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(54) METHOD OF PROCESSING A BITUMEN STREAM USING A MEMBRANE

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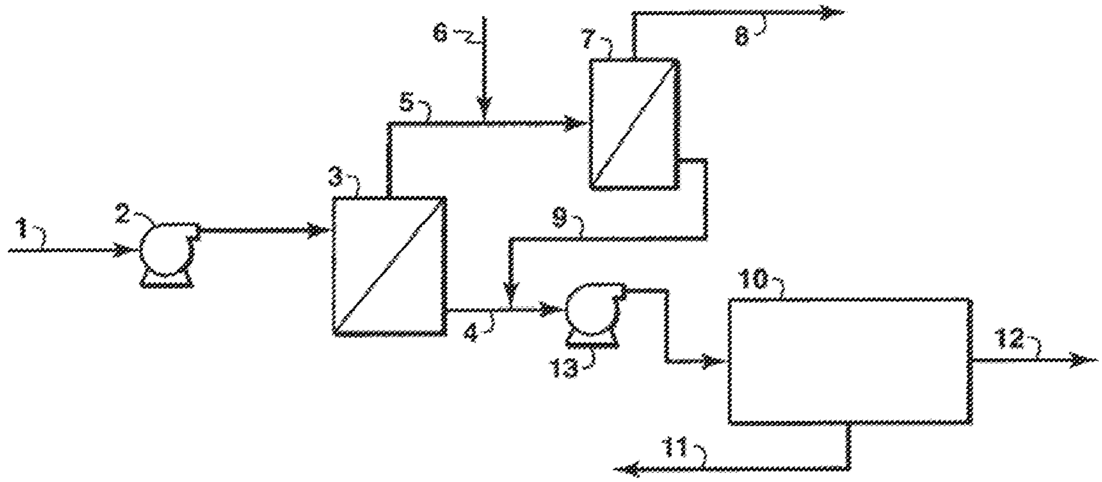
(57) **ABSTRACT**

Disclosed is a method of processing bitumen streams using membrane filtration. In one aspect, membrane filtration replaces paraffinic froth treatment, with one or more filtration steps replacing gravity settling. In another aspect, the bitumen stream is subjected to paraffmic solvent treatment at much higher flow rates, with an "almost cleaned" product being subsequently filtered by the membrane system. In this case, some contaminants are removed by conventional gravity settling equipment, while additional contaminants are removed by membrane filtration. In another aspect, membrane filtration is applied to a bitumen product effluent stream following naphthenic froth treatment. In another aspect, membrane filtration is applied to a bitumen product effluent stream from a solvent-based extraction process. In yet another aspect, membrane filtration is applied to a bitumen product effluent stream from a solvent extraction with solids agglomeration process. In still another aspect, membrane filtration is applied to bitumen produced by SAGD.



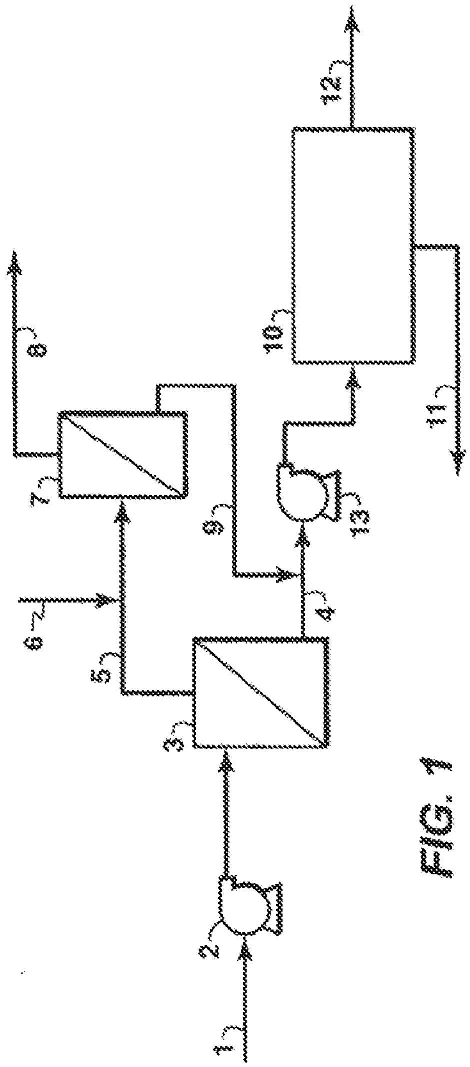

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FIG. 1

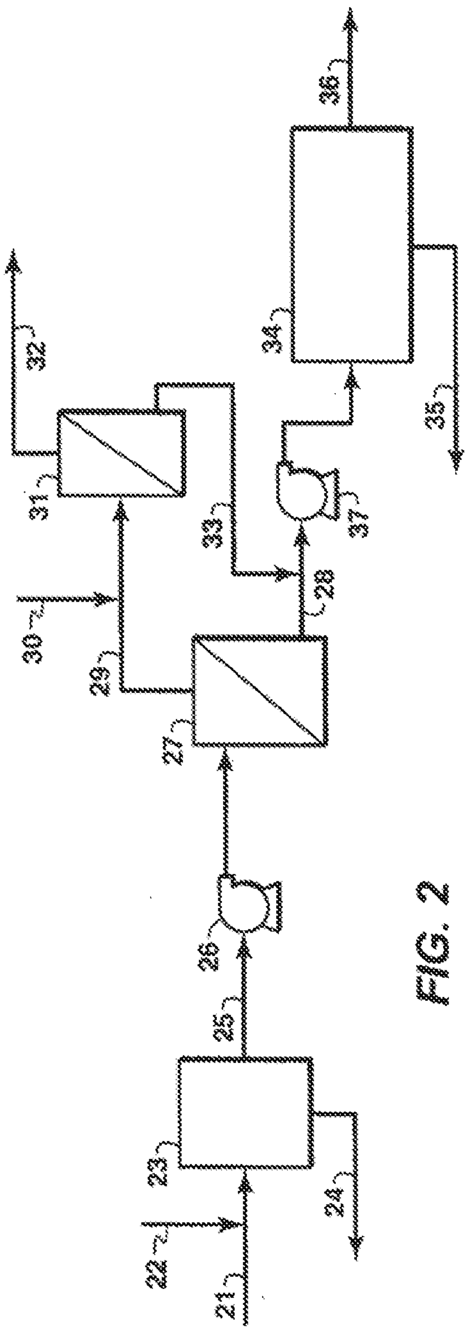
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FIG. 2

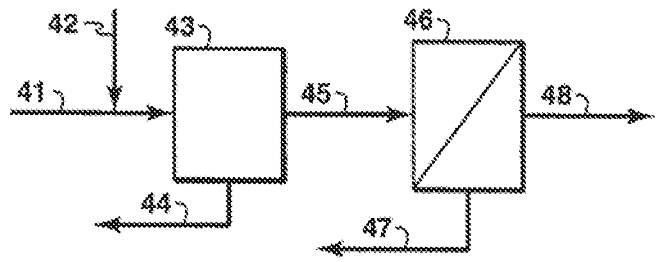

FIG. 3

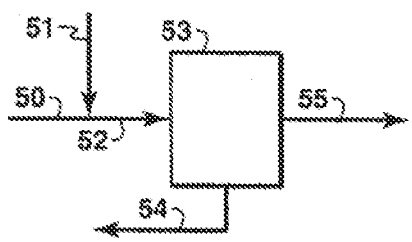

FIG. 4

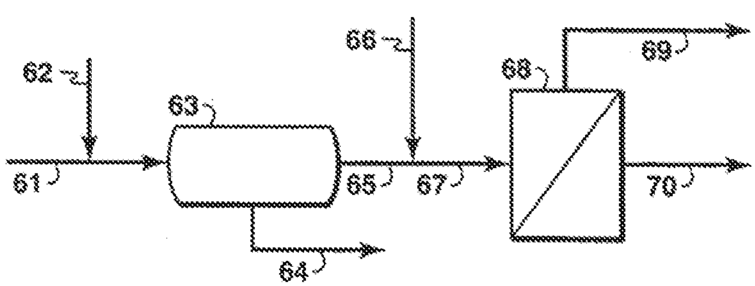

FIG. 5

METHOD OF PROCESSING A BITUMEN STREAM USING A MEMBRANE

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Canadian Patent Application 2,741,876 filed Jun. 1, 2011 entitled, METHOD OF PROCESSING A BITUMEN STREAM USING A MEMBRANE; the entirety of which is incorporated by reference herein.

FIELD

[0002] The present disclosure relates generally to treating bitumen streams. More particularly, the present disclosure relates to filtering bitumen streams from mined oil sands or from in situ production.

BACKGROUND

[0003] Much of the world's oil is found in the form of oil sands, large deposits of which are found in Alberta, Canada. The bitumen in oil sands cannot typically be pumped from the ground in its natural form. Oil sand deposits near the surface may be recovered by open-pit mining techniques, using powered shovels to remove the oil sand and load the trucks for transport to an extraction plant. Because the bitumen itself is a highly viscous material, separating it from the sands poses certain practical difficulties. The extraction of bitumen from oil sands mined in such a manner involves the liberation and separation of bitumen from the associated sands in a form that is suitable for further processing to produce a marketable product. Among several processes for bitumen extraction, the Clark Hot Water Extraction (CHWE) process represents a well-developed commercial recovery technique. In the CHWE process, mined oil sands are mixed with hot water to create a slurry suitable for extraction. Caustic is added to adjust the slurry pH to a desired level and thereby enhance the efficiency of the separation of bitumen. Recent industry developments have shown the feasibility of operating at lower temperatures and without caustic addition in the slurrying process.

[0004] The result of most of the Clark Hot Water extraction process is an extract that typically comprises two parts: a hydrocarbon predominant phase (known as a bitumen froth stream), and an aqueous phase (known as a tailings stream) made up of coarse solids, some fine solids, and water. The specific properties of the tailings will vary depending on the extraction method used, but essentially comprise spent water, reagents (e.g. surfactants), and waste ore once the recovered bitumen has been removed. A typical composition of the bitumen froth stream is about 60 wt % bitumen, 30 wt % water and 10 wt % mineral matter (solids), with some variations to account for the extraction and processing conditions. The water and mineral matter in the froth are considered as contaminants and must be either essentially eliminated or reduced to a level suitable for feed to an oil refinery or an upgrading facility.

[0005] The process to reject the water and mineral matter contaminants are known as froth treatment processes. Due to the high viscosity of bitumen, the first step in such processes is usually the introduction of a solvent. There are two major commercial approaches to reject the froth contaminants, namely naphtha solvent-based froth treatment and paraffinic solvent-based froth treatment. Solvent addition (dilution) increases the density differential between bitumen and water and mineral matter and enables contaminants rejection, which can be carried out by any number of methods, such as centrifugation or gravity separation using multi-stage gravity settling units. The separation schemes generally result in a product effluent stream of diluted bitumen ("dilbit") and a reject or tailings stream, commonly referred to as the froth treatment tailings, comprising mineral matter, water, residual solvent, and some residual bitumen. More specifically, in a paraffinic froth treatment process the solvent dilution induces the precipitation of asphaltenes from the bitumen as an additional contaminant that results in an improvement in the efficiency of the contaminant rejection process.

[0006] An example of naphtha froth treatment (NFT) is disclosed in U.S. Pat. No. 5,236,577. Addition of naphtha and separation may yield a bitumen product containing 1 to 3 wt % water and <1.0 wt % solids. Such product composition does not meet pipeline specifications and renders the NFT product stream unsuitable for transportation through a common pipeline carrier.

[0007] An example of paraffinic froth treatment (PFT) is described in Canadian Patents Nos. 2,149,737 and 2,217,300. Addition of sufficient amounts of paraffinic solvent results in asphaltene precipitation, formation of aggregates with the contaminants (entrained water and carryover solids in the froth), and settling. Conventional treaters which separate water and mineral matter will not remove very fine particulate ("fines") from the froth. Therefore, PFT settling vessels are sized to allow gravity settling of fines and other contaminants to provide a solids-free dry bitumen product (<300 ppm solids, <0.5% BS&W) suitable for transportation in a common carrier to refineries. Bitumen of such quality is termed "fungible" because it can be processed in conventional refinery processes, such as hydroprocessing, without dramatically fouling the refinery equipment. However, PFT is energy-intensive and expensive and results in a waste stream of asphaltenes—a potentially valuable commodity.

[0008] In general, water-based extraction and solvent-based extraction are the two processes that have been used to extract bitumen from mined oil sands. The CHWE process, described above, is the most commonly employed water-based extraction process. In the case of water-based extraction, water is the dominant liquid in the process and the extraction occurs by having water displace the bitumen on the surface of the solids. In the case of solvent-based extraction, the solvent is the dominant liquid and the extraction of the bitumen occurs by dissolving bitumen into the solvent.

[0009] Solvent-based extraction processes for the recovery of the hydrocarbons have been proposed as an alternative to water-based extraction of mined oil sands. However, the commercial application of a solvent-based extraction process has, for various reasons, eluded the oil sands industry. A major challenge to the application of solvent-based extraction to oil sands is the tendency of fine particles within the oil sands to hamper the separation of solids from the hydrocarbon extract. Solvent extraction with solids agglomeration is a technique that has been proposed to deal with this challenge. The original application of this technology was coined Solvent Extraction Spherical Agglomeration (SESA). A more recent description of the SESA process can be found in Sparks et al., Fuel 1992(71); pp 1349-1353.

[0010] Previously described methodologies for SESA have not been commercially adopted. In general, the SESA process involves mixing oil sands with a hydrocarbon solvent, adding a bridging liquid to the oil sands slurry, agitating the mixture in a slow and controlled manner to nucleate particles, and continuing such agitation to permit these nucleated particles to form larger multi-particle spherical agglomerates for removal. The bridging liquid is preferably water or an aqueous solution since the solids of oil sands are mostly hydrophilic and water is immiscible with hydrocarbon solvents.

[0011] The SESA process described by Meadus et al. in U.S. Pat. No. 4,057,486, involves combining solvent extraction with solids agglomeration to achieve dry tailings suitable for direct mine refill. In the process, organic material is separated from oil sands by mixing the oil sands material with an organic solvent to form a slurry, after which an aqueous bridging liquid is added in the amount of 8 to 50 wt % of the feed mixture. By using controlled agitation, solid particles from oil sands come into contact with the aqueous bridging liquid and adhere to each other to form macro-agglomerates of a mean diameter of 2 mm or greater. The formed agglomerates are more easily separated from the organic extract compared to un-agglomerated solids. This process permitted a significant decrease in water use, as compared with conventional water-based extraction processes. Furthermore, the organic extract produced has significantly lower amounts of solids entrained within compared to previously described solvent-based extraction methods.

[0012] Solvent extracted bitumen has a much lower solids and water content than that of bitumen froth produced in the water-based extraction process. However, the residual amounts of water and solids contained in solvent extracted bitumen may nevertheless render the bitumen unsuitable for marketing. Removing contaminants from solvent extracted bitumen is difficult using conventional separation methods such as gravity settling, centrifugation or filtering.

[0013] Solvent deasphalting has previously been proposed for product cleaning of solvent extracted bitumen. Deasphalting technologies are described in U.S. Pat. No. 4,572,777 (Peck) issued Feb. 25, 1986 entitled "Recovery of a Carbonaceous Liquid With a Low Fines Content"; and U.S. Pat. No. 4,888,108 (Farnand) issued Dec. 19, 1989 entitled "Separation of Fines Solids from Petroleum Oils and the Like". The solvent deasphalting processes described in these patents do not indicate the formation of a fungible product in a deasphalting step. The processes described in these patents are limited by the type of deasphalting solvent used and the proper deasphalting solvent to bitumen ratio required for optimal solids removal. The deasphalting process described were not specific and relied more on conventional deasphalting technologies, such as those commonly used in refineries to produce heavy crude oils to upgrade heavy bottoms streams to deasphalt oil. However, these conventional deasphalting technologies operate at high temperatures and pressures, and at a low feed rate, compared to what would be required for a large scale production facility. These, deasphalting technologies are expected to be even more energy-intensive and expensive than the PFT process. Furthermore, like PFT, a portion of the potentially valuable asphaltenes are removed from the bitumen product.

[0014] Where deposits lie well below the surface, bitumen may be extracted using in situ ("in place") techniques. One example of an in situ technique is the steam-assisted gravity drainage method (SAGD). In SAGD, directional drilling is employed to place two horizontal wells in the oil sands—a lower well and an upper well positioned above it. Steam is injected into the upper well to heat the bitumen and lower its viscosity. The bitumen and condensed steam will then drain downward through the reservoir under the action of gravity and flow into the lower production well, whereby these liquids can be pumped to the surface. At the surface of the well, the condensed steam and bitumen are separated, and the bitumen is diluted with appropriate light hydrocarbons for transport to a refinery or an upgrader. An example of SAGD is described in U.S. Pat. No. 4,344,485 (Butler).

SUMMARY

[0015] Generally, there is provided a method of processing bitumen streams using an anti-fouling membrane system. In one aspect, the anti-fouling membrane or membrane filtration process replaces paraffinic froth treatment, with one or more filtration steps replacing gravity settling. In another aspect, the bitumen stream is subjected to paraffinic solvent treatment at much higher flow rates, with a "partially cleaned" product being subsequently filtered by the membrane system. In this case, some contaminants are removed by conventional gravity settling equipment, while additional contaminants are removed by membrane filtration. In another aspect, membrane filtration is applied to a bitumen product effluent stream (as defined below) following naphthenic froth treatment. In another aspect, membrane filtration is applied to a bitumen product effluent stream from a solvent-based extraction process. In yet another aspect, membrane filtration is applied to a bitumen product effluent stream from a solvent extraction with solids agglomeration process. In still another aspect, membrane filtration is applied to bitumen produced by SAGD or other in-situ bitumen recovery methods.

[0016] In one aspect , there is provided a method of processing a bitumen product effluent stream, the method comprising: providing a bitumen product effluent stream; and passing the bitumen product effluent stream through a membrane system with anti-fouling characteristics to filter contaminants out of the bitumen product effluent stream to produce a primary permeate stream and a primary concentrated effluent stream; wherein the bitumen product effluent stream comprises: a) a bitumen product stream from an aqueous extraction process; b) a bitumen product stream from a paraffinic froth treatment; c) a bitumen product stream from a naphthenic froth treatment; d) a bitumen product stream from a solvent-based extraction process; or e) an in situ bitumen production stream.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Embodiments of the present disclosure will now be described, by way of example only, with reference to the attached Figures, wherein:

[0018] FIG. **1** is a schematic of a use of a membrane for filtering a bitumen product stream from an aqueous extraction process thereby replacing paraffinic froth treatment processing;

[0019] FIG. **2** is a schematic of a use of a membrane for filtering a bitumen effluent stream to debottleneck paraffinic froth treatment processing. In this process, membrane filtration is applied subsequent to PFT.

[0020] FIG. **3** is a schematic of a use of a membrane for filtering a bitumen effluent stream following naphthenic froth treatment (NFT); and

[0021] FIG. **4** is a schematic of a use of a membrane for filtering a bitumen effluent stream derived from a solvent based extraction process.

[0022] FIG. **5** is a schematic of a use of a membrane for filtering a bitumen steam-assisted gravity drainage (SAGD) production stream.

DETAILED DESCRIPTION

[0023] Generally, embodiments of the present disclosure provide a use of micro- or ultra-filtration, anti-fouling, membrane system for filtering contaminants from bitumen streams such as, for example, bitumen product streams from aqueous extraction, bitumen product effluent streams, bitumen steam-assisted gravity drainage (SAGD) production streams or solvent-based extraction process derived bitumen streams. The solvent-based extraction process may include, but is not limited to, those described above in the background section, and those described in Canadian Patent Application Serial No. 2,724,806 ("Adeyinka et al."), filed Dec. 10, 2010 and entitled "Processes and Systems for Solvent Extraction of Bitumen from Oil Sands".

[0024] To extract bitumen from oil sands in a manner that employs solvent and solids agglomeration, as described by Adeyinka et al. in Canadian Patent Application No. 2,724,806, a solvent is combined with a bituminous feed derived from oil sand to form an initial slurry. Separation of the initial slurry into a fine solids stream and coarse solids stream may be followed by agglomeration of solids from the fine solids stream to form an agglomerated slurry. The agglomerated slurry can be separated into agglomerates and a low solids bitumen extract. Optionally, the coarse solids stream may be reintroduced and further extracted in the agglomerated slurry. A low solids bitumen extract can be separated from the agglomerated slurry for further processing. Optionally, the mixing of a second solvent with the low solids bitumen extract to extract bitumen may take place, forming a solvent-bitumen low solids mixture, which can then be separated further into low grade and high grade bitumen extracts. Recovery of solvent from the low grade and/or high grade extracts is conducted, to produce bitumen products of commercial value.

[0025] Canadian Patent No. 2,012,305 discloses a process for removing fines from oil sands-derived extracts. In one embodiment, the extract is contacted with a solvent to form agglomerates which include asphaltenes. The agglomerates are then separated from the remaining extract. Contemplated separation methods include gravitational separation, centrifugation, and filtration.

[0026] Canadian Patent Application No. 2,632,801 teaches a filter system for separating particulate solids from a hydrocarbon slurry liquid such as a Fischer-Tropsch type hydrocarbon synthesis slurry. The slurry is contained in a reactor and may be contacted with a filter as it exits the reactor. The filter system comprises at least one membrane with pore elements of less than 10 microns and at least one membrane with pore elements of 10 microns or greater. The small-pore filter serves to exclude particulate and fines from the hydrocarbon liquid as it is removed from the reactor. Large-pore filters are permeable to the particulate and fines, but retain larger catalyst particles. The application contemplates filter materials with surfaces that reduce fouling, including coatings of titania, zirconia, or ceramic materials. Other anti-fouling qualities contemplated include reduced surface roughness and treatments such as anodization and nitridization.

[0027] U.S. Pat. No. 5,256,297 discloses a method of ultra-filtering heavy hydrocarbons through a multi-stage membrane ultra-filtration system. The patent describes at least two identical and sequential ultra-filtration steps to remove metals, Conradson Carbon Residue (CCR), and asphaltenes. It was found that the second ultra-filtration step, despite being identical to the first ultra-filtration step, yielded a permeate with substantially lower levels of CCR and metals. Thus, the process use at least two identical filtration steps. A variety of membrane materials are contemplated, including membranes of polyimide, polysulfone, polyaryl sulfone, polycarbonate, polyamide, polyacrylonitrile, or ceramic materials.

[0028] U.S. Pat. No. 5,785,860 teaches a process for the selective removal of asphaltenes and metal compounds from heavy oil by ultra-filtration using a membrane. The contemplated membrane is preferably a ceramic membrane and is initially non-fouled. However, pores become blocked during operation and are eventually too small to enable viable operation. At such a point, the Patent contemplates back-flushing or other such regeneration to restore the membrane to a substantially non-fouled condition. With regard to de-fouling, intermittent back-pulsing through back-flowing the permeate is contemplated.

[0029] U.S. Pat. No. 6,524,469 is directed towards a process for upgrading a heavy oil feedstock. The disclosed process involves first thermally cracking the heavy oil to produce a product stream, which is then cooled to an intermediate temperature at which light ends and water can be volatized and removed in a flash tower. Following further cooling, the stream is mixed with an alkane solvent and mixed to facilitate asphaltene precipitation. However, asphaltenes do not settle due to the high viscosity of the liquid. The Patent then contemplates a two-step membrane ultra-filtration of this feed stream. The first membrane permeating unit may be a centrifugal membrane system which creates high shear between the rotating membrane surface and the fluid to be filtered. Another embodiment contemplates a tubular membrane system. In both embodiments, a pressure gradient may be employed in filtration.

[0030] A "bitumen product effluent stream" may be produced through a number extraction methods known in the art. The bitumen product effluent stream may comprise bitumen, solvent, water, and mineral matter. During the application of paraffinic froth treatment or other deasphalting technologies the bitumen product effluent stream may also comprise precipitated asphaltenes in addition to water, solvent, and mineral matter. The water, precipitated asphaltenes, and mineral matter contaminants may be removed by filtration methods, for example by micro-filtration, ultra-filtration, or nano-filtration, disclosed herein. Mineral matter may comprise clay, sand, particulate matter, bulkier contaminants (coal, wood, shale, or large particles, etc.), and other solids.

[0031] The term "bitumen product effluent stream" is used herein to refer to one of the following streams:

[0032] a) a bitumen product stream from an aqueous extraction process;

[0033] b) a bitumen product stream from a paraffinic froth treatment;

[0034] c) a bitumen product stream from a naphthenic froth treatment;

[0035] d) a bitumen product stream from a solvent-based extraction process; or

[0036] e) an in situ bitumen production stream.

[0037] An exemplary solvent-based extraction process includes a solvent extraction with solids agglomeration process, such as that described in Canadian Patent Application No. 2,724,806 (Adeyinka et al).

[0038] An exemplary in situ bitumen production stream is one derived from solvent-assisted gravity drainage (SAGD). An example of SAGD is described in U.S. Pat. No. 4,344,485 (Butler).

[0039] A bitumen product from another type of froth treatment could also be used.

[0040] The term "permeate stream" refers to a stream that has been allowed to pass through the membrane. The "primary permeate" is understood as referring to the stream that passes through the first membrane filter. The "secondary permeate" is understood as referring to the permeate that passes through the second membrane filter. The composition of the "primary permeate" or "secondary permeate" is understood to be dependent on the composition and properties of the bitumen product effluent stream and the membrane that is selected for use.

[0041] The term "concentrate stream" refers to a stream that does not pass through the membrane filter. The "primary concentrate stream" is understood to refer to the membrane reject stream from the first membrane filter. Similarly, the "secondary concentrate stream" refers to the reject stream from the second membrane filter. The primary concentrate may comprise bitumen, bound water, precipitated asphaltenes and/or solids whereas the second or secondary concentrate stream may comprise solids, bound water, precipitated asphaltenes and residual bitumen.

[0042] The term "paraffinic solvent" used herein means solvents comprising normal paraffins, isoparaffins, and blends thereof in amounts greater than 50 wt %. Presence of other components such as olefins, aromatics or naphthenes counteract the function of the paraffinic solvent and hence should not be present more than 1 to 20 wt % combined and preferably, no more than 3 wt % is present. The paraffinic solvent may be a C_4 to C_{20} paraffinic hydrocarbon solvent or any combination of thereof.

[0043] The term "naphthenic solvent" used herein would be understood by one skilled in the art and refers chiefly to contain carboxylic acids with saturated cyclic hydrocarbons, including monocarboxylic acids derived from naphthenes, such as cycloalkanes, especially cyclopentane, cyclohexane, and their alkyl derivatives.

[0044] In paraffinic and naphthenic treatments, following the addition of a sufficient amount of solvent, the bitumen stream separates, for example, by way of gravity settling, into a bitumen component (the "bitumen product effluent stream") comprising mainly bitumen and solvent, and a tailings component which may comprise mainly water, mineral matter, some solvent, and very small amounts of unrecovered bitumen. In the case of paraffinic solvents or other deasphalting technologies, the tailings also comprise precipitated asphaltenes. In PFT, the cleaned bitumen product stream may meet fungible product specifications for pipeline transportation and therefore may have a basic solids content of less than 300 ppmw (parts per million weight) and a combined water and solids content of less than 0.5 wt % on a dry bitumen basis. The particular membrane may be tailored to the specific process. Generally, filterable solids are defined as being greater than 0.45 micron diameter, as in the ASTM D4807 standard test for sediment. This size is in the range of the generally accepted "micro-filtration" range (0.1-2 μm). Tighter ultra-filtration membranes (pores of 0.01-0.1 μm) could also be used to achieve a cleaned bitumen product stream. In certain cases, it may be advantageous to use "tighter" membranes than would be normally expected based on contaminant particle size alone. For example, nano-filtration membranes (0.001 microns<pores<0.01 microns) may be desirable in some applications, as the smaller diameter pore openings should not be fouled with the relatively larger solid particles.

Membrane Filtration of a Bitumen Product Stream from an Aqueous Extraction Process

[0045] In a first aspect, as exemplified in FIG. **1**, a membrane is used to filter a bitumen product effluent stream, which may be a bitumen product stream from an aqueous extraction process. The bitumen product effluent stream (**1**) is pumped by a pump (**2**) and filtered with a filtration membrane (**3**) to remove contaminants (**5**) from the bitumen product effluent stream (**1**). The bitumen product effluent stream (**1**) may be heated to reduce viscosity, hence increasing the membrane flux rate. The primary permeate stream (**4**) that comprises primarily water and bitumen are forwarded to conventional dewatering equipment (**10**) if required, to recover hydrocarbon product. The primary concentrated effluent stream (**5**), comprised of mainly solids and associated residual water and some bitumen may be optionally subjected to additional dilution with additional solvent (**6**) to further reduce the viscosity of the bitumen and may be optionally membrane filtered again using another membrane (**7**) to remove additional contaminants (**8**), namely solids and some associated water and to increase the recovery of valuable bitumen product. This solvent could be any light hydrocarbon, but would generally be the diluent used in the process such as a paraffin, naphthene or other solvent. The resulting secondary permeate effluent stream (**9**) comprised of mainly hydrocarbons may be optionally commingled with the clean hydrocarbon stream (**12**) recovered from primary cleaned permeate effluent (**4**) or may be optionally commingled with the primary permeate stream (**4**), and pumped (using pump (**13**)) to a conventional treater (**10**) to remove additional water (**11**) or pumped to a dilbit tank. This process may yield a cleaned product (**12**) suitable for, for example, transportation, recovery, upgrading, or sale.

[0046] In one embodiment, the bitumen product effluent stream (**1**) is first conditioned with a paraffinic solvent. Solvents may include, but are not limited to, a C_5 alkane, a C_6 alkane, or mixtures thereof. If a paraffinic solvent is chosen, the conditioned bitumen may be flocculated just to the point of asphaltene precipitation. Membrane filtration (**3**) is then used to filter contaminants to form the primary concentrated effluent stream (**5**). Additional solvent (**6**) may be optionally added to the primary concentrated effluent stream (**5**) to promote separation of contaminants prior to an additional filtration step (**7**), as described above.

[0047] In another embodiment, contaminants forming the primary concentrated effluent stream (**5**) mainly comprise mineral solids and associated water whereas stream (**8**) may comprise precipitated asphaltenes, water, mineral matter, or a combination thereof. Mineral matter may comprise clay, sand, solids, particulate matter, or other mineral matter.

[0048] In another embodiment, membranes (**3**) or (**7**) may be used to selectively filter one or more contaminants.

[0049] In one embodiment, the primary concentrated effluent stream (**5**), contaminants (**8**), or secondary permeate stream (**9**) may be passed through an additional membrane to selectively dewater them.

[0050] In another embodiment, the additional filtration membranes may be used to filter solids or asphaltenes together with some water.

Membrane Filtration of a PFT Bitumen Product Effluent Stream

[0051] A second aspect is exemplified in FIG. **2**. This aspect provides a use of a filtration membrane to filter a bitumen product effluent stream arising from paraffinic solvent treatment (PFT) of a bitumen froth stream, for instance, to meet fungible product specifications. A bitumen froth stream (**21**) is diluted with a paraffinic solvent (**22**). The stream is treated using conventional equipment, including but not limited to multi-stage gravity settling units (**23**). Gravity settling permits removal of certain contaminants (**24**), namely precipitated asphaltenes, water, and solids which may comprise bulkier contaminants. The resulting PFT bitumen product effluent stream (**25**) which may require further contaminant removal is pumped (**26**) and then filtered with a filtration membrane (**27**) to remove contaminants yielding a primary permeate stream (**28**) and a primary concentrated effluent stream (**29**). In this example, primary permeate stream (**28**) is comprised of bitumen and residual water which may be optionally pumped (**37**) to a conventional treater (**34**) to remove water (**35**) or to a dilbit tank. The primary concentrated effluent stream (**29**) may be diluted with additional solvent (**30**) to further reduce viscosity and may be subjected to an additional membrane filtration (**31**) to remove additional contaminants (**32**). In this example, the additional solvent (**30**) may be paraffinic to facilitate recovery of the hydrocarbons from asphaltenes, water and mineral solids or it may be chosen so as to redissolve the precipitated asphaltenes for subsequent recovery as secondary permeate (**33**) via membrane filtration (**31**). The secondary permeate effluent stream (**33**) may be optionally pumped (using pump (**37**)) to a conventional treater (**34**) to remove excess water (**35**) or to a dilbit tank. This process yields a cleaned product (**36**) that may or may not contain asphaltenes and is suitable for, for example, transportation, recovery, upgrading, or sale.

[0052] In one embodiment, conventional PFT equipment, including gravity settling units (**23**), are de-bottle-necked to handle higher flow rates. Contaminants (**24**) removed by gravity settling may comprise bulkier contaminants including precipitated asphaltenes and solids.

[0053] In one embodiment, contaminants (**24**), (**29**) or (**32**) may comprise precipitated asphaltenes, water, mineral matter, or a combination thereof. Mineral matter may comprise clay, sand, solids, particulate matter, or other mineral matter.

[0054] In another embodiment, membranes (**27**) or (**31**) may be used to selectively filter one or more contaminants.

[0055] In one embodiment, the concentrated effluent stream (**29**) may be passed through an additional filtration membrane (**31**) for selective dewatering. Although not shown in FIG. **2**, the concentrated effluent stream (**32**) could also be passed through an additional filtration membrane for selective dewatering.

[0056] In another embodiment, the additional filtration membrane (**31**) may be used to filter solids together with some water. Due to the hydrophilic nature of some mineral components, filtering solids will also result in the removal of water associated with mineral solids (e.g. contained within the mineral interlayer).

[0057] The number of membrane filtration steps may also be more than two.

[0058] Currently, PFT is able to treat bitumen product effluent streams and arrive at fungible pipeline specifications. However, the process is energy-intensive and expensive. One skilled in the art will appreciate the economic advantage to be gained through the higher sustained flow rates and faster processing times provided by embodiments described herein through use of membrane filtration in place of, or together with, existing methods, comprising gravity settling.

Membrane Filtration of an NFT Bitumen Product Effluent Stream

[0059] Another aspect provides a use of a membrane for filtration of a bitumen product effluent stream arising from naphthenic froth treatment. This aspect is exemplified in FIG. **3**. In this aspect, a bitumen product effluent stream (**41**) is mixed with a naphthenic solvent (**42**). After mixing, the diluted bitumen froth separates, for example, by way of gravity settling or centrifugation (**43**) of contaminants (**44**). These contaminants (**44**) comprise froth treatment tailings comprising water, mineral matter, and unrecovered bitumen. The bitumen product effluent stream (**45**) may comprise bitumen, solvent, and additional contaminants such as solids and water. Typically, the product of naphthenic froth treatment (NFT) (**45**) is a bitumen that comprises 2-3% w/w solids and/or water and does not meet pipeline specifications for transportation. The NFT bitumen product effluent stream (**45**) is then filtered with a membrane (**46**) to remove the residual contaminants as a primary concentrated effluent stream (**47**) to yield a primary permeate effluent stream (**48**). The primary permeate effluent stream (**48**) may be dewatered and sent for pipeline transportation, sale, upgrading, recovery, etc.

[0060] In one embodiment, the additional contaminants (**47**) removed by filtration comprise some water associated with mineral matter, mineral matter, or unrecovered bitumen that may be directed towards NFT, extraction by other means, secondary clean up, use as a fuel, or use as a feed source for solvent extraction processes known in the art.

[0061] In a further embodiment, the primary concentrated effluent stream (**47**) may be subjected to additional membrane filtration steps to remove additional contaminants and yield a secondary concentrated effluent stream that may be a cleaner product suitable for pipeline transportation, sale, upgrading, recovery, etc.

[0062] One skilled in the art will readily appreciate the economic advantage to be gained by adapting the NFT process, through membrane filtration, to achieve fungible product specifications while simultaneously retaining asphaltenes; a product not available with other technology currently being practiced. Asphaltenes are a valuable commodity which are lost as waste stream in many current treatment methods. Retention of asphaltenes in the cleaned product would result in approximately a 5-8% increase in production volume for the same quantity of ore versus existing PFT methods that achieve fungible product.

Membrane Filtration of a Solvent Extracted Bitumen Product Effluent Stream

[0063] Another aspect provides a use of a membrane for filtration of a bitumen product effluent stream arising from a solvent-based extraction process. The extracted bitumen stream typically has a solids content of approximately 0.1 to 2 wt % on a bitumen basis. The water content of the extracted bitumen stream is usually less than 1 wt %. Although the solids and water content of the extracted bitumen stream is much less than that of a bitumen froth stream, the residual solids and water may still render the extracted bitumen stream unsuitable for pipeline transport.

[0064] This aspect is exemplified in FIG. **4**. In this aspect, the extracted bitumen stream (**50**) is mixed with a solvent (**51**). The solvent may be the same or different from the solvent used within the solvent-based extraction process. After mixing, the diluted bitumen extract (**52**) is filtered with a membrane (**53**) to remove the residual contaminants (**54**) and yield a primary permeate effluent stream (**55**) that may be a cleaned product suitable for pipeline transportation, sale, upgrading, recovery, etc. If necessary, the primary permeate effluent stream may be dewatered.

[0065] In one embodiment, the residual contaminants (**54**) removed by filtration comprise water, mineral matter, or unrecovered bitumen that may be recycled back to the solvent-based extraction process, directed to secondary clean up, or used as a fuel.

[0066] In another embodiment, the primary permeate effluent stream (**55**) would be upgraded as membrane filtration may remove heavier components of the bitumen.

[0067] In a further embodiment, the primary permeate effluent stream (**55**) may be subjected to additional membrane filtration steps to remove additional contaminants and yield a secondary permeate effluent stream that may be a cleaner product suitable for pipeline transportation, sale, upgrading, recovery, etc.

[0068] One skilled in the art will readily appreciate the economic advantage to be gained by adapting the solvent-based extraction process, through membrane filtration, to achieve fungible product specifications while simultaneously retaining asphaltenes; a product not available with other technology currently being practiced. Asphaltenes are a valuable commodity which are lost as waste stream in current process the yields a fungible bitumen product. Retention of asphaltenes in the cleaned product may result in approximately a 5-8% increase in production volume for the same quantity of ore versus existing PFT or other deasphalting methods that achieve fungible product.

Membrane Filtration of a Bitumen SAGD Production Stream

[0069] In another aspect exemplified in FIG. **5**, a use of a membrane to filter a bitumen SAGD production stream (**61**) is provided. Following addition of a solvent (**62**) to increase the density difference between bitumen and water, the stream is subjected to free water knockout (**63**), to remove water (**64**). The de-watered stream (**65**) is diluted with sufficient additional solvent (**66**) to cause asphaltene precipitation. The resulting stream (**67**) may be passed through an membrane (**68**) to remove contaminants (**69**), yielding a cleaned and higher value primary concentrated effluent stream (**70**).

[0070] In one embodiment, the solvent (**62**) may be a light hydrocarbon, for instance a C_3 to C_7 alkane, an isomer thereof, or a C_5 alkane.

[0071] In another embodiment, the de-watered stream (**65**) and additional solvent (**66**) are mixed and the resulting stream (**67**) is transported in a pipeline through a sufficient distance to facilitate precipitation and separation of precipitated asphaltenes.

[0072] In a further embodiment, the contaminants (**69**) comprise asphaltenes, and the primary permeate effluent (**70**) comprises partially de-asphalted oil.

[0073] In another embodiment, the contaminants (**69**) are removed as asphaltenes, that may comprise some residual bitumen and due to the low solids content, represent a viable fuel or higher value product than mineral contaminated asphaltenes.

[0074] In further embodiment, the primary permeate effluent stream (**70**) may be passed through an additional filtration membrane or a microfiltration membrane to remove additional contaminants and yield a secondary primary effluent stream and a secondary concentrated effluent stream.

Conditioning

[0075] In a further embodiment, a bitumen product effluent stream may be first conditioned with water or steam, or both water and steam to form an emulsion. The water content may be 5% by weight or higher and may be greater than or equal to the weight percent of asphaltenes. If the feedstock already comprises an emulsion, slurry, or froth, the amount of water used for conditioning may be reduced or completely eliminated. A conditioning solvent comprising a light hydrocarbon is then added. This solvent may be C_3 to C_7, or mixtures thereof, with substantially no aromatic content. The solvent may comprise a non-aromatic or low-aromatic mixture comprising C_4 to C_6 components, or mixtures thereof. Pressure may be controlled to limit or prevent vaporization of the solvent. The solvent: bitumen ratio may vary, but may be in the range of 0.2 to 10 (weight/weight) and may be less than 2.5 (weight/weight). It is important that the emulsion remain substantially intact during conditioning. The temperature may be maintained in the range of 70° C. to 200° C. The residency time during the conditioning step depends on temperature, but may be minutes (for higher temperatures) to hours or days (for low temperatures). The residency time may be 30 minutes for reasons of cost and efficiency. The mixture may then be flocculated and asphaltene particles may precipitate and aggregate. Additional solvent may be added to break the emulsion. The additional solvent may be hot. The cumulative solvent: bitumen ratio may between 1 to 10 (weight/weight) and may be below 3.5 (weight/weight). Temperature may be maintained at 70° C. to 200° C. and the temperature may be increased compared to the conditioning step. The de-emulsified mixture may be then be subjected to membrane ultra-filtration at the desired temperature suitable for the membrane.

Ultra-Filtration Membranes

[0076] Micro-filtration, ultra-filtration, and nano-filtration, are types of membrane filtration in which pressure forces a liquid against a semi-permeable membrane. Suspended solids and solutes of high molecular weight are retained, while low molecular weight solutes pass through the membrane. In addition to size exclusion, other exclusions may occur, for example, clays may be too large to pass through the membrane, but due to the hydrophilic nature, the clay surface may be water-wet; such that rejecting the clay also rejects water. Membrane configurations may include, for instance, flat membranes, spiral wound modules, tubular membranes, or hollow fiber membranes.

[0077] Contemplated membranes permit separation of water, mineral matter, or asphaltenes, or a combination thereof, from a bitumen stream through the incorporation of anti-fouling technologies. Such anti-fouling technologies serve to maintain membrane flux and increase membrane life. Anti-fouling may be achieved, for example, through generation of a high shear rate, for example, by high velocity cross flow at the membrane surface or by mechanical enhancement through vibration, rotation, or oscillation. Anti-fouling may also be assisted by, for example, application-appropriate surface charge or a high degree of wetting (either hydrophobic or hydrophilic, depending on the transmitted phase). Suitable membrane materials may comprise, but are not limited to ceramics, metals, or polymers (organic or inorganic).

[0078] One known high shear system is the VSEP (Vibratory Enhanced Shear Processing) system, manufactured by New Logic Research, Emeryville, Calif. VSEP's separation technology is based upon an oscillating movement of the membrane surface with respect to the liquid to be filtered. The result is that binding of the membrane surface due to the build up of solids is eliminated and free access to the membrane pores is provided to the liquid fraction to be filtered. The shear created from the lateral displacement causes suspended solids and colloidal materials to be repelled and held in suspension above the membrane surface. This combined with laminar flow of the fluid across the membrane surface keeps the filtered liquid homogeneous and allows very high levels of recovery of filtrate from the feed material. The VSEP system uses filtration membranes with torsional oscillation and is described in U.S. Patent Publication No. U.S. 2007/0221575.

[0079] The paper "Filtration of Aliphatic Base Oils With VSEP", written by Reinout Holland, Nordcap International Svenska AB Backa Bergogata 18, SE-422 46 Hisings Backan, Gothenburg, Sweden, and Asbjorn Strand, Thermtech AS, P.O. Box 130, Kokstad, N-5863 Bergen, Norway, describes the application of VSEP technology in de-ashing aliphatic based oils used in oil drilling activities and that is typically present in spent drilling mud. The filtration takes place at high temperature and high solids concentrations with stable fluxes throughout the operational range. The process is operated in a semi-batch mode with concentrations reaching up to 70 percent volume in the concentrate. After each batch, the membrane is rinsed with permeate which proved sufficient to clean the membrane. The oil contaminated waste comprises water, oil, and rock/clay. The clays (typically barite and bentonite) are components in the drilling mud and the rock is the cuttings from the drilled hole. The oils are specially refined low toxic aliphatic oils with the required properties for operation, and represent a significant departure from the concept proposed herein of filtering bitumen. The VSEP technology is used to reduce fouling by causing shear at the membrane surface through vibrating the membrane surface. The vibration produces shear waves that propagate sinusoidally from the membrane's surface. As a result of this, the stagnant boundary layer is eliminated through creation of a high back transport factor, as a result, higher feed pressures can subsequently be applied and filtration rate increases. Industrial VSEP units containing number of membrane sheets that are arrayed as parallel discs separated by gaskets. The disc stack is contained within a fibre glass reinforced plastic cylinder. The entire assembly is exited into a torsional oscillation mode by means of a rotating eccentric mass, similar to the agitation of a washing machine. The resulting shear can reach 150,000 inverse seconds, which is ten times greater than the shear in certain other cross-flow systems. Such high shear rates tend to eliminate or at least significantly reduce the fouling of many materials. However, it is believed that the VSEP system has not been applied to bitumen streams. Various types of non-fouling, high shear membrane technologies are available in addition to VSEP, such as Spintek™, high velocity tubular, other rotating disk systems.

[0080] Suitable membranes may comprise membrane stacks, and membranes may be used singly, in sequence, or reiteratively. Suitable membranes or membrane systems may include, but are not limited to, those marketed under the names SpinTek™ or VSEP™ and tubular cross-flow systems such as, for example, those marketed by Graver, Pall, Porex, and Siemens. One skilled in the art will appreciate that selection of membranes with appropriate characteristics is dependent on the intended ultra-filtration application.

[0081] Micro-filtration is defined herein as >0.1 micron, ultra-filtration is defined herein as between 0.01 and 0.1 micron, nano-filtration is defined herein as >0.001 and <0.01 micron, consistent with "Fouling in Membranes and Thermal Units", Roya Shiekholeslami, 2007 (ISBN 0-86689-066-1).

[0082] Pipeline specification is generally 0.5% BS&W; using a membrane system to reduce the filterable solids to less than 300 ppm would enable the bitumen product effluent stream to meet fungible specifications even with limited water removal. Membrane size, material, surface charge and roughness can be tailored to meet the specific needs contemplated.

[0083] In the preceding description, for purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the embodiments. However, it will be apparent to one skilled in the art that these specific details are not required.

[0084] The above-described embodiments are intended to be examples only. Alterations, modifications and variations can be effected to the particular embodiments by those of skill in the art without departing from the scope, which is defined solely by the claims appended hereto.

1. A method of processing a bitumen product effluent stream, the method comprising:

providing a bitumen product effluent stream; and

passing the bitumen product effluent stream through a membrane system with anti-fouling characteristics to filter contaminants out of the bitumen product effluent stream to produce a primary permeate stream and a primary concentrated effluent stream;

wherein the bitumen product effluent stream comprises:

a) a bitumen product stream from a paraffinic froth treatment;

b) a bitumen product stream from a naphthenic froth treatment;

c) a bitumen product stream from a solvent-based extraction process; or

d) an in situ bitumen production stream.

2.-**3**. (canceled)

4. The method of claim **1**, wherein said bitumen product stream has been preconditioned with one of (i) a solvent and (ii) a deasphalting solvent and asphaltenes have been flocculated to the point of precipitation prior to membrane filtration.

5.-**7**. (canceled)

8. The method of claim **1**, wherein said bitumen product effluent stream is b) the bitumen product stream from a paraffinic froth treatment, and wherein said contaminants comprise water, mineral matter, precipitated asphaltenes, wood, coal, or a combination thereof.

9. The method of claim **1**, further comprising one of (i) treating said primary concentrated effluent stream with additional solvent after the membrane system and (ii) subjecting said primary concentrated effluent stream to additional membrane filtration to remove additional contaminants and yield a secondary concentrated effluent stream and a secondary permeate stream, wherein said additional contaminants comprise water, mineral matter, precipitated asphaltenes, or a combination thereof.

10.-**11**. (canceled)

12. The method of claim **9**, further comprising adding the additional solvent to the primary concentrated effluent to redissolve precipitated asphaltenes and release asphaltene associated water.

13. (canceled)

14. The method of claim **1**, wherein said bitumen product effluent stream is c) the bitumen product stream from a naphthenic bitumen froth treatment, and wherein said contaminants comprise water, mineral matter, wood, coal, or a combination thereof.

15. The method of claim **1**, wherein said bitumen product effluent stream is c) the bitumen product stream from the naphthenic bitumen froth treatment, and wherein solids are retained in said primary concentrated effluent stream during membrane filtration.

16. The method of claim **1**, wherein said bitumen product effluent stream is c) the bitumen product stream from the naphthenic bitumen froth treatment, and further comprising subjecting said primary concentrated stream to further membrane filtration to remove additional contaminants and yield a secondary permeate and concentrated effluent stream.

17. (canceled)

18. The method of claim **1**, wherein said bitumen product effluent stream is d) the bitumen product stream from a solvent-based extraction process, and wherein said solvent-based extraction process is a solvent-based extraction with solids agglomeration.

19. The method of claim **1**, wherein said bitumen product effluent stream is d) the bitumen product stream from a solvent-based extraction process and wherein said contaminants comprise water, mineral matter, wood, coal, or a combination thereof, and wherein said contaminants further comprise precipitated asphaltenes.

20. (canceled)

21. The method of claim **1**, wherein said bitumen product effluent stream is d) the bitumen product stream from a solvent-based extraction process, and wherein solids are retained in said primary concentrated effluent stream during membrane filtration.

22. The method of claim **1**, wherein said bitumen product effluent stream is d) the bitumen product stream from a solvent-based extraction process, and wherein asphaltenes are retained in said primary concentrated effluent stream during membrane filtration.

23. The method of claim **1**, wherein said bitumen product effluent stream is d) the bitumen product stream from a solvent-based extraction process, and further comprising subjecting said primary concentrated stream to further membrane filtration to remove additional contaminants and yield a secondary concentrated effluent stream and secondary permeate effluent stream, and wherein said additional contaminants comprise water, mineral matter, asphaltenes, wood, coal, or a combination thereof.

24. The method of claim **1**, wherein said bitumen product effluent stream is d) the bitumen product stream from a solvent-based extraction process, and wherein the primary concentrated stream is directed back to the solvent-based extraction process.

25. The method of claim **23**, wherein the secondary concentrated stream is directed back to the solvent-based extraction process.

26.-**27**. (canceled)

28. The method of claim **1**, wherein the bitumen product effluent stream is e) the in situ bitumen production stream, and wherein said in situ oil bitumen production stream is one of (i) a steam assisted gravity drainage production stream, (ii) from one of the following in situ production methods: cyclic steam stimulation (CSS), solvent-assisted SAGD (SA-SAGD), steam and as push (SAGP), combined vapor and steam extraction (SAVEX), expanding solvent SAGD (ES-SAGD), constant steam drainage (CSD), liquid addition to steam for enhancing recovery (LASER), cyclic solvent dominated recovery process (CSDRP), water flooding, steam flooding process, or a derivative thereof, and (iii) mixed with a solvent to cause asphaltene precipitation prior to membrane filtration.

29.-**30**. (canceled)

31. The method of claim **28**, wherein said solvent is a C_3 to C_7 alkane, or an isomer thereof.

32. The method of claim **1**, wherein the bitumen product effluent stream is e) the in situ bitumen production stream, and wherein said production stream is one of (i) mixed with a solvent and transported through a pipeline over a sufficient distance to facilitate asphaltene precipitation and separation, (ii) first mixed with a first solvent, then subjected to free-water knock-out prior to membrane filtration, and (iii) subjected to a secondary water separation step prior to membrane filtration.

33.-**34**. (canceled)

35. The method of claim **1**, wherein one of (i) said bitumen product effluent or primary concentrated effluent stream is heated to reduce viscosity prior to filtration (ii) said membrane is an ultra-filtration membrane, a micro-filtration membrane, or a nano-filtration membrane and (iii) said anti-fouling characteristics comprise appropriate pore size, controlled roughness, hydrophilicity, appropriate membrane material, anti-fouling coatings, chemical addition to the feed, or high shear.

36.-**37**. (canceled)

38. The method of claim **35**, wherein one of said high shear is produced by high velocity cross-flow at a surface of the membrane system and said high shear is shear above one of 20,000 s^{-1} and 100,000 s^{-1}.

39.-**42**. (canceled)

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