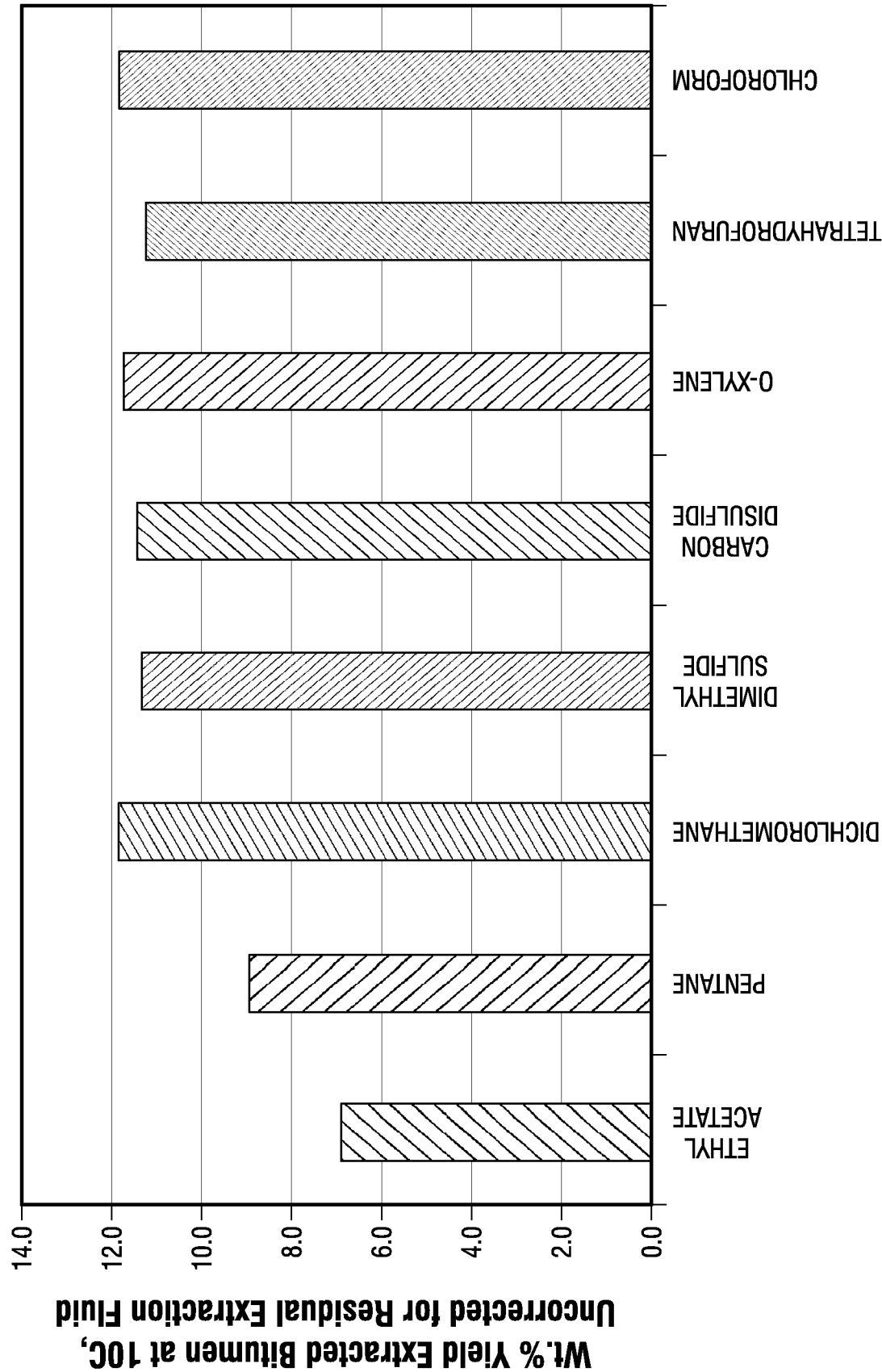
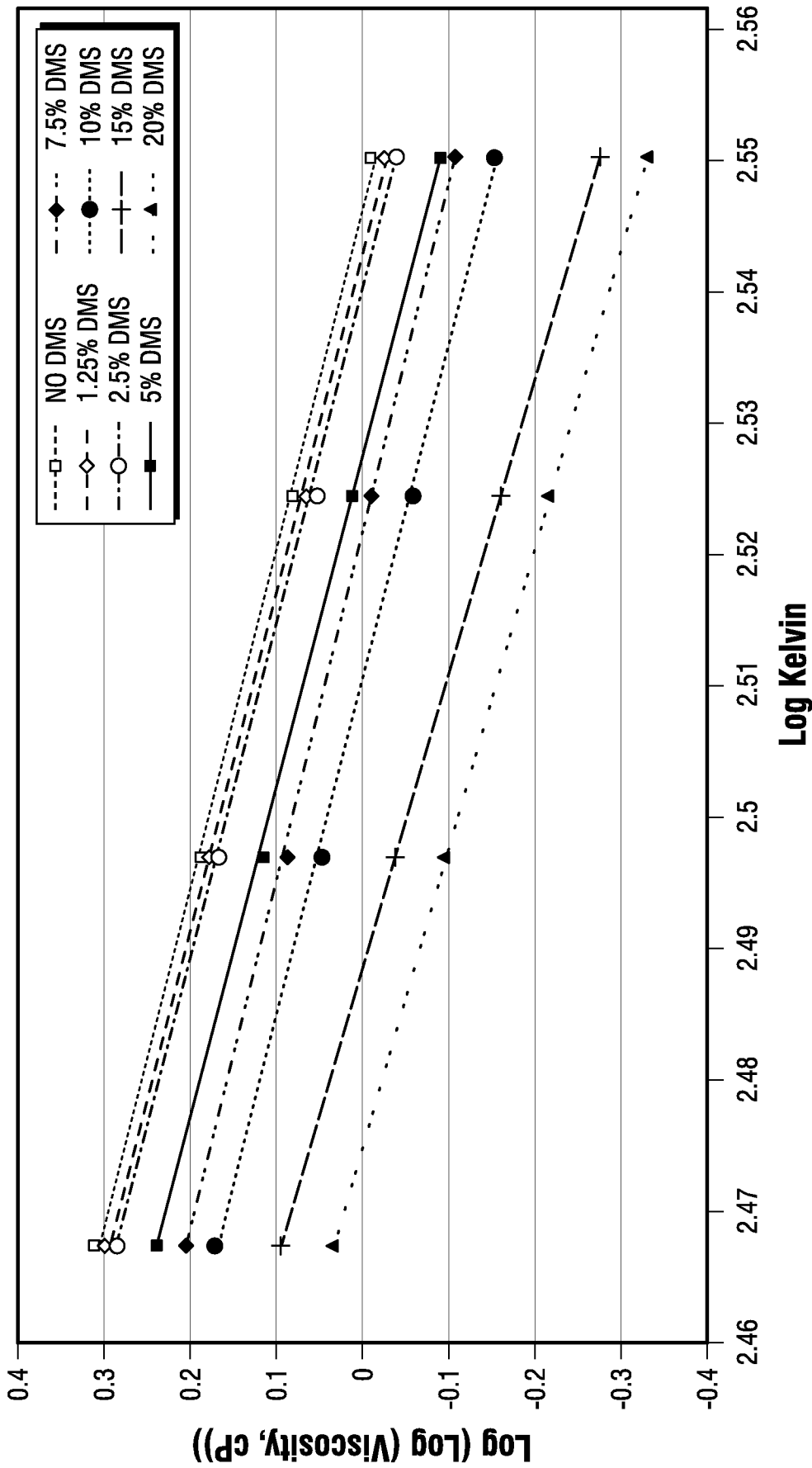


FIG. 5

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Log Kelvin
FIG. 6

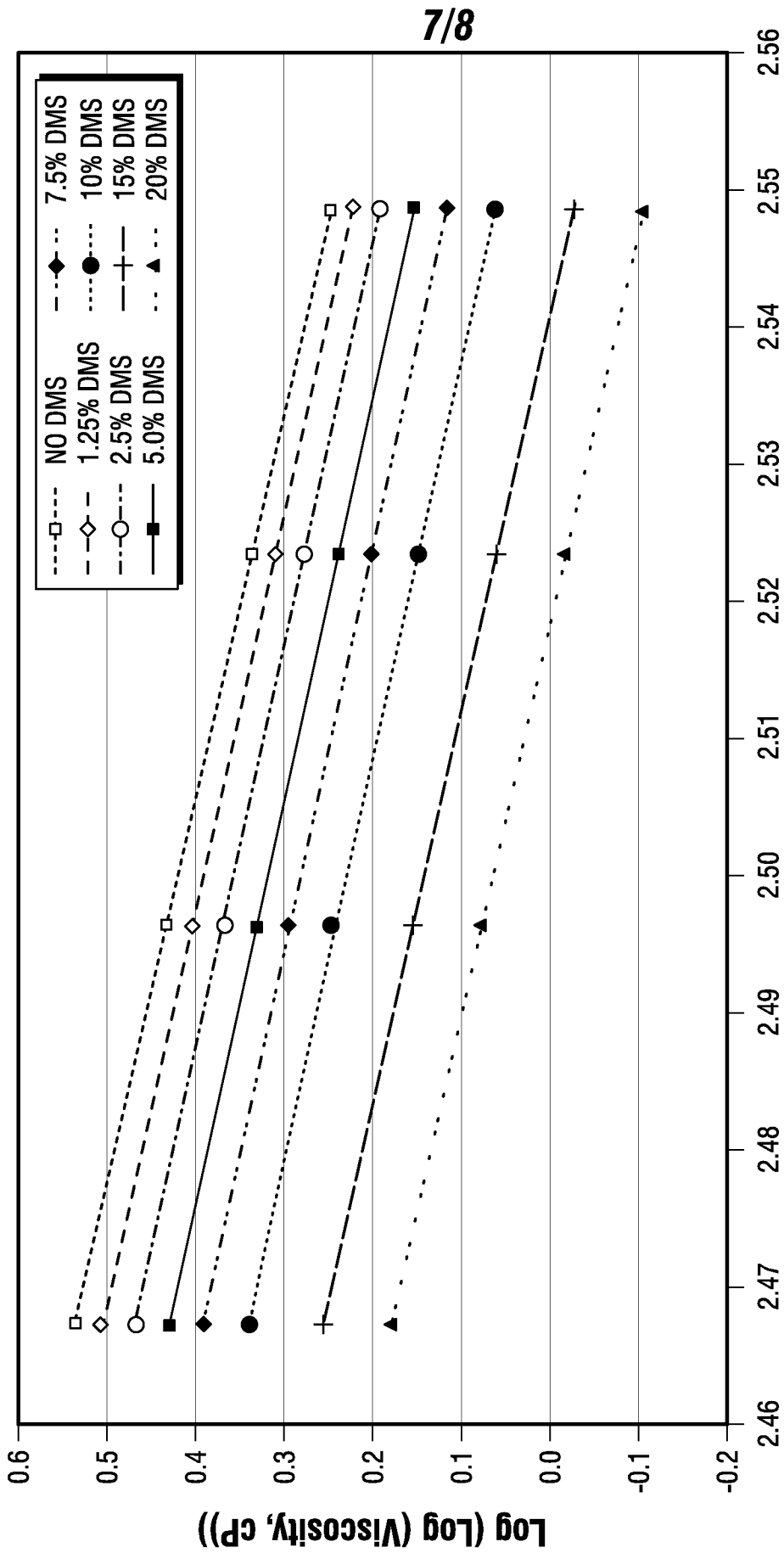
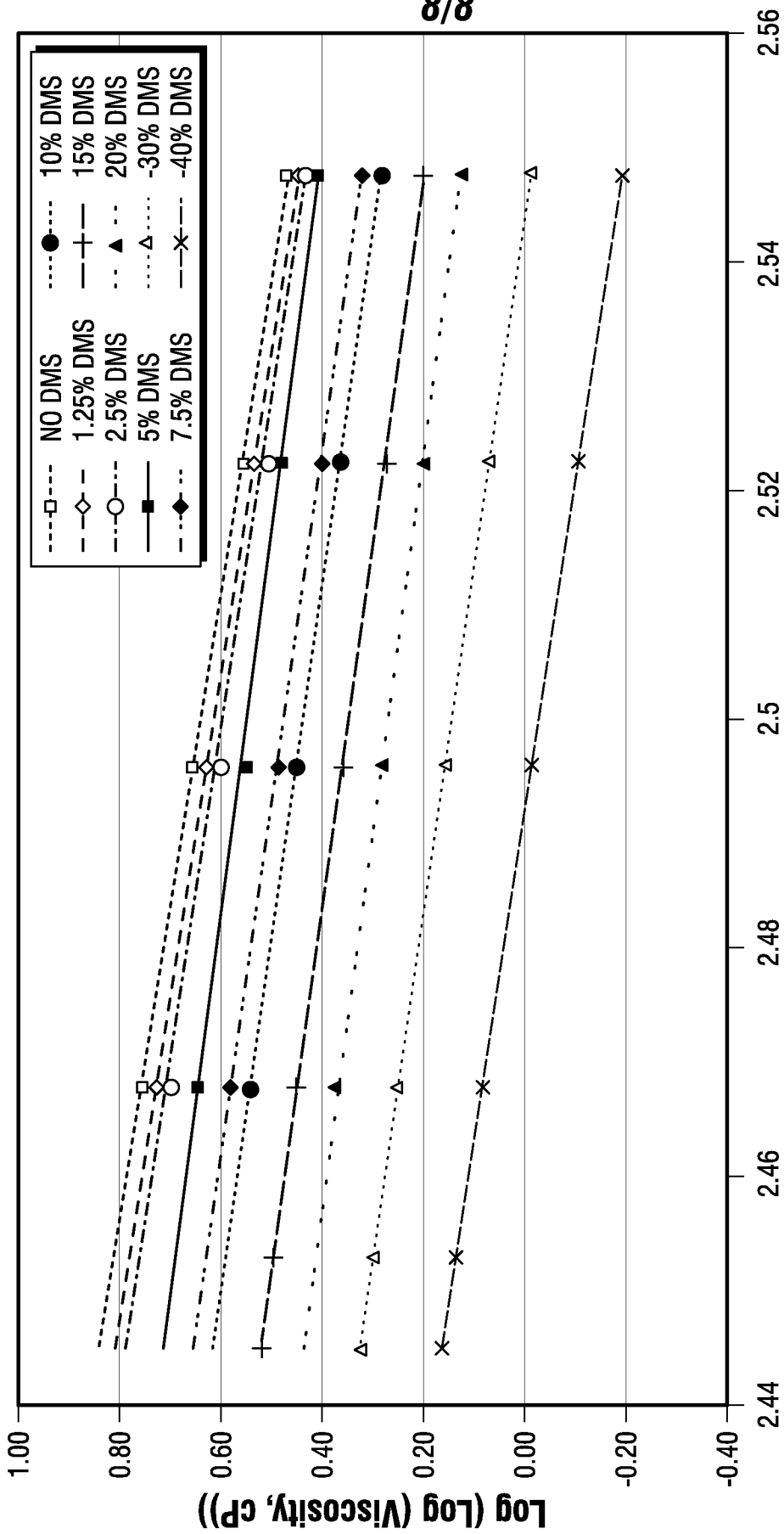


FIG. 7

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Log Kelvin
FIG. 8

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2013/074354

A. CLASSIFICATION OF SUBJECT MATTER

INV. C10G1/04

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C10G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 572 777 A (PECK LAWRENCE B [US]) 25 February 1986 (1986-02-25) table I claims 4, 6, 7 -----	1-24
X	US 4 699 709 A (PECK LAWRENCE B [US]) 13 October 1987 (1987-10-13) table I claims 1, 3-4 -----	1-24
X	CA 1 209 077 A1 (AMOCO CORP) 5 August 1986 (1986-08-05) claims 5, 7-8 -----	1-24



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2013/074354

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4572777	A	25-02-1986	NONE
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