

## RESIDUE HYDROCRACKING PROCESSING

### FIELD OF THE DISCLOSURE

**[0001]** Embodiments disclosed herein relate generally to hydroconversion processes, including processes for hydrocracking residue and other heavy hydrocarbon fractions. More specifically, embodiments disclosed herein relate to solvent deasphalting of a residuum hydrocarbon feedstock, processing the resulting deasphalted oil in a residue desulfurization unit and a residue hydrocracking unit, and processing the pitch from the solvent deasphalting unit in a separate residue hydrocracking unit.

### BACKGROUND

**[0002]** As the worldwide demand for gasoline and other distillate refinery products such as kerosene, jet and diesel has steadily increased, there has been a significant trend toward conversion of higher boiling compounds to lower boiling ones. To meet the increasing demand for distillate fuels, refiners have investigated various reactions, such as hydrocracking, residual desulfurization (RDS), and solvent deasphalting (SDA), to convert Residuum, Vacuum Gas Oil (VGO) and other heavy petroleum feedstocks to jet and diesel fuels.

**[0003]** Catalysts have been developed that exhibited excellent distillate selectivity, reasonable conversion activity and stability for heavier feedstocks. The conversion rates attainable by the various processes are limited, however. For example, RDS units alone can produce a 1 wt% sulfur fuel from high sulfur residues, but conversions are generally limited to about 35% to 40%. Others have proposed to use SDA units to solvent deasphalt the residuum feed and process the deasphalted oil only in a Residuum Hydrocracking Unit (RHU). Also, others have processed the unconverted vacuum residuum from a RHU in an SDA unit and recycled the deasphalted oil (DAO) back to the front end of the RHU. Still others have proposed to process the SDA pitch directly in a RHU. Nonetheless, economic processes to achieve high hydrocarbon conversions and sulfur removal are desired.

## SUMMARY

[0004] In one aspect, embodiments disclosed herein relate to a process for upgrading residuum hydrocarbons. The process includes the following steps: solvent deasphalting a residuum hydrocarbon fraction to produce a deasphalted oil fraction and an asphalt fraction; contacting the asphalt fraction and hydrogen with a first hydroconversion catalyst in a first ebullated bed hydroconversion reactor system; recovering an effluent from the first ebullated bed hydroconversion reactor system; fractionating the effluent from the first ebullated bed hydroconversion reactor system to recover one or more hydrocarbon fractions; contacting the deasphalted oil fraction and hydrogen with a second hydroconversion catalyst in a residue hydrodesulfurization unit; recovering an effluent from the residue hydrodesulfurization unit; contacting the residue hydrodesulfurization unit effluent or a portion thereof with a third hydroconversion catalyst in a hydrocracking reactor system; recovering an effluent from the hydrocracking reactor system; and fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions.

[0005] In another aspect, embodiments disclosed herein relate to a process for upgrading residuum hydrocarbons which includes the following steps: solvent deasphalting a residuum hydrocarbon fraction to produce a deasphalted oil fraction and an asphalt fraction; contacting the asphalt fraction and hydrogen with a first hydroconversion catalyst in a first ebullated bed hydroconversion reactor system; recovering an effluent from the first ebullated bed hydroconversion reactor system; fractionating the effluent from the first ebullated bed hydroconversion reactor system to recover one or more hydrocarbon fractions; contacting the deasphalted oil fraction and hydrogen with a second hydroconversion catalyst in a residue hydrodesulfurization unit; recovering an effluent from the residue hydrodesulfurization unit; contacting the residue hydrodesulfurization unit effluent with a third hydroconversion catalyst in a hydrocracking reactor system; recovering an effluent from the hydrocracking reactor system; and fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions.

[0006] In another aspect, embodiments disclosed herein relate to a process for upgrading residuum hydrocarbons which includes the following steps: solvent deasphalting a residuum hydrocarbon fraction to produce a deasphalted oil fraction and an asphalt fraction; contacting the asphalt fraction and hydrogen with a first hydroconversion catalyst in a first ebullated bed hydroconversion reactor system; recovering an effluent from the first ebullated bed hydroconversion reactor system; fractionating the effluent

from the first ebullated bed hydroconversion reactor system to recover one or more hydrocarbon fractions; contacting the deasphalted oil fraction and hydrogen with a second hydroconversion catalyst in a residue hydrodesulfurization unit; recovering an effluent from the residue hydrodesulfurization unit; fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions including a vacuum residua hydrocarbon fraction; contacting the vacuum residua hydrocarbon fraction with a third hydroconversion catalyst in a hydrocracking reactor system; recovering an effluent from the hydrocracking reactor system; and fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions.

In another aspect, embodiments disclosed herein relate to a process for upgrading residuum hydrocarbons which includes the following steps: solvent deasphalting a residuum hydrocarbon fraction to produce a deasphalted oil fraction and an asphalt fraction; contacting the asphalt fraction and hydrogen with a first hydroconversion catalyst in a first ebullated bed hydroconversion reactor system; recovering an effluent from the first ebullated bed hydroconversion reactor system; contacting the effluent from the first ebullated bed hydroconversion reactor with a second hydroconversion catalyst prior to fractionating the effluent from the first ebullated bed hydroconversion reactor system to recover one or more hydrocarbon fractions; contacting the deasphalted oil fraction and hydrogen with a third hydroconversion catalyst in a residue hydrodesulfurization unit; recovering an effluent from the residue hydrodesulfurization unit; contacting the residue hydrodesulfurization unit effluent with a fourth hydroconversion catalyst in a hydrocracking reactor system; recovering an effluent from the hydrocracking reactor system; and fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions.

In another aspect, embodiments disclosed herein relate to a process for upgrading residuum hydrocarbons which includes the following steps: solvent deasphalting a residuum hydrocarbon fraction to produce a deasphalted oil fraction and an asphalt fraction; contacting the asphalt fraction and hydrogen with a first hydroconversion catalyst in a first ebullated bed hydroconversion reactor system; recovering an effluent

from the first ebullated bed hydroconversion reactor system; fractionating the effluent from the first ebullated bed hydroconversion reactor system to recover one or more hydrocarbon fractions; contacting the deasphalted oil fraction and hydrogen with a second hydroconversion catalyst in a residue hydrodesulfurization unit; recovering an effluent from the residue hydrodesulfurization unit; contacting the residue hydrodesulfurization unit effluent or a portion thereof with a third hydroconversion catalyst in a hydrocracking reactor system; recovering an effluent from the hydrocracking reactor system; and contacting the effluent from the hydrocracking reactor system with a fourth hydroconversion catalyst prior to fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions.

[0007] Other aspects and advantages will be apparent from the following description and the appended claims.

#### BRIEF DESCRIPTION OF DRAWINGS

[0008] Figure 1 is a simplified process flow diagram of a process for upgrading residuum hydrocarbon feedstocks according to embodiments disclosed herein.

[0009] Figure 2 is a simplified process flow diagram of a process for upgrading residuum hydrocarbon feedstocks according to embodiments disclosed herein.

[0010] Figure 3 is a simplified process flow diagram of a process for an integrated hydroprocessing reactor system to be used with a process for upgrading residuum hydrocarbon feedstocks according to embodiments disclosed herein.

[0011] Figure 4 is a simplified alternate process flow diagram of a process for an integrated hydroprocessing reactor system to be used with a process for upgrading residuum hydrocarbon feedstocks according to embodiments disclosed herein.

#### DETAILED DESCRIPTION

[0012] In one aspect, embodiments herein relate generally to hydroconversion processes, including processes for hydrocracking residue and other heavy hydrocarbon fractions. More specifically, embodiments disclosed herein relate to solvent deasphalting of a residuum hydrocarbon feedstock, processing the resulting deasphalted oil in a residue desulfurization unit and a residue hydrocracking unit, and processing the pitch from the solvent deasphalting in a separate residue hydrocracking unit.

[0013] Hydroconversion processes disclosed herein may be used for reacting residuum hydrocarbon feedstocks at conditions of elevated temperatures and pressures in the presence of hydrogen and one or more hydroconversion catalyst to convert the feedstock to lower molecular weight products with reduced contaminant (such as sulfur and/or nitrogen) levels. Hydroconversion processes may include, for example, hydrogenation, hydrodesulfurization, hydrodenitrogenation, hydrocracking, hydrodemetallization, hydroDeCCR or hydrodeasphaltenization, etc.

[0014] As used herein, residuum hydrocarbon fractions, or like terms referring to residuum hydrocarbons, are defined as a hydrocarbon fraction having boiling points or a boiling range above about 340°C but could also include whole heavy crude processing. Residuum hydrocarbon feedstocks that may be used with processes disclosed herein may include various refinery and other hydrocarbon streams such as petroleum atmospheric or vacuum residua, deasphalted oils, deasphalter pitch, hydrocracked atmospheric tower or vacuum tower bottom, straight run vacuum gas oils, hydrocracked vacuum gas oils, fluid catalytically cracked (FCC) slurry oils, vacuum gas oils from an ebullated bed hydrocracking process, shale-derived oils, coal-derived oils, tar sands bitumen, tall oils, bio-derived crude oils, black oils, as well as other similar hydrocarbon streams, or a combination of these, each of which may be straight run, process derived, hydrocracked, partially desulfurized, and/or partially demetallized streams. In some embodiments, residuum hydrocarbon fractions may include hydrocarbons having a normal boiling point of at least 480°C, at least 524°C, or at least 565°C.

[0015] Referring now to Figure 1, a residuum hydrocarbon fraction (residuum) 10 is fed to a Solvent Deasphalting Unit (SDA) 12. In SDA 12, the residuum hydrocarbon is contacted with a solvent to selectively dissolve asphaltenes and similar hydrocarbons to produce a deasphalted oil (DAO) fraction 14 and a pitch fraction 15.

[0016] Solvent deasphalting may be performed in SDA 12, for example, by contacting the residuum hydrocarbon feed with a light hydrocarbon solvent at temperatures in the range from about 38°C to about 204°C and pressures in the range from about 7 barg to about 70 barg. Solvents useful in SDA 12 may include C3, C4,

C5, C6 and/or C7 hydrocarbons, such as propane, butane, isobutene, pentane, isopentane, hexane, heptane, or mixtures thereof, for example. The use of the light hydrocarbon solvents may provide a high lift (high DAO yield). In some embodiments, the DAO fraction 14 recovered from the SDA unit 12 may contain 500 wppm to 5000 wppm asphaltenes (i.e., heptane insoluble), 50 to 150 wppm metals (such as Ni, V, and others), and 5 wt% to 15 wt% Conradson Carbon Residue.

[0017] Pitch fraction 15 may then be mixed with a diluent 17, such as SRVGO (straight run vacuum gas oil) to produce a diluted pitch (residuum) fraction 19. Diluted pitch fraction 19 and hydrogen 21 may then be fed to an ebullated bed reactor system 42, which may include one or more ebullated bed reactors, where the hydrocarbons and hydrogen are contacted with a hydroconversion catalyst to react at least a portion of the pitch with hydrogen to form lighter hydrocarbons, demetallize the pitch hydrocarbons, remove Conradson Carbon Residue, or otherwise convert the residuum to useful products.

[0018] Reactors in ebullated bed reactor 42 may be operated at temperatures in the range from about 380°C to about 450°C, hydrogen partial pressures in the range from about 70 bara to about 170 bara, and liquid hourly space velocities (LHSV) in the range from about 0.2 h<sup>-1</sup> to about 2.0 h<sup>-1</sup>. Within the ebullated bed reactors, the catalyst may be back mixed and maintained in random motion by the recirculation of the liquid product. This may be accomplished by first separating the recirculated oil from the gaseous products. The oil may then be recirculated by means of an external pump, or, as illustrated, by a pump having an impeller mounted in the bottom head of the reactor.

[0019] Target conversions in ebullated bed reactor system 42 may be in the range from about 40 wt% to about 75 wt%, depending upon the feedstock being processed. In any event, target conversions should be maintained below the level where sediment formation becomes excessive and thereby prevent continuity of operations. In addition to converting the residuum hydrocarbons to lighter hydrocarbons, sulfur removal may be in the range from about 40 wt% to about 80 wt%, metals removal may be in the range from about 60 wt% to 85 wt% and Conradson Carbon Residue (CCR) removal may be in the range from about 30 wt% to about 65 wt%.

[0020] Following conversion in ebullated bed reactor system 42, the partially converted hydrocarbons may be recovered via flow line 44 as a mixed vapor / liquid effluent and fed to a fractionation system 46 to recover one or more hydrocarbon fractions. As illustrated, fractionation system 46 may be used to recover an offgas 48 containing light hydrocarbon gases and hydrogen sulfide ( $H_2S$ ), a light naphtha fraction 50, a heavy naphtha fraction 52, a kerosene fraction 54, a diesel fraction 56, a light vacuum gas oil fraction 58, a heavy gas oil fraction 60, and a vacuum residuum fraction 62. In some embodiments, vacuum residuum fraction 62 may be recycled for further processing, such as to SDA unit 12, ebullated bed reactor system 42, or other reaction units 16, 20 discussed below. In other embodiments, vacuum residuum fraction 62 may be blended with a cutter fraction 66 to produce a fuel oil.

[0021] Fractionation system 46 may include, for example, a high pressure high temperature (HP/HT) separator to separate the effluent vapor from the effluent liquids. The separated vapor may be routed through gas cooling, purification, and recycle gas compression, or may be first processed through an Integrated Hydroprocessing Reactor System (which may include one or more additional hydroconversion reactors), alone or in combination with external distillates and/or distillates generated in the hydrocracking process, and thereafter routed for gas cooling, purification, and compression.

[0022] The separated liquid from the HP/HT separator may be flashed and routed to an atmospheric distillation system along with other distillate products recovered from the gas cooling and purification section. The atmospheric tower bottoms, such as hydrocarbons having an initial boiling point of at least about  $340^{\circ}C$ , such as an initial boiling point in the range from about  $340^{\circ}C$  to about  $427^{\circ}C$ , may then be further processed through a vacuum distillation system to recover vacuum distillates.

[0023] The vacuum tower bottoms product, such as hydrocarbons having an initial boiling point of at least about  $480^{\circ}C$ , such as an initial boiling point in the range from about  $480^{\circ}C$  to about  $565^{\circ}C$ , may then be routed to tankage after cooling, such as by direct heat exchange or direct injection of a portion of the residuum hydrocarbon feed into the vacuum tower bottoms product.

- [0024] In some embodiments, the fuel oil fraction 62 recovered following processing in ebullated bed reactor system 42 and fractionation system 46 may have a sulfur content of 2.25 wt% or less; 2.0 wt% or less in other embodiments; and 1.75 wt% or less in yet other embodiments.
- [0025] The deasphalted oil fraction 14 recovered from SDA unit 12 may be optionally heated, combined with a hydrogen rich gas 23, and fed to a residue desulfurization (RDS) unit 16. RDS unit 16 may include one or more residue desulfurization reactors.
- [0026] In some embodiments, RDS unit 16 may include one or more upflow reactors (UFR) (not illustrated) upstream of the RDS reactors. The DAO feed may be mixed with the hydrogen rich gas 23 upstream of the reactors or with the feed entering the bottom of the UFRs (s), and in some embodiments with the effluent recovered from the UFRs. The UFR may help to increase the catalyst life in the downstream RDS catalyst beds, as well as remove some sulfur, Conradson Carbon Residue, and asphaltenes in the feed.
- [0027] Operating conditions in the RDS unit 16, including the UFRs and/or RDS reactors, may include temperatures in the range from about 360°C to about 400°C and hydrogen partial pressures ranging from about 70 barg to about 170 barg. The RDS may achieve a desulfurization rate of at least 70 wt% in some embodiments, at least 80 wt% in other embodiments, and up to or above 92 wt% in yet other embodiments.
- [0028] Effluent 18, recovered from the RDS unit 16, may then be further processed in a hydrocracking reactor system 20, which may include one or more hydrocracking reactors, arranged in series or parallel.
- [0029] In reactor system 20, the RDS effluent may be hydrocracked under hydrogen partial pressures in the range from about 70 bara to about 170 bara, temperatures in the range from about 380°C to about 450°C, and LHSV in the range from about 0.2 h<sup>-1</sup> to about 2.0 h<sup>-1</sup> in the presence of a catalyst. In some embodiments, operating conditions in hydrocracking reactor system 20 may be similar to those described above for ebullated bed reactor system 42. In other embodiments, such as where hydrocracking reactor system 20 includes one or more ebullated bed reactors, the ebullated bed reactors may be operated at higher severity conditions than those in reactor system 42,

higher severity referring to a higher temperature, a higher pressure, a lower space velocity or combinations thereof.

[0030] Depending on the vacuum residuum feedstock properties, the extent to which metals and Conradson Carbon Residue are removed in the RDS unit 16, and the SDA solvent used, the DAO recovered may be treated in a fixed bed reaction system or an ebullated bed reactor system 20, as illustrated, which may be similar to that described above for ebullated bed reactor system 42 with respect to gas / liquid separations and catalyst recirculation, among other similarities. A fixed bed reactor system may be used, for example, where the metals and Conradson Carbon Residue content of the DAO is less than 80 wppm and 10 wt%, respectively, such as less than 50 wppm and 7 wt%, respectively. An ebullated bed reactor system may be used, for example, when the metals and Conradson Carbon Residue contents are higher than those listed above for the fixed bed reactor system. In either hydrocracking reactor system, the number of reactors used may depend on the charge rate, the overall target residue conversion level, and the level of conversion attained in RDS unit 16, among other variables. In some embodiments, one or two hydrocracking reactors may be used in hydrocracking reactor system 20.

[0031] Following conversion in hydrocracking reactor system 20, the partially converted hydrocarbons may be recovered via flow line 22 as a mixed vapor / liquid effluent and fed to a fractionation system 24 to recover one or more hydrocarbon fractions. As illustrated, fractionation system 24 may be used to recover an offgas 26, a light naphtha fraction 28, a heavy naphtha fraction 30, a kerosene fraction 32, a diesel fraction 34, a light vacuum gas oil fraction 36, a heavy vacuum gas oil fraction 38, and a vacuum resid fraction 40. In some embodiments, vacuum resid fraction 40 may be recycled for further processing. In other embodiments, vacuum resid fraction 40 may be blended with a cutter fraction 64 to produce a fuel oil.

[0032] Fractionation system 24 may include, for example, a high pressure high temperature (HP/HT) separator to separate the effluent vapor from the effluent liquids. The separated vapor may be routed through gas cooling, purification, and recycle gas compression, or may be first processed through an Integrated Hydroprocessing Reactor

System (IHRS) which may include one or more additional hydroconversion reactors, alone or in combination with external distillates and/or distillates generated in the hydrocracking process and thereafter routed for gas cooling, purification, and compression.

[0033] The separated liquid from the HP/HT separator may be flashed and routed to an atmospheric distillation system along with other distillate products recovered from the gas cooling and purification section. The atmospheric tower bottoms, such as hydrocarbons having an initial boiling point of at least about 340°C, such as an initial boiling point in the range from about 340°C to about 427°C, may then be further processed through a vacuum distillation system to recover vacuum distillates.

[0034] The vacuum tower bottoms product, such as hydrocarbons having an initial boiling point of at least about 480°C, such as an initial boiling point in the range from about 480°C to about 565°C, may then be routed to tankage after cooling, such as by direct heat exchange or direct injection of a portion of the residuum hydrocarbon feed into the vacuum tower bottoms product.

[0035] Overall conversion of the DAO fraction through the RDS unit 16 and the hydrocracking reaction system 20 may be in the range from about 75 wt% to about 95 wt%, such as in the range from about 85 wt% to about 90 wt%.

[0036] In some embodiments, the fuel oil fraction 40 recovered following processing in RDS unit 16, hydrocracking reactor system 20 and fractionation system 24 may have a sulfur content of 1.25 wt% or less; 1.0 wt% or less in other embodiments; and 0.75 wt% or less in yet other embodiments.

[0037] Catalysts useful in the RDS reactors, the URFs, and the ebullated bed reactors may include any catalyst useful for the hydrotreating or hydrocracking of a hydrocarbon feedstock. A hydrotreating catalyst, for example, may include any catalyst composition that may be used to catalyze the hydrogenation of hydrocarbon feedstocks to increase its hydrogen content and/or remove heteroatom contaminants. A hydrocracking catalyst, for example, may include any catalyst composition that may be used to catalyze the addition of hydrogen to large or complex hydrocarbon molecules as well as the cracking of the molecules to obtain smaller, lower molecular weight molecules.

[0038] Hydroconversion catalyst compositions for use in the hydroconversion process according to embodiments disclosed herein are well known to those skilled in the art and several are commercially available from W.R. Grace & Co., Criterion Catalysts & Technologies, and Albemarle, among others. Suitable hydroconversion catalysts may include one or more elements selected from Groups 4-12 of the Periodic Table of the Elements. In some embodiments, hydroconversion catalysts according to embodiments disclosed herein may comprise, consist of, or consist essentially of one or more of nickel, cobalt, tungsten, molybdenum and combinations thereof, either unsupported or supported on a porous substrate such as silica, alumina, titania, or combinations thereof. As supplied from a manufacturer or as resulting from a regeneration process, the hydroconversion catalysts may be in the form of metal oxides, for example. In some embodiments, the hydroconversion catalysts may be pre-sulfided and/or pre-conditioned prior to introduction to the hydrocracking reactor(s).

[0039] Distillate hydrotreating catalysts that may be useful include catalyst selected from those elements known to provide catalytic hydrogenation activity. At least one metal component selected from Group 8-10 elements and/or from Group 6 elements is generally chosen. Group 6 elements may include chromium, molybdenum and tungsten. Group 8-10 elements may include iron, cobalt, nickel, ruthenium, rhodium, palladium, osmium, iridium and platinum. The amount(s) of hydrogenation component(s) in the catalyst suitably range from about 0.5% to about 10% by weight of Group 8-10 metal component(s) and from about 5% to about 25% by weight of Group 6 metal component(s), calculated as metal oxide(s) per 100 parts by weight of total catalyst, where the percentages by weight are based on the weight of the catalyst before sulfiding. The hydrogenation components in the catalyst may be in the oxidic and/or the sulphidic form. If a combination of at least a Group 6 and a Group 8 metal component is present as (mixed) oxides, it will be subjected to a sulfiding treatment prior to proper use in hydrocracking. In some embodiments, the catalyst comprises one or more components of nickel and/or cobalt and one or more components of molybdenum and/or tungsten or one or more components of platinum and/or palladium. Catalysts containing nickel and molybdenum, nickel and tungsten, platinum and/or palladium are useful.

[0040] Residue hydrotreating catalysts that may be useful include catalysts generally composed of a hydrogenation component, selected from Group 6 elements (such as molybdenum and/or tungsten) and Group 8-10 elements (such as cobalt and/or nickel), or a mixture thereof, which may be supported on an alumina support. Phosphorous (Group 15) oxide is optionally present as an active ingredient. A typical catalyst may contain from 3 to 35 wt % hydrogenation components, with an alumina binder. The catalyst pellets may range in size from 1/32 inch to 1/8 inch, and may be of a spherical, extruded, trilobate or quadrilobate shape. In some embodiments, the feed passing through the catalyst zone contacts first a catalyst preselected for metals removal, though some sulfur, nitrogen and aromatics removal may also occur. Subsequent catalyst layers may be used for sulfur and nitrogen removal, though they would also be expected to catalyze the removal of metals and/or cracking reactions. Catalyst layer(s) for demetallization, when present, may comprise catalyst(s) having an average pore size ranging from 125 to 225 Angstroms and a pore volume ranging from 0.5-1.1 cm<sup>3</sup>/g. Catalyst layer(s) for denitrogenation/desulfurization may comprise catalyst(s) having an average pore size ranging from 100 to 190 Angstroms with a pore volume of 0.5-1.1 cm<sup>3</sup>/g. U.S. Pat. No. 4,990,243 describes a hydrotreating catalyst having a pore size of at least about 60 Angstroms, and preferably from about 75 Angstroms to about 120 Angstroms. A demetallization catalyst useful for the present process is described, for example, in U.S. Pat. No. 4,976,848, the entire disclosure of which is incorporated herein by reference for all purposes. Likewise, catalysts useful for desulfurization of heavy streams are described, for example, in U.S. Pat. Nos. 5,215,955 and 5,177,047, the entire disclosures of which are incorporated herein by reference for all purposes. Catalysts useful for desulfurization of middle distillate, vacuum gas oil streams and naphtha streams are described, for example, in U.S. Pat. No. 4,990,243, the entire disclosures of which are incorporated herein by reference for all purposes.

[0041] Useful residue hydrotreating catalysts include catalysts having a porous refractory base made up of alumina, silica, phosphorous, or various combinations of these. One or more types of catalysts may be used as residue hydrotreating catalyst, and where two or more catalysts are used, the catalysts may be present in the reactor zone as layers. The

catalysts in the lower layer(s) may have good demetallization activity. The catalysts may also have hydrogenation and desulfurization activity, and it may be advantageous to use large pore size catalysts to maximize the removal of metals. Catalysts having these characteristics are not optimal for the removal of Conradson Carbon Residue and sulfur. The average pore size for catalyst in the lower layer or layers will usually be at least 60 Angstroms and in many cases will be considerably larger. The catalyst may contain a metal or combination of metals such as nickel, molybdenum, or cobalt. Catalysts useful in the lower layer or layers are described in U.S. Pat. Nos. 5,071,805 5,215,955, and 5,472,928. For example, those catalysts as described in U.S. Patent No. 5,472,928 and having at least 20% of the pores in the range of 130 to 170 Angstroms, based on the nitrogen method, may be useful in the lower catalyst layer(s). The catalysts present in the upper layer or layers of the catalyst zone should have greater hydrogenation activity as compared to catalysts in the lower layer or layers. Consequently catalysts useful in the upper layer or layers may be characterized by smaller pore sizes and greater Conradson Carbon Residue removal, denitrogenation and desulfurization activity. Typically, the catalysts will contain metals such as, for example, nickel, tungsten, and molybdenum to enhance the hydrogenation activity. For example, those catalysts as described in U.S. Patent No. 5,472,928 and having at least 30% of the pores in the range of 95 to 135 Angstroms, based on the nitrogen method, may be useful in the upper catalyst layers. The catalysts may be shaped catalysts or spherical catalysts. In addition, dense, less friable catalysts may be used in the upflow fixed catalyst zones to minimize breakage of the catalyst particles and the entrainment of particulates in the product recovered from the reactor.

[0042] One skilled in the art will recognize that the various catalyst layers may not be made up of only a single catalyst type, but may be composed of an intermixture of different catalyst types to achieve the optimal level of metals or Conradson Carbon Residue removal and desulfurization for that layer. Although some hydrogenation will occur in the lower portion of the zone, the removal of Conradson Carbon Residue, nitrogen, and sulfur may take place primarily in the upper layer or layers. Obviously additional metals removal also will take place. The specific catalyst or catalyst mixture

selected for each layer, the number of layers in the zone, the proportional volume in the bed of each layer, and the specific hydrotreating conditions selected will depend on the feedstock being processed by the unit, the desired product to be recovered, as well as commercial considerations such as cost of the catalyst. All of these parameters are within the skill of a person engaged in the petroleum refining industry and should not need further elaboration here.

[0043] Referring now to Figure 2, where like numerals represent like parts, a simplified flow diagram of a process for upgrading residuum hydrocarbon feedstocks according to embodiments disclosed herein is illustrated. As described above with respect to Figure 1, the residuum hydrocarbon feedstock 10 is processed through SDA unit 12, and the resulting pitch fraction is processed in ebullated bed reactor system 42 and fractionation system 46. Deasphalted oil fraction 14 may be combined with a hydrogen rich gas 23 and fed to RDS unit 16, which may include one or more residue desulfurization reactors.

[0044] Effluent 18 recovered from RDS unit 16 may then be processed in a fractionation system 24 to produce one or more hydrocarbon fractions 26, 28, and 38, among others, as well as a vacuum residua fraction 40. The vacuum residua fraction 40 and optionally one or more of additional heavier hydrocarbon fractions recovered in fractionation system 24 may then be fed to a hydrocracking reactor system 20 to produce additional distillate range hydrocarbons. Following conversion in reaction system 20, effluent 22 may be fractionated to recover various distillate hydrocarbon fractions. In some embodiments, effluent 22 may be fractionated along with effluent 18 in fractionation system 24 (as illustrated) or a combined fractionation system processing effluents 18 and 44.

[0045] By advantageously combining SDA and RDS with ebullated bed hydrocracking reactors, for example, the conversion of the DAO fraction can be increased to very high levels, such as 85 wt% to 90 wt%, while still producing a 1 wt% sulfur stable fuel oil, even when processing high sulfur containing residues, such as those having up to or greater than 6.5 wt% sulfur. The processing of SDA pitch in a separate reaction / separation train may allow the production of a 2 wt% sulfur stable

fuel oil while converting 40 wt% to 65 wt% of the pitch to atmospheric and vacuum distillate boiling range materials. The resulting combined overall conversion from both processing trains may be in the range from about 55 wt% or 60 wt% to as high as about 95 wt% or more, such as in the range from about 65 wt% to about 85 wt%. Further, such conversions may be advantageously achieved without sediment formation that could otherwise cause plugging and intermittent operation.

[0046] Example

[0047] In the following example, a 40 k BPSD of Arabian Heavy vacuum residue is first processed in an SDA unit at a 73 vol% lift. The resulting properties of the DAO and SDA pitch are summarized in Table 1. The DAO, containing 4.27 wt% sulfur, 10 wt% CCR and 47 wppm Ni + V, is then processed in an RDS unit so as to reduce the sulfur content of the feed by 85 to 87 wt%. Concurrently the residue fraction in the feed is converted 35 to 45%. In this example the RDS effluent is then hydrocracked in single ebullated bed reactor, which is close coupled to the RDS reactors, increasing the overall conversion to 85 vol% and overall HDS to 91.8 wt%. It is estimated that the resulting unconverted oil (UCO) has a sulfur content and API gravity of approximately 1.0 wt% and 11.9 °, respectively. It is envisaged the UCO from this reaction system will meet the low sulfur fuel oil specifications without any additional cutterstock addition. The overall space velocity required to achieve this level of conversion and desulfurization is estimated to be about 0.2 hr<sup>-1</sup>.

| Table 1<br>DAO & SDA Pitch Properties |         |        |           |
|---------------------------------------|---------|--------|-----------|
| Properties                            | VR Feed | DAO    | SDA Pitch |
| Feed rate, kBPSD                      | 40.0    | 29.2   | 10.8      |
| API Gravity                           | 4.81    | 10.58  | -8.68     |
| Specific Gravity                      | 1.0381  | 0.9959 | 1.1521    |
| Sulfur, wt%                           | 5.2     | 4.27   | 7.37      |
| Nitrogen, wt%                         | 0.40    | 0.25   | 0.75      |
| Oxygen, wt%                           | 0.12    | 0.09   | 0.19      |
| CCR, wt%                              | 25      | 10     | 60        |
| Ni+ V, wppm                           | 270     | 47     | 790       |
| 565°C-, vol%                          | 10      | 13.7   |           |
| 565°C+, vol%                          | 90      | 86.3   | 100       |

[0048] Fifty-five (55) vol% of the SDA pitch is then also converted a separate ebullated bed reactor system, containing a single reactor, operating in parallel with the RDS and hydrocracking reactors, producing a medium sulfur vacuum residue which contains 2.6 wt% sulfur. After cutterstock addition, the resulting fuel oil will contain less than 2 wt% sulfur and more than likely less than 1.5 wt% sulfur, depending on the fuel oil blending components. The reactor space velocity for the pitch conversion unit is estimated to be about  $0.25 \text{ h}^{-1}$ , resulting in an overall space velocity for the RDS plus DAO hydrocracking reactor and the pitch conversion reactor of  $0.22 \text{ h}^{-1}$ .

[0049] The resulting overall conversion for this configuration is 75 vol%, producing approximately 12,096 BPSD of diesel, 12,332 BPSD of hydrocracker or FCC feed, 4,056 BPSD of LS fuel oil and 4,760 BPSD of medium sulfur vacuum residue. The overall yields and product properties for this processing configuration are provided in Table 2.

| Table 2<br>Residue Hydrocracking Process<br>Overall Yields and Properties |         |        |            |       |           |           |             |            |             |
|---------------------------------------------------------------------------|---------|--------|------------|-------|-----------|-----------|-------------|------------|-------------|
| Feed                                                                      | Wt%     | Vol %  | Sp.<br>Gr. | API   | S,<br>wt% | N,<br>wt% | CCR,<br>wt% | V,<br>wppm | Ni,<br>wppm |
| 360-565<br>C                                                              | 9.3     | 10.0   | 0.9659     | 15.00 | 3.75      | 0.20      | 0.50        | 1          | 0.5         |
| 565 C+                                                                    | 90.7    | 90.0   | 1.046      | 3.770 | 5.35      | 0.42      | 27.51       | 226        | 72          |
| Total                                                                     | 100.0   | 100.0  | 1.038      | 4.815 | 5.2       | 0.40      | 25          | 205        | 65          |
| Overall Product Yields & Properties                                       |         |        |            |       |           |           |             |            |             |
| Products                                                                  | Wt%     | Vol %  | Sp.<br>Gr. | API   | S,<br>wt% | N,<br>wt% | CCR,<br>wt% | V,<br>wppm | Ni,<br>wppm |
| H <sub>2</sub> S                                                          | 4.75    |        |            |       |           |           |             |            |             |
| NH <sub>3</sub>                                                           | 0.22    |        |            |       |           |           |             |            |             |
| H <sub>2</sub> O                                                          | 0.09    |        |            |       |           |           |             |            |             |
| C1                                                                        | 1.17    |        |            |       |           |           |             |            |             |
| C2                                                                        | 1.04    |        |            |       |           |           |             |            |             |
| C3                                                                        | 1.51    |        |            |       |           |           |             |            |             |
| C4                                                                        | 1.44    | 2.57   | 0.584      |       |           |           |             |            |             |
| C5-145C                                                                   | 11.08   | 15.73  | 0.7313     | 61.99 | 0.04      | 0.02      |             |            |             |
| 145-370C                                                                  | 30.24   | 36.46  | 0.8608     | 32.89 | 0.23      | 0.07      |             |            |             |
| 370-565C                                                                  | 28.00   | 30.83  | 0.9428     | 18.59 | 0.85      | 0.24      | 0.5         | 1          | <1          |
| LS Resid<br>(565 C+)                                                      | 9.64    | 10.14  | 0.9868     | 11.90 | 1.02      | 0.27      | 15.5        | 18         | 13.2        |
| MS Resid<br>(565 C+)                                                      | 12.91   | 11.90  | 1.1262     | -5.86 | 2.60      | 0.73      | 53.4        | 164        | 111         |
| Total                                                                     | 102.09  | 107.63 |            |       |           |           |             |            |             |
| C5+                                                                       | 91.87   | 105.06 | 0.9077     | 24.39 | 0.8119    | 0.2292    |             |            |             |
| C4+                                                                       | 93.31   | 107.63 | 0.8999     | 25.73 | 0.7993    | 0.2256    |             |            |             |
| Chemical<br>H <sub>2</sub> S Cons                                         | 1425.98 |        |            |       |           |           |             |            |             |
| Overall Removals, wt%                                                     |         |        |            |       |           |           |             |            |             |
| HDS                                                                       | 85.9    |        |            |       |           |           |             |            |             |
| HDN                                                                       | 45.4    |        |            |       |           |           |             |            |             |
| CCR                                                                       | 65.9    |        |            |       |           |           |             |            |             |
| Vanadium                                                                  | 88.7    |        |            |       |           |           |             |            |             |
| Nickel                                                                    | 75.6    |        |            |       |           |           |             |            |             |

[0050] Figures 3 and 4 illustrate two embodiments for the IHRS and are described below, however other embodiments will be obvious to those skilled in the art as being possible. Figure 3 describes an embodiment where the IHRS is installed downstream of the ebullated bed reactor system 42. Figure 4 illustrates an embodiment where the IHRS is installed downstream of the hydrocracking reactor system 20.

[0051] As shown in Figure 3, the effluent stream 44 from ebullated bed hydroprocessing reactor 42 may be cooled in a heat exchanger (not shown) and fed to a HP/HT V/L separator 81 where a vapor stream including the light products and distillates boiling below about 1000°F normal boiling point and a liquid stream including unconverted residuum may be separated and processed separately in downstream equipment. A vapor stream 67 may be fed to a fixed-bed hydroprocessing reactor 86 to carry out hydrotreating, hydrocracking or a combination thereof. An effluent stream 68 from the IHRS fixed-bed reactor system 86 is fed to a fractionation system 147 which recovers an offgas stream 48, light hydrotreated or hydrocracked naphtha stream 50, heavy hydrotreated or hydrocracked naphtha stream 52, hydrotreated or hydrocracked kerosene stream 54, hydrotreated or hydrocracked diesel stream 56, as described above. The liquid stream 63 may be cooled in a heat exchanger (not shown) and depressurized in a pressure letdown system (not shown) before being fed to a vacuum fractionation system 72 which recovers a light hydrotreated or hydrocracked VGO stream 58, a heavy hydrotreated or hydrocracked VGO stream 60 and an unconverted vacuum residuum stream 62. In some embodiments, the vacuum tower bottoms product stream, such as hydrocarbons having an initial boiling point of at least about 480°C, such as an initial boiling point in the range from about 480°C to about 565°C, may be routed to tankage after cooling, such as by direct heat exchange or direct injection of a portion of the residuum hydrocarbon feed into the vacuum tower bottoms product.

[0052] As shown in Figure 4, in an alternate IHRS flow scheme, the effluent stream 22 from the ebullated bed reactor system 20 may be cooled in a heat exchanger (not shown) and fed to a HP/HT V/L separator 181 where a vapor stream including the light

products and distillates boiling below about 1000°F normal boiling point and a liquid stream including unconverted residuum may be separated and processed separately in downstream equipment. A vapor stream 167 is fed to a fixed-bed hydroprocessing reactor 186 to carry out hydrotreating, hydrocracking or a combination thereof. An effluent stream 168 from the IHRS fixed-bed reactor system 166 may be fed to an atmospheric fractionation system 146 which recovers an offgas stream 26, light hydrotreated or hydrocracked naphtha stream 28, heavy hydrotreated or hydrocracked naphtha stream 30, hydrotreated or hydrocracked kerosene stream 32, hydrotreated or hydrocracked diesel stream 34. A liquid stream 163 is cooled in a heat exchanger (not shown) and depressurized in a pressure letdown system (not shown) and may be fed to a vacuum fractionation system 172 which recovers a light hydrotreated or hydrocracked VGO stream 36, a heavy hydrotreated or hydrocracked VGO stream 38 and an unconverted vacuum residuum stream 40. In some embodiments, the vacuum tower bottoms product stream, such as hydrocarbons having an initial boiling point of at least about 480°C, such as an initial boiling point in the range from about 480°C to about 565°C, may then be routed to tankage after cooling, such as by direct heat exchange or direct injection of a portion of the residuum hydrocarbon feed into the vacuum tower bottoms product.

**[0053]** While described above with respect to two separate fractionation systems 24, 46, embodiments disclosed herein also contemplate fractionating the effluents 22, 44 in a common fractionation system. For example, the effluents may be fed into a common gas cooling, purification, and compression loop before further processing in an atmospheric tower and a vacuum tower as described above. The use of a combined separation scheme may provide for a reduced capital investment, when desired, but may result in the production of a single fuel oil fraction having a sulfur level intermediate those achieved by separate processing. The combined separation scheme may also be used along with the IHRS being installed downstream of both the ebullated bed reactor system 42 and the hydrocracking reactor system 20 and being fed by the combined effluents 22, 44.

[0054] As described above, embodiments disclosed herein effectively integrate SDA and RDS with residue hydrocracking, extending the residue conversion limits above those which can be attained by residue hydrocracking alone. Further, the higher conversions may be attained using less catalytic reactor volume as compared to other schemes proposed to achieve similar conversions. As a result, embodiments disclosed herein may provide comparable or higher conversions but requiring a lower capital investment. Further, embodiments disclosed herein may be used to produce a fuel oil having less than 1 wt% sulfur from a high sulfur containing residue feed while maximizing overall conversion.

[0055] Advantageously, the initial SDA may allow the hydrocracking of the pitch to be operated at relatively high temperatures and space velocities, without the tendency to form excessive sediments, by limiting conversion. The hydrocracking of the DAO may also be performed at relatively high temperatures and space velocities, as the DAO may have a very low asphaltene content. As a result, the overall processing schemes disclosed herein may be performed using low reactor volumes while still achieving high conversions. Likewise, other resulting advantages may include: reduced catalyst consumption rates due to rejecting metals in the asphalt from the SDA unit; reduced capital investment; and elimination or significant reduction in the need for injection of slurry oil upstream of the ebullated bed reactors, among other advantages.

[0056] While the disclosure includes a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments may be devised which do not depart from the scope of the present disclosure. Accordingly, the scope should be limited only by the attached claims.

## CLAIMS

What is claimed:

1. A process for upgrading residuum hydrocarbons, the process comprising:
  - solvent deasphalting a residuum hydrocarbon fraction to produce a deasphalted oil fraction and an asphalt fraction;
  - contacting the asphalt fraction and hydrogen with a first hydroconversion catalyst in a first ebullated bed hydroconversion reactor system;
  - recovering an effluent from the first ebullated bed hydroconversion reactor system;
  - fractionating the effluent from the first ebullated bed hydroconversion reactor system to recover one or more hydrocarbon fractions;
  - contacting the deasphalted oil fraction and hydrogen with a second hydroconversion catalyst in a residue hydrodesulfurization unit;
  - recovering an effluent from the residue hydrodesulfurization unit;
  - contacting the residue hydrodesulfurization unit effluent or a portion thereof with a third hydroconversion catalyst in a hydrocracking reactor system;
  - recovering an effluent from the hydrocracking reactor system; and
  - fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions.
2. The process of claim 1, further comprising mixing the asphalt fraction with a diluent to form a diluted asphalt fraction prior to the contacting.
3. The process of claim 2, wherein the diluent comprises at least one of FCC cycle oils, slurry oils, aromatics extracts, and straight run vacuum gas oils.
4. The process of claim 1, wherein the hydrocracking reactor system includes a second ebullated bed hydroconversion reactor system comprising one or more ebullated bed reactors.
5. The process of claim 4, wherein the deasphalted oil fraction has a metals content of greater than about 80 wppm and a Conradson Carbon Residue (CCR) content of greater than about 10 wt%.

6. The process of claim 1, wherein the effluent from the first ebullated bed hydroconversion reactor system and the hydrocracking reactor system are fractionated in a common fractionation system.
7. The process of claim 1, wherein the one or more hydrocarbon fractions produced in fractionating the effluents from one or both the first ebullated bed hydroconversion reactor systems and the hydrocracking reactor system includes a vacuum residua hydrocarbon fraction.
8. The process of claim 6, further comprising recycling the vacuum residua hydrocarbon fraction to at least one of the solvent deasphalting, the first ebullated bed hydroconversion reactor system, and the hydrocracking reactor system.
9. The process of claim 1, wherein the residuum hydrocarbon fraction comprises at least one of petroleum atmospheric or vacuum residua, deasphalted oils, deasphalter pitch, hydrocracked atmospheric tower or vacuum tower bottoms, straight run vacuum gas oils, hydrocracked vacuum gas oils, fluid catalytically cracked (FCC) slurry oils, vacuum gas oils from an ebullated bed process, shale-derived oils, coal-derived oils, bio-derived crude oils, tar sands bitumen, tall oils, black oils.
10. The process of claim 1, wherein contacting in the first ebullated bed hydroconversion reactor system results in a hydrocarbon conversion in the range from about 40 wt% to about 75 wt%, sulfur removal is in the range from about 40 wt% to about 80 wt%, metals removal is in the range from about 60 wt% to about 85 wt% and Conradson Carbon Residue (CCR) removal is in the range from about 30 wt% to about 65 wt%.
11. The process of claim 1, wherein an overall conversion of the deasphalted oil fraction through both the residue desulfurization unit and the hydrocracking reactor system is in the range from about 75 wt% to about 95 wt%.
12. The process of claim 1, wherein a fuel oil produced via the fractionation of the hydrocracking reaction system effluent has a sulfur content of 1 wt% or less.
13. The process of claim 1, wherein a fuel oil produced via the fractionation of the ebullated bed reaction system effluent has a sulfur content of less than 2 wt% or less.
14. The process of claim 1, wherein an overall conversion of the residuum hydrocarbon fraction is in the range from about 60 wt% to about 95 wt%.

15. The process of claim 1, wherein a solvent used in the solvent deasphalting unit is a light hydrocarbon containing from 3 to 7 carbon atoms.
16. The process of claim 1, further comprising contacting the effluent from the first ebullated bed hydroconversion reactor with a second hydroconversion catalyst prior to fractionating the effluent from the first ebullated bed hydroconversion reactor system.
17. The process of claim 1, further comprising contacting the effluent from the hydrocracking reactor system with a second hydroconversion catalyst prior to fractionating the effluent from the hydrocracking reactor system.
18. A process for upgrading residuum hydrocarbons, the process comprising:
  - solvent deasphalting a residuum hydrocarbon fraction to produce a deasphalted oil fraction and an asphalt fraction;
  - contacting the asphalt fraction and hydrogen with a first hydroconversion catalyst in a first ebullated bed hydroconversion reactor system;
  - recovering an effluent from the first ebullated bed hydroconversion reactor system;
  - fractionating the effluent from the first ebullated bed hydroconversion reactor system to recover one or more hydrocarbon fractions;
  - contacting the deasphalted oil fraction and hydrogen with a second hydroconversion catalyst in a residue hydrodesulfurization unit;
  - recovering an effluent from the residue hydrodesulfurization unit;
  - contacting the residue hydrodesulfurization unit effluent with a third hydroconversion catalyst in a hydrocracking reactor system;
  - recovering an effluent from the hydrocracking reactor system; and
  - fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions.
19. A process for upgrading residuum hydrocarbons, the process comprising:
  - solvent deasphalting a residuum hydrocarbon fraction to produce a deasphalted oil fraction and an asphalt fraction;
  - contacting the asphalt fraction and hydrogen with a first hydroconversion catalyst in a first ebullated bed hydroconversion reactor system;

recovering an effluent from the first ebullated bed hydroconversion reactor system;  
fractionating the effluent from the first ebullated bed hydroconversion reactor system to recover one or more hydrocarbon fractions;  
contacting the deasphalted oil fraction and hydrogen with a second hydroconversion catalyst in a residue hydrodesulfurization unit;  
recovering an effluent from the residue hydrodesulfurization unit;  
fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions including a vacuum residua hydrocarbon fraction;  
contacting the vacuum residua hydrocarbon fraction with a third hydroconversion catalyst in a hydrocracking reactor system;  
recovering an effluent from the hydrocracking reactor system; and  
fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions.

20. A process for upgrading residuum hydrocarbons, the process comprising:

solvent deasphalting a residuum hydrocarbon fraction to produce a deasphalted oil fraction and an asphalt fraction;  
contacting the asphalt fraction and hydrogen with a first hydroconversion catalyst in a first ebullated bed hydroconversion reactor system;  
recovering an effluent from the first ebullated bed hydroconversion reactor system;  
contacting the effluent from the first ebullated bed hydroconversion reactor with a second hydroconversion catalyst prior to fractionating the effluent from the first ebullated bed hydroconversion reactor system to recover one or more hydrocarbon fractions;  
contacting the deasphalted oil fraction and hydrogen with a third hydroconversion catalyst in a residue hydrodesulfurization unit;  
recovering an effluent from the residue hydrodesulfurization unit;  
contacting the residue hydrodesulfurization unit effluent with a fourth hydroconversion catalyst in a hydrocracking reactor system;

recovering an effluent from the hydrocracking reactor system; and  
fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions.

21. A process for upgrading residuum hydrocarbons, the process comprising:
- solvent deasphalting a residuum hydrocarbon fraction to produce a deasphalted oil fraction and an asphalt fraction;
  - contacting the asphalt fraction and hydrogen with a first hydroconversion catalyst in a first ebullated bed hydroconversion reactor system;
  - recovering an effluent from the first ebullated bed hydroconversion reactor system;
  - fractionating the effluent from the first ebullated bed hydroconversion reactor system to recover one or more hydrocarbon fractions;
  - contacting the deasphalted oil fraction and hydrogen with a second hydroconversion catalyst in a residue hydrodesulfurization unit;
  - recovering an effluent from the residue hydrodesulfurization unit;
  - contacting the residue hydrodesulfurization unit effluent or a portion thereof with a third hydroconversion catalyst in a hydrocracking reactor system;
  - recovering an effluent from the hydrocracking reactor system; and
  - contacting the effluent from the hydrocracking reactor system with a fourth hydroconversion catalyst prior to fractionating the effluent from the hydrocracking reactor system to recover one or more hydrocarbon fractions.