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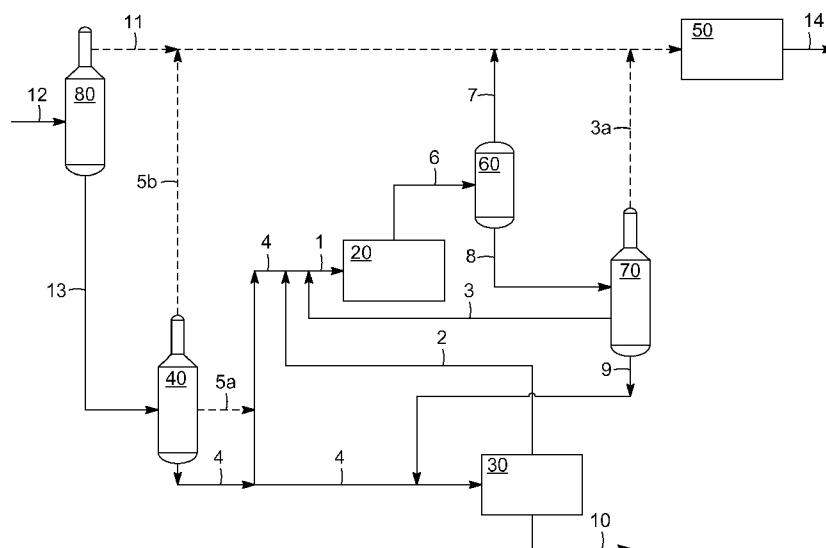


FIG. 1

(57) Abstract: Integrated slurry hydrocracking (SHC) and coking methods for making slurry hydrocracking (SHC) distillates are disclosed. Representative methods involve passing a slurry comprising a recycle SHC gas oil, a coker gas oil, a vacuum column resid, and a solid particulate through an SHC reaction zone in the presence of hydrogen to obtain the SHC distillate. Recovery of an SHC pitch from fractionation of the SHC reaction zone effluent provides an additional possibility for integration with the coker, and particularly via the upgrading of the SHC pitch in the coker to provide coke and lighter hydrocarbons such as SHC vacuum gas oil (VGO).



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INTEGRATED SLURRY HYDROCRACKING AND COKING PROCESS

FIELD OF THE INVENTION

[0001] The present invention relates to methods for preparing distillate hydrocarbons using slurry hydrocracking (SHC) to upgrade gas oils obtained from refinery operations and particularly delayed coking. The integration of SHC with coking and optionally other processes such as crude oil fractionation and/or hydrotreating may be used to obtain a high quality (e.g., high API gravity and/or low sulfur) distillate.

DESCRIPTION OF RELATED ART

[0002] Gas oils and particularly vacuum gas oil (VGO) are produced in a number of refinery operations that process heavy hydrocarbon feedstocks. Such operations include coking, crude oil fractionation, and visbreaking. Coking processes (e.g., delayed coking or fluidized coking) involve thermal (i.e., non-catalytic) cracking of atmospheric and vacuum column residues to generate lighter hydrocarbons and solid coke. See, for example, Meyers, R.A., HANDBOOK OF PETROLEUM REFINING PROCESSES, 3rd Ed., Ch. 12, McGraw-Hill (2004). Delayed coking in particular has become a predominant process for upgrading “bottom of the barrel” refinery process streams. However, the gas oils produced from coking operations, such as delayed coker VGO, are regarded as low quality products requiring further upgrading with fluid catalytic cracking (FCC), hydrocracking, and/or hydrotreating. Coker gas oils are unfortunately not easily processed according to such conventional methods, due to the significant levels of contaminants (e.g., metals and sulfur compounds) that deactivate supported metal catalysts, as well as coke precursors in these streams. The conversion of coker gas oils to more salable distillate and naphtha blending components for transportation fuels is therefore associated with a number of drawbacks.

[0003] Another process known to generate gas oils is slurry hydrocracking, which refers to the conversion of heavy hydrocarbon feedstocks in the presence of hydrogen and solid catalyst particles (e.g., as a metal nanoaggregate) in a slurry phase or optionally in a homogenous catalyst system using an oil-soluble metallic catalyst such as a metal sulfide compound. Representative slurry hydrocracking processes are described, for example, in US 5,755,955 and US 5,474,977. In addition to the VGO normally present in the reactor effluent, slurry hydrocracking produces a low-value, refractory pitch stream that normally

cannot be economically upgraded or even blended into other products such as fuel oil or synthetic crude oil, due to its high viscosity and solids content.

[0004] A particular source of synthetic crude oil of increasing interest, and for which blending components are sought to improve its flow characteristics, is bitumen. This low-quality hydrocarbonaceous material is recovered from oil sand deposits, such as those found in the vast Athabasca region of Alberta, Canada, as well as in Venezuela and the United States. Bitumen is recognized as a valuable source of “semi-solid” petroleum, which can be refined into many valuable end products including transportation fuels such as gasoline or even petrochemicals.

[0005] There is an ongoing need in the art for process in which heavy hydrocarbons (e.g., atmospheric column and vacuum column resid as well as gas oils) are converted or upgraded with improved efficiency. There is also a need for such processes in which the net production of low-value end products, including gas oils and pitch, is minimized. There is further a need for overall crude oil refining processes that include the upgrading of crude oil residues and particularly those obtained in significant proportions from heavy crude oil feedstocks.

SUMMARY OF THE INVENTION

[0006] Aspects of the invention relate to the finding that slurry hydrocracking (SHC) can be effectively integrated with other refining processes such as coking, hydrotreating, and/or crude oil fractionation to produce a high value distillate stream while recycling unwanted gas oils, preferably to extinction. SHC is generally known in the art for its ability to convert vacuum column residues to lighter products. However, it has now been surprisingly discovered that the use of coker gas oil (e.g., delayed coker VGO) as a heavy hydrocarbon feedstock component or incremental feed to SHC can suppress coke formation, in addition to being converted to more valuable naphtha and distillate products, in the SHC reactor and provide other important benefits associated with the resulting SHC/coking integrated process.

[0007] In a representative integrated process, low-quality coker gas oil is utilized in combination with recycled SHC gas oil, recovered from downstream fractionation/separation of the SHC effluent, in the overall heavy hydrocarbon feedstock to SHC. While portions of this feedstock also generally include conventional components such as vacuum column resid, the presence of coker gas oil improves the SHC reactor effluent quality, particularly with

respect to a reduced coke yield as well as an increased naphtha and distillate yield, as discussed above. Moreover, coker gas oil is (1) often readily available in large quantities, particularly in the case of refineries processing heavy crude oils, and (2) difficult to further upgrade using FCC, hydrocracking, or hydrotreating due to the high levels of contaminants that poison (deactivate) catalysts used in these processes. However, it has now been determined that coker gas oil is an attractive incremental feedstock (e.g., in combination with a vacuum column residue) which is efficiently cracked using SHC to yield lighter and more valuable net distillate and optionally naphtha products. Moreover, the integration of SHC with coking (e.g., delayed coking or fluidized coking) offers the further advantage, according to some embodiments, of passing the pitch byproduct of SHC to the coker inlet, together with atmospheric column or vacuum column resids that are conventionally processed in coking operations. The processing of SHC pitch in the coker thus allows for conversion/upgrading of this byproduct to higher value hydrocarbons and solid coke. Whether or not the SHC pitch is processed in the coker, the reduced yield of gas oil end products, such as hydrocarbons boiling the VGO range, in the integrated SHC/coking process, diminishes the need for the separate hydrotreating and/or hydrocracking of such products.

[0008] According to one representative embodiment, an integrated SHC/coking process is combined with hydrotreating of the SHC distillate. As a result of the low (or non-existent) net yield of gas oil products such as VGO, due to recycling of these heavy-boiling fractions back to the SHC reaction zone, the hydrotreated distillate has a sufficiently high API gravity (e.g., at least 20°), making it attractive for blending into a synthetic crude oil that is transported via a pipeline. Thus, the hydrotreated distillate, or even the SHC distillate without hydrotreating, may be obtained as a high quality transportation fuel blending component with only a minor amount or essentially no hydrocarbons boiling at a temperature representative of gas oils (e.g., greater than 343°C (650°F)).

[0009] The SHC process may also be integrated with an existing refinery hydrotreating process, conventionally used for sulfur- and nitrogen-containing compound removal from distillates, by hydrotreating a recovered SHC distillate product in conjunction with a straight-run distillate obtained from crude oil fractionation and/or other refinery distillate streams.

This integration may advantageously reduce overall capital costs of the complex. As discussed above, the integration of SHC with existing coking, optionally hydrotreating, and optionally other conventional refinery operations has the potential to provide significant

benefits in terms of improved processing efficiency and product yields, reduction or elimination of low-value refractory byproducts, and/or the associated capital cost reduction. According to a specific embodiment of the invention, a crude oil vacuum column bottoms residue stream provides a part of the heavy hydrocarbon feedstock to an SHC reactor, and is combined at the inlet of the SHC reactor with coker gas oil (e.g., coker VGO). Other portions of the residue from the vacuum column or other fractions from this column, may also be processed in the coker itself. In another embodiment, a coker gas oil or a portion of this refinery gas oil component provides, optionally together with a straight-run gas oil (e.g., straight-run VGO), a portion of the heavy hydrocarbon feedstock processed using SHC, and SHC pitch that is separated from the SHC effluent by fractionation may be in turn passed to the coker (e.g., delayed coker or fluidized coker) for upgrading.

[0010] These and other aspects and embodiments relating to the present invention are apparent from the following Detailed Description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 depicts a representative process in which slurry hydrocracking is integrated into a typical refinery flowscheme having an existing coker to produce net products of a hydrotreated distillate and coke from crude oil, with little or no overall production of refractory gas oils such as VGO.

[0012] FIG. 2 depicts a second representative integrated process.

DETAILED DESCRIPTION

[0013] Embodiments of the invention relate to the use of slurry hydrocracking (SHC) in combination with coking to upgrade a heavy hydrocarbon feedstock. A representative heavy hydrocarbon feedstock to the SHC is a mixture of SHC gas oil, recovered from the SHC effluent and recycled to an SHC reactor (or reaction zone), and a refinery coker gas oil.

According to one embodiment, for example, the heavy hydrocarbon feedstock comprises both a vacuum column residue and a coker gas oil (e.g., obtained from a delayed coker or a fluidized coker). Integration of a refinery coker operation with SHC provides important benefits as discussed above. The heavy hydrocarbon feedstock, in addition to recycled SHC gas oil and coker gas oil, may contain further components that can benefit from the SHC operation to decrease the overall molecular weight of the heavy hydrocarbon feedstock,

and/or remove organic sulfur and nitrogen compounds and metals. According to various embodiments, SHC is improved (e.g., by the suppression of coke formation) when a significant portion of the heavy hydrocarbon feedstock boils in a representative gas oil range (e.g., from 343°C (650°F) to 566°C (1050°F)) and only at most 80% by weight, and often at most 60% by weight, of the heavy hydrocarbon feedstock are compounds boiling above 566°C (1050°F).

[0014] In addition to SHC gas oil and coker gas oil, representative further components of the heavy hydrocarbon feedstock include residual oils such as a crude oil atmospheric distillation column residuum boiling above 343°C (650°F), a crude oil vacuum distillation column residuum boiling above 566°C (1050°F), tars, bitumen, coal oils, and shale oils. Other asphaltene-containing materials such as whole or topped petroleum crude oils including heavy crude oils may also be used as components processed by SHC. In addition to asphaltenes, these further possible components of the heavy 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 1,000 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. Overall, many of the heavy hydrocarbon feedstock components of the SHC process, including the coker gas oil, have properties that render them detrimental to other types of catalytic conversion processes such as hydrocracking and fluid catalytic cracking.

[0015] Integrated methods of processes for preparing SHC distillates generally involve passing a heavy hydrocarbon feedstock comprising a coker gas oil through an SHC reaction zone in the presence of hydrogen to provide an SHC effluent. The heavy hydrocarbon feedstock may be, but is not necessarily, present in a heterogeneous slurry catalyst system in the SHC reactor, in which the catalyst is in the form of a solid particulate. For purposes of the present disclosure, however, homogeneous catalyst systems, in which the catalytically active metal is present in the liquid phase and is dissolved in the heavy hydrocarbon feedstock (e.g., as an oil-soluble metal compound such as a metal sulfide), also fall within the definition of an SHC process, since homogeneous processes are equally applicable for

upgrading the same types of heavy hydrocarbon feedstocks with the same advantageous results associated with the embodiments discussed herein.

[0016] The SHC reaction is carried out in the presence of a combined recycle gas containing hydrogen and under conditions sufficient to crack at least a portion of the heavy hydrocarbon feedstock to a lighter-boiling SHC distillate fraction that is recovered from the effluent of the SHC reactor. The combined recycle gas is a mixture of a hydrogen-rich gas stream, recovered from the SHC effluent (e.g., as an overhead gas stream from a high pressure separator) and fresh make-up hydrogen that is used to replace hydrogen consumed in the SHC reactor or reaction zone and lost in any purge or vent gas streams or through dissolution. Operation without hydrogen recycle (i.e., with "once-through" hydrogen) represents an alternative mode of operation, in which a number of possible hydrogen sources of varying purity may be used.

[0017] The recovery of SHC distillate typically involves the use of flash separation and/or distillation of the SHC effluent, or a lower boiling fraction or cut thereof (e.g., a fraction having a lower distillation endpoint), to separate the SHC distillate as a lower boiling component from the co-produced (or unconverted) SHC gas oil in the SHC effluent. SHC distillate may therefore be recovered using a single stage of flash separation of the SHC effluent in an SHC high pressure separator or, alternatively, using a plurality of separation stages in an SHC fractionator, for example an atmospheric fractionator or SHC atmospheric distillation column. A particular representative embodiment involves passing the SHC effluent to an atmospheric or pressurized fractionator and recovering the SHC distillate as either an overhead product or a side cut (e.g., with some of the light end, C₄ hydrocarbon products removed). Further product recovery is then carried out by passing a bottoms product or residue from this first (e.g., atmospheric) SHC fractionator to a second (e.g., vacuum) SHC fractionator and recovering the SHC gas oil (e.g., heavy VGO). At least a portion of the SHC gas oil is then recycled to the SHC reactor or reaction zone, as discussed above. An SHC vacuum fractionator may be used to separate not only the SHC gas oil, for example as a side cut, but also the SHC pitch, for example as a vacuum column bottoms product or residue, as well as an SHC light VGO that may optionally be subjected to hydrotreating as described in greater detail below.

[0018] If a slurry is formed with the heavy hydrocarbon feedstock, normally passed upwardly through the SHC reaction zone, the slurry generally has a solid particulate content

in the range from 0.01% to 10% by weight. The solid particulate is generally a compound of a catalytically active metal, or a metal in elemental form, either alone or supported on a refractory material such as an inorganic metal oxide (e.g., alumina, silica, titania, zirconia, and mixtures thereof). Other suitable refractory materials include carbon, coal, and clays. Zeolites and non-zeolitic molecular sieves are also useful as solid supports. One advantage of using a support is its ability to act as a “coke getter” or adsorbent of asphaltene precursors that might otherwise lead to fouling of process equipment.

[0019] Catalytically active metals for use in hydroprocessing include those from Group IVB, Group VB, Group VIB, Group VIIB, or Group VIII of the Periodic Table, which are incorporated in the heavy hydrocarbon feedstock in amounts effective for catalyzing desired hydrotreating and/or hydrocracking reactions to provide, for example, lower boiling hydrocarbons that may be fractionated from the hydroprocessing slurry effluent as naphtha and/or distillate products in the substantial absence of the solid particulate. Representative metals include iron, nickel, molybdenum, vanadium, tungsten, cobalt, ruthenium, and mixtures thereof. The catalytically active metal may be present as a solid particulate in elemental form or as an organic compound or an inorganic compound such as a sulfide (e.g., iron sulfide) or other ionic compound. Metal or metal compound nanoaggregates may also be used to form the solid particulates.

[0020] Often, it is desired to form such metal compounds, as solid particulates, in situ from a catalyst precursor such as a metal sulfate (e.g., iron sulfate monohydrate) that decomposes or reacts in the hydroprocessing reaction zone environment, or in a pretreatment step, to form a desired, well-dispersed and catalytically active solid particulate (e.g., as iron sulfide). Precursors also include oil-soluble organometallic compounds containing the catalytically active metal of interest that thermally decompose to form the solid particulate (e.g., iron sulfide) having catalytic activity. Such compounds are generally highly dispersible in the heavy hydrocarbon feedstock and normally convert under pretreatment or hydroprocessing reaction zone conditions to the solid particulate that is contained in the slurry effluent. An exemplary in situ solid particulate preparation, involving pretreating the heavy hydrocarbon feedstock and precursors of the ultimately desired metal compound, is described, for example, in US 5,474,977.

[0021] Other suitable precursors include metal oxides that may be converted to catalytically active (or more catalytically active) compounds such as metal sulfides. In a

particular embodiment, a metal oxide containing mineral may be used as a precursor of a solid particulate comprising the catalytically active metal (e.g., iron sulfide) on an inorganic refractory metal oxide support (e.g., alumina). Bauxite represents a particular precursor in which conversion of iron oxide crystals contained in this mineral provides an iron sulfide catalyst as a solid particulate, whereby the iron sulfide after conversion being supported on the alumina that is predominantly present in the bauxite precursor.

[0022] Conditions in the SHC reactor or reaction zone generally include a temperature from 343°C (650°F) to 538°C (1000°F), a pressure from 3.5 MPa (500 psig) to 21 MPa (3000 psig), and a space velocity from 0.1 to 30 volumes of heavy hydrocarbon feedstock per hour per volume of said SHC zone. The catalyst and conditions used in the SHC reaction zone are suitable for upgrading the heavy hydrocarbon feedstock to provide a lower boiling component, namely an SHC distillate fraction, in the SHC effluent exiting the SHC reaction zone. The SHC distillate is generally recovered from the total SHC effluent (optionally after the removal of a hydrogen-rich gas stream for recycle to the SHC reactor, as discussed above) as a fraction having a distillation end point which is normally above that of naphtha. The SHC distillate, for example, may be recovered as a fraction having a distillation end point temperature typically in the range from 204°C (400°F) to 399°C (750°F), and often from 260°C (500°F) to 343°C (650°F), with heavier boiling compounds being recycled with the SHC gas oil or recovered in an SHC pitch stream that is optionally passed to a coker.

[0023] According to a particular embodiment, the SHC distillate and a higher-boiling SHC fraction may be recovered as an overhead and a bottoms stream, respectively, exiting a hot high pressure separator to which the SHC effluent is fed (optionally after the removal of the hydrogen-rich gas stream). Fractionation of the higher-boiling SHC fraction (e.g., in a vacuum distillation column) can then provide the SHC gas oil (e.g., a heavy VGO) and SHC pitch. As an alternative to single-stage separation in a high pressure separator, the SHC distillate may be recovered as a lower boiling component from the SHC effluent by fractionation (i.e., using multiple vapor-liquid equilibrium separation stages), for example as a side cut of an SHC atmospheric fractionator or distillation column. The residue or bottoms from this first SHC fractionator column can then be fed to a second SHC fractionator such as a vacuum distillation column to provide the SHC gas oil, SHC pitch, and optionally other fractions, such as an SHC light VGO. In integrated SHC/coking process that are combined with hydrotreating of the SHC distillate, all or a portion of this SHC light VGO may be used

together (mixed or combined) with the SHC distillate as a feed to a hydrotreating zone, as discussed below.

[0024] According to representative embodiments of the invention, the yield of SHC distillate (having a distillation end point in these ranges), is generally at least 30% by weight (e.g., from 30% to 65% by weight), normally at least 35% by weight (e.g., from 35% to 55% by weight), and often at least 40% by weight (e.g., from 40% to 50% by weight), of the combined SHC effluent weight (e.g., the combined weight of the SHC distillate and SHC gas oil). Depending on the desired end products, the SHC distillate may itself be fractionated to yield, for example, naphtha and diesel fuel having varying distillation end point temperatures. For example, a relatively light naphtha may be separated from the SHC distillate, having a distillation end point temperature from 175°C (347°F) to 193°C (380°F). According to other embodiments, a relatively heavy naphtha may be separated, having a distillation end point temperature from 193°C (380°F) to 204°C (400°F). The naphtha may be fractionated into one or more naphtha fractions, for example light naphtha, gasoline, and heavy naphtha, with representative distillation end points being in the ranges from 138°C (280°F) to 160°C (320°F), from 168°C (335°F) to 191°C (375°F), and from 193°C (380°F) to 216°C (420°F), respectively.

[0025] Also, depending on the particular separation/fractionation conditions used to recover the SHC distillate, this stream will normally contain quantities of organic nitrogen compounds and organic sulfur compounds. For example, the amount of total sulfur, substantially present in the form of organic sulfur compounds such as alkylbenzothiophenes, in this stream is generally from 0.1% to 4%, normally from 0.2% to 2.5%, and often from 0.5% to 2%. The amount of total nitrogen in the SHC distillate, substantially present in the form of organic nitrogen compounds such as non-basic aromatic compounds including cabazoles, will normally be from 100 ppm to 2%, and often from 100 ppm to 750 ppm. The SHC distillate will also generally contain a significant fraction of polyaromatics such as 2-ring aromatic compounds (e.g., fused aromatic rings such as naphthalene and naphthalene derivatives) as well as multi-ring aromatic compounds. According to some representative embodiments, the combined amount of 2-ring aromatic compounds and multi-ring aromatic compounds is at least 50% by weight of the SHC distillate, whereas the amount of mono-ring aromatic compounds (e.g., benzene and benzene derivatives such as alkylaromatic compounds) typically represents only at most 20% by weight.

[0026] The heavy hydrocarbon feedstock to the SHC reactor or reaction zone, as discussed above, comprises, in addition to the SHC gas oil (e.g., a heavy SHC VGO), a coker gas oil (e.g., a heavy coker gas oil) produced from delayed or fluidized coking, and often a vacuum column resid. In addition to the SHC and coker gas oils, other representative gas oil components that may be included in the heavy hydrocarbon feedstock include straight-run gas oils such as vacuum gas oil, recovered by fractional distillation of crude petroleum. Other gas oils produced in refineries include deasphalted gas oil and visbreaker gas oil. Gas oils, as well as the combined heavy hydrocarbon feedstock to the SHC reaction zone that comprises these gas oils, can therefore be a mixture of hydrocarbons boiling in range from 343°C (650°F) to an end point of 593°C (1100°F), with other representative distillation end points being 566°C (1050°F), 538°C (1000°F), and 482°C (900°F). A representative SHC gas oil has a distillation end point temperature from 427°C (800°F) to 538°C (1000°F). In the case of a straight-run vacuum gas oil, the distillation end point is governed by the crude oil vacuum fractionation column and particularly the fractionation temperature cutoff between the vacuum gas oil and vacuum column bottoms split. Thus, refinery gas oil components suitable in heavy hydrocarbon feedstocks to the SHC reactor, such as straight-run fractions, often result from crude oil fractionation or distillation operations, while other gas oil components are obtained following one or more hydrocarbon conversion reactions.

[0027] The SHC may be beneficially combined with hydrotreating, such that the recovered SHC distillate or a fraction thereof, (e.g., a naphtha fraction or a diesel fuel fraction) is catalytically hydrotreated in a hydrotreating zone to reduce the content of total sulfur and/or total nitrogen. According to specific embodiments, for example, a hydrotreated naphtha fraction may be obtained having a sulfur content of less than 30 ppm by weight, often less than 10 ppm by weight, and even less than 5 ppm by weight. A hydrotreated diesel fuel may be obtained having a sulfur content of less than 50 ppm by weight, often less than 20 ppm by weight, and even less than 10 ppm by weight. Hydrotreating of SHC distillates to provide a hydrotreated distillate, or hydrotreating of fractions of the SHC distillates, may therefore provide low-sulfur products and even ultra low sulfur naphtha and diesel fractions in compliance with applicable tolerances. According to a preferred embodiment, the SHC distillate has a sufficient API gravity for incorporation into a crude oil or synthetic crude oil obtained, for example, from tar sands. Representative API gravity values are greater than 20° (e.g., from 25° to 40°) and greater than 35° (e.g., from 40° to 55°).

[0028] In other embodiments, integration of the SHC process with hydrotreating can involve, for example, passing an additional refinery distillate stream, such as a straight-run distillate, to the hydrotreating zone or reactor. Whether or not one or more additional streams are hydrotreated in combination with the SHC distillate, the hydrotreating is normally carried out in the presence of a fixed bed of hydrotreating catalyst and a combined recycle gas stream containing hydrogen. Typical hydrotreating conditions include a temperature from 260°C (500°F) to 426°C (800°F), a pressure from 7.0 MPa (1000 psig) to 21 MPa (3000 psig), and a liquid hourly space velocity (LHSV) from 0.1 hr⁻¹ to 10 hr⁻¹. As is understood in the art, the Liquid Hourly Space Velocity (LHSV, expressed in units of hr⁻¹) is the volumetric liquid flow rate over the catalyst bed divided by the bed volume and represents the equivalent number of catalyst bed volumes of liquid processed per hour. The LHSV is closely related to the inverse of the reactor residence time. Suitable hydrotreating catalysts comprise a metal selected from the group consisting of nickel, cobalt, tungsten, molybdenum, and mixtures thereof, on a refractory inorganic oxide support.

[0029] As discussed above, the SHC process is advantageously integrated with refinery coking operations such as a delayed coker or a fluidized coker, wherein a coker gas oil such as heavy coker gas oil or coker VGO from delayed coking or fluidized coking is passed to the SHC reaction zone for upgrading, thereby beneficially suppressing coke formation in the SHC reactor. Another possibility for additional SHC/coking integration involves further utilization of an SHC pitch recovered from downstream separation and/or fractionation of the SHC effluent or a higher boiling fraction or cut of this effluent (e.g., a fraction having a higher initial boiling point). A typical SHC pitch stream may be recovered, for example, from the bottoms of an SHC vacuum column. According to a particular embodiment, in which a higher-boiling SHC effluent fraction is recovered as a bottoms stream exiting a hot high pressure separator or an SHC atmospheric fractionator, vacuum fractionation of this bottoms stream may be performed to yield the SHC gas oil that is recycled to the SHC reactor and the heavier SHC pitch stream. The SHC pitch may be passed to the coker (e.g., delayed coker or fluidized coker) for further integration of SHC and coking, such that the coker is used to convert not only a vacuum column bottoms residuum, but also the SHC pitch, thereby obtaining additional higher-value products from this SHC product. A typical SHC pitch will comprise or consist essentially of hydrocarbons boiling at temperatures greater than 482°C (900°F), usually greater than 538°C (1000°F), and often greater than 593°C (1100°F).

[0030] The present invention therefore relates to overall refinery flowschemes or processes for upgrading crude oil in the manner discussed above, and especially such overall processes wherein coker gas oil is part of the heavy hydrocarbon feedstock to an SHC process. Due to the internal recycle of SHC gas oil and SHC pitch in such overall flowschemes or processes, substantially all of the net products are either distillates or coke, with little or no production of low-value SHC gas oil and SHC pitch. According to representative embodiments of the invention, the yields of distillate products (e.g., a hydrotreated distillate as discussed above) and coke account for at least 80% of the overall process yields (e.g., from 80% to 99%), and often account for at least 85% of these yields (e.g., from 85% to 95%).

[0031] Further aspects of the invention relate to utilizing the SHC processes discussed above for making a synthetic crude oil or synthetic crude oil blending component. The processes involve passing a gas oil derived from a delayed coker or fluidized coker to an SHC process, with optional integration of the process with a hydrotreater as discussed above. Depending on the fractionation conditions used for downstream processing of the SHC effluent, an SHC distillate may be obtained having hydrocarbons essentially all boiling in the distillate range or lower. In representative embodiments, less than 20% by weight, and often less than 10% by weight, of the SHC distillate are hydrocarbons boiling at a temperature of greater than 343°C (650°F). Such SHC processes may additionally be integrated with crude oil fractionation columns, such that a straight-run distillate from a crude oil atmospheric distillation column is hydrotreated together the SHC distillate. Also, a VGO and/or vacuum residuum (or resid) from the vacuum distillation column may be passed to the SHC reactor or reaction zone (i.e., such that the VGO is part of the heavy hydrocarbon feedstock, together with the recycled SHC gas oil and coker gas oil).

[0032] A representative process flowscheme illustrating a particular embodiment for carrying out the methods described above is depicted in FIG. 1. FIG. 1 is to be understood to present an illustration of the invention and/or principles involved. As is readily apparent to one of skill in the art having knowledge of the present disclosure, methods according to various other embodiments of the invention will have configurations, components, and operating parameters determined, in part, by the specific feedstocks, products, and product quality specifications.

[0033] According to the embodiment illustrated in FIG. 1, a slurry hydrocracking (SHC) reactor or reaction zone 20 is integrated into a refinery flowscheme. The heavy hydrocarbon feedstock 1 to this reaction zone 20 is a combination of a coker vacuum gas oil (VGO) stream 2 from a delayed coking process 30 and an SHC VGO (e.g., SHC heavy VGO) recycle stream 3. An additional component of heavy hydrocarbon feedstock 1 to SHC process 20 is a vacuum column residue stream (or resid) 4 from crude vacuum column or tower 40, typically containing hydrocarbons boiling above (i.e., having a cutpoint temperature) of 566°C (1050°F). As shown in FIG. 1, atmospheric column 80 generates atmospheric residue or reduced crude stream 13, with a typical cutpoint temperature of 343°C (650°F) that is fractionated in vacuum column 40.

[0034] Optionally, the heavy hydrocarbon feedstock 1 further includes a VGO fraction 5a from vacuum column 40, which, for example, contains hydrocarbons boiling in the range from 343°C (650°F) to 566°C (1050°F). A portion of this VGO fraction 5a or a different VGO fraction 5b from vacuum column 40 may optionally be fed directly to distillate hydrotreating process 50. Another stream optionally used as an incremental feedstock to hydrotreating process 50 is straight-run distillate 11 obtained as a distillate fraction of crude oil stream 12, fractionated in crude atmospheric column or tower 80. A further stream which may be hydrotreated is a portion of the SHC VGO recycle stream 3 from SHC fractionator 70 or a different SHC VGO fraction 3a, such as light VGO that is a lower-boiling fraction compared to SHC VGO recycle stream 3. Thus, SHC distillate 7, optionally with any combination or all of streams 11, 5b, and/or 3a, is used to obtain hydrotreated distillate 14 as a product of the overall process having reduced nitrogen compound and sulfur compound impurities and/or an API gravity as discussed above that may be utilized as a blending component for synthetic crude oil.

[0035] The SHC process, including SHC reaction zone 20, is therefore utilized in an integrated manner to upgrade VGO stream 2 from delayed coking process 30, which, as discussed above, beneficially suppresses coke formation in the SHC reactor or reaction zone. The total SHC effluent stream 6 is then subjected to downstream separation/fractionation operations to recover upgraded products, remove pitch, and recycle intermediates. According to the embodiment illustrated in FIG. 1, total SHC effluent is separated using hot high pressure separator (HHPS) 60 to recover SHC distillate 7, generally boiling in a range above that of naphtha. A higher-boiling fraction 8 recovered from SHC effluent and in particular

from the bottoms of HHPS 60 is then fractionated in SHC fractionator 70, typically operating as a vacuum column. SHC fractionator separates SHC VGO recycle stream 3 from SHC pitch stream 9, which, as discussed above, is advantageously used as a feedstock to delayed coker 30. Delayed coker 30 generates coke 10 and coker VGO stream 2 as a recycle stream (internal to the overall process) that is a refinery gas oil component of heavy hydrocarbon feedstock 1 to SHC process 20.

[0036] FIG. 2 depicts an alternative flowscheme that is a variation of the embodiment depicted in FIG. 1, with the reference numbers of FIG. 1 being used to represent similar process streams and equipment shown in FIG. 2. According to this embodiment, a first (e.g., atmospheric) SHC fractionator 60-A is used in place of HHPS (reference number 60 in FIG. 1) to recover SHC distillate 7-A, which is a side cut removed from first SHC fractionator 60-A, for example having light ends (e.g., C_4 hydrocarbon products) in the total SHC effluent stream 6 removed. A higher boiling fraction 8-A is removed as a bottoms product from first SHC fractionator 60-A and then fractionated in a second (e.g., vacuum) SHC fractionator 70, corresponding to fractionator 70 in FIG. 1. The bottoms product may be fractionated in second vacuum fractionator 70 to yield SHC VGO recycle stream 3, SHC pitch stream 9, and SHC VGO fraction 3a, which may be a lighter boiling fraction, such as light VGO, compared to SHC VGO recycle stream 3.

[0037] As shown in FIG. 2, SHC pitch stream 9 is used as a feedstock to a delayed coker and particularly coker fractionator 30-A. The coker fractionator bottoms product 16 is passed to one of two coker drums 30-B using T-valve or switch valve 30-C. Coke 10 is then removed and recovered coker liquid 15 is sent back to coker fractionator 30-A, which is used to fractionate coker VGO 2, for example as a heavy coker gas oil, and optionally one or more lighter coker hydrocarbon products 17 such as a coker distillate and/or coker naphtha that may be hydrotreated in hydrotreating process 50 in combination with SHC distillate 7-A and optionally other streams as mentioned above.

[0038] The overall processes illustrated in both FIG. 1 and FIG. 2, in which an SHC process is integrated with a delayed coker, therefore produces essentially the net products of coke 10 and hydrotreated distillate 14. As is apparent from this description, overall aspects of the invention are directed to the integration of slurry hydrocracking (SHC) and coking to optimize refinery operations. In view of the present disclosure, it will be seen that several advantages may be achieved and other advantageous results may be obtained. Those having

skill in the art will recognize the applicability of the methods disclosed herein to any of a number of integrated SHC processes. Those having skill in the art, with the knowledge gained from the present disclosure, will recognize that various changes could be made in the above processes without departing from the scope of the present disclosure.

CLAIMS:

1. An integrated process for preparing a slurry hydrocracking (SHC) distillate, the process comprising:

- 5 a) passing a heavy hydrocarbon feedstock comprising a coker gas oil through an SHC reaction zone in the presence of hydrogen to provide an SHC effluent; and
 b) recovering said SHC distillate from said SHC effluent.

2. The process of claim 1, wherein said coker gas oil is obtained from a delayed coker or a fluidized coker.

10 3. The process of claim 1 or 2, further comprising recovering an SHC gas oil from said SHC effluent, and recycling said SHC gas oil to said SHC zone, whereby said heavy hydrocarbon feedstock comprises said SHC gas oil and said coker gas oil.

4. The process of claim 3, wherein said SHC distillate is separated, as a lower boiling component, from said SHC gas oil by flash separation or fractionation of said SHC effluent.

15 5. The process of any of claims 1 to 4, further comprising hydrotreating a distillate feedstock comprising said SHC distillate in a hydrotreating zone to obtain a hydrotreated distillate.

6. The process of claim 5, wherein said distillate feedstock further comprises, in addition to said SHC distillate, a straight-run distillate.

20 7. The process of claim 5 or 6, wherein said hydrotreated distillate has an API gravity of at least 20°.

8. The process of any of claims 1 to 7, further comprising recovering an SHC pitch, as a higher boiling component, by flash separation or fractionation of said SHC effluent.

25 9. The process of claim 8, further comprising passing said SHC pitch to a coker that produces said coker gas oil.

10. A method for making a distillate hydrocarbon component by integrating slurry hydrocracking (SHC), coking, and hydrotreating, the method comprising:

- 30 a) passing a slurry comprising an SHC gas oil, a coker gas oil obtained from a delayed coker or a fluidized coker, and a solid particulate through an SHC reaction zone in the presence of hydrogen to provide an SHC effluent;
 b) recovering said SHC gas oil, an SHC distillate, and SHC pitch from said SHC effluent;

- c) recycling said SHC gas oil to said SHC reaction zone;
- d) hydrotreating said SHC distillate to obtain said synthetic crude oil as a hydrotreated distillate; and
- e) passing said SHC pitch to said delayed coker or said fluidized coker to obtain a coke product.

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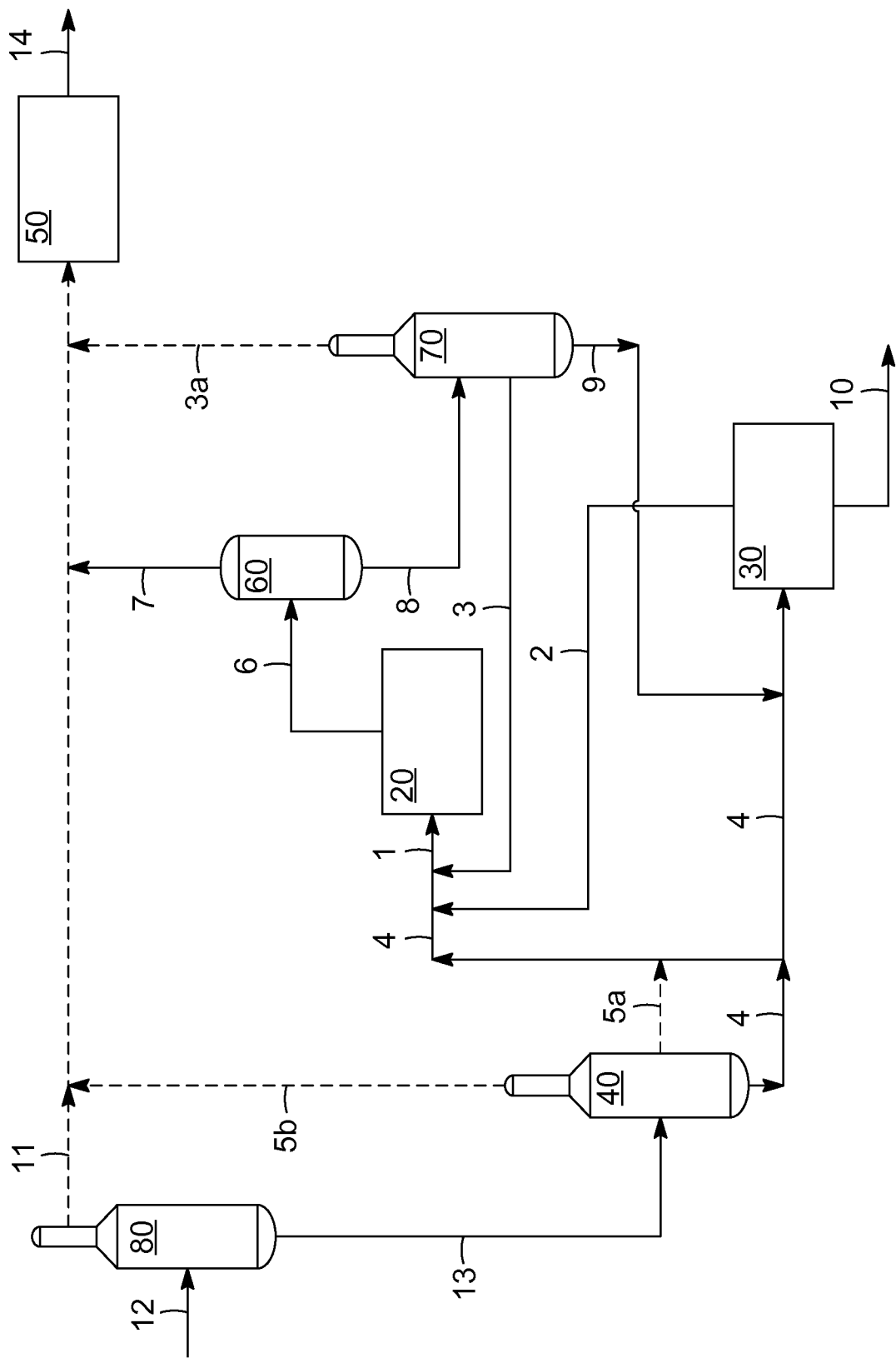


FIG. 1

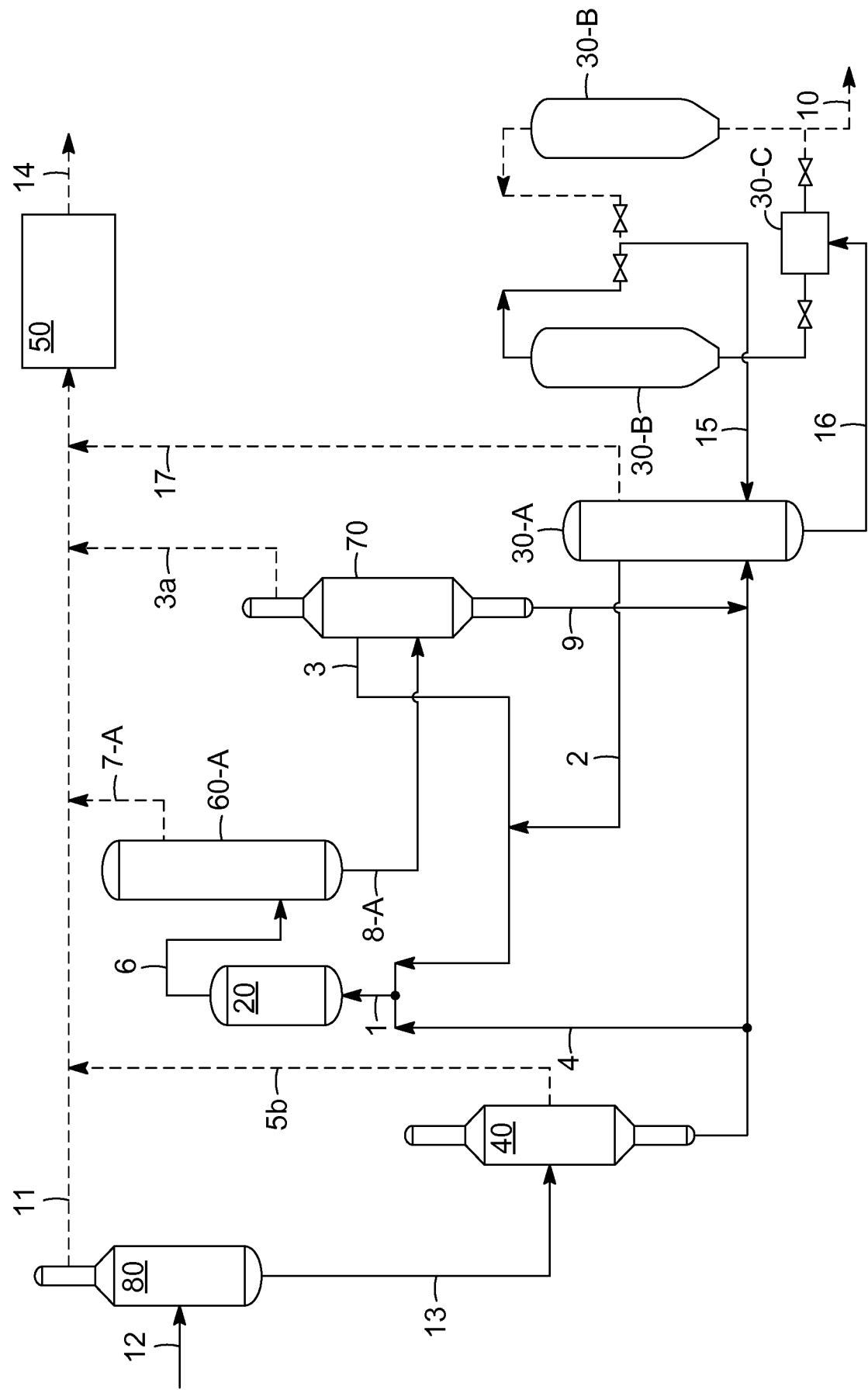


FIG. 2