MULTI-STAGE SOLVENT EXTRACTION PROCESS AND APPARATUS

STATEMENT OF PRIORITY

[0001] This application claims priority from United States Provisional Application No. 63/132,750, filed December 31, 2020, which is incorporated herein in its entirety.

FIELD OF INVENTION

[0002] The field relates to multi-stage solvent extraction for extracting product streams. Particularly, the field relates to using different solvents in multiple extraction columns.

BACKGROUND

[0003] In a refinery, crude oil is typically separated into products initially by distillation. Lighter products are first removed by distillation at atmospheric pressure because heavier products require higher temperatures for separation. Separation of these heavier compounds are typically performed under vacuum fractionation. Typical atmospheric equivalent cut point temperatures of these products are 360°C (680°F) to 430°C (800°F) such as for LVGO, typically 430°C (800°F) to 570°C (1050°F) for HVGO, and/or 570°C (1050°F) or above for vacuum residue.

[0004] While this separation method is typically used for producing feedstock for downstream conversion units such as fluid catalytic cracking, hydrotreating, hydrocracking and coking the products produced from this vacuum distillation contain a variety of component types. Often the bottom stream from an atmospheric distillation includes several multi-ring aromatic components that are more difficult to process in the downstream units. If the heavy product from the atmospheric distillation column may be separated by component type versus component distillation, then the downstream conversion units may be optimized thus reducing the cost of these conversion units and improving refinery economics.

[0005] One such conversion unit is a solvent deasphalting unit in which the separation of residue or product occurs in the presence of solvents. The solvent deasphalting technology rejects the multi-ring components from the atmospheric column bottoms to produce a higher quality product. A light paraffinic solvent such as propane is typically used to extract a small quantity of material for lube oil production. A heavier solvent such as butane is used to recover a middle range product that is typically fed to a fluid catalytic cracking or hydrocracking unit.

While pentane or a heavier solvent such as C6 or C7+ heavier range hydrocarbons are used to recover the maximum volume of material from the vacuum residue.

[0006] When using a light solvent such as propane, a high-quality product is obtained such as deasphalted oil. However, the maximum recovered yield of high-quality product is limited. For a three-product configuration solvent deasphalting unit, the middle resin yield is also limited because the operating conditions of the unit are typically set to recover the highest quality deasphalted oil (DAO). This often limits the resin yield to 15-25%. For recovering both a high-quality DAO and a minimum amount of pitch, using multiple solvents and extracting multiple products, the products produced can be separated by component type and directed to an optimal downstream processing unit.

[0007] Using a typical two-product solvent deasphalting unit to separate an atmospheric residue or a vacuum residue may often result in a low-quality product because the quantity of material recovered tends to recover some undesirable higher boiling range components. Therefore, for at least this reason a higher solvent-to-oil ratio is necessary which results in a higher utility requirement. The utility requirements may be reduced by employing an optimal process design and heat exchange. Hence, there is a need to maximize product recovery with improved product quality and minimal process utilities requirement.

SUMMARY

[0008] Various embodiments contemplated herein relate to processes and apparatuses for a multi-stage solvent extraction of a hydrocarbon feedstock to recover high-quality products. The exemplary embodiments taught herein provide a process and apparatus for solvent extraction occurring in two stage and in the presence of a fresh or recycle solvent streams to recover solvent streams as well as hydrocarbon product streams including deasphalted oil, resins or pitch.

[0009] In accordance with an exemplary embodiment, a process is provided for producing a high quality deasphalted oil as a first product stream and a second product stream. The multi-stage extraction process comprises the steps of passing a heavy hydrocarbon feed stream and a first fresh solvent to a first extraction column to generate a first overhead stream and a first bottom stream. The first overhead stream is then passed to a first stripping column to generate a first product stream and a first stripped solvent stream. The first bottom stream taken from the bottom of the first extraction column and an additional second fresh solvent stream are

passed to a second extraction column to generate a second overhead stream and a second bottom stream. The second overhead stream is further passed to a second stripping column to generate a second product stream and a second stripped solvent stream.

[0010] In accordance with another exemplary embodiment, a process is provided for multi-stage extraction of hydrocarbon feedstocks, the process comprising passing a heavy hydrocarbon feed stream and a first fresh solvent to a first extraction column to generate a first overhead stream and a first bottom stream and passing the first overhead stream to a first stripping column to generate a first product stream and a first stripped solvent stream. The first bottom stream from the first extraction column and a second fresh solvent are passed to a second extraction column to generate a second overhead stream and a second bottom stream. The second overhead stream is sent to a second stripping column to generate a second product stream and a second stripped solvent stream and passing the second bottom stream from the second extraction column and a third fresh solvent to a third extraction column to generate a third overhead stream and a third bottom stream. The process further comprising passing a final bottom stream taken from the third bottom stream to a pitch stripping column to generate a pitch stream from a bottom of the pitch stripper and a heavy stripped solvent stream from an overhead of the pitch stripper.

[0011] In accordance with yet another exemplary embodiment, an apparatus is provided for a multi-stage extraction of heavy hydrocarbons, the apparatus comprising a first extraction column to produce a first overhead stream and a first bottom stream. A first stripping column is provided in downstream communication with an overhead line of the first extraction column to produce a first product stream and a first stripped solvent stream from the first overhead stream. A second extraction column is provided which is in downstream communication with a bottoms line of the first extraction column to produce a second overhead stream and a second bottom stream from the first bottom stream. A second stripping column which is in downstream communication with an overhead line of the second extraction column to produce a second product stream and a second stripped solvent stream from the second overhead stream. Additionally, a pitch stripper is provided in downstream communication with a bottoms line of the second extraction column to produce a pitch stream and a heavy stripped solvent stream from the second bottom stream.

[0012] These and other features, aspects, and advantages of the present disclosure are further explained by the following detailed description, drawing and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The various embodiments will hereinafter be described in conjunction with the drawings, wherein like numerals denote like elements.

[0014] FIG.1 illustrates a schematic diagram of a three-product recovery from two extraction columns in accordance with an exemplary embodiment.

[0015] FIG.2 illustrates a schematic diagram of a four-product recovery from three extraction columns in accordance with an exemplary embodiment.

DEFINITIONS

[0016] The term "communication" means that material flow is operatively permitted between enumerated components.

[0017] The term "downstream communication" means that at least a portion of material flowing to the subject in downstream communication may operatively flow from the object with which it communicates.

[0018] The term "upstream communication" means that at least a portion of the material flowing from the subject in upstream communication may operatively flow to the object with which it communicates.

[0019] The term "column" means a distillation column or columns for separating one or more components of different volatilities. Unless otherwise indicated, each column includes a condenser on an overhead of the column to condense and reflux a portion of an overhead stream back to the top of the column and a reboiler at a bottom of the column to vaporize and send a portion of a bottoms stream back to the bottom of the column. Feeds to the columns may be preheated. The top pressure is the pressure of the overhead vapor at the vapor outlet of the column. The bottom temperature is the liquid bottom outlet temperature. Overhead lines and bottoms lines refer to the net lines from the column downstream of any reflux or reboil to the column. Stripping columns omit a reboiler at a bottom of the column and instead provide heating requirements and separation impetus from a fluidized inert media such as steam.

[0020] The term "rich" is intended to indicate a concentration of the indicated compound or class of compounds greater than 50 mol-%.

[0021] As used herein, the term "overhead stream" can mean a stream withdrawn at or near a top of a vessel, such as a column.

[0022] As used herein, the term "bottom stream" can mean a stream withdrawn at or near a bottom of a vessel, such as a column.

[0023] As used herein, "pitch" means the hydrocarbon material boiling above 524°C (975°F) AEBP as determined by any standard gas chromatographic simulated distillation method such as ASTM D2887, D6352 or D7169, all of which are used by the petroleum industry.

[0024] As used herein, the term "separator" means a vessel which has an inlet and at least an overhead vapor outlet and a bottoms liquid outlet and may also have an aqueous stream outlet from a boot.

[0025] As used herein, solvent "insolubles" means materials not dissolving in the solvent named.

[0026] As used herein, the term "passing" includes "feeding" and "charging" and "sending" means that the material passes from a conduit or vessel to an object.

[0027] As used herein, the term "stream" can include various hydrocarbon molecules, such as straight-chain, branched, or cyclic alkanes, alkenes, alkadienes, and alkynes, and optionally other substances, such as gases, e.g., hydrogen, or impurities, such as heavy metals, and sulfur and nitrogen compounds. The stream can also include aromatic and nonaromatic hydrocarbons. Also, the term "stream" can include or consist of other fluids, such as a hydrogen. As an example, the abbreviation "A9" may represent one or more aromatic C9 hydrocarbons.

[0028] As used herein, the term "light olefins" means the hydrocarbon material boiling in the range less than 38°C atmospheric equivalent boiling point (AEBP) as determined by any standard gas chromatographic simulated distillation method such as ASTM D2887, all of which are used by the petroleum industry. The term "light olefins" includes C_2, C_3, and C_4 olefins.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0029] The following detailed description is exemplary in nature and is not intended to limit the various embodiments or the application and uses thereof. Furthermore, there is no intention to be bound by any theory presented in the preceding background or the following detailed description. The figures have been simplified by the deletion of large number of apparatuses customarily employed in a process of this nature, such as vessel internals,

temperature and pressure controls systems, flow control valves, recycle pumps, etc. which are not specifically required to illustrate the performance of the invention. Furthermore, the illustration of the process of this invention in the embodiment of a specific drawing is not intended to limit the invention to specific embodiments set out herein.

[0030] As depicted, process flow lines in the drawings can be referred to, interchangeably, as, e.g., lines, pipes, branches, distributors, streams, effluents, feeds, products, portions, catalysts, withdrawals, recycles, suctions, discharges, and caustics.

[0031] An embodiment for a multi-stage extraction of a heavy residue stream to obtain a high-quality product is described herein which relates to a process and an apparatus 100 according to an embodiment as shown in FIG.1. Referring to FIG. 1, the process and apparatus 100 comprises an extraction column 10 receiving a heavy residue stream 11 as a feedstock for extraction, recovered as a bottom product from a crude distillation column (not shown). According to one embodiment, the heavy residue stream 11 comprises a heavy petroleum feedstock or other heavy components or multi-ring aromatics or a combination thereof. The hydrocarbon feedstock may further comprise a vacuum column residue. Representative further components of the hydrocarbon feedstock include residual oils such as an atmospheric residuum or a crude oil vacuum distillation column residuum initial boiling point ranging above 566°C (>1050°F), tars, bitumen, coal oils, and shale oils. Bitumen is natural asphalt, tar sand or oil sand defined as rock containing hydrocarbons more viscous than 10,000 cp or hydrocarbons that may be extracted from mined or quarried rock. Other asphaltene-containing materials such as whole or topped petroleum crude oils including heavy crude oils may also be used as components processed by slurry hydrocracking. In addition to asphaltenes, these further possible components of the hydrocarbon feedstock, as well as others, generally also contain significant metallic contaminants, *e.g.*, nickel, iron and vanadium, a high content of organic sulfur and nitrogen compounds, and a high Conradson carbon residue. The metals content of such components, for example, may be 100 ppm to 1000 ppm by weight, the total sulfur content may range from 1% to 7% by weight, and the API gravity may range from −5° to 35°. The Conradson carbon residue of such components is generally at least 5% and is often from 10% to 30% by weight.

[0032] The heavy residue stream in line 11 is fed as a heavy hydrocarbon feed stream to a first extraction column 10 along with a light solvent stream 13. The light solvent stream in line 13 is a first fresh solvent stream to be provided to solubilize the heavy component of the heavy

hydrocarbon feed stream. The light solvent stream may be a light paraffinic solvent stream such as propane is provided to first extraction column 10 to dissolve a high-quality hydrocarbon product into a light paraffinic solvent stream 13 while the remaining heavy components are precipitated. The heavy hydrocarbon feed stream 11 solubilized in the light solvent stream in line 13 in the first extraction column 10 results in a first overhead stream recovered from a top of the first extraction column flowing in line 12 and a remaining heavier bottoms stream recovered from a bottom of the first extraction column via line 14. The first overhead stream in line 12 is extracted with a portion of a first solvent. The first overhead stream in line 12 comprising heavy hydrocarbons and the portion of the first solvent are passed to a first separation vessel 20 which is in downstream communication with the first extraction vessel 10. The first overhead stream 12 is passed through a heat exchanger 15 and heated to a supercritical temperature by indirect heat exchange with heated recycle solvent stream in an overhead line 22 and further heated by passing it through a heater 17 installed in upstream communication with the first separation vessel 20. The heater 17 is utilized to raise the temperature of the first overhead stream in line 12 to form a heated first overhead stream in line 16 before passing it to the first separation vessel 20. The first separation vessel 20 separates the first overhead stream coming in line 16 into a hydrocarbon effluent stream recovered from a bottom of the first separation vessel in line 24 and a first recycle solvent stream recovered from a top of the first separation vessel in line 22 to be recycled to the first extraction column 10. The first recycled solvent stream in line 22 is added as an additional solvent, to the bottom of the first extraction column 10 via line 28. The first extraction column 10 will typically operate at 82°C (180°F) to 204°C (400°F) and 3.8 MPag (550 psig) to 6.0 MPag (870 psig). An air cooler 23 is installed in downstream communication with first separation vessel 20 on the first recycle solvent line 22 and in further downstream communication with the first extraction column 10. The air cooler 23 is utilized to cool and lower the temperature of the first recycle solvent stream in line 22 before passing the first recycle solvent stream 22 to the first extraction vessel 10. The cooled first recycle solvent stream in line 27 is passed through a heat exchanger 25 to cool a first bottom stream in line 14 and heat the first recycle solvent stream in line 27. A heated first recycle solvent stream in line 28 is then passed to the bottom of the first extraction vessel 10. The heavier portions of the heavy hydrocarbon feed stream 11 are insoluble and precipitate out as an asphaltene, heavy vacuum gas oil or pitch stream in line 14 taken from the bottom of the first extraction column 10. The first bottom stream taken from a bottom of the first extraction

column in line 14 is passed to a second extraction column 40 which is in downstream communication with the first extraction column 10. The first bottom stream in line 14 contains a greater concentration of aromatic compounds than the feed stream in the feed line 11.

[0033] A first effluent stream recovered from a bottom of the first separation vessel 20 in line 24 is rich in deasphalted oil. The first effluent stream in line 24 is passed through an additional heating device 19 installed in bottoms line 24 in downstream communication with the first separation vessel 20. The heated first effluent stream in line 26 is then passed to a first stripping column 30. The first stripping column 30 is in downstream communication with the first separation vessel 20 and yields a high-quality deasphalted oil stream as a first product stream recovered from a bottom of the first stripping column 30 in line 34 and a first stripped solvent stream recovered from a top of the stripping column 30 in line 32 which is sent to a solvent recovery column 80. The solvent recovery column 80 is in downstream communication with the overhead line 32 of the first stripping column 30. Steam is passed to the stripping column in line 31 to strip off the excess solvent contained in stripping column feed line 26. The first stripped solvent stream recovered in line 32 is passed to the solvent recovery column 80 for further recovery of light solvent such as propane. The solvent recovery column 80 produces a light solvent stream such as propane as a first recovered solvent stream in line 84 to be recycled to the first extraction column 10. The first separation vessel 20 will typically operate at 149°C (300°F) to 287°C (550°F) and 3.5 MPag (510 psig) to 5.2 MPag (750 psig). The first bottom stream in line 14 recovered from the bottom of the first extraction column 10 is heated by passing through a heat exchanger 25 where the heat of the bottom stream is exchanged with the cooled first recycle solvent stream coming in line 27. The heated bottom stream in line 14 is passed to the second extraction column 40. The first recycle solvent stream in line 27 is mixed with the first recovered solvent stream in line 84 to form a first recycle loop in line 27 before passing the first recycle solvent stream to heat exchanger 25. Hence, the mixed stream forming the recycle loop is involved in the bottom heat exchange. The mixed stream in line 27 after passing through heat exchanger forms the heated first recycle solvent stream in line 28 to be recycled to the first extraction column at the side bottom.

[0034] Similar, to the first extraction column 10 there is provided a second extraction column 40 installed in a downstream communication with the bottom line of the first extraction column 10 and with the first bottom stream14. A second fresh solvent stream in line 41 is supplied to the second extraction column 40 as a second fresh or a make-up solvent stream.

Preferably, the second fresh solvent may be butane. The second extraction column 40 yields a second bottom stream recovered in line 44 from a bottom of the second extraction column 40 and a second overhead stream recovered from a top of the second extraction column in an overhead line 42. The second overhead stream in line 42 is rich in heavy hydrocarbon compounds such as resins. The second overhead stream in line 42 is passed to a second separation vessel 50 installed in a downstream communication with the second overhead solvent line 42, to separate the heavy hydrocarbon compounds into a resin rich product. The second separation vessel 50 generates a second effluent stream in line 54 from a bottom of the second separation vessel 50 and a second recycle solvent stream from a top of the second separation vessel flowing in line 52. The second recycle solvent stream in line 52 is a heated solvent stream as recovered from the top and used for heat exchange in a heat exchanger 43 located in the second overhead stream in line 42 recovered from the top of the second extraction column 40. The second overhead stream in line 42 is comparatively cool when recovered and thus required to be heat exchanged in 43 to further raise the temperature of second overhead stream 42 before passing the second overhead stream 42 to the second separation vessel 50. The second recycle solvent stream in line 52 is recycled to the bottom of the second extraction column 40 as a recycle solvent stream in line 58. The second overhead stream in line 42 after being heat exchanged in 43 is again heated in a heater 45 to supercritical temperature and the heated overhead stream in line 46 is then passed to the second separation vessel 50. A second air cooler 47 is installed in a downstream communication with the second recycle solvent line 52 and the second extraction column 40. The air cooler 47 is utilized to cool or lower the temperature of the second recycle solvent stream in line 52 and form a cooled second recycle solvent stream in line 57. The cooled second recycle solvent stream in line 57 is passed through another heat exchanger 49 where the stream 57 exchanges heat with the heated second bottom stream in line 44 and forms a second recycle solvent stream in line 58 to be passed to the bottom of the second extraction vessel 40. The heated second bottom stream 44 is passed to second extraction vessel 40.

[0035] The second effluent stream 54 recovered from the bottom end of the second separation vessel 50 is passed through a heating device 55 installed in a downstream communication with the effluent line 54 of the second separation column 50 to form a heated effluent stream in line 56 which is passed to a second stripping column 60. The second stripping column 60 is in downstream communication with the heating device 55 and the bottom line of

the second separation vessel 50. There is provided an additional stream of steam to the second stripping column 60 via line 61. Steam may be used as a stripping fluid in the second stripping column 60. The second stripping column 60 strips off the excess solvent such as butane from a top of the second stripping column collected in line 62 and yields a heavy product stream such as a resin rich stream from a bottom of the second stripping column 60 in line 64. The second stripped solvent stream in line 62 is passed to the solvent recovery column 80 to recover a maximum amount of the second solvent stream rich in butane.

[0036] The second recovered solvent stream in line 86 from the solvent recovery column 80 is mixed with the second recycle solvent stream in line 57 to form a second recycle loop in line 57. The mixed cool recycle stream formed in the second recycle loop is passed through a heat exchanger 49 installed in the second bottom line 44 where the heated second bottom stream imparts heat to the mixed cool recycle stream whereby the temperature of the recycle stream rises and it is passed to the bottom of the second extraction column 40 as second recycled solvent stream in line 58. The cooled second recycle solvent stream in line 57 and the second recovered solvent stream in line 86 provides an additional extraction of products in the second extraction column 40 thereby improving the rate of extraction in column 40. The second separation vessel 50 will typically operate at 149°C (300°F) to 288°C (550°F) and 3.1 MPag (450 psig) to 4.8 MPag (700 psig).

[0037] In another embodiment, the second bottom stream recovered from a bottom of the second extraction column 40 in line 44 cooled in the heat exchanger 44 by heat exchange with the mixed cool recycle stream in line 57 is passed to a pitch stripper 70. The second bottom stream in line 44 is cooled by passing through the heat exchanger 49 before passing to a pitch stripper 70. The pitch stripper column 70 may be in a downstream communication with the bottom line 44 of the second extraction column 40. The pitch stripper 70 produces a solvent-lean pitch stream or a heavy product stream recovered from a bottom of the pitch stripping column in line 74 and a heavy solvent stream recovered in line 72 flowing from a top of the pitch stripping column 70. Steam in line 71 may be used as stripping fluid in the pitch stripping column 70. The pitch stripping column 70 will typically operate at 204°C (400°F) to 315°C (600°F) and 344 kPag (50 psig) to 1,034 kPag (150 psig).

[0038] In an embodiment it is shown how using light solvents such as propane to recover the highest quality product, such as deasphalted oil even though the yield per run is limited. Thereafter, using a heavier solvent such as butane or pentane allows for a higher total yield,

however, the initial products recovered have a lower product quality. In the embodiments described herein, in the initial separation of hydrocarbon feedstock solvent such as propane is used to recover a high-quality deasphalted oil and then a subsequent extraction using a heavier solvent such as butane or pentane to recover an additional resin product. The Applicants have found that at times when multi-stage solvent extraction is taking place then during the solvent extraction phase a heavier solvent such as butane or pentane may be used to extract more than one resin products such as resin1, or resin2 and so on. The instant application provides benefits and flexibility of integrating or utilizing more than one or two solvent extraction columns in continuation to the second extraction column to extract multiple resin-based products as deemed suitable before separating out a final heavy product stream such as pitch. Therefore, to maximize the number of recovered products, further extractions can be made to separate the feed stream into 4 or more product components. Additional heavier solvents and additional resin products can be obtained by using heavier hydrocarbon feeds, heavier solvents and modifying the extraction processes and apparatuses.

[0039] In an alternative embodiment as shown in FIG. 2, refers to the process and apparatus 200 comprising the second bottom stream in line 44 may alternatively be sent to a third extraction column 90. The third extraction column may be installed in downstream communication with the bottom line 44 of the second extraction column 40. The third extraction column 90 can be arranged in a manner like the second extraction column 40 is connected with the first extraction column 10 in downstream communication with the bottoms line or like the pitch stripping column 70 is connected with the second extraction column 40 is connected in downstream communication with a bottoms line of the second extraction column 40. The third extraction column is provided for further processing of the heavy bottom stream in line 44 recovered from the second extraction column. The third extraction column 90 may be added after the second extraction column 40 as an intermediate stage to recover some more resinous products even if they are of lower or lesser quality at reduced pressures as compared to resin product recovered in line 64. The third extraction column 90 extracts a third stream of product from the second bottom stream 44 in a presence of a heavy solvent. For enhanced extraction, a third fresh solvent stream via line 91 is passed to the third extraction column 90 in the middle. The third fresh solvent stream in line 91 is comparatively a heavier solvent such as pentane, hexane or heptane, or a mixture thereof, for recovering a comparatively heavier product from the bottom stream 44.

[0040] The third extraction column 90 generates a third solvent lean bottom stream in line 94 recovered from a bottom of the third extraction column 90 and a third overhead stream in line 92 recovered from a top of the third extraction column 90 wherein the third overhead stream comprises a resinous hydrocarbon stream and a portion of a third fresh solvent stream. The third overhead stream in line 92 is then passed to a third separation vessel 110 installed in downstream communication with the third extraction column 90 to separate the third overhead stream in line 92 into a resin rich effluent stream in line 114 recovered from a bottom of the third separation vessel 110 and a heavy solvent rich stream in line 112 recovered from a top of the third separation vessel 110. The heavy solvent stream is passed through an air cooler 97 before passing to the bottom of the third extraction column 90 as a third recycle solvent stream in line 118. The third overhead stream in line 92 is passed through a heat exchanger 93 and heated to a supercritical temperature by indirect heat exchange with heated third recycle solvent stream in an overhead line 112 and further heated by passing it through a heater 95 installed in an upstream communication with the third separation vessel 110. The heater 95 is utilized to raise the temperature of the third overhead stream in line 92 to form a heated third overhead stream in line 96 before passing it to the third separation vessel 110. The recycled solvent stream in line 112 when passed through the air cooler 97 is cooled before reaching to the bottom of the third extraction column to lower the temperature of the third solvent stream forming a cooled third recycle solvent stream in line 117. The cooled recycle stream in line 117 is heated by passing through another heat exchanger 99 installed in a further downstream with the air cooler 97 and with the third recycle solvent line 117, thereby forming a heated third recycle solvent stream in line 118.

[0041] The resin rich effluent stream in line 114 recovered from the bottom of the third separation vessel is heated in a heater 115 and the heated effluent stream in line 116 is passed to a third stripping column 120 located in downstream communication with the third separation vessel 110. Steam is passed to the third stripping column via line 121 to promote stripping. The third stripping column 120 generates a stripped solvent rich stream in an overhead line 122 comprising heavy solvents such as pentane, or hexane, or a mixture thereof. The heavy solvent stream in line 122 is passed to the solvent recovery column 80 to recover and regenerate a maximum amount of heavier solvent streams used for extraction purposes and this recovered solvent may be further used as a recycled solvent or a make-up solvent stream in any of the second or third extraction columns. The third stripping column 120 also generates a heavy

product stream from the bottom of the third stripping column as a third bottom stream in line 124 which is rich in resins. The resins product stream is recovered and stored to be used for end-product making or mixing purposes.

[0042] The third stripped solvent stream in line 122 passed to the solvent recovery column 80 is recovered from the solvent recovery column and recycled as a third recovered solvent stream in line 88 to the third extraction column 90 upon mixing with the third recycle solvent stream in line 117. A portion of the third recovered solvent stream in line 88 is recycled to the bottom of the solvent recovery column 80 by passing the third recovered solvent stream 88 through a reboiler 89 located at the bottom of the solvent recovery column 80. The third recovered solvent stream in line 88 may be rich in heavier solvents such as pentane, hexane or heptane, etc. The third bottom stream in line 94 from the third extraction column 90 may be passed to the pitch stripper 70 to further separate the third bottom stream 94 into a useful heavy solvent stream as the overhead stream in line 72 and a heavy bottom product stream from the bottom of the pitch stripper in line 74. The third bottom stream in line 94 is heated by passing through a heat exchanger 99 before passing to the pitch stripper 70. The heavy bottom product may be a pitch stream.

[0043] In an exemplary embodiment as shown in figures 1 and 2, a solvent recovery column 80 is shown which is used to recover all the solvent streams received from the first stripping column 30, the second stripping column 60 or the third stripping column 120 and the pitch stripper 70 in the overhead lines 32, 62, 122 and 72, respectively. The solvent recovery column 80 generally depicts how a fractionation column work to recover the solvent streams in a way that the light, the middle and the heavy solvent streams are recovered separately based upon the difference in their boiling points from the three separate sections of the column like an upper section, a middle section and a lower section. Most of the heavier solvents are recovered from the middle and lower sections of the solvent recovery columns. On the other hand, the light solvent stream often gets carried away with the excess water as per line 82 shown in the upper section of the solvent recovery column 80.

[0044] The solvent recovery column 80 discards excess water out of the column in line 83 after passing through a condenser 81 to a receiver 85 installed in downstream communication with the solvent recovery column. The stream 82 contains water and light solvent stream which are condensed and separated into the water stream and a light middle solvent stream. A portion of the light solvent stream is recycled to the first extraction column 10 and another portion is

recovered as such. The light solvent stream such as propane is recovered in line 84 as the first recovered solvent stream in line 84 and recycled to the bottom of the first extraction column 10. The middle solvent stream such as butane is recovered from the middle section of the solvent recovery column in line 86 as the second recovered solvent stream and recycled to the bottom of the second extraction column. Similarly, a heavy solvent stream such as pentane, hexane, heptane or other C7+ components, are recovered from the lower section of the solvent recovery column 80 as the third recovered solvent stream in line 88 and recycled to the third extraction column.

[0045] Any of the above lines, conduits, units, devices, vessels, surrounding environments, zones or similar may be equipped with one or more monitoring components including sensors, measurement devices, data capture devices or data transmission devices. Signals, process or status measurements, and data from monitoring components may be used to monitor conditions in, around, and on process equipment. Signals, measurements, and/or data generated or recorded by monitoring components may be collected, processed, and/or transmitted through one or more networks or connections that may be private or public, general or specific, direct or indirect, wired or wireless, encrypted or not encrypted, and/or combination(s) thereof; the specification is not intended to be limiting in this respect. Nevertheless, there may be sensors present on every stream to control the corresponding parameter(s) accordingly.

[0046] Signals, measurements, and/or data generated or recorded by monitoring components may be transmitted to one or more computing devices or systems. Computing devices or systems may include at least one processor and memory storing computer-readable instructions that, when executed by the at least one processor, cause the one or more computing devices to perform a process that may include one or more steps. For example, the one or more computing devices may be configured to receive, from one or more monitoring component, data related to at least one piece of equipment associated with the process. The one or more computing devices or systems may be configured to analyze the data. Based on analyzing the data, the one or more computing devices or systems may be configured to determine one or more recommended adjustments to one or more parameters of one or more processes described herein. The one or more computing devices or systems may be configured to transmit encrypted or unencrypted data that includes the one or more recommended adjustments to the one or more parameters of the one or more processes described herein.

[0047] While at least one exemplary embodiment has been presented in the foregoing detailed description of the invention, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the invention in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the invention. It being understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the invention as set forth in the appended claims.

SPECIFIC EMBODIMENTS

[0048] While the following is described in conjunction with specific embodiments, it will be understood that this description is intended to illustrate and not limit the scope of the preceding description and the appended claims.

[0049] A first embodiment of the invention is a multi-stage solvent extraction process comprising passing a heavy hydrocarbon feed stream and a first fresh solvent to a first extraction column to generate a first overhead stream and a first bottom stream; passing the first overhead stream to a first stripping column to generate a first product stream and a first stripped solvent stream; passing the first bottom stream from the first extraction column and a second fresh solvent to a second extraction column to generate a second overhead stream and a second bottom stream; passing the second overhead stream to a second stripping column to generate a second product stream and a second stripped solvent stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising passing the first stripped solvent stream from the first stripping column to a solvent recovery column to generate a first recovered solvent stream; and passing the second stripped solvent stream from the second stripping column to the solvent recovery column to generate a second recovered solvent stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising recycling at least a portion of the first recovered solvent stream to the first extraction column; and recycling at least a portion of the second recovered solvent stream to the second extraction column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising passing the second bottom stream from the

second extraction column to a pitch stripper to generate a pitch stream from a bottom of the pitch stripper and a heavy stripped solvent stream from an overhead of the pitch stripper. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising passing the heavy stripped solvent stream from the pitch stripper to the solvent recovery column to generate a heavy recovered solvent stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising passing the first overhead stream from the first extraction column to a first separation vessel prior to passing the first overhead stream to the first stripping column to generate a first recycle solvent stream from an overhead of the first separation vessel and a first separator bottoms stream from a bottom of the first separation vessel; and passing the first separator bottoms stream to the first stripping column to generate the first product stream from a bottom of the first stripping column and the first stripped solvent stream from an overhead of the first stripping column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising passing the first recycle solvent stream from the overhead of the first separation vessel to the first extraction column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising passing the second overhead stream from the second extraction column to a second separation vessel prior to passing the second overhead stream to the second stripping column to generate a second recycle solvent stream from an overhead of the second separation vessel and a second effluent stream from a bottom of the second separation vessel; and passing the second effluent stream to the second stripping column to generate the second product stream from a bottom of the second stripping column and the second stripped solvent stream from an overhead of the second stripping column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising passing the second recycle solvent stream from the overhead of the second separation vessel to the second extraction column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising passing the second bottom stream and a third fresh solvent to a third extraction column to generate a third overhead stream and a third bottom stream; passing the third overhead stream from the third extraction column to a third separation vessel to generate

a third recycle solvent stream from an overhead of the third separation vessel and a third effluent stream from a bottom of the third separation vessel; and passing the third effluent stream from the bottom of the third separation vessel to a third stripping column to generate a third product stream from a bottom of the third stripping column and a third stripped solvent stream from an overhead of the third stripping column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising passing the third recycle solvent stream from the overhead of the third separation vessel to the third extraction column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the first embodiment in this paragraph further comprising passing the third stripped solvent stream from the third stripping column to the solvent recovery column to generate a third recovered solvent stream; and recycling at least a portion of the third recovered solvent stream from the solvent recovery column to the third extraction column.

[0050] A second embodiment of the invention is a multi-stage solvent extraction process comprising passing a heavy hydrocarbon feed stream and a first fresh solvent to a first extraction column to generate a first overhead stream and a first bottom stream; passing the first overhead stream to a first stripping column to generate a first product stream and a first stripped solvent stream; passing the first bottom stream from the first extraction column and a second fresh solvent to a second extraction column to generate a second overhead stream and a second bottom stream; passing the second overhead stream to a second stripping column to generate a second product stream and a second stripped solvent stream; passing the second bottom stream from the second extraction column and a third fresh solvent to a third extraction column to generate a third overhead stream and a third bottom stream; and passing the third bottom stream to a pitch stripping column to generate a pitch stream from a bottom of the pitch stripper and a heavy stripped solvent stream from an overhead of the pitch stripper. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph further comprising passing the first stripped solvent stream, the second stripped solvent stream, and the heavy stripped solvent stream to a solvent recovery column; and recovering from the solvent recovery column at least a portion of the first recovered solvent stream, at least a portion of the second recovered solvent stream, and at least a portion of the heavy recovered solvent stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in

this paragraph further comprising recycling at least a portion of the first recovered solvent stream to the first extraction column; recycling at least a portion of the second recovered solvent stream to the second extraction column; and recycling at least a portion of the heavy recovered solvent stream to the third extraction column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph further comprising passing the third overhead stream to a third separation vessel to generate a third recycle solvent stream from an overhead of the third separation vessel and a third effluent stream from a bottom of the third separation vessel; and passing the third effluent stream from the bottom of the third separation vessel to a third stripping column to generate a third product stream from a bottom of the third stripping column and a third stripped solvent stream from an overhead of the third stripping column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph further comprising passing at least a portion of the third recycle solvent stream to the third extraction column. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the second embodiment in this paragraph further comprising passing the third stripped solvent stream from the third stripping column to the solvent recovery column; recovering from the solvent recovery column at least a portion of the third recovered solvent stream; and recycling at least a portion of the third recovered solvent stream to the third extraction column.

[0051] A third embodiment of the invention is an apparatus for multi-stage solvent extraction comprising: a first extraction column to produce a first overhead stream and a first bottom stream; a first stripping column in downstream communication with an overhead line of the first extraction column to produce a first product stream and a first stripped solvent stream from the first overhead stream; a second extraction column in downstream communication with a bottoms line of the first extraction column to produce a second overhead stream and a second bottom stream from the first bottom stream; a second stripping column in downstream communication with an overhead line of the second extraction column to produce a second product stream and a second stripped solvent stream from the second overhead stream. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the third embodiment in this paragraph further comprising a pitch stripper in downstream communication with a bottoms line of the second extraction column to produce a pitch stream and a heavy stripped solvent stream from the second bottom stream. An

embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the third embodiment in this paragraph further comprising a solvent recovery column in downstream communication with an overhead line of the first stripping column, an overhead line of the second stripping column and an overhead line of the pitch stripper. An embodiment of the invention is one, any or all of prior embodiments in this paragraph up through the third embodiment in this paragraph further comprising a first separation vessel in an upstream communication with an input line of the first stripping column to generate a first effluent stream and a first recycle solvent stream from the first overhead stream; and a second separation vessel in an upstream communication with an input line of the second stripping column to generate a second effluent stream and a second recycle solvent stream.

[0052] Without further elaboration, it is believed that using the preceding description that one skilled in the art can utilize the present invention to its fullest extent and easily ascertain the essential characteristics of this invention, without departing from the spirit and scope thereof, to make various changes and modifications of the invention and to adapt it to various usages and conditions. The preceding preferred specific embodiments are, therefore, to be construed as merely illustrative, and not limiting the remainder of the disclosure in any way whatsoever, and that it is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims. In the foregoing, all temperatures are set forth in degrees Celsius and, all parts and percentages are by weight, unless otherwise included.

CLAIMS:

1. A multi-stage solvent extraction process comprising:

passing a heavy hydrocarbon feed stream and a first fresh solvent to a first extraction column to generate a first overhead stream and a first bottom stream;

passing the first overhead stream to a first stripping column to generate a first product stream and a first stripped solvent stream;

passing the first bottom stream from the first extraction column directly to a second extraction column and passing a second fresh solvent to the second extraction column to generate a second overhead stream and a second bottom stream;

passing the second overhead stream to a second stripping column to generate a second product stream and a second stripped solvent stream

passing the first stripped solvent stream from the first stripping column and the second stripped solvent stream from the second stripping column to a solvent recovery column to generate a first recovered solvent stream and a second recovered solvent stream;

recycling a portion of the first recovered solvent stream to the first extraction column; and

recycling a portion of the second recovered solvent streams to the second extraction column.

2. The process of claim 1 further comprising passing the second bottom stream from the second extraction column to a pitch stripper to generate a pitch stream from a bottom of the pitch stripper and a heavy stripped solvent stream from an overhead of the pitch stripper.

3. The process of claim 2 further comprising passing the heavy stripped solvent stream from the pitch stripper to the solvent recovery column to generate a heavy recovered solvent stream.

4. The process of claim 1 further comprising:

passing the first overhead stream from the first extraction column to a first separation vessel prior to passing the first overhead stream to the first stripping column to generate a first recycle solvent stream from an overhead of the first separation vessel and a first separator bottoms stream from a bottom of the first separation vessel; and

passing the first separator bottoms stream to the first stripping column to generate the first product stream from a bottom of the first stripping column and the first stripped solvent stream from an overhead of the first stripping column.

5. The process of claim 4 further comprising passing the first recycle solvent stream from the overhead of the first separation vessel to the first extraction column.

6. The process of claim 1 further comprising:

passing the second overhead stream from the second extraction column to a second separation vessel prior to passing the second overhead stream to the second stripping column to generate a second recycle solvent stream from an overhead of the second separation vessel and a second effluent stream from a bottom of the second separation vessel; and

passing the second effluent stream to the second stripping column to generate the second product stream from a bottom of the second stripping column and the second stripped solvent stream from an overhead of the second stripping column.

7. The process of claim 6 further comprising passing the second recycle solvent stream from the overhead of the second separation vessel to the second extraction column.

8. An apparatus for multi-stage solvent extraction comprising:

a first extraction column to produce a first overhead stream and a first bottom stream;

a first stripping column in downstream communication with an overhead line of the first extraction column to produce a first product stream and a first stripped solvent stream from the first overhead stream;

a second extraction column in direct downstream communication with a bottoms line of the first extraction column to produce a second overhead stream and a second bottom stream from the first bottom stream;

a second stripping column in downstream communication with an overhead line of the second extraction column to produce a second product stream and a second stripped solvent stream from the second overhead stream; and

a solvent recovery column in communication with the first stripping column and the second stripping column to receive the first stripped solvent stream and the second stripped solvent stream to generate a first recovered solvent stream and a second recovered stream and to recycle the first

recovered solvent stream to the first extraction column and recycle the second recovered solvent stream to the second extraction column.