

AN INTEGRATED LUBRICANT UPGRADING PROCESS USING
ONCE-THROUGH, HYDROGEN-CONTAINING TREAT GAS

FIELD OF THE INVENTION

[0001] The invention relates to a process for preparing lubricating oil basestocks from lube oil boiling-range feeds. More particularly, the invention is directed at a process wherein a wax-containing feedstock is solvent extracted to produce at least a lube oil boiling-range raffinate, and the raffinate is hydrotreated to produce a hydrotreated raffinate. The hydrotreated raffinate is dewaxed to produce a dewaxed raffinate, and the dewaxed raffinate is hydrofinished.

BACKGROUND OF THE INVENTION

[0002] Lubricating oil products for use in applications such as automotive engine oils generally contain at least one basestock. The basestock can be combined with additives to improve specific basestock properties to make a suitable finished lubricating oil product. An increasingly stringent regulatory environment has led to increased performance requirements for both finished product and basestock. American Petroleum Institute (API) requirements for Group II basestocks include a saturates content of at least 90%, a sulfur content of 0.03% or less, and a viscosity index (VI) between 80 and 120. There is a trend in the lube oil market to use Group II basestocks instead of Group I basestocks in order to meet the demand for higher quality basestocks and finished lubricating oil products that provide for desirable properties such as increased fuel economy and reduced emissions.

[0003] Conventional processes (i.e., techniques known to those skilled in the art of lubricating oil processing) for preparing improved Group I and Group II basestocks, such as hydrocracking or solvent extraction of aromatics, often require severe operating conditions such as high pressure and temperature or

high solvent:oil ratios and high extraction temperatures. Such processes can be costly. Moreover, solvent extraction processes have significantly lower basestock yield as process severity is increased.

[0004] In addition to hydrocracking and solvent extraction, paraffinic lubricating oil feedstocks are dewaxed in order to produce basestock which will remain fluid when the finished lubricating oil is used at a low temperature. Dewaxing is the process of separating or converting hydrocarbons which solidify readily (i.e., waxes) in petroleum fractions. Conventional catalytic dewaxing of waxy feeds boiling in the lubricating oil range generally utilize catalysts comprising at least one molecular sieve component and at least one component containing one or more Group VIII and/or Group VIB metals of the Periodic Table of the Elements.

[0005] Increasingly stringent basestock performance specifications have resulted in a need for new and different processes, catalysts, and catalyst systems that exhibit improved activity, increased yields, selectivity and/or longevity. Thus, there is a need for processes that can produce lube oil basestocks in ever-increasing yields that would be suitable for making an improved lubricating oil.

SUMMARY OF THE INVENTION

[0006] In an embodiment, the invention relates to a process to prepare lubricating oil basestocks from lube oil boiling-range raffinate feedstreams. The process comprises:

- (a) contacting a lube oil boiling-range raffinate feed containing nitrogen and sulfur heteroatoms with a hydrotreating catalyst in a first reaction stage operated under effective hydrotreating conditions in the presence of a hydrogen-containing gaseous product from a third reaction stage to produce a hydrotreated raffinate;

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- (b) stripping the hydrotreated raffinate by contacting the hydrotreated raffinate with a first fresh, once-through, hydrogen-containing treat gas to separate sulfur-containing and nitrogen-containing species from the hydrotreated raffinate to produce a stripped raffinate;
- (c) contacting the stripped raffinate with a catalytically effective amount of a hydrodewaxing catalyst in the presence of a second fresh once-through, hydrogen-containing treat gas in a second reaction stage operated under effective hydrodewaxing conditions to produce a second-stage reaction product comprising a second-stage gaseous product and a second-stage liquid product, wherein the second-stage gaseous product comprises hydrogen and the second-stage liquid product comprising a dewaxed raffinate;
- (d) cascading, with disengagement, at least a portion of the second reaction stage product to a hydrofinishing reaction stage;
- (e) contacting the cascaded portion of the second reaction-stage product with a catalytically effective amount of a hydrofinishing catalyst in the third reaction stage operated under effective hydrofinishing conditions to produce a third-stage reaction product comprising the third-stage gaseous product comprising hydrogen and a third-stage liquid product comprising a lubricating oil basestock, wherein the second-stage gaseous product provides hydrogen for the third reaction stage;
- (f) separating the third-stage gaseous product from the third stage reaction product; and
- (g) cascading the third-stage gaseous product, without heteroatom disengagement, to the first reaction stage.

[0007] In another embodiment, the process further comprises:

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- (a) extracting a lubricating oil feed in a solvent extraction zone with an extraction solvent under conditions effective at producing at least an aromatics-lean raffinate solution containing extraction solvent; and
- (b) removing at least a portion of the extraction solvent from the aromatics-lean raffinate solution to produce at least a lube oil boiling-range raffinate feedstream.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figure 1 is a simplified process flow diagram, which shows the reactor configuration, treat gas circulation, heat integration, and product recovery facilities.

[0009] Figure 2 is a schematic diagram of the hydrogen flow through the instant invention.

DETAILED DESCRIPTION OF THE INVENTION

[0010] The present invention relates to a process for producing lubricating oil basestocks from lube oil boiling-range feeds such as raffinates. The process involves contacting a lube oil boiling-range raffinate containing nitrogen and sulfur heteroatoms with a hydrotreating catalyst in the presence of hydrogen-containing treat gas in a first reaction stage. The first reaction stage is operated under effective hydrotreating conditions to produce a hydrotreated effluent comprising at least a first-stage gaseous product and a hydrotreated raffinate containing fewer nitrogen and sulfur heteroatoms than the lube oil boiling-range feed. The hydrotreated raffinate is stripped using fresh, once-through, hydrogen-containing treat gas as the stripper gas. The stripping separates at least a portion of the sulfur-containing and nitrogen-containing species from the hydrotreated effluent to produce a stripped raffinate. The sulfur-containing and nitrogen-containing species stripped from the hydrotreated raffinate, e.g., ammonia and hydrogen sulfide, are conducted away from the process. The stripped raffinate is then dewaxed in a second reaction stage by contacting it with a catalytically

effective amount of a dewaxing catalyst in the presence of the once-through, hydrogen-containing treat gas which can be obtained from the same source as the fresh treat gas used in the prior stripping stage. In other words, the fresh first and second once-through treat gas can be obtained from a common treat gas source. The second reaction stage is operated under effective dewaxing conditions. The contacting of the stripped raffinate with the dewaxing catalyst produces a second-stage reaction product comprising at least a second-stage gaseous product and a second-stage liquid product, wherein the second-stage gaseous product comprises hydrogen and the second-stage liquid product comprises a dewaxed raffinate. At least a portion of the second-reaction product is cascaded, without liquid-vapor disengagement, to a hydrofinishing reaction stage, referred to herein as the third reaction stage. It should also be noted that the phrase "without liquid-vapor disengagement" as used herein means that the particular gaseous (vapor) product, liquid product, etc., is not depressurized between the respective reaction stages and/or stripping stages. In the hydrofinishing reaction stage, or third reaction stage, at least a portion of the second-reaction product is contacted with a catalytically effective amount of hydrofinishing catalyst in the presence of a hydrogen-containing treat gas, with the second-stage gaseous product comprising hydrogen serving as the hydrogen-containing treat gas therein. The contacting of the cascaded portion of the second-stage reaction product with the hydrofinishing catalyst produces a third-stage reaction product comprising at least a third-stage gaseous product and a third-stage liquid product. The third-stage gaseous product comprises hydrogen and the third-stage liquid product comprises a lubricating oil basestock. At least a portion of the third-stage gaseous product is separated from the third-stage reaction product and then cascaded, without heteroatom disengagement, to the first reaction stage, wherein the separated third-stage gaseous product serves as the hydrogen-containing treat gas in the first reaction stage.

[0011] In an embodiment, the process makes lubricating oil basestocks from lube oil boiling-range feed (also commonly referred to as "feedstock" and/or "feedstream"). Thus, the process may optionally further comprise solvent extracting a lubricating oil feedstock in a solvent extraction zone under conditions effective at producing at least an aromatics-lean raffinate solution containing extraction solvent. At least a portion of the extraction solvent can be separated and conducted away from the aromatics-lean raffinate solution to produce a raffinate feedstream containing nitrogen and sulfur heteroatoms.

Lubricating Oil Feeds

[0012] In an embodiment, the lube oil feeds used in the process are wax-containing feeds that contain hydrocarbon and boil in the lubricating oil boiling-range, typically having a 10% distillation point greater than 650°F (343°C), measured by ASTM D86 or ASTM 2887. As used herein, the term "lubricating (or lube) oil feed" means a feed to one or more processes that makes a lube oil or lube oil basestock, such as solvent extraction, solvent dewaxing, catalytic dewaxing, finishing, hydrofinishing, and trim dewaxing. Such feeds are derived from mineral sources, synthetic sources, or a mixture of the two. Non-limiting examples of suitable lubricating oil feeds include oils derived from solvent refining processes such as raffinates, partially solvent dewaxed oils, deasphalted oils, distillates, vacuum gas oils, coker gas oils, slack waxes, foots oils, dewaxed oils, automatic transmission fluid feedstocks, and Fischer-Tropsch waxes.

[0013] Though not required, feeds may have high contents of nitrogen and sulfur contaminants. For example, feeds containing 0.2 wt.% of nitrogen, based on the weight of the feed and 3.0 wt.% of sulfur, can be used in the process. Sulfur and nitrogen contents may be measured by standard ASTM methods D5453 and D4629, respectively. Feeds having a high wax content typically have high viscosity indexes of up to 200 or more.

Solvent Extraction

[0014] In an embodiment, the process relates to producing lubricating oil basestocks from lube oil boiling-range feeds. For example, the lubricating oil feed (e.g., a distillate such as a lube distillate) is solvent-extracted to produce a raffinate and an extract. The solvent extraction process selectively dissolves the feed's aromatic components into an aromatics-rich extract while leaving the more paraffinic components in an aromatics-lean raffinate. Naphthenes are distributed between the extract and raffinate phases. By controlling the solvent-to-oil ratio, extraction temperature and method of contacting distillate to be extracted with solvent, one can control the degree of hydrocarbon species separation between the extract and raffinate phases.

[0015] Solvent extraction of the lube oil feed occurs in a solvent extraction zone, where the lube oil feed contacts the extraction solvent. The extraction solvent used herein is not critical and can be any solvent that has an affinity for aromatic hydrocarbons in preference to non-aromatic hydrocarbons. Non-limiting examples of such solvents include sulfolane, furfural, phenol, and N-methyl pyrrolidone ("NMP").

[0016] The contacting of the lube oil boiling-range feed with the extraction solvent can be accomplished by any suitable solvent extraction method including conventional methods. Non-limiting examples of such include batch, semi-batch, or continuous. It is preferred that the extraction process be a continuous process, and it is more preferred that the continuous process be operated in a counter-current fashion. In a counter-current configuration, it is preferred that the lube oil boiling-range feed be introduced into the bottom of an elongated contacting zone or tower and caused to flow in an upward direction while the extraction solvent is introduced at the top of the tower and allowed to flow in a downward direction, counter-current to the upflowing lube oil boiling-range feed. In this configuration, the lube oil boiling-range feed flows counter-

currently to the extraction solvent, resulting in the intimate contact between the extraction solvent and the lube oil boiling-range feed. The extraction solvent and the lube oil boiling-range feedstream thus migrate to opposite ends of the contacting zone.

[0017] The contacting of the lube oil boiling-range feed with the extraction solvent produces at least an aromatics-lean raffinate solution, which contains extraction solvent. The aromatics-lean raffinate solution is then treated to remove at least a portion of the extraction solvent contained therein, thus producing a raffinate. The removal of at least a portion of the extraction solvent can be done by any process effective for separating at least a portion of an extraction solvent from an aromatics-lean raffinate solution, including conventional treatment processes. Preferably the raffinate is produced by separating at least a portion of the first extraction solvent from the aromatics-lean raffinate solution in a stripping or distillation tower. By at least a portion, it is meant that at least about 80 vol.%, preferably about 90 vol.%, more preferably 95 vol.% of the extraction solvent based on the aromatics-lean raffinate solution, is removed from the aromatics-lean raffinate solution. Most preferably, substantially all of the extraction solvent is removed.

[0018] It should be noted that the phrase "aromatics-lean raffinate solution" is not synonymous with the term "raffinate". The phrase "aromatics-lean raffinate solution" refers to the products of solvent extraction before the solvent has been removed, i.e., distilled or stripped from the respective phases. The term "raffinate" refers to the material that remains after at least a portion of the solvent contained in the "aromatics-lean raffinate solution" is separated and removed. As discussed, the raffinate is a suitable lubricating oil feed for the process.

Hydrotreating

[0019] The term "hydrotreating" as used herein refers to processes wherein a treat gas that contains hydrogen is used in the presence of a catalytically effective amount of a catalyst that is active for the removal of heteroatoms such as sulfur, and/or nitrogen, and for the saturation of aromatics. In an embodiment of the present process, the lube oil boiling-range feed (e.g., a raffinate) is contacted with a hydrotreating catalyst in a first reaction stage operated under conditions effective for heteroatom removal and/or aromatics saturation. The contacting of the lube oil boiling-range feed with the catalyst in the presence of hydrogen produces a hydrotreated effluent comprising at least a first reaction stage gaseous product and a hydrotreated product (e.g., a hydrotreated raffinate) containing fewer nitrogen and sulfur heteroatoms than the lube oil feed.

[0020] The choice of hydrotreating catalysts and hydrotreating conditions used in the process is not critical and can be conventional hydrotreating catalyst and conditions. Conventional hydrotreating catalysts include those which comprise at least one metal selected from Group VIII of the Periodic Table of the Elements (Sargent-Welch Scientific Company, 1968), the "Periodic Table", preferably Fe, Co and Ni, more preferably Co and/or Ni, and most preferably Ni; and at least one metal selected from Group VIB of the Periodic Table, preferably Mo and W, more preferably Mo, on a high surface area support material, preferably alumina. The Group VIII metal is typically present in an amount ranging from about 2 and 20 wt.%, preferably from about 4 to 12 wt.%. The Group VI metal will typically be present in an amount ranging from about 5 to 50 wt.%, preferably from about 10 to 40 wt.%, and more preferably from about 20 to 30 wt.%. All metal weight percents are on support. The term "on support" means that the percents are based on the weight of the support. For example, if the support was to weigh 100 grams, then 20 wt.% Group VIII metal would mean that 20 grams of Group VIII metal was on the support.

[0021] Effective hydrotreating conditions are those conditions effective for removing at least a portion of the nitrogen and sulfur heteroatoms from the lube oil feed. Preferably, the conditions are those conditions that result in a hydrotreated raffinate having a sulfur content below about 200 wppm, more preferably less than 150 wppm, and most preferably less than 100 wppm. In an embodiment, effective hydrotreating conditions are those that reduce the nitrogen content of the hydrotreated raffinate to below about 50 wppm, more preferably less than 25 wppm, and most preferably less than 10. In an embodiment, the hydrotreating conditions include temperatures of from about 150°C to about 400°C, a hydrogen partial pressure of from about 1.48 MPa to about 20.8 MPa (about 200 psig to about 3000 psig), a total pressure of about 3.55 MPa to about 34.58 MPa (about 500 psig to about 5000 psig), preferably about 7.0 MPa to about 20.8 MPa (1000 psig to about 3000 psig), a space velocity of from about 0.1 to about 10 liquid hourly space velocity (LHSV), and a hydrogen-to-feed ratio of from about 89 to about 1780 m³/m³ (500 to 10,000 SCF H₂/B). While some cracking of the components of the lube oil feed may occur under effective hydrotreating conditions, it is preferred that the cracking be limited to less than about 35 wt.% conversion, based on the weight of the raffinate feed, more preferably less than about 20 wt.%, and most preferably to less than about 10 wt.%. Since the treat gas used in the hydrotreating stage is typically cascaded from the hydrofinishing stage, the total pressure and hydrogen partial pressure at the outlet of the hydrofinishing stage will typically exceed the total pressure and hydrogen partial pressure at the inlet of the hydrotreating stage.

[0022] Hydrogen-containing treat gases suitable for use in the reaction stage can comprise substantially pure hydrogen or hydrogen in combination with one or more species typically found in refinery hydrogen streams. In an embodiment, the hydrogen-containing treat gas used in the first reaction stage is supplied by the third-stage gaseous product, which is cascaded, without heteroatom

disengagement, to the first reaction stage. The hydrogen-containing treat gas purity is not critical. In an embodiment, the treat gas used in the hydrotreating stage is at least about 50% by volume hydrogen, preferably at least about 75% by volume hydrogen, and more preferably at least about 90% by volume hydrogen. It should be noted that the term "cascaded" as used herein is meant to refer to the fact that a gaseous product, liquid product, etc., is conducted from a reaction stage, stripping stage, etc., of the process directly to the designated subsequent reaction stage, stripping stage, etc., of the process without any additional processing such as stripping. It should also be noted that the phrase "without disengagement" as used herein means that the particular gaseous product, liquid product, etc., is not depressurized between the respective reaction and/or stripping stages.

[0023] The first reaction stage comprises one or more fixed bed reactors or reaction zones each of which can comprise one or more catalyst beds of the same or different catalyst. In other words, the catalyst used in a particular zone or bed is independently selected, and need not be the same catalyst used in any other zone or bed. Mixtures of different catalysts can be used. Although other types of catalyst beds can be used, fixed beds are preferred. Such other types of catalyst beds include fluidized beds, ebullating beds, slurry beds, and moving beds. Interstage cooling or heating between reactors, reaction zones, or between catalyst beds in the same reactor, can be employed since some aromatics and/or olefin saturation can take place, and olefin saturation and the desulfurization reaction are generally exothermic. A portion of the heat generated during hydrotreating can be recovered. Where this heat recovery option is not available or economically feasible, conventional cooling may be performed through cooling utilities such as cooling water or air, or through use of a hydrogen quench stream so as to maintain optimal reaction temperatures.

Stripping

[0024] The hydrotreated raffinate feedstream may be conducted directly to the hydrodewaxing step or, preferably, is first stripped to remove heteroatom contaminants such as hydrogen sulfide and ammonia prior to dewaxing. The raffinate recovered from the stripping stage is referred to as a stripped raffinate. Conventional technology can be used for stripping the hydrotreated raffinate, such as flash drums, fractionators, vertical towers, and the like, but any method for effective removal of gaseous contaminants can be used. Preferably, the hydrotreated raffinate is stripped by contacting the raffinate in a stripping tower with fresh, once-through, hydrogen-containing treat gas. The term "once-through" hydrogen-containing treat gas means that the hydrogen-containing treat gas is derived from a source other than the present process. Thus, "once-through" hydrogen-containing treat gas does not contain an appreciable amount of gaseous reaction product from a reaction and/or stripping stage of the present process. Preferably, the "once-through" hydrogen-containing treat gas does not contain any gaseous reaction product from a reaction and/or stripping stage of the present process. It should be noted, however, that the term "once-through" is not meant to exclude the situation wherein a gaseous reaction product from the present process is conducted to a hydrogen-containing treat "pool" within a refinery, etc., wherein the gas is upgraded (e.g., cleaned of impurities) and made ready for use in refinery processes.

[0025] In an embodiment, fresh, once-through, hydrogen-containing treat gases suitable for use in the present process can comprise substantially pure hydrogen or mixtures of hydrogen in admixture with other components typically found in refinery hydrogen streams. It is preferred that the hydrogen-containing treat gas stream contains little, more preferably no, hydrogen sulfide. Though not required, the once-through, hydrogen-containing treat gas can be substantially pure hydrogen.

[0026] In another embodiment, at least a portion of the stripper gas is obtained by cascading the third stage gaseous product (which contains hydrogen) to the stripper. Use of the third-stage gaseous product in the stripper gas can be advantageous when the lubricating oil feed contains less than about 0.2 wt.% nitrogen and less than about 3.0 wt.% sulfur, preferably substantially less than those amounts, so that the amounts of sulfur and nitrogen in the stripper bottoms will not appreciably affect the catalyst used for hydrodewaxing.

Hyrodewaxing

[0027] In an embodiment, the stripped raffinate is contacted with a catalytically effective amount of a hydrodewaxing catalyst and a fresh once-through, hydrogen-containing treat gas in a second reaction stage. The second reaction stage is operated under effective hydrodewaxing conditions such as conventional hydrodewaxing conditions to produce a second stage reaction product comprising a second stage gaseous product and a second stage liquid product. The second stage gaseous product comprises hydrogen and the second stage liquid product comprises a dewaxed raffinate.

[0028] In an embodiment, the catalytic hydrodewaxing conditions of the present process include temperatures ranging from about 250°C to about 400°C, preferably from about 275°C to about 375°C, pressures of from about 0.7 MPa to about 20.8 MPa (100 psig to 3000 psig), preferably from about 1.48 MPa to about 18.7 MPa (200 psig to 2700 psig), liquid hourly space velocities of from about 0.1 to about 10 hr⁻¹, preferably from about 0.1 to about 5 hr⁻¹, and hydrogen treat gas rates from about 45 m³/m³ to about 1780 m³/m³ (250 SCF H₂/B to 10,000 SCF H₂/B), preferably from about 89 m³/m³ to about 890 m³/m³ (500 SCF H₂/B to 5000 SCF H₂/B).

[0029] In a preferred embodiment, hydrodewaxing conditions include temperatures between from about 300°C to about 400°C, preferably from about

300°C to about 380°C, total pressure ranging from 3.55 MPa to about 34.58 MPa (about 500 to about 5000 psig), preferably from about 7 MPa to about 20.8 MPa (about 1000 psig to about 3000 psig), hydrogen partial pressure ranging from about 1.48 MPa to about 20.8 MPa (about 200 psig to about 3000 psig), hydrogen treat gas rates of from about 89 to about 1780 m³/m³ (about 500 to about 10,000 SCF H₂/B), preferably from about 356 to about 890 m³/m³ (about 2000 to about 5000 SCF H₂/B), and liquid hourly space velocities ("LHSV") of from about 0.5 to about 5 V/V/hr, preferably from about 0.5 to 2 V/V/hr, for a time sufficient to reduce the wax content in the feed to below about 40 wt.%, preferably from about 35 wt.% to about 25 wt.%, preferably less than 15 wt.%.

[0030] The second reaction stage generally comprises one or more fixed bed reactors or reaction zones each of which can comprise one or more catalyst beds of independently selected catalyst and/or catalyst mixtures. Although other types of catalyst beds can be used, fixed beds are preferred. Such other types of catalyst beds include fluidized beds, ebullating beds, slurry beds, and moving beds. Interstage cooling or heating between reactors, reaction zones, or between catalyst beds in the same reactor, can be employed. A portion of any heat generated during hydrodewaxing can be recovered. Where this heat recovery option is not available, cooling may be performed through cooling utilities such as cooling water or air, or through use of a hydrogen-rich quench stream. In this manner, optimum reaction temperatures can be more easily maintained.

Hyrodewaxing Catalyst

[0031] The hydrodewaxing catalyst generally contains crystalline materials such as molecular sieves that contain at least one 10- or 12-ring channel. The molecular sieve can contain one or more of aluminosilicates (zeolites) and aluminophosphates such as silicoaluminophosphates (SAPOs) and MAPOs. In an embodiment, the molecular sieve contains at least one 10- or 12-ring channel. Examples of such zeolites include ZSM-22, ZSM-23, ZSM-35, ZSM-48,

ZSM-57, ferrierite, ITQ-13, MCM-68 and MCM-71. Examples of aluminophosphates containing at least one 10-ring channel include ECR-42. Examples of molecular sieves containing 12-ring channels include zeolite beta, and MCM-68. Some molecular sieves suitable for use herein are described in U.S. Patent Numbers 5,246,566, 5,282,958, 4,975,177, 4,397,827, 4,585,747, 5,075,269 and 4,440,871, which are incorporated by reference herein. MCM-68 is described in U.S. Patent No. 6,310,265, incorporated by reference herein. MCM-71 and ITQ-13 are described in PCT published applications WO 0242207 and WO 0078677, both incorporated by reference herein. ECR-42 is disclosed in US 6,303,534. Suitable SAPOs for use herein include SAPO-11, SAPO-31, SAPO-41, and suitable MAPOs include MAPO-11. SSZ-31 is also suitable.

[0032] In an embodiment, the hydrodewaxing catalyst contains zeolite. Preferred zeolite hydrodewaxing catalysts include ZSM-48, ZSM-22 and ZSM-23. ZSM-48 is especially preferred. The molecular sieves are preferably in the hydrogen form, i.e., in a reduced state, though they can contain metals. Reduction can be accomplished *in situ* or *ex situ*.

[0033] Bifunctional hydrodewaxing catalysts are suitable for use in the present process. Such catalysts are loaded with one or more metal hydrogenation components selected from Group VIB metals, Group VIII metals, or mixtures thereof. Preferred metals are selected from Group VIII metals. Especially preferred are Group VIII noble metals such as Pt, Pd or mixtures thereof. These metals are loaded at the rate of 0.1 to 30 wt.%, based on catalyst. Catalyst preparation and metal loading methods are described for example in U.S. Patent No. 6,294,077 (incorporated by references herein), and include for example ion exchange and impregnation using decomposable metal salts. Metal dispersion techniques and catalyst particle size control techniques are described in U.S. Patent No. 5,282,958, also incorporated by reference herein. Catalysts with small particle size and well-dispersed metal are preferred.

[0034] The molecular sieves can be composited with binder materials which are resistant to high temperatures which may be employed under hydrodewaxing conditions, or they can be binderless (self-bound). The binder materials when used can be inorganic oxides such as silica, alumina, silica-aluminas, binary combinations of silicas with other metal oxides such as titania, magnesia, thoria, zirconia and the like and tertiary combinations of these oxides such as silica-alumina -thoria and silica-alumina-magnesia. The amount of molecular sieve in the finished hydrodewaxing catalyst is from 10 to 100, preferably 35 to 100 wt.%, based on the weight of the finished catalyst. Such catalysts are formed by methods such spray drying, extrusion and the like. The hydrodewaxing catalyst may be used in the sulfided or unsulfided form, and though the sulfided form is preferred.

Hydrofinishing

[0035] In an embodiment, at least a portion of the second reaction stage product is cascaded to a third reaction stage of hydrofinishing. The term "cascaded" means that the second reaction stage product flows under the influence of a pressure gradient established by the higher pressure at the outlet of the hydrodewaxing (second) stage and the comparatively lower pressure at the inlet of the hydrofinishing (third) stage. In the hydrofinishing stage, the dewaxed raffinate product of the hydrodewaxing stage is contacted with a catalytically effective amount of a hydrofinishing stage under catalytic hydrofinishing conditions. The hydrofinishing stage produces a third-stage reaction product comprising at least a third-stage gaseous product comprising hydrogen and a third-stage liquid product comprising a lubricating oil basestock. The gaseous product of the second reaction stage serves as the hydrogen-containing treat gas in the third reaction stage.

[0036] In an embodiment, at least a portion, preferably substantially all, of the gaseous effluent and dewaxed raffinate from the hydrodewaxing stage, i.e.,

second reaction stage, is conducted directly to the hydrofinishing step, without disengagement. It is preferred to hydrofinish the dewaxed raffinate (the liquid portion of the second reaction stage product) in order to adjust product qualities to desired specifications. Hydrofinishing is a form of mild hydrotreating directed to saturating lube-range olefins and residual aromatics as well as to substantially removing at least a portion, preferably substantially all, remaining heteroatoms and color bodies.

[0037] The hydrofinishing of the cascaded dewaxed raffinate is conducted under effective hydrofinishing conditions. Effective hydrofinishing conditions herein, are conditions which make a lubricating oil basestock product meeting the desired specifications with respect to oxidation stability, color, etc. Thus, effective hydrotreating conditions are those hydrofinishing conditions that saturate at least a portion of any lube range olefins and/or residual aromatics and/or remove at least a portion of any remaining heteroatoms and/or color bodies. In an embodiment, effective hydrofinishing conditions are selected to saturate at least a portion of any lube range olefins and residual aromatics and remove at least a portion of any remaining heteroatoms and color bodies. Preferred hydrofinishing conditions include temperatures from about 150°C to about 350°C, preferably from about 180°C to about 250°C. Total pressure typically ranges from about 2.86 MPa to about 20.8 MPa (about 400 to 3000 psig). Liquid hourly space velocity is typically from about 0.1 to about 5 LHSV (hr^{-1}), preferably from about 0.5 to about 3 hr^{-1} , and hydrogen treat gas rates of from about 44.5 to about 1780 m^3/m^3 (250 to 10,000 SCF H_2/B). Hydrogen partial pressure typically ranges from about 1.48 MPa to about 20.8 MPa (about 200 psig to about 3000 psig). Since the gaseous product of the hydrodewaxing stage is typically cascaded to the inlet of the hydrofinishing stage, the total pressure at the inlet of the hydrofinishing stage should be lower than the total pressure at the outlet of the hydrodewaxing stage.

[0038] Hydrofinishing catalysts for the process contain at least one metal selected from Group VIB and/or Group VIII of the Periodic Table. Preferred metals include at least one noble metal having a strong hydrogenation function, especially platinum, palladium and mixtures thereof. The mixture of metals may also be present as bulk metal catalysts wherein the amount of metal is 30 wt.% or greater based on catalyst. The metals referred to are not in the oxide state. Supports include low acidic oxides such as silica, alumina, silica-aluminas or titania, preferably alumina. The preferred hydrofinishing catalysts for aromatics saturation comprises at least one metal having relatively strong hydrogenation function on a porous support. Typical support materials include amorphous or crystalline oxide materials such as alumina, silica, and silica-alumina. The metal content of the catalyst is often as high as about 20 wt.% for non-noble metals. Noble metals are usually present in amounts no greater than about 2 wt.%.

[0039] The hydrofinishing catalyst can contain an ordered mesoporous material, such as those belonging to the M41 class or family of catalysts. The M41 family of catalysts is mesoporous materials having high silica contents whose preparation is further described in J. Amer. Chem. Soc., 1992, 114, 10834. Examples included MCM-41, MCM-48 and MCM-50. Mesoporous refers to catalysts having pore sizes from 15 to 100 Å. A preferred member of this class is MCM-41 whose preparation is described in U.S. Patent No. 5,098,684, incorporated by reference herein. MCM-41 is an ordered, inorganic, porous, non-layered phase having a hexagonal arrangement of uniformly-sized pores. The morphology of MCM-41 is conceptually similar to a bundle of straws wherein the opening of the straws (the cell diameter of the pores) ranges from 15 to 100 Angstroms. MCM-48 has a cubic symmetry and is described for example is U.S. Patent No. 5,198,203 whereas MCM-50 has a lamellar structure. MCM-41 can be made with different size pore openings in the mesoporous range. The mesoporous materials may bear a metal hydrogenation component,

such as one or more Group VIII metal. Group VIII noble metals are preferred; Pt, Pd or mixtures thereof are more preferred.

[0040] The contacting of the second-stage reaction product with the hydrofinishing catalyst in the hydrofinishing reaction stage produces a third-stage reaction product comprising at least a third-stage gaseous product comprising hydrogen and a third-stage liquid product comprising a lubricating oil basestock. The third-stage liquid product and the third-stage gaseous product are separated from the third-stage reaction product. The manner in which the third-stage reaction product is separated is not critical, and can be achieved by, e.g., stripping (as described above), fractionation, knock-out drums, settling drum, flashing etc. However, it is preferred that a flash drum or knock-out drum be used. The separated third-stage gaseous product is cascaded to the inlet of the first reaction stage, where it serves as the treat gas for the hydrotreating stage. Since the separated gaseous product is cascaded to the inlet of the first stage, the total pressure at the outlet of the hydrofinishing stage should be greater than the total pressure at the inlet of the hydrotreating stage. The pressure differential should be great enough for the gaseous effluent of the third-stage to flow solely under the influence of the pressure differential, from the outlet of the hydrofinishing stage, through any interstage processing such as liquid-vapor separation, to the inlet of the hydrotreating stage.

[0041] The third reaction stage comprises one or more fixed bed reactors or reaction zones each of which can comprise one or more catalyst beds of independently selected catalyst or catalyst mixtures. Although other types of catalyst beds can be used, fixed beds are preferred. Such other types of catalyst beds include fluidized beds, ebullating beds, slurry beds, and moving beds. While not generally needed, interstage cooling or heating can be employed between reactors, reaction zones, or between catalyst beds in the same reactor.

[0042] Operation of the embodiments described above, including the hydrogen-containing treat gas loop, achieves high yields of the lubricating oil basestock. By using the above-described reaction steps and hydrogen-containing treat gas loop, the process achieves lubricating oil basestock yields of greater than 70%, based on the lube oil boiling-range raffinate feedstream, preferably in the range of from about 70 to about 90%, more preferably from about 70 to about 80%. When a higher basestock target VI is desired, e.g., 140 VI or higher using slack wax feeds, the yield is typically in the range of about 35% to 45%.

[0043] In one embodiment, at least 2, preferably at least 3, more preferably a plurality, of lubricating oil product streams can be separated from the liquid product of the hydrofinishing stage. Non-limiting examples of lubricating oil product streams that can be produced include 50N, 60N, 80N, 100N, and 150N. The form of separation used herein is not critical, and can be fractionation, for example. Non-limiting examples of suitable fractionations include atmospheric and vacuum, preferably vacuum fractionation. It should be noted that the number of lubricating oil product streams, and their weight, i.e., boiling point, depends on the nature of the feedstock, the desired product slate, and the operating conditions the practitioner selects for the fractionation. The lube oil boiling-range product streams produced can be recovered and used to produce finished oils.

[0044] Referring now to Figure 1, a lube oil boiling-range raffinate feed ("raffinate feed") is conducted via line 1 to heat exchanger 2 wherein it is heated through indirect heat exchange with stream 3, taken from distillation tower 4. Stream 1 continues to heat exchanger 5, wherein the temperature of the raffinate feed, stream 1, is increased again by direct heat exchange with stream 6, the second reaction stage product obtained from hydrodewaxing (second reaction stage) unit 13. From heat exchanger 5, stream 1 continues to heat exchanger 7 wherein stream 1 is again heated by indirect heat exchange with stream 8, the

stripped raffinate obtained by stripping the hydrotreated effluent 9 in stripper 12. Stream 1 is then combined with stream 20a, the third stage gaseous reaction product, to form stream 1a that is conducted to feed furnace 10 wherein it is heated to the feed inlet reaction temperature of hydrotreating (first reaction stage) unit 11. In hydrotreating unit 11, the raffinate feed is contacted with a hydrotreating catalyst, as described above, thus producing hydrotreated effluent 9. Hydrotreated effluent 9 is conducted to hydrogen treat gas heat exchanger 15 thence to stripper 12. In stripping unit 12, fresh, once-through, hydrogen-containing treat gas stream 16a, obtained from fresh hydrogen treat gas feed 16 contacts the hydrotreated effluent 9, thus separating the hydrotreated effluent into stream 17 (the first-stage gaseous product) and stripped raffinate 8. Stream 17, containing any unused hydrogen-containing treat gas and heteroatom gas such as H_2S is conducted away from the process to, for example, upgrading and addition to the hydrogen-treat gas pool. Since the pressure in hydrotreating unit 11 is lower than in hydrodewaxing unit 13, and since stripper 12 operates at a still lower pressure, a pump 24 is used to boost the pressure of the stripped raffinate 8 for hydrodewaxing. Stream 8 passes through heat exchanger 18 and heat exchanger 7 wherein the temperature of stream 8 is adjusted to the inlet reaction temperature of hydrodewaxing unit 13, and then combined with fresh, once-through, hydrogen-containing treat gas supplied via line 16 thus forming stream 8a. In hydrodewaxing unit 13, stream 8a is contacted with a hydrodewaxing catalyst in order to produce second reaction stage product 6. Second reaction stage product 6, which comprises at least a second-stage gaseous product containing hydrogen and a second stage liquid product containing dewaxed raffinate, is cascaded through heat exchangers 19 and 5 and, without disengagement, into hydrofinishing unit (the third reaction stage) 14. In hydrofinishing unit 14, stream 6 is contacted with a hydrofinishing catalyst to produce a third reaction stage product 20, which comprises a third-stage gaseous product comprising hydrogen and a third-stage liquid product comprising a

lubricating oil basestock. Third reaction stage product 20 is conducted to flash drum 21 wherein a third-stage liquid product 20b and a third-stage gaseous product 20a are separated from the third reaction stage product 20. Stream 20a which contains hydrogen is added to raffinate feed 1. Stream 20b which contains lubricating oil basestock is conducted through heat exchanger 19 and heat exchanger 18 to distillation tower 4. In distillation tower 4, lubricating oil boiling-range product fractions, e.g. 60N, 80N, 100N, 150N, etc. (denoted by streams 22 and 23, herein) are separated from stream 20b and conducted away from the process. A major amount of lubricating boiling range product fraction and a minor amount of one or more additives can be combined to form a finished lubricating oil product. Suitable additives include dispersants, antioxidants, dewaxing aids, viscosity modifiers, lubricity aids, anticorrosion agents, and the like. A major amount is preferably more than 50 wt.%, based on the weight of the finished lubricating oil product, preferably greater than 75 wt. % and more preferably greater than 90 wt.%.

[0045] The process uses three heat exchangers prior to feed furnace 10 to preheat the raffinate feed to the inlet temperature of hydrotreater 11. The use of these three heat exchangers, 2, 5, and 7, reduces furnace requirements. Four heat exchangers control the inlet temperature into units 13 and 14. It should be noted that in preferred embodiments, the three reaction stages operate in a temperature cascade where the first reaction stage is the hottest and the third reaction stage is the coolest.

[0046] Figure 2 is a schematic diagram of the hydrogen flow through the process. Fresh, once-through, hydrogen-containing treat gas is conducted to hydrodewaxing unit 13 via line 16. Second reaction stage product 6, which comprises a second-stage gaseous product containing hydrogen and a second-stage liquid product containing dewaxed raffinate, is cascaded, without disengagement, into hydrofinishing unit (the third reaction stage) 14. In the third

reaction stage 14, the second stage gaseous product serves as the hydrogen-containing treat gas. Third reaction stage product 20 is conducted to separator 21 wherein the third-stage gaseous product comprising hydrogen 20a is separated therefrom. In the first reaction stage 11, the third reaction stage gaseous product 20a serves as the hydrogen-containing treat gas. Hydrotreated effluent 9 is stripped with fresh, once-through, hydrogen-containing treat gas stream 16a, separating from the hydrotreated effluent a stream 17 containing heteroatom impurities. Stream 17 is conducted away from the process for, e.g., the recovery of any unused hydrogen.

[0047] The above description is directed to embodiments of the present process. Those skilled in the art will recognize other embodiments that are within the invention.

EXAMPLES

EXAMPLE 1 (Comparative)

[0048] In a simulation, 10,000 barrels per day of lubricating oil boiling-range distillate feed was conducted to a solvent extraction step to produce a solvent extracted raffinate with a VI of 97 with a yield of 65 wt.%. In the simulation, the raffinate was conducted to a hydrotreating stage, hydrodewaxing stage, and hydrofinishing state, each operating under simulated conventional conditions. Hydrogen-containing treat gas was introduced into the hydrotreating stage, and the gaseous effluent from the hydrotreating stage was compressed and then conducted to the hydrodewaxing stage. The compressor was needed because the hydrodewaxing stage was simulated at a higher total pressure than the hydrotreating stage, as set forth in the following table. Gaseous effluent from the hydrodewaxing stage was cascaded to the hydrofinishing stage, both operating under simulated conventional conditions.

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TABLE

		<u>HDT</u>	<u>MSDW</u>	<u>HDF</u>
Total Pressure	In	17.89/2580	17.75/2760	18.37/2650
(MPa/psig)	Out	17.68/2550	18.72/2700	18.20/2625
H ₂ Partial Pressure	In	16.30/2350	18.17/2620	16.79/2420
(MPa/psig)	Out	14.58/2100	17.06/2460	16.58/2390

[0049] Simulated yields at target VI were 90 wt.% for hydrotreating, 75 wt.% for hydrodewaxing, and 99 wt.% for hydrofinishing, resulting in a lubricating oil base stock yield of 4,344 barrels per day.

EXAMPLE 2

[0050] The distillate feed of Example 1 was subjected to simulated solvent extraction under conditions that resulted in VI of 93 for the solvent-extracted raffinate with a yield of 69 wt.%. The raffinate feed was conducted to a hydrotreating stage, stripping stage, hydrodewaxing stage, and hydrofinishing stage. The hydrotreating, hydrodewaxing, and hydrofinishing stages were simulated under the same conditions as in Example 1. Conventional stripping conditions were used in the simulation. In accordance with an embodiment of the invention, fresh, once-through, treat gas having the same characteristics as in Example 1 was conducted to the hydrodewaxing stage and the stripping stage. Gaseous effluent from the hydrodewaxing stage was cascaded for use as treat gas in the hydrofinishing stage, and gaseous effluent from the hydrofinishing stage was cascaded for use as the treat gas in the hydrotreating stage. The same total pressures and hydrogen partial pressures of Example 1 were used in the simulation of Example 2. Unit yields resulting from the simulation: hydrotreater - 69 wt.%; hydrodewaxer - 75 wt.%; and hydrofinisher - 99 wt.%. Yield of a lubricating oil basestock having the same target VI as in Example 1 was 4,500 barrels per day, a 4% yield improvement over the yield of Example 1.

EXAMPLE 3

[0051] Similar conditions were simulated as in Example 2, with the same scheme, but with distillate feed of Examples 1 and 2 solvent-extracted to a VI of 89 with a solvent extraction yield of 74%. Under the same simulated conditions as used in Example 2, the following yield values were obtained: hydrotreating - 86 wt.%; hydrodewaxing - 75 wt.%; hydrofinishing - 99 wt.%. The simulation produced 4,700 barrels per day of lubricating oil base stock, with an 8% yield improvement over Example 1.

[0052] It should be noted that the simulation of Examples 2 and 3 also showed a reduction in operating costs resulting from, for example, the elimination of the treat gas compressor used in Example 1.

CLAIMS:

1. A process to prepare a lubricating oil basestock comprising:
 - (a) contacting a lube oil boiling-range raffinate feed containing nitrogen and sulfur heteroatoms with a catalytically effective amount of a hydrotreating catalyst in a first reaction stage operated under effective hydrotreating conditions in the presence of a hydrogen-containing gaseous product from a third reaction stage to produce a hydrotreated raffinate;
 - (b) stripping the hydrotreated raffinate by contacting the hydrotreated raffinate with a first once-through, hydrogen-containing treat gas to separate sulfur-containing and nitrogen-containing species from the hydrotreated raffinate to produce a stripped raffinate;
 - (c) contacting the stripped raffinate with a catalytically effective amount of a hydrodewaxing catalyst in the presence of a second once-through, hydrogen-containing treat gas in a second reaction stage operated under effective hydrodewaxing conditions to produce a second-stage reaction product comprising a second-stage gaseous product and a second-stage liquid product, wherein the second-stage gaseous product comprises hydrogen and the second-stage liquid product comprises a dewaxed raffinate;
 - (d) cascading, without disengagement, at least a portion of the second reaction stage product to a hydrofinishing reaction stage;
 - (e) contacting the cascaded portion of the second reaction stage product with a catalytically effective amount of a hydrofinishing catalyst in the third reaction stage operated under effective hydrofinishing conditions to produce a third-stage reaction

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product comprising the third-stage gaseous product comprising hydrogen and a third-stage liquid product comprising a lubricating oil basestock, wherein said second-stage gaseous product provides hydrogen for the third reaction stage;

- (f) separating the third-stage gaseous product from the third-stage reaction product; and
- (g) cascading the third-stage gaseous product, without heteroatom disengagement, to the first reaction stage.

2. The process according to claim 1 wherein said lube oil boiling-range raffinate feed is produced by:

- (a) extracting a lubricating oil feed in a solvent extraction zone with an extraction solvent under conditions effective to produce at least an aromatics-lean raffinate solution containing extraction solvent; and
- (b) removing at least a portion of the extraction solvent from the aromatics-lean raffinate solution to produce at least a lube oil boiling-range raffinate feed.

3. The process according to claim 2 wherein the lubricating oil feed has a 10% distillation point greater than 650°F (343°C), measured by ASTM D 86 or ASTM 2887, and are derived from mineral sources, synthetic sources, or a mixture of the two.

4. The process according to claim 2 wherein the lubricating oil feed is one or more oil selected from raffinates, partially solvent dewaxed oils, deasphalted oils, distillates, vacuum gas oils, coker gas oils, slack waxes, foots oils and the like, dewaxed oils, and Fischer-Tropsch waxes.

5. The process according to claim 2 wherein the lubricating oil feed contains up to 0.2 wt.% of nitrogen, based on the weight of the lubricating oil feed, and up to 3.0 wt.% of sulfur, based on the weight of the lubricating oil feed.

6. The process according to claim 1 wherein said hydrodewaxing catalyst is selected from ZSM-5, ZSM-22, ZSM-23, ZSM-35, ZSM-48, ZSM-57, Beta, SSZ-31, SAPO-11, SAPO-31, SAPO-41, MAPO-11, ECR-42, fluorided alumina, silica-alumina, fluorided silica alumina, synthetic Ferrierites, Mordenite, Offretite, erionite, chabazite, and mixtures thereof.

7. The process according to claim 6 wherein the hydrodewaxing catalyst further comprises at least one metal hydrogenation component, which is selected from Group VIB metals, Group VIII metals, or mixtures thereof.

8. The process according to claim 1 wherein the hydrodewaxing catalyst comprises a zeolite.

9. The process according to claim 8 wherein the zeolite is selected from ZSM-48, ZSM-22 and ZSM-23.

10. The process according to claim 6 wherein the hydrodewaxing catalyst further comprises a binder material selected from inorganic oxides containing one or more of silica, alumina, titania, magnesia, thoria, and zirconia.

11. The process according to claim 1 wherein the effective hydrodewaxing conditions include a temperature from about 250°C to about 400°C, a pressure from about 0.7 MPa to about 20.8 MPa (about 100 to 3000 psig), a liquid hourly space velocity from about 0.1 to about 10 hr⁻¹, and a once-through, hydrogen-containing treat gas rate from about 45 to about 1780 m³/m³ (250 to 10000 SCF H₂/B); and wherein the first and second once-through, hydrogen-

containing treat gases are fresh and are obtained from a common fresh treat gas source.

12. The process according to claim 1 wherein the hydrotreating catalyst is selected from supported hydrotreating catalysts comprising about 2 to 20 wt.% of at least one Group VIII metal, and about 5 to 50 wt.% of at least one Group VI metal, on a support material.

13. The process according to claim 12 wherein the Group VIII metal is Co and/or Ni, and mixtures thereof, and wherein the Group VI metal is Mo and/or W.

14. The process according to claim 1 wherein the effective hydrotreating conditions include a temperature from about 150°C to about 400°C, a hydrogen partial pressure from about 1.48 to about 20.8 MPa (200 to 3000 psig), a space velocity from about 0.1 to about 10 liquid hourly space velocity (LHSV), and a hydrogen to feed ratio from about 89 to about 1780 m³/m³ (500 to 10000 SCF H₂/B).

15. The process according to claim 14 wherein the effective hydro-treating conditions are selected such that cracking of the lube oil boiling-range raffinate feed is limited to less than 10 wt.% conversion, based on the weight of the lube oil boiling-range raffinate feed.

16. The process according to claim 1 wherein the hydrofinishing catalyst comprises a support and at least one metal selected from Group VIB metals, Group VIII metals, and mixtures thereof.

17. The process according to claim 1 wherein the support comprises amorphous or crystalline oxide materials containing one or more of alumina, silica, and silica-alumina.

18. The process according to claim 1 wherein the hydrofinishing catalyst comprises a mesoporous material belonging to the M41S class or family of catalysts.

19. The process according to claim 18 wherein the mesoporous material is selected from MCM-41, MCM-48 and MCM-50.

20. The process according to claim 9 wherein the zeolite is ZSM-48, and wherein the hydrofinishing catalyst comprises MCM-41.

21. The process according to claim 18 wherein the hydrofinishing catalyst comprising a mesoporous material further comprises at least one metallic hydrogenation component, and wherein the hydrofinishing conditions include temperatures from about 150°C to about 350°C, total pressure ranges from about 2.86 MPa to about 20.8 MPa (about 400 to 3000 psig), liquid hourly space velocity from about 0.1 to about 5 LHSV (hr^{-1}), hydrogen treat gas rates of from about 44.5 to about 1780 m^3/m^3 (250 to 10,000 SCF H_2/B), and hydrogen partial pressure ranges from about 1.48 MPa to about 20.4 MPa (about 200 psig to about 3000 psig).

22. The process according to claim 1, further comprising separating at least one lubricating oil basestock from the third-stage reaction product.

23. The process of claim 22, further comprising adding to a major amount of the lubricating oil basestock a minor amount of at least one additive to make a finished lubricating oil product.

24. A process to prepare lubricating oil basestocks from lube oil boiling-range raffinate feed comprising:

- (a) extracting a lubricating oil feedstock in a solvent extraction zone with an extraction solvent under conditions effective at produc-

ing at least an aromatics-lean raffinate solution containing extraction solvent;

- (b) separating at least a portion of the extraction solvent from the aromatics-lean raffinate solution to produce at least a lube oil boiling-range raffinate feed;
- (c) contacting a lube oil boiling-range raffinate feed containing nitrogen and sulfur heteroatoms with a catalytically effective amount of hydrotreating catalyst in a first reaction stage operated under effective hydrotreating conditions in the presence of a hydrogen-containing gaseous product from a third reaction stage to produce a hydrotreated raffinate;
- (d) stripping the hydrotreated raffinate by contacting the hydrotreated raffinate with first fresh, once-through, hydrogen-containing treat gas to separate sulfur-containing and nitrogen-containing species from the hydrotreated raffinate to produce a stripped raffinate;
- (e) contacting the stripped raffinate with a catalytically effective amount of a hydrodewaxing catalyst in the presence of the fresh once-through, hydrogen-containing treat gas in a second reaction stage operated under effective hydrodewaxing conditions to produce a second-stage reaction product comprising at least a second-stage gaseous product and a second-stage liquid product, wherein the second-stage gaseous product comprises hydrogen and the second-stage liquid product comprising a dewaxed raffinate;
- (f) cascading, without disengagement, at least a portion of the second reaction stage product to a hydrofinishing reaction stage;

- (g) contacting the cascaded portion of the second-reaction stage product with a catalytically effective amount of a hydrofinishing catalyst in the third reaction stage operated under effective hydrofinishing conditions to produce a third stage reaction product comprising the third stage gaseous product comprising hydrogen and a third-stage liquid product comprising a lubricating oil basestock, wherein the second-stage gaseous product provides hydrogen for the third reaction stage.
- (h) separating the third-stage gaseous product from the third-stage reaction product; and
- (i) cascading the third-stage gaseous product, without heteroatom disengagement, to the first reaction stage.