

PROCESS FOR IMPROVING BASE OIL YIELDS**CROSS REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims the benefit of priority to U.S. Provisional Patent Appl. Ser. No. 62/885,359, filed on August 12, 2019, the disclosure of which is herein incorporated in its entirety.

FIELD OF THE INVENTION

[0002] The invention concerns a process for improving base oil yields by combining an atmospheric resid feedstock with a base oil feedstock to form a combined feedstream and forming a base oil product therefrom via hydroprocessing.

BACKGROUND OF THE INVENTION

[0003] High quality lubricating base oils, such as those having a viscosity index (VI) of 120 or greater (Group II and Group III), may generally be produced from high-boiling point vacuum distillates, such as vacuum gas oils (VGO), by hydrocracking to raise VI, followed by catalytic dewaxing to lower pour point and cloud point, and followed by hydrofinishing to saturate aromatics and improve stability. In hydrocracking, high-boiling molecules are cracked to lower-boiling molecules which raises VI but also lowers the viscosity. In order to make a high VI and high viscosity grade base oil at high yield, the hydrocracker feed must contain a certain quantity of high-boiling molecules. Typically, VGOs are limited in their ability to recover very high-boiling molecules from atmospheric resid (AR) in a vacuum column because of practical limits on temperature and pressure. One possible means of feeding higher-boiling molecules to the hydrocracker is to feed the AR directly, but such an approach is not normally possible or workable because the AR usually contains materials that are extremely harmful to the hydrocracker catalyst, including, e.g., nickel, vanadium, micro-carbon residue (MCR) and asphaltenes. These materials shorten the hydrocracker catalyst life to an unacceptable degree, making the use of such feeds impracticable.

[0004] One approach to using difficult whole crude and other intermediate feeds for making base oils is to first process the feed, such as AR or vacuum resid (VR), in a solvent deasphalting (SDA) unit. Such treatment is usually necessary to separate the bulk of undesirable materials while producing a deasphalted oil (DAO) of acceptable hydrocracker feed quality. The very high capital requirements and high operating cost of such SDA units, and the overall process approach, make them undesirable alternatives, however. Other approaches that attempt to minimize or eliminate the need for solvent deasphalting steps have been implemented but have not provided a clear benefit in terms of cost or other process improvements.

[0005] The production of Group III base oils and finished motor oils has usually required the use of expensive and supply-limited viscosity index improvers such as polyalphaolefins, or other expensive processing techniques, such as the use of gas-to-liquid (GTL) feedstocks or, e.g., through multi-hydrocracking processing of mineral oils. The production of Group III base oils also generally requires high quality feedstock(s) and processing at high conversion to meet a VI targets at the expense of product yield. Despite continuing industry efforts, however, a comparatively inexpensive and suitable feedstock, and a simplified process for making such products, remains to be developed and commercialized.

[0006] Despite the progress in producing base oils from differing and challenging feeds, a continuing need exists for improved processes to both utilize different feedstocks and to increase the yield of valuable base oil products.

SUMMARY OF THE INVENTION

[0007] The present invention is directed to a process for making a base oil product, particularly a light grade base oil product and a heavy grade base oil product through hydroprocessing of a base oil feedstream. While not necessarily limited thereto, one of the goals of the invention is to provide increased base oil yield of a heavy grade base oil product and to the production of Group II and/or Group III/III+ base oils.

[0008] In general, a first process according to the invention comprises making a base oil by combining an atmospheric resid feedstock and a base oil feedstock to form a base oil feedstream; contacting the base oil feedstream with a hydrocracking catalyst under hydrocracking conditions to form a hydrocracked product; separating the hydrocracked product into a gaseous fraction and a liquid fraction; contacting the liquid fraction with a dewaxing catalyst under hydroisomerization conditions, to produce a dewaxed product; and, optionally, contacting the dewaxed product with a hydrofinishing catalyst under hydrofinishing conditions to produce a hydrofinished dewaxed product.

[0009] The invention also relates to a method for modifying a base oil process through the addition of an atmospheric resid feedstock to a base oil feedstock in a conventional base oil process that comprises subjecting a base oil feedstream to hydrocracking and dewaxing steps to form a dewaxed product comprising a light product and a heavy product. As such, the modified base oil process comprises combining an atmospheric resid feedstock and a base oil feedstock to form a base oil feedstream; contacting the base oil feedstream with a hydrocracking catalyst under hydrocracking conditions to form a hydrocracked product; separating the hydrocracked product into at least a gaseous fraction and a liquid fraction; contacting the liquid fraction with a dewaxing catalyst under hydroisomerization conditions, to produce a dewaxed product; and, optionally,

contacting the dewaxed product with a hydrofinishing catalyst under hydrofinishing conditions to produce a hydrofinished dewaxed product.

[0010] A second process according to the invention comprises making a base oil having a viscosity index of 120 or greater by contacting a base oil feedstock having a viscosity index of about 100 or greater that comprises a medium vacuum gas oil (MVGO) having a front end cut point of about 700°F or greater and a back end cut point of about 900°F or less with a hydrocracking catalyst under hydrocracking conditions to form a hydrocracked product; separating the hydrocracked product into a gaseous fraction and a liquid fraction; dewaxing of the liquid fraction to produce a dewaxed product; and optionally, hydrofinishing of the dewaxed product to produce a hydrofinished dewaxed product.

[0011] The invention further relates to a combined process for making a base oil product from a base oil feedstock that combines the first process and the second process to make base oils meeting Group II and/or Group III/III+ specifications. The combined process generally provides for making a base oil from a base oil feedstock, or a fraction thereof, and includes the use of an atmospheric resid fraction from a base oil feedstock, or a fraction thereof; separation of the base oil feedstock, or a fraction thereof, and/or the base oil atmospheric resid fraction into a narrow vacuum gas oil cut-point fraction having a front end cut point of about 700°F or greater and a back end cut point of about 900°F or less to form a medium vacuum gas oil (MVGO) fraction and a residual heavy VGO (HHVGO) fraction; and use of the HHVGO fraction as the atmospheric resid feedstock in the first process; and/or use of the MVGO fraction as the base oil feedstock in the second process.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The scope of the invention is not limited by any representative figures accompanying this disclosure and is to be understood to be defined by the claims of the application.

[0013] FIG. 1 is a general block diagram schematic illustration of a prior art process to make a base oil product.

[0014] FIG. 2a is a general block diagram schematic illustration of an embodiment of a process to make a base oil product using a blend of VGO and atmospheric resid (VGO/AR) according to the invention.

[0015] FIG. 2b is a general block diagram schematic illustration of an embodiment of a process to make a Group III/III+ base oil product using an MVGO fraction from an atmospheric resid and a Group II base oil product using a blend of VGO and an HHVGO residual fraction from an atmospheric resid (VGO/HHVGO) according to the invention.

[0016] FIG. 3a is a process schematic illustration of an embodiment of a process to make a base oil product according to the invention, as described in the examples.

[0017] FIG. 3b is a process schematic illustration of an embodiment of a process to make a base oil product according to the invention, as described in the examples.

[0018] FIG. 4 is a process schematic illustration of an embodiment of a process to make a base oil product according to the invention, as described in the examples.

[0019] FIG. 5 is a process schematic illustration of an embodiment of a process to make a base oil product according to the invention, as described in the examples.

DETAILED DESCRIPTION

[0020] Although illustrative embodiments of one or more aspects are provided herein, the disclosed processes may be implemented using any number of techniques. The disclosure is not limited to the illustrative or specific embodiments, drawings, and techniques illustrated herein, including any exemplary designs and embodiments illustrated and described herein, and may be modified within the scope of the appended claims along with their full scope of equivalents.

[0021] Unless otherwise indicated, the following terms, terminology, and definitions are applicable to this disclosure. If a term is used in this disclosure but is not specifically defined herein, the definition from the IUPAC Compendium of Chemical Terminology, 2nd ed (1997), may be applied, provided that definition does not conflict with any other disclosure or definition applied herein, or render indefinite or non-enabled any claim to which that definition is applied. To the extent that any definition or usage provided by any document incorporated herein by reference conflicts with the definition or usage provided herein, the definition or usage provided herein is to be understood to apply.

[0022] "API Base Oil Categories" are classifications of base oils that meet the different criteria shown in Table 1:

Table 1: Base Oil Stock Properties (4 cSt @100°C viscosity stocks, no additives)

Group Designation	Composition	Sulfur, wt. %	Saturates, wt. %	Viscosity Index, VI	Volatility, %	Polarity	Pour Point, °C	Flash Point, °C
Group I	Distilled, solvent refined, ≥10% aromatics	>0.03	and/or <90	80-119	15-20	med-high	-5 to 15	100
Group II	Distilled, solvent refined, hydrocracked, <10% aromatics	≤0.03	and ≥90	80-119	10-15	med	-10 to -20	170
Group III	Distilled, solvent refined, severely hydrocracked, <10% aromatics	≤0.03	and ≥90	≥120	5-15	med	-10 to 25	190

Group III+	Group III oils additionally hydroisomerized, or otherwise processed, <1% aromatics	--	--	≥ 130	≤ 5	low	-15 to -30	200
Group IV	Polyalphaolefins (PAO) 100% catalytically synthesized from olefins derived from thermally cracking wax	--	--	135-140	1.8	low	-53	270
Group V	100% catalytically synthesized by reacting acids and alcohols; All base oils not included in Groups I-IV	--	--	140	1.0	high	-21	260

[0023] "API gravity" refers to the gravity of a petroleum feedstock or product relative to water, as determined by ASTM D4052-11 or ASTM D1298.

[0024] "ISO-VG" refers to the viscosity classification that is recommended for industrial applications, as defined by ISO3448:1992.

[0025] "Viscosity index" (VI) represents the temperature dependency of a lubricant, as determined by ASTM D2270-10(E2011).

[0026] "Aromatic Extraction" is part of a process used to produce solvent neutral base oils. During aromatic extraction, vacuum gas oil, deasphalted oil, or mixtures thereof are extracted using solvents in a solvent extraction unit. The aromatic extraction creates a waxy raffinate and an aromatic extract, after evaporation of the solvent.

[0027] "Atmospheric resid" or "atmospheric residuum" (AR) is a product of crude oil distillation at atmospheric pressure in which volatile material has been removed during distillation. AR cuts are typically derived at 650°F up to a 680°F cut point.

[0028] "Vacuum gas oil" (VGO) is a byproduct of crude oil vacuum distillation that can be sent to a hydroprocessing unit or to an aromatic extraction for upgrading into base oils. VGO generally comprises hydrocarbons with a boiling range distribution between 343°C (649°F) and 538°C (1000°F) at 0.101 MPa.

[0029] "Deasphalted oil" (DAO) generally refers to the residuum from a vacuum distillation unit that has been deasphalted in a solvent deasphalting process. Solvent deasphalting in a refinery is described in J. Speight, Synthetic Fuels Handbook, ISBN 007149023X, 2008, pages 64, 85-85, and 121.

[0030] "Treatment," "treated," "upgrade," "upgrading" and "upgraded," when used in conjunction with an oil feedstock, describes a feedstock that is being or has been subjected to hydroprocessing, or a resulting material or crude product, having a reduction in the molecular weight of the feedstock, a reduction in the boiling point range of the feedstock, a reduction in the

concentration of asphaltenes, a reduction in the concentration of hydrocarbon free radicals, and/or a reduction in the quantity of impurities, such as sulfur, nitrogen, oxygen, halides, and metals.

[0031] "Solvent Dewaxing" is a process of dewaxing by crystallization of paraffins at low temperatures and separation by filtration. Solvent dewaxing produces a dewaxed oil and slack wax. The dewaxed oil can be further hydrofinished to produce base oil.

[0032] "Hydroprocessing" refers to a process in which a carbonaceous feedstock is brought into contact with hydrogen and a catalyst, at a higher temperature and pressure, for the purpose of removing undesirable impurities and/or converting the feedstock to a desired product. Examples of hydroprocessing processes include hydrocracking, hydrotreating, catalytic dewaxing, and hydrofinishing.

[0033] "Hydrocracking" refers to a process in which hydrogenation and dehydrogenation accompanies the cracking/fragmentation of hydrocarbons, e.g., converting heavier hydrocarbons into lighter hydrocarbons, or converting aromatics and/or cycloparaffins (naphthenes) into non-cyclic branched paraffins.

[0034] "Hydrotreating" refers to a process that converts sulfur and/or nitrogen-containing hydrocarbon feeds into hydrocarbon products with reduced sulfur and/or nitrogen content, typically in conjunction with hydrocracking, and which generates hydrogen sulfide and/or ammonia (respectively) as byproducts.

[0035] "Catalytic dewaxing", or hydroisomerization, refers to a process in which normal paraffins are isomerized to their more branched counterparts in the presence of hydrogen and over a catalyst.

[0036] "Hydrofinishing" refers to a process that is intended to improve the oxidation stability, UV stability, and appearance of the hydrofinished product by removing traces of aromatics, olefins, color bodies, and solvents. As used in this disclosure, the term UV stability refers to the stability of the hydrocarbon being tested when exposed to UV light and oxygen. Instability is indicated when a visible precipitate forms, usually seen as Hec or cloudiness, or a darker color develops upon exposure to ultraviolet light and air. A general description of hydrofinishing may be found in U.S. Patent Nos. 3,852,207 and 4,673,487.

[0037] The term "Hydrogen" or "hydrogen" refers to hydrogen itself, and/or a compound or compounds that provide a source of hydrogen.

[0038] "Cut point" refers to the temperature on a True Boiling Point (TBP) curve at which a predetermined degree of separation is reached.

[0039] "TBP" refers to the boiling point of a hydrocarbonaceous feed or product, as determined by Simulated Distillation (SimDist) by ASTM D2887-13.

[0040] “Hydrocarbonaceous”, “hydrocarbon” and similar terms refer to a compound containing only carbon and hydrogen atoms. Other identifiers may be used to indicate the presence of particular groups, if any, in the hydrocarbon (e.g., halogenated hydrocarbon indicates the presence of one or more halogen atoms replacing an equivalent number of hydrogen atoms in the hydrocarbon).

[0041] “Group IIB” or “Group IIB metal” refers to zinc (Zn), cadmium (Cd), mercury (Hg), and combinations thereof in any of elemental, compound, or ionic form.

[0042] “Group IVA” or “Group IVA metal” refers to germanium (Ge), tin (Sn) or lead (Pb), and combinations thereof in any of elemental, compound, or ionic form.

[0043] “Group V metal” refers to vanadium (V), niobium (Nb), tantalum (Ta), and combinations thereof in their elemental, compound, or ionic form.

[0044] “Group VIB” or “Group VIB metal” refers to chromium (Cr), molybdenum (Mo), tungsten (W), and combinations thereof in any of elemental, compound, or ionic form.

[0045] “Group VIII” or “Group VIII metal” refers to iron (Fe), cobalt (Co), nickel (Ni), ruthenium (Ru), rhodium (Rh), rhodium (Ro), palladium (Pd), osmium (Os), iridium (Ir), platinum (Pt), and combinations thereof in any of elemental, compound, or ionic form.

[0046] The term “support”, particularly as used in the term “catalyst support”, refers to conventional materials that are typically a solid with a high surface area, to which catalyst materials are affixed. Support materials may be inert or participate in the catalytic reactions, and may be porous or non-porous. Typical catalyst supports include various kinds of carbon, alumina, silica, and silica-alumina, e.g., amorphous silica aluminates, zeolites, alumina-boria, silica-alumina-magnesia, silica-alumina-titania and materials obtained by adding other zeolites and other complex oxides thereto.

[0047] “Molecular sieve” refers to a material having uniform pores of molecular dimensions within a framework structure, such that only certain molecules, depending on the type of molecular sieve, have access to the pore structure of the molecular sieve, while other molecules are excluded, e.g., due to molecular size and/or reactivity. Zeolites, crystalline aluminophosphates and crystalline silicoaluminophosphates are representative examples of molecular sieves.

[0048] W220 and W600 refer to waxy medium and heavy Group II base oil product grades, with W220: referring to a waxy medium base oil product having a nominal viscosity of about 6 cSt at 100°C, and W600: referring to a waxy heavy base oil product having a nominal viscosity of about 12 cSt at 100°C. Following dewaxing, typical test data for Group II base oils are as follows:

Property	Standard Test	220N	600N
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API Base Stock Category	(API 1509 E.1.3)	Group II	Group II
API Gravity	ASTM D1298	32.1	31.0
Specific Gravity at 60/60°F	ASTM D1298	0.865	0.871
Density, lb/gal	ASTM D1298	7.202	7.251
Viscosity, Kinematic	ASTM D445		
cSt at 40°C		41.0	106
cSt at 100°C		6.3	12.0
Viscosity, Saybolt	ASTM D2161	212	530
SUS at 100°F			
Viscosity Index	ASTM D2270	102	102
Pour Point, °C	ASTM D97	-15	-15
Evaporation Loss, NOACK, wt %	CEC-L-40-A-93	11	2
Flash Point, COC, °C	ASTM D92	230	265
Color	ASTM D1500	L 0.5	L 0.5
Sulfur, ppm	Chevron	<6	<6
Water, ppm	ASTM D1744	<50	<50
Saturates, HPLC, wt %	Chevron	>99	>99
Aromatics, HPLC, wt %	Chevron	<1	<1

[0049] In this disclosure, while compositions and methods or processes are often described in terms of “comprising” various components or steps, the compositions and methods may also “consist essentially of” or “consist of” the various components or steps, unless stated otherwise.

[0050] The terms “a,” “an,” and “the” are intended to include plural alternatives, e.g., at least one. For instance, the disclosure of “a transition metal” or “an alkali metal” is meant to encompass one, or mixtures or combinations of more than one, transition metal or alkali metal, unless otherwise specified.

[0051] All numerical values within the detailed description and the claims herein are modified by “about” or “approximately” the indicated value, and take into account experimental error and variations that would be expected by a person having ordinary skill in the art.

[0052] In one aspect, the present invention is a process for making a base oil product, comprising

combining an atmospheric resid feedstock and a base oil feedstock to form a base oil feedstream;

contacting the base oil feedstream with a hydrocracking catalyst under hydrocracking conditions to form a hydrocracked product;

separating the hydrocracked product into a gaseous fraction and a liquid fraction;

contacting the liquid fraction with a dewaxing catalyst under hydroisomerization conditions, to produce a dewaxed product; and

optionally, contacting the dewaxed product with a hydrofinishing catalyst under hydrofinishing conditions to produce a hydrofinished dewaxed product.

[0053] The base oil feedstock generally meets one or more of the following property conditions:

API gravity in the range of 15-40 or 15-30 or 15-25, or at least 15, or at least 17, optionally, less than the atmospheric resid feedstock;

VI in the range of 30-90 or 40-90 or 50-90 or 50-80, optionally, less than the VI of the atmospheric resid feedstock;

viscosity at 100°C in the range of 3-30 cSt or 3-25 cSt or 3-20 cSt, or at least 3 cSt, or at least 4 cSt;

viscosity at 70°C in the range of 5-25 cSt or 5-20 cSt or 5-15 cSt, or at least 5 cSt, or at least 6 cSt;

hot C₇ asphaltene content in the range of 0.01-0.3 wt.% or 0.01-0.2 wt.% or 0.02-0.15 wt.%, or less than 0.3 wt. %, or less than 0.2 wt.%;

wax content in the range of 5-40 wt.% or 5-30 wt.% or 10-25 wt.%, or at least 5 wt.% or at least 10 wt.%, or at least 15 wt.%, or, optionally, greater than the wax content of the base oil feedstock;

nitrogen content of less than 2500 ppm or less than 2000 ppm or less than 1500 ppm or less than 1000 ppm or less than 500 ppm or less than 200 ppm or less than 100 ppm;

sulfur content of less than 8000 ppm or less than 6000 ppm or less than 4000 ppm or less than 2000 ppm or less than 1000 ppm or less than 500 ppm or less than 200 ppm, or in the range of 100-8000 ppm or 100-6000 ppm or 100-4000 ppm or 100-2000 ppm or 100-1000 ppm or 100-500 ppm or 100-200 ppm; and/or

1050+°F content in the range of 5-50 wt.% or 5-40 wt.% or 8-40 wt.%, or, optionally, greater than the 1050+°F content of the base oil feedstock.

[0054] Suitable base oil feedstocks may be from any crude oil feedstock, or a fraction thereof, including hydroprocessed intermediate streams or other feeds. Generally, the base oil feedstock contains materials boiling within the base oil range. Feedstocks may include atmospheric and vacuum residuum from a variety of sources, whole crudes, and paraffin-based crudes.

[0055] The atmospheric resid (AR) feedstock generally meets one or more of the following property conditions:

API gravity in the range of 20-60 or 20-45 or 25-45, or at least 20, or at least 22, or, optionally, greater than the API of the base oil feedstock;

VI in the range of 50-200 or 70-190 or 90-180, or at least 80, or, optionally, greater than the VI of the base oil feedstock;

viscosity at 100°C in the range of 3-30 cSt or 3-25 cSt or 3-20 cSt, or at least 3 cSt, or at least 4 cSt;

viscosity at 70°C in the range of 5-25 cSt or 5-20 cSt or 5-15 cSt, or at least 5 cSt, or at least 6 cSt;

hot C₇ asphaltene content in the range of 0.01-0.3 wt.% or 0.01-0.2 wt.% or 0.02-0.15 wt.%, or less than 0.3 wt. %, or less than 0.2 wt.%;

wax content in the range of 5-40 wt.% or 5-30 wt.% or 10-25 wt.%, or at least 5 wt.% or at least 10 wt.%, or at least 15 wt.%, or, optionally, greater than the wax content of the base oil feedstock;

nitrogen content of less than 2500 ppm or less than 2000 ppm or less than 1500 ppm or less than 1000 ppm or less than 500 ppm or less than 200 ppm or less than 100 ppm;

sulfur content of less than 8000 ppm or less than 6000 ppm or less than 4000 ppm or less than 2000 ppm or less than 1000 ppm or less than 500 ppm or less than 200 ppm, or in the range of 100-8000 ppm or 100-6000 ppm or 100-4000 ppm or 100-2000 ppm or 100-1000 ppm or 100-500 ppm or 100-200 ppm; and/or

1050+°F content in the range of 5-50 wt.% or 5-40 wt.% or 8-40 wt.%, or, optionally, greater than the 1050+°F content of the base oil feedstock.

[0056] In some aspects, AR feedstocks having property characteristics described herein may be advantageously derived from a light tight oil (LTO, e.g., shale oil typically having an API of >45). Suitable feedstocks may be Permian Basin feedstocks and elsewhere, including Eagle Ford, Avalon, Magellan, Buckeye, and the like.

[0057] Both the base oil feedstock and the atmospheric resid feedstock may have any of the foregoing properties within any of the noted broad and narrower ranges and combinations of such ranges.

[0058] The base oil feedstream generally comprises 10--60 wt.% atmospheric resid feedstock and 40-90 wt.% base oil feedstock, or 10-40 wt.% atmospheric resid feedstock and 60-90 wt.% base oil feedstock, or 10-30 wt.% atmospheric resid feedstock and 70-90 wt.% base oil feedstock, or 30-60 wt.% atmospheric resid feedstock and 40-70 wt.% base oil feedstock, or 40-60 wt.% atmospheric resid feedstock and 40--60 wt.% base oil feedstock.

[0059] In certain embodiments, the base oil feedstream does not contain an added whole crude oil feedstock, and/or does not contain a vacuum residue feedstock, and/or does not contain a deasphalted oil feedstock component, and/or contains only atmospheric resid feedstock and base oil feedstock.

[0060] While not limited to a straight run process, the process need not include recycle of a liquid feedstock as part of the base oil feedstream or as either or both of the atmospheric resid feedstock and the base oil feedstock. In certain embodiments, recycle of one or more intermediate streams may be desired, however.

[0061] The base oil feedstock may comprise vacuum gas oil, or consist essentially of vacuum gas oil, or consist of vacuum gas oil. The vacuum gas oil may be a heavy vacuum gas oil obtained from vacuum gas oil that is cut into a light fraction and a heavy fraction, with the heavy fraction having a cut point temperature range of about 950-1050°F.

[0062] The dewaxed product and/or the hydrofinished dewaxed product is typically obtained as a light base oil product and a heavy base oil product. The light base oil product generally has a nominal viscosity in the range of 4-8 cSt or 5-7 cSt at 100°C and/or with the heavy base oil product generally having a nominal viscosity in the range of 10-14 cSt or 11-13 cSt at 100°C. The dewaxed product may be further separated into at least a light product having a nominal viscosity of about 6 cSt at 100°C, and/or at least a heavy product having a nominal viscosity of about 12 cSt at 100°C, or a combination thereof.

[0063] One of the advantages associated with the process is that the yield of the heavy base oil product relative to the light base oil product may be increased by at least about 2 Lvol.%, or at least about 5 Lvol.% (liquid volume %) compared with the same process that does not include the atmospheric resid feedstock in the lubricating oil feedstream. In some embodiments, the yield of the heavy base product may be increased by at least about 10 Lvol.%, or at least about 20 Lvol.%, or at least about 30 Lvol.%, or at least about 40 Lvol.%, compared with the same process that does not include the atmospheric resid feedstock in the base oil feedstream.

[0064] In another aspect, the invention concerns a method for modifying a conventional or existing base oil process. In particular, a base oil process that comprises subjecting a base oil feedstream to hydrocracking and dewaxing steps to form a dewaxed product comprising a lighter product and a heavier product may be modified according to the invention by combining an atmospheric resid feedstock with a base oil feedstock to form the base oil feedstream and subjecting the base oil feedstream comprising the atmospheric resid feedstock to the hydrocracking and dewaxing steps of the base oil process to produce a dewaxed product. The dewaxed product may be optionally further contacted with a hydrofinishing catalyst under hydrofinishing conditions to produce a hydrofinished dewaxed product.

[0065] The invention further relates to a process for making a base oil, comprising contacting a base oil feedstock having a viscosity index of about 100 or greater with a

hydrocracking catalyst under hydrocracking conditions to form a hydrocracked product, wherein the base oil feedstock comprises vacuum gas oil having a front end cut point of about 700°F or greater and a back end cut point of about 900°F or less; separating the hydrocracked product into a gaseous fraction and a liquid fraction; contacting the liquid fraction with a dewaxing catalyst under hydroisomerization conditions, to produce a dewaxed product; and optionally, contacting the dewaxed product with a hydrofinishing catalyst under hydrofinishing conditions to produce a hydrofinished dewaxed product; wherein, the dewaxed product and/or the hydrofinished dewaxed product has a viscosity index of 120 or greater after dewaxing. The dewaxed product and/or the hydrofinished dewaxed product may have a viscosity index of 130 or greater after dewaxing, or 135 or greater after dewaxing, or 140 or greater after dewaxing. The hydrocracked product may have a viscosity index of at least about 135, or 140, or 145, or 150. The dewaxed products prepared by the process may be a Group III or Group III+ product.

[0066] By comparison to the use of a conventional VGO feedstock, the use of a vacuum gas oil having a front end cut point of about 700°F or greater and a back end cut point of about 900°F or less, herein referred to as a medium vacuum gas oil (MVGO) provides an improved waxy product yield at a Group III or Group III+ viscosity of 4cSt 100°C of the MVGO that is at least about 3 vol.% greater than the same process that does not include the MVGO as the base oil feedstock.

[0067] The invention further relates to a process that combines the two process aspects, i.e., in which a feedstock is used to derive the narrow cut-point fraction and the same or a different feedstock is used for the atmospheric resid fraction. The combined process for making a base oil from a base oil feedstock, or a fraction thereof, comprises providing an atmospheric resid fraction from a base oil feedstock, or a fraction thereof; separating the base oil feedstock, or a fraction thereof, and/or the base oil atmospheric resid fraction into a narrow vacuum gas oil cut-point fraction having a front end cut point of about 700°F or greater and a back end cut point of about 900°F or less to form an MVGO fraction and a residual HHVGO fraction; using the HHVGO fraction as the atmospheric resid feedstock in the first process to prepare a dewaxed product and/or hydrofinished dewaxed product; and/or using the MVGO fraction as the base oil feedstock in a second process to prepare a dewaxed product and/or hydrofinished dewaxed product having a viscosity index of 120 or greater after dewaxing. In certain embodiments, the base oil feedstock may comprise tight oil, particularly a light tight oil, or a fraction thereof. The narrow vacuum gas oil cut-point fraction may also be derived from the atmospheric resid fraction, including an atmospheric resid fraction derived from light tight oil.

[0068] Advantageously, the fractionation of the AR feedstock into MVGO and HHVGO fractions provides the ability to produce Group III/III+ base oil product while still allowing the HHVGO fraction

to be used with a conventional VGO base oil feedstock to produce a Group II base oil product. In some embodiments, the use of MVGO to produce Group III/III+ base oil product results in greater yields of such products.

[0069] An illustration of a method or process according to an embodiment of the invention is shown schematically in FIG. 2a, in which conventional base oil hydrotreating, hydrocracking, hydrodewaxing, and hydrofinishing process steps, conditions, and catalysts are used. By comparison to a prior art base oil process schematic illustrated in FIG 1, FIG. 2a shows the use of a feed blend of VGO and atmospheric resid (AR) where the conventional process typically uses VGO base oil feedstock. FIG 2b further illustrates the use of an AR feedstock to form a medium vacuum gas oil fraction (MVGO) and a heavy VGO fraction (HHVGO), with the MVGO fraction feedstream being used to produce a Group III/III+ base oil product and the HHVGO fraction feedstream being combined with a conventional VGO base oil feedstock to produce a Group II base oil product.

[0070] Catalysts suitable for use as the hydrocracking, dewaxing, and hydrofinishing catalysts in the process and method and associated process conditions are described in a number of publications, including, e.g., US Patent Publication Nos. 3,852,207; 3,929,616; 6,156,695; 6,162,350; 6,274,530; 6,299,760; 6,566,296; 6,620,313; 6,635,599; 6,652,738; 6,758,963; 6,783,663; 6,860,987; 7,179,366; 7,229,548; 7,232,515; 7,288,182; 7,544,285; 7,615,196; 7,803,735; 7,807,599; 7,816,298; 7,838,696; 7,910,761; 7,931,799; 7,964,524; 7,964,525; 7,964,526; 8,058,203; 10,196,575; WO 2017/044210; and others.

[0071] Catalysts suitable for hydrocracking, e.g., comprise materials having hydrogenation-dehydrogenation activity, together with an active cracking component support. Such catalysts are well described in many patent and literature references. Exemplary cracking component supports include silica-alumina, silica- oxide zirconia composites, acid-treated clays, crystalline aluminosilicate zeolitic molecular sieves such as zeolite A, faujasite, zeolite X, and zeolite Y, and combinations thereof. Hydrogenation-dehydrogenation components of the catalyst preferably comprise a metal selected from Group VIII metals and compounds thereof and Group VIB metals and compounds thereof. Preferred Group VIII components include cobalt and nickel, particularly the oxides and sulfides thereof. Preferred Group VIB components are the oxides and sulfides of molybdenum and tungsten. Examples of a hydrocracking catalyst which would be suitable for use in the hydrocracking process step are the combinations of nickel-tungsten-silica-alumina, nickel-molybdenum-silica-alumina and cobalt-molybdenum-silica-alumina. Such catalysts may vary in their activities for hydrogenation and for cracking and in their ability to sustain high activity during long periods of use depending on their compositions and preparation.

[0072] Typical hydrocracking reaction conditions include, for example, a temperature of from 450°F to 900°F (232°C to 482°C), e.g., from 650°F to 850°F (343°C to 454°C); a pressure of from 500 psig to 5000 psig (3.5 MPa to 34.5 MPa gauge), e.g., from 1500 psig to 3500 psig (10.4 MPa to 24.2 MPa gauge); a liquid reactant feed rate, in terms of liquid hourly space velocity (LHSV) of from 0.1 hr⁻¹ to 15 hr⁻¹ (v/v), e.g., from 0.25 hr⁻¹ to 2.5 hr⁻¹; a hydrogen feed rate, in terms of H₂/hydrocarbon ratio, of from 500 SCF/bbl to 5000 SCF/bbl (89 to 890 m³ H₂/m³ feedstock) of liquid base oil (lubricating) feedstock, and/or a hydrogen partial pressure of greater than 200 psig, such as from 500 to 3000 psig; and hydrogen re-circulation rates of greater than 500 SCF/B, such as between 1000 and 7000 SCF/B.

[0073] Hydrodewaxing is used primarily for reducing the pour point and/or for reducing the cloud point of the base oil by removing wax from the base oil. Typically, dewaxing uses a catalytic process for processing the wax, with the dewaxer feed is generally upgraded prior to dewaxing to increase the viscosity index, to decrease the aromatic and heteroatom content, and to reduce the amount of low boiling components in the dewaxer feed. Some dewaxing catalysts accomplish the wax conversion reactions by cracking the waxy molecules to lower molecular weight molecules. Other dewaxing processes may convert the wax contained in the hydrocarbon feed to the process by wax isomerization, to produce isomerized molecules that have a lower pour point than the non-isomerized molecular counterparts. As used herein, isomerization encompasses a hydroisomerization process, for using hydrogen in the isomerization of the wax molecules under catalytic hydroisomerization conditions.

[0074] Dewaxing generally includes processing the dewaxer feedstock by hydroisomerization to convert at least the n-paraffins and to form an isomerized product comprising isoparaffins. Suitable isomerization catalysts for use in the dewaxing step can include, but are not limited to, Pt and/or Pd on a support. Suitable supports include, but are not limited to, zeolites CIT-1, IM-5, SSZ-20, SSZ-23, SSZ-24, SSZ-25, SSZ-26, SSZ-31, SSZ-32, SSZ-32, SSZ-33, SSZ-35, SSZ-36, SSZ-37, SSZ-41, SSZ-42, SSZ-43, SSZ-44, SSZ-46, SSZ-47, SSZ-48, SSZ-51, SSZ-56, SSZ-57, SSZ-58, SSZ-59, SSZ-60, SSZ-61, SSZ-63, SSZ-64, SSZ-65, SSZ-67, SSZ-68, SSZ-69, SSZ-70, SSZ-71, SSZ-74, SSZ-75, SSZ-76, SSZ-78, SSZ-81, SSZ-82, SSZ-83, SSZ-86, SUZ-4, TNU-9, ZSM-S, ZSM-12, ZSM-22, ZSM-23, ZSM-35, ZSM-48, EMT-type zeolites, FAU-type zeolites, FER-type zeolites, MEL-type zeolites, MFI-type zeolites, MTT-type zeolites, MTW-type zeolites, MWW-type zeolites, MRE-type zeolites, TON-type zeolites, other molecular sieves materials based upon crystalline aluminophosphates such as SM-3, SM-7, SAPO-II, SAPO-31, SAPO-41, MAPO-II and MAPO-31. Isomerization may involve also a Pt and/or Pd catalyst supported on an acidic support material such as beta or zeolite Y molecular sieves, silica, alumina,

silica-alumina, and combinations thereof. Suitable isomerization catalysts are well described in the patent literature, see, e.g., US. Pat. Nos. 4,859,312; 5,158,665; and 5,300,210.

[0075] Hydrodewaxing conditions generally depend on the feed used, the catalyst used, whether or not the catalyst is sulfided, the desired yield, and the desired properties of the base oil. Typical conditions include a temperature of from 500°F to 775°F (260°C to 413°C); a pressure of from 15 psig to 3000 psig (0.10 MPa to 20.68 MPa gauge); a LHSV of from 0.25 hr⁻¹ to 20 hr⁻¹; and a hydrogen to feed ratio of from 2000 SCF/bbl to 30,000 SCF/bbl (356 to 5340 m³ H₂/m³ feed). Generally, hydrogen will be separated from the product and recycled to the isomerization zone. Suitable dewaxing conditions and processes are described in, e.g., U.S. Pat. Nos. 5,135,638; 5,282,958; and 7,282,134.

[0076] Waxy products W220 and W600 may be dewaxed to form 220N and 600N products that may be suitable (or better suited) for use as a lubricating base oil or in a lubricant formulation. For example, the dewaxed product may be mixed or admixed with existing lubricating base oils in order to create new base oils or to modify the properties of existing base oils, e.g., to meet particular target conditions, such as viscometric or Noack target conditions, for particular base oil grades like 220N and 600N. Isomerization and blending can be used to modulate and maintain pour point and cloud point of the base oil at suitable values. Normal paraffins may also be blended with other base oil components prior to undergoing catalytic isomerization, including blending normal paraffins with the isomerized product. Lubricating base oils that may be produced in the dewaxing step may be treated in a separation step to remove light product. The lubricating base oil may be further treated by distillation, using atmospheric distillation and optionally vacuum distillation to produce a lubricating base oil.

[0077] Typical hydrotreating conditions vary over a wide range. In general, the overall LHSV is about 0.25 hr⁻¹ to 10 hr⁻¹ (v/v), or alternatively about 0.5 hr⁻¹ to 1.5 hr⁻¹. The total pressure is from 200 psig to 3000 psig, or alternatively ranging from about 500 psia to about 2500 psia. Hydrogen feed rate, in terms of H₂/hydrocarbon ratio, are typically from 500 SCF/Bbl to 5000SCF/bbl (89 to 890 m³ H₂/m³ feedstock), and are often between 1000 and 3500 SCF/Bbl. Reaction temperatures in the reactor will typically be in the range from about 300°F to about 750°F (about 150°C to about 400°C), or alternatively in the range from 450°F to 725°F (230°C to 385°C).

[0078] In practice, layered catalyst systems may be used comprising hydrotreating (HDT, HDM, DEMET, etc.), hydrocracking (HCR), hydrodewaxing (HDW), and hydrofinishing (HFN) catalysts to produce intermediate and/or finished base oils using single or multireactor systems. A typical configuration includes two reactors with the first reactor comprising layered catalysts providing DEMET, HDT pretreatment, HCR, and/or HDW activity. Differing catalysts performing similar

functions, e.g., different levels of hydrocracking activity, may be used as well, e.g., in different layers within a single reactor or in separate reactors.

EXAMPLES

[0079] Samples of vacuum gas oil (VGO) and atmospheric resid (AR) were obtained from commercially available sources and used in the process schemes illustrated in FIG's. 3a, 3b, 4, and 5. FIG's 3a and 3b show larger process research unit configurations that were generally used to evaluate larger quantities of feedstocks when available. FIG's 4 and 5 show smaller bench scale units used to evaluate smaller feedstocks quantities and were primarily used to evaluate all AR samples.

[0080] Research unit process conditions used included 0.5 LHSV⁻¹, reactor H₂ partial pressure of 1750 psia, hydrogen feed gas oil (recycle) ratio of 4500 scfb, and reactor temperatures in range of 700-770+°F, with the downstream reactor R2 temperature being maintained at 20°F hotter than the upstream R1 reactor. An ascending temperature profile was imposed, 120°F and 40°F ΔT for R1 and R2, respectively. Waxy product target viscosity indexes (VI's) were set at 109 at 6.0 cSt at 100°C (W220) and 11.8 cSt at 100°C (W600).

[0081] Bench scale process conditions used included 0.5 LHSV⁻¹, reactor pressure of 1850 psig, hydrogen feed gas oil ratio of 4500 scfb, and reactor temperatures in range of 700-770+°F, with the downstream reactor R2 temperature being maintained at 20°F hotter than the upstream R1 reactor. Waxy product target viscosity indexes (VI's) were set at 109 at 6.1 cSt at 100°C (220R) and 11.8 cSt at 100°C (600R).

[0082] The catalyst loading in each of reactors R1 and R2 (according to each of FIG's 3a, 3b, 4, and 5) was a conventional scheme for base oil production comprising layered hydrometallation, hydrotreating, and hydrocracking catalysts. Typical configurations included layered catalyst systems comprising one or more DEMET layers, high activity HCR/HDT, HCR, and low activity HCR catalysts for both R1 and R2.

[0083] FIG's 3a, 3b, 4, and 5 each show feedstreams 10 and H₂ inlet 11 to each of reactors R1 and R2, and other intermediate flow streams 20, 30, H₂ recycle stream 31, whole liquid product (WLP) stream 32 that are sent to separators and/or condensers (C1 to C4, S1, and V3) to provide the respective product streams C2B, C3B, C4O, C4B, STO, STB, V3O, and V3B shown in each figure and as noted in the following examples.

Example 1 - Vacuum Gas Oil (VGO) Feedstock (comparative feedstock)

[0084] A sample of vacuum gas oil (VGO) feedstock from a commercially available source used to produce base oil products was obtained and analyzed as a comparative base case. The VGO

feedstock was used in the following examples according to the process configurations shown in FIG's. 3a, 3b, 4, and 5. The properties of this VGO feedstock (sample ID 2358) are shown in Table 1.

Table 1 - Properties of Vacuum Gas Oil (VGO) Feedstock

Feed Property	VGO Property Value
API Gravity	18
Viscosity Index, VI (D2270)	52
Viscosity, 100°C (cSt)	13.23
Viscosity, 70°C (cSt)	37.56
Hot C7 Asphaltenes (wt.%)	
wax content (wt.%)	7
N content (ppm)	1620
S content (ppm)	31420
1050+ (wt.%)	4.7
Simdist (°F)	
IBP	525
5%	707
15%	776
20%	795
30%	827
35%	841
40%	855
45%	870
50%	883
55%	897
60%	912
65%	927
70%	941
75%	957
80%	975
85%	994
90%	1016
95%	1048
99%	1099
EP	1116

Example 2 - Properties of Atmospheric Resid (AR) Feedstocks

[0085] Samples of atmospheric resid (AR1 to AR5) from commercially available sources were obtained and analyzed. The properties of these AR samples, which were used as feedstock components according to the invention, are shown in Table 2.

Table 2 - Properties of Atmospheric Resid (AR) Feedstocks

Feed Property	AR Sample Property Value				
	AR1	AR2	AR3	AR4	AR5
Sample ID	2147	2188	2361	2591	2614
API Gravity	26.6	36.5	28.9	32.6	32.6
Viscosity Index, VI (D2270)	108	137	106	134	123
Viscosity, 100°C (cSt)	13.23	3.843	8.683	6.425	6.511
Viscosity, 70°C (cSt)		6.957		13.04	13.5
Hot C7 Asphaltenes (wt.%)			0.12	0.0234	0.0379
wax content (wt.%)		24	14	25	21

N content (ppm)	808	70.7	623	340	271
S content (ppm)	5654	805	3938	2266	558
1050+°F (wt.%)	24.2	8.3	15.6	11.9	14.3
Simdist (°F)					
IBP	439	319	573	431	310
5%	644	477	672	589	543
15%	737	578	722	673	677
20%	766	608	741	699	717
30%	814	666	775	746	774
35%	837	691	792	767	796
40%	860	715	810	785	816
45%	884	737	828	804	836
50%	907	761	849	824	856
55%	931	785	871	845	876
60%	956	809	893	869	896
65%	984	836	918	893	919
70%	1013	865	944	920	942
75%	1045	897	976	948	971
80%	1078	932	1011	982	1003
85%	1116	974	1056	1022	1044
90%	1163	1028	1111	1070	1096
95%	1224	1103	1185	1136	1173
99%	1312	1217	1268	1230	1312
EP	1329	1250	1279	1230	1339

Example 3 - Properties of Blends of Atmospheric Resid (AR) Feedstocks with Vacuum Gas Oil (VGO)

Feedstock

[0086] Samples of the atmospheric resid AR1 to AR5 of example 2 were blended with the vacuum gas oil (VGO) feedstock of example 1 on a weight ratio basis and the blends analyzed. The properties of these AR/VGO blend samples, which were used as illustrative feedstocks according to the invention, are shown in Table 3.

Table 3 - Properties of Atmospheric Resid (AR) and Vacuum Gas Oil (VGO) Feedstock Blends

Feed Property	AR/VGO Blend (wt/wt) Sample Property Value				
	45% AR1/ 55% VGO	50% AR2/ 50% VGO	53% AR3/ 47% VGO	20% AR4/ 80% VGO	20% AR5/ 80% VGO
Sample ID	2148	2190	2394	3294	4122
API Gravity	20.9	25.9	19.9	19.9	20.6
Viscosity Index, VI (D2270)	73	100	63	72	69
Viscosity, 100°C (cSt)	13.68	6.912	11.99	11.63	11.12
Viscosity, 70°C (cSt)	37.28	15.21	32.4	30.59	29.12
Hot C7 Asphaltenes (wt.%)			0.0386		
wax content (wt.%)		18	8		
N content (ppm)	1540	1050	1460	1230	1270
S content (ppm)	20490	15630	26160	26620	25880
1050+ (wt.%)		6.4	6	6.8	7.3
Simdist (°F)					
IBP		346	551	500	431
5%	702	551	692	693	676
15%		674	760	765	761
20%	804	716	781	786	784
30%	840	778	815	820	818

35%		802	830	835	833
40%	871	823	844	850	848
45%		841	857	865	864
50%	899	860	871	880	879
55%		877	884	895	894
60%	930	894	898	910	910
65%		912	913	927	926
70%	960	929	927	942	942
75%		947	942	960	960
80%	999	969	958	979	980
85%		992	975	1000	1002
90%	1058	1021	993	1027	1030
95%	1132	1064	1015	1066	1075
99%		1172	1046	1166	1246
EP	1327	1216	1051	1204	1313

Example 4 - Evaluation of Group II Base Oil Production from Blends of Atmospheric Resid (AR)

Feedstock with Vacuum Gas Oil (VGO) Feedstock

[0087] The blend feedstock samples AR1 to AR5 of the atmospheric resid with vacuum gas oil (VGO) of example 3 were evaluated for Group II base oil production according to the process represented by FIG. 3b. Group II results were also obtained using the VGO feedstock of example 1 (according to the process of FIG. 3a) for comparison.

[0088] Bench scale process conditions used included 0.5 LHSV⁻¹, reactor pressure of 1850 psig, hydrogen feed gas oil ratio of 4500 scfb, and reactor temperatures in range of 700-770+°F, with the downstream reactor R2 temperature being maintained at 20°F hotter than the upstream R1 reactor. Waxy product target viscosity indexes (VI's) were set at 109 at 6.1 cSt at 100°C (220R) and 11.8 cSt at 100°C (600R).

[0089] Base oil production results compared with VGO feedstock alone for the AR1/VGO blend are shown in Table 4a, results for blends of AR2 and AR3 with VGO are shown in Table 4b, and results for blends of AR4 and AR5 with VGO are shown in Table 4c, with each set of results determined using the AR/VGO blends of example 3.

[0090] As shown in Table 4a, using the AR1/VGO blend as lube oil process feed showed an improvement in heavy base oil product W600 yield of 57.5 vol% vs. 19.3 vol% when the feed does not include the atmospheric resid AR1 component. This improvement in heavy base oil yield is significant even though the AR1/VGO blend did show some loss in hydrocracking (~15°F) and HDN activity loss (19°F or above). The advantage of high W600 yield suggests a more active and robust HDN catalyst system would also be beneficial, particularly for high nitrogen-containing feedstocks.

Table 4a – Base Oil Production for AR1/VGO (wt/wt) blend

Feed	VGO	45% AR1/55% VGO		
Sample ID	2018	2148	2148	2148
Apparent Conversion < 700 °F, (lvol.%)	30.0	22.5	22.0	36.0
Run ID	90-326 866-	90-326 1250-	90-326 1514-	90-326 2042-
R1 Temperature (°F)	890	1274	1538	2066
R2 Temperature (°F)	720	720	728	754
H ₂ Average Pressure (psia)	740	740	748	774
Recycle Gas (SCF/B)	1855	1808	1812	1872
No Loss Product Yields (wt.%):	4444	4488	4467	4493
C1	0.06	0.12	0.11	0.19
C2	0.1	0.12	0.12	0.22
C3	0.2	0.19	0.2	0.37
i-C4	0.09	0.05	0.05	0.16
n-C4	0.21	0.14	0.14	0.37
C5-180 °F	1.1	0.99	0.95	1.5
180-250 °F	1.9	0.98	0.98	2.4
250-550 °F	15.2	10.1	9.9	18.0
550-650 °F	9.3	7.6	7.5	10.1
650-700 °F	6.0	5.5	5.4	6.2
700-750 °F	7.0	7.2	6.8	7.0
750-800 °F	9.3	9.5	9.2	8.8
800-900 °F	23.4	22.8	22.7	18.8
900-EP °F	25.2	33.6	34.9	25.0
TOTAL C4-	0.66	0.62	0.61	1.31
TOTAL C5+	98.3	98.3	98.3	97.9
H ₂ Consumption (CHEM)(SCF/B)	1229	794	804	961
Mass Closure (wt.%)	99.5	100.5	100.1	99.9
Actual yield:				
Waxy W220 Yield (vol.%)	49.1	19.0	19.6	25.6
Waxy W600 Yield (vol.%)	19.3	57.5	57.5	36.7
Total Lube Yield (vol.%)	68.4	76.5	77.1	62.3
C4O:				
API	30	30.7	30.4	32.7
Density (g/ml)	0.8406	0.8372	0.8383	0.8264
Temperature (°C)	70	70	70	70
N content (ppm)	2.1	5.3	7.9	1.82
S content (ppm)	< 5	< 5		< 5
Viscosity, 70°C (cSt)	14.27	10.33	10.34	9.706
Viscosity, 100°C (cSt)	6.620	5.066	5.067	4.918
Viscosity Index, VI (D2270)	105	102	102	117
C4B:				
API	30.5	30	29.9	31.8
Density (g/ml)	0.8381	0.8406	0.8415	0.8313
Temperature (°C)	70	70	70	70
N content (ppm)	1.3	4.6	6.6	1.45
S content (ppm)	5.6	7.73		< 5
Viscosity, 70°C (cSt)	28.48	28.94	29.42	26.68
Viscosity, 100°C (cSt)	12.02	12.18	12.31	11.68
Viscosity Index, VI (D2270)	114	113	112	127
Ascending profile, °F/°F in R1/R2	120/40	120/40	70/30	70/30
C2B:				
API	35.9	36.3	36.2	39
Density (g/ml)	0.8447	0.8423	0.843	0.8289
Temperature (°C)	15.56	15.56	15.56	15.57

Feed	VGO	45% AR1/55% VGO		
Sample ID	2018	2148	2148	2148
C2B Simdist (wt.%) °F				
0.5%	96	94	97	95
5%	217	219	221	209
10%	270	296	299	259
15%	320	360	362	310
20%	367	404	406	358
25%	403	441	443	392
30%	434	475	477	421
35%	464	505	506	452
40%	492	529	531	480
50%	540	573	573	529
55%	562	591	591	550
60%	580	607	607	573
65%	600	625	624	592
70%	618	639	639	611
75%	635	653	652	630
80%	652	666	665	649
85%	667	678	677	666
90%	682	691	689	682
95%	698	704	702	698
99%	719	722	720	719
99.5%	725	729	728	726
C4O Simdist (wt.%) °F				
1%	692	685	685	690
5%	725	712	711	717
10%	742	724	722	729
15%	757	733	732	739
20%	771	741	739	748
25%	784	749	748	757
30%	795	756	756	765
35%	807	764	763	774
40%	818	771	771	782
50%	840	786	786	799
55%	851	793	793	808
60%	862	801	801	817
65%	873	810	810	827
70%	884	818	818	837
75%	895	828	828	848
80%	908	839	839	859
85%	921	851	851	873
90%	937	865	865	888
95%	959	886	886	911
99%	994	922	921	948
100%	1004	935	934	963
C4B Simdist (wt.%) °F				
0.5%	740	710	708	718
5%	828	770	769	786
10%	865	801	800	820
15%	888	824	823	844
20%	906	843	842	863
25%	920	860	859	880
30%	932	875	874	894
35%	942	889	888	907
40%	952	902	902	920

Feed	VGO	45% AR1/55% VGO		
Sample ID	2018	2148	2148	2148
50%	971	929	929	945
55%	979	942	943	958
60%	988	957	958	973
65%	996	973	975	988
70%	1005	991	993	1005
75%	1014	1011	1014	1025
80%	1024	1037	1041	1049
85%	1036	1068	1073	1079
90%	1050	1114	1122	1123
95%	1071	1184	1197	1192
99%	1111	1284	1308	1296
99.5%	1127	1305	1330	1318

[0091] Table 4b presents the results obtained for atmospheric resid samples AR2 and AR3 that are each blended with vacuum gas oil (VGO). As shown, the AR2/VGO blend (90-326-3242-3266) provided significant improvements in both actual waxy W600 yield and total actual waxy yield if the same W220 VI (109 or close) is targeted, 36.6% vs. 18.6 for waxy 600R yield, and 69.4% vs. 53.5% for total waxy yield. While a higher waxy product nitrogen content was obtained, the high product N content could be reduced, as shown in 90-326-3098-3122, at the expense of waxy W600R yield and total waxy base oil yield (6% yield decrease for W600R and 2% yield decrease for total waxy base oil yield).

[0092] From Table 4b, the AR3/VGO blend (88-342-3726-3750) showed significant actual waxy W600R yield improvement compared to VGO feed alone, 31.9% vs. 18.6%. The total actual waxy base oil yield remained the same, while the waxy products from the AR3/VGO blend showed slightly higher nitrogen content.

[0093] Table 4c presents the results obtained for atmospheric resid samples AR4 and AR5 that are each blended with vacuum gas oil (VGO). As shown, two separate runs were performed at different hydrocracking severities for each of the VGO comparative feed and the AR4/VGO and AR5/VGO blends.

Table 4b - Base Oil Production from AR2/VGO and AR3/VGO (wt/wt) blends

Feed	VGO	53% AR3/47% VGO		50% AR2/50% VGO	
Sample ID	2358	2394		2190	
Conversion, 700°F- (lvol.%)	40.2	31.3	25.6	31.7	27.5
Run ID	88-342 3342-366	88-342 3726-3750	88-342 3846-3870	90-326 3098-3122	90-326 3242-3266
R1 Temperature (°F)	723	718	713	715	703
R1 Temperature (°F)	743	738	733	735	723
Overall LHSV (hr ⁻¹)	0.5	0.5	0.5	0.49	0.49

Pressure (psig)	2000		2000		2000		2127		2127	
H ₂ Avg Pressure (psia)	1729		1771		1782		1914		1936	
Recycle Gas (SCF/B)	4397		4522		4465		4576		4545	
No Loss Product Yields:	Wt.%	Vol.%	Wt.%	Vol.%	Wt.%	Vol.%	Wt.%	Vol.%	Wt.%	Vol.%
C5-250 °F	4.1	5.3	3.2	4.2	2.2	2.9	1.5	1.9	0.8	1.0
250-700 °F	37.9	42.3	30.3	33.7	25.9	28.8	31.5	33.9	27.8	29.9
700-EP °F	55.1	59.8	64.3	68.7	69.7	74.4	66.0	68.3	70.5	72.5
Total C4-	1.6		0.9		0.7		0.46		0.32	
Total C5+	97.0	107.4	97.8	106.6	97.8	106.0	98.95	104.18	99.05	103.5
H ₂ Consumption (CHEM)(SCF/B)	1311		982		857		714		689	
Mass Closure (wt.%)	98.6		98.9		99.8		99.75		99.39	
Actual waxy product yield, feed basis	W220	W600	W220	W600	W220	W600	W220	W600	W220	W600
Waxy product yield (vol.%)	34.9	18.6	21.6	31.9	23.4	37.1	36.8	30.6	32.8	36.6
Total Lube Yield (vol.%)	53.5		53.5		60.5		67.4		69.4	
N (ppm)	0.8	0.5	1.8	1.4	3.2	2.9	2.47	1.91	7.85	7.48
S (ppm)	< 5	6.3	5.7	6.9	6.8	10.0	< 5	7.25	10.1	15.6
Viscosity, 70 °C (cSt)	12.07	28.21	11.98	28.99	11.96	30.77	11.13	28.56	11.39	29.1
Viscosity, 100 °C (cSt)	5.802	12	5.767	12.13	5.715	12.67	5.461	12.14	5.515	12.14
Viscosity Index, VI (D2270)	109	117	109	112	104	108	113	117	107	110

Table 4c - Base Oil Production from AR4/VGO and AR5/VGO (wt/wt) Blends

Feed	VGO		VGO		20% AR4/80% VGO		20% AR4/80% VGO		20% AR5/80% VGO		20% AR5/80% VGO		
Sample ID	2358		2358		3924		3924		4122		4122		
Run ID	4536-4368		4560-4776		4968-5040		5328-5424		6554-6722		7010-7154		
R1 Temperature (°F)	717		730		725		715		733		718		
R2 Temperature (°F)	737		750		745		735		753		738		
LHSV R1/R2	1.0/0.97		1.03/1.0		1.0/0.97		1.0/1.0		1.0/1.0		1.0/1.0		
Total Pressure (psig)	1827		1845		1843		1820		1858		1851		
Gas Rate (SCF/B)	4405		4407		4423		4463		4350		4404		
No Loss Product Yields (wt.%):													
C5-180 °F	1.5		2.1		1.7		1.3		2.0		1.3		
180-250 °F	1.0		1.9		1.5		0.7		1.8		0.7		
250-550 °F	13.7		19.6		16.3		10.6		19.2		11.2		
550-700 °F	16.4		18.1		16.6		15.2		17.6		23.7		
700+ °F	64.0		54.5		60.8		69.5		56.7		60.5		
C5+	96.6		96.3		97.0		97.2		97.2		97.5		
Mass Closure (wt.%)	100		99.4		98.9		99.2		99		99		
Average CAT (°F)	727		740		735		725		743		728		
Waxy product yield:	W2 20	W6 00	W2 20	W6 00	W22 0	W60 0	W22 0	W60 0	W22 0	W60 0	W22 0	W60 0	
Product Rate, 40 KBPD feed basis (KBPD)	4.7	18.92	18.6	8.45	16.1	9.39	17.43	11.92	18.03	5.97	17.6	10.95	
Viscosity, 100°C (cSt)	6.396	11.801	6.064	11.799	6.008	11.801	6.118	11.798	6.003	11.8	6.291	11.8	
Viscosity Index, VI (D2270)	86	102	114	122	116	119	107	109	118	122	105	107	
Noack Volatility (D5800, wt.%)	14.1	3	11.5	0.9	11.3	1.3	12.7	1.8	11.4	1.1	12.2	1.7	

[0094] Results from Table 4c provide a basis for comparison of waxy base oil yields at a viscosity index (VI) of 109 for W220 for AR2/VGO, AR4/VGO, and AR5/VGO blends, as shown in Table 4d. At 109 W220 VI, compared to VGO feed alone, the 50% AR2/VGO blend feed showed a waxy base oil yield improvement in W600 yield of 33.7% compared with a W600 yield of 25.8% for VGO feed alone that does not include the atmospheric resid AR2 component. A total waxy base oils yield of 68.7% for the AR2/VGO blend was obtained compared with a total waxy base oils yield of 66.1% when the feed did not contain the AR2 blend component.

[0095] The 20% AR4/VGO blend also showed improvements in both W600 yield of the AR4/VGO blend compared with the VGO feed by itself (28.4% vs. 25.8%), in W220 yield of the AR4/VGO blend compared with the VGO feed by itself (42.9% vs. 40.3%), and the total waxy base oil yield of the AR4/VGO blend compared with the VGO feed by itself (71.3% vs. 66.1%).

[0096] Similarly, the 20% AR5/VGO showed improvement in W220 yield of the AR5/VGO blend compared with the VGO feed by itself (44.4% vs. 40.3%) and in total waxy base oil W600 yield of the AR5/VGO blend compared with the VGO feed by itself (68.1% vs. 66.1%).

Table 4d - Atmospheric Resid/Vacuum Gas Oil (AR/VGO) Blend Yield Comparison

Feed	VGO	50% AR2/50% VGO	20% AR4/80% VGO	20% AR5/80% VGO
Sample ID	2358	2190	3924	4122
W220 VI	109	109	109	109
W220 yield (vol.%)	40.3	35.0	42.9	44.4
W600 yield (vol.%)	25.8	33.7	28.4	23.8
Total waxy yield (vol.%)	66.1	68.7	71.3	68.1
Average CAT (°F)	738	713	727	740

Example 5 - Evaluation of Atmospheric Resids (AR) to Provide Medium Grade Vacuum Gas Oils (MVGO) for Group III/III+ Base Oil Production

[0097] Samples of atmospheric resid (AR) were evaluated to provide medium grade vacuum gas oils (MVGO) for use in producing group III/III+ base oils. The MVGO samples were derived from the corresponding AR samples as distillation cuts in the following ranges: AR2 cut range of 717-876°F; AR4 cut range of 725-882°F; and, AR5 cut range of 716-882°F. Table 5a presents properties of the AR samples AR2, AR4, and AR5 and the corresponding MVGO derived cuts MVGO2, MVGO4, and MVGO5. Properties for the comparative vacuum gas oil (VGO) are also included.

[0098] The three atmospheric resid (AR) derived MVGO's were evaluated using the process configuration of FIG. 4 for the production of group III base oils at different dewaxing severities with different waxy viscosity indexes (VI) at a kinematic viscosity (KV100) of about 4 cSt at 100°C. Table 5b summarizes the yields for the comparative case of VGO by itself, and MVGO's derived from AR2, AR4, and AR5 feeds, designated as MVGO2, MVGO4, and MVGO5 feeds, respectively.

Table 5a - Properties of Atmospheric Resid (AR) and MVGO Feeds

Feed	VGO	AR2	MVGO2	AR4	MVGO4	AR5	MVGO5
Sample ID:	2326	2411	3106	2591	3816	2614	4108
API Gravity	25.3	36.1	35.6	32.6	34.2	32.6	33.4
Density (g/ml)	0.8672	0.809	0.8112	0.827	0.8184	0.8271	0.8229
Temperature (°C)	70	70	70	70	70	70	70
Viscosity Index, VI (D2270)	72	151	128	134	124	123	117
Viscosity, 100°C (cSt)	4.208	4.575	4.339	6.425	4.635	6.511	5.138
Viscosity, 70°C (cSt)	8.436	8.455	8.167	13.04	8.914	13.5	10.25
Hot C7 Asphaltenes (wt.%)	0.0045		0.0046		0.0063	0.0379	0.0105
Low Level N (ppm)	735	72.8	59.2	340	142		126
S (ppm)	21710		705	2266			443
Cl (ppm)		41		7.2		58	
H by NMR			14.06				13.81
Dewaxed Oil (DWO)							
Viscosity Index, VI (D2270)	53		111		106	108	100
Viscosity, 100°C (cSt)	4.484		4.716		5.115	7.038	5.665
Viscosity, 40°C (cSt)	27.49		24.54		28.68	46.84	34.91
Cloud point (°C)	-13		-11		-11		-12
Pour point (°C)	-16		-14		-14		-14
Wax content (wt.%)	8.4		22.2	25.5	21.5	21.5	17.5
VI droop from SDW	19		17		18	15	17
SIMDIST TBP (wt.%, °F)							
0.5%	527	337	696	484	694	330	683
5%	631	496	718	589	727	543	725
10%	668	565	732	636	740	625	742
20%	706	642	749	699	759	717	766
30%	730	698	764	746	775	774	784
40%	747	747	779	785	790	816	800
50%	762	794	794	824	804	856	814
60%	776	844	810	869	818	896	828
70%	790	903	827	920	834	942	843
80%	805	973	844	982	850	1003	858
90%	825	1067	864	1070	869	1096	878
95%	841	1143	878	1136	882	1173	894
99.5%	907	1330	908	1253	916	1339	942

Table 5b - Comparison of Yields for VGO and MVGO Feeds for Group III Base Oil Production

Feed	VGO		MVGO2		MVGO4			MVGO5	
Sample ID	2326	2326	3106	3106	3816	3816	3816	4108	4108
Run ID	601-65-3837-4029	601-65-4101-4269	601-62-669-885	601-62-1077-1221	601-65-4893-5037	601-65-5109-5277	601-65-5469-5613	601-65-6093-6309	601-65-6549-6717
R1 Temperature °F	720	740	680	660	720	710	695	705	720
R2 Temperature °F	740	760	700	680	740	730	715	725	740
LHSV (hr ⁻¹)	0.55	0.55	0.56	0.55	0.55	0.55	0.55	0.55	0.55
Total Pressure (psig)	1850	1850	1900	1900	1850	1850	1850	1850	1850
Gas Rate (SCFB)	3989	3985	4350.5	4400	4034	3990	3991	4395	4362
No Loss Yields (wt.%):									
C1	0.2	0.3	0.0	0.0	0.1	0.1	0.0	0.1	0.1
C2	0.2	0.4	0.1	0.0	0.1	0.1	0.1	0.1	0.1
C3	0.5	0.8	0.3	0.1	0.9	0.4	0.2	0.3	0.5
i-C4	0.3	0.6	0.8	0.3	1.1	0.8	0.4	0.6	1.0
n-C4	0.5	0.8	0.4	0.2	0.7	0.5	0.2	0.4	0.7
C5-180°F	2.4	3.9	3.6	1.6	5.2	3.3	2.1	3.1	6.0
180-250°F	2.7	4.9	3.2	1.2	4.4	3.2	1.5	3.1	5.2
250-550°F	24.6	34.8	24.1	12.0	29.3	22.7	14.5	22.2	35.1
550-700°F	26.4	24.6	13.2	8.8	13.8	12.0	8.9	12.3	15.6
700°F+	45.5	34.3	55.9	77.0	46.4	58.5	73.2	61.6	42.1
C5+°F	101.7	102.5	100.1	100.6	99.0	99.8	100.2	102.3	104.0
Mass Closure (wt.%)	99.8	99.5	99.2	99.7	99.8	99.7	99.9	99.2	99.5
STB Results:									
Viscosity Index, VI (D2270)	123	133	144	136	142	140	136	135	138
Viscosity, 100°C (cSt)	3.829	3.682	4.125	4.128	3.936	4.036	4.235	4.366	4.133
Viscosity, 70°C (cSt)	7.05	6.633	7.516	7.604	7.116	7.358	7.844	8.15	7.595
Actual STB yield, on feed basis (wt%)	41.5	27.0	37.0	67.8	38.1	51.4	66.4	54.5	33.2

Example 6 - Evaluation of Medium Vacuum Gas Oils (MVGO) Fractions Derived from Atmospheric Resid Feed AR3

[0099] Samples of atmospheric resid feed sample AR3 were evaluated to provide medium grade vacuum gas oils (MVGO) for use in producing group III/III+ base oils. The MVGO samples were derived from the corresponding AR3 samples as distillation cuts in the 725-895 °F range, designated as MVGO3b (broad temperature range cut), and 725-855°F, designated as MVGO3n (narrow temperature range cut).

[00100] Table 6 presents the results using the MVGO3b and MVGO3n feeds to produce group III 4cSt base oils using the process configuration of FIG. 3a. Properties for the comparative vacuum gas oil (VGO) are also included. Both MVGO feeds MVGO3b and MVGO3n provided increased waxy Group III product yield for 4 cSt base oil production, with the broad cut MVGO3b showing a 4.5 lvol.% and the narrow MVGO cut MVGO3n showing a 6.6 lvol.% increase compared against the use of the vacuum gas oil (VGO) feed.

Table 6 - MVGO Use for Group III 4 cSt Base Oil Production

Feed	VGO		MVGO3b		MVGO3n	
Sample ID	2326		2365		2366	
Run ID	70-562-1370-1394		70-562-4346-4370		70-562-4922-4946	
R1 Temperature (°F)	720		720		720	
R1 Temperature (°F)	740		740		740	
Overall LHSV (hr ⁻¹)	0.55		0.55		0.55	
Pressure (psig)	2025		2050		2025	
H ₂ Average Pressure (psia)	1777		1846		1810	
Recycle Gas (SCF/B)	4482		4550		4461	
No Loss Product Yields:	Wt. %	Vol. %	Wt. %	Vol. %	Wt. %	Vol. %
C5-180 °F	3.5	4.8	5.9	7.9	3.9	5.2
180-550 °F	39.6	45.4	46.6	52.2	45.3	50.5
550-700 °F	22.9	24.5	17.0	17.8	17.6	18.3
700- EP °F	31.7	33.8	28.8	30.0	31.4	32.6
Total C4- °F	2.0		2.7		2.8	
Total C5+ °F	97.7	108.4	98.3	107.9	98.2	106.6
H ₂ Consumption (CHEM)(SCF/B)	1281		758		718	
Mass Closure, wt. %	99.6		99.6		99.7	
C3B Viscosity, 100°C (cSt)	4.071		3.996		3.774	
C3B Viscosity, 70°C (cSt)	7.462		7.307		6.822	
C3B Viscosity Index, VI	137		136		135	
Actual waxy yield, C3B, of feed (lvol. %)	18.2		22.7		24.8	
Average CAT (°F)	730		730		730	

Example 7 - Evaluation of Heavy-Heavy Vacuum Gas Oil (HHVGO) Fractions Derived from

Atmospheric Resids (AR) to Produce Group II Base Oils

[00101] As noted in Example 5, samples of atmospheric resid (AR) were used to provide medium grade vacuum gas oils (MVGO) for use in producing group III/III+ base oils. The remaining fraction, absent the MVGO fraction, was designated as an HHVGO fraction. These HHVGO fractions were evaluated for use as feed components blended with vacuum gas oils (VGO) to produce Group II base oils.

[00102] Table 7a presents the properties of the HHVGO samples HHVGO2, HHVGO4, and HHVGO5 and blend of 9%HHVGO/VGO and 9%HHVGO/VGO. Properties of the comparative VGO feed are also shown.

Table 7a - Properties of HHVGO Fractions and HHVGO/VGO blends

Feed	VGO	HHVGO2	9% HHVGO2	HHVGO4	9% HHVGO4	HHVGO5
Sample ID:	2358	3107	3574	3187	3915	4109
Yield from Feed Source (vol.%)	100	44.8		40.4		42.4
API Gravity	18	31.5	19	27.8	18.9	28.8
density (g/ml)	0.9113	0.8261	0.9045	0.8528	0.9057	0.8473
Temperature (°C)	70	80	70	70	70	70
Viscosity Index, VI (D2270)	52	N/A	62	114		99
Viscosity, 100°C (cSt)	13.23	15.19	13.42	20.59		18.18
Viscosity, 70°C (cSt)	37.56		37.34	53.83		48.68
Hot C7 Asphaltenes (wt.%)	0.008	0.0402	0.0152	0.0534		0.0517
Low Level N (ppm)	1620	138	1600	670	1350	498
S (ppm)	31420	1037	27950	3485	28920	826
H by NMR	11.82				11.81	13.54
Micro carbon residue (wt.%)		0.47		1.63		0.92
Dewaxed Oil (DWO):						
Viscosity Index, VI (D2270)	31	101	37	90		91
Viscosity, 100°C (cSt)	250	16.91	15.15	26.15		21.53
Viscosity, 40°C (cSt)	14.94	177.5	245.9	387.9		282.7
Wax content (wt.%)	6.9	43.4	9.9	29.9		21.8
VI droop from SDW	21		25	24		8
SIMDIST TBP (wt.%), °F						
0.5%	577	849	602	855	591	844
5%	700	884	713	885	711	876
10%	744	900	755	900	755	891
20%	793	926	803	926	803	915
30%	824	949	836	949	837	937
40%	853	976	866	977	869	960
50%	882	1004	894	1008	898	987

60%	911	1036	923	1044	928	1018
70%	941	1072	952	1086	959	1055
80%	975	1118	987	1141	997	1102
90%	1017	1189	1033	1222	1052	1170
95%	1048	1253	1068	1294	1114	1223
99.5%	1115	1383	1236	1371	1370	1334

[00103] Table 7b presents the results using the HHVGO/VGO blend feeds to produce group II base oils using the process configuration of FIG. 5. Results for the comparative vacuum gas oil (VGO) are also included. The results are further summarized in Table 7c. Both HHVGO feeds, i.e., 9% HHVGO2/VGO and 9% HHVGO4/VGO, provided comparable waxy Group II base oil product yields compared with the use of the VGO feed by itself. The combination of using an MVGO cut to produce a Group III base oil and of using the remaining HHVGO fraction to produce a Group II base oil therefore provides technical and economic advantages compared with the use of a vacuum gas oil feed.

Table 7b - Waxy Base Oil Yields from HHVGO/VGO Blend Feeds

Feed Sample ID	VGO						9% HHVGO2/VGO			
	2358						3574			
Run ID	911-176-4560-4776		911-176-4368-4536		911-176-3984-4272		601-63-2397		601-63-2229	
R1 Temperature (°F)	730		717		709		718		708	
R2 Temperature (°F)	750		737		729		738		728	
LHSV (hr ⁻¹)	0.5		0.5		0.5		0.5		0.5	
Total Pressure (psig)	1845		1827		1835		1850		1850	
Gas Rate (SCFB)	4407		4405		4408		4387		4385	
No Loss Yields (wt.%):										
C1	0.3		0.2		0.2		0.2		0.2	
C2	0.3		0.2		0.2		0.2		0.2	
C3	0.5		0.4		0.3		0.4		0.3	
i-C4	0.2		0.1		0.1		0.1		0.1	
n-C4	0.5		0.4		0.3		0.4		0.3	
C5-180°F	2.1		1.5		1.1		1.5		1.1	
180-250°F	1.9		1.0		0.7		1.6		1.1	
250-550°F	19.6		13.7		10.4		16.2		12.7	
550-737°F	23.5		22.2		20.9					
550-749°F							22.6		21.5	
737°F+	49.1		58.3		63.6					
749°F+							54.7		60.3	
C5+	96.3		96.6		96.7		96.7		96.8	
Synthetic Conversion										
737°F- (wt.%)	55.9		45.9		40.0					
Synthetic Conversion										
749°F- (wt.%)							49.9		43.7	
Mass Closure (wt.%)	99.4		99.6		99.2		99.5		99.2	
V3O Results:										
Viscosity Index, VI (D2270)							83		73	
Viscosity, 40°C, (cSt)							19.74		21.51	
Viscosity, 100°C, (cSt)							3.904		4.041	
V3B Results:										
Viscosity Index, VI							117		111	
Viscosity, 100°C, (cSt)							8.985		9.505	
Viscosity, 70°C (cSt)							20.08		21.73	
STO API							34.9		33.3	
Average CAT (°F)	740		727		719		728		718	
Waxy Product Yield:	W220	W600	W220	W600	W220	W600	W220	W600	W220	W600
Rate, 40 KBPD feed basis (KBPD)	18.6	8.45	4.7	18.92	14.92	15.52	16.97	8.98	14.72	13.09
Kinematic Viscosity, KV100 (cSt)	6.064	11.799	6.396	11.801	6.397	11.802	6.316	11.799	6.366	11.802
Viscosity Index, VI (D2270)	114	122	86	102	92	103	111	118	104	113
Noack Volatility, (wt.%)	11.5	0.9	14.1	3	13	1.8	11.9	1.6	12.7	2.1
Yield on feed basis (vol.%)	46.5	21.1	11.8	47.3	37.3	38.8	42.4	22.5	36.8	32.7

Table 7b (continued) - Waxy Base Oil Yields from HHVGO/VGO Blend Feeds

Feed Sample ID	VGO						9% HHVGO4/VGO			
	2358						3915			
Run ID	911-176-4560-		911-176-4368-		911-176-3984-		911-177-6218-		911-177-5714-	
	4776		4536		4272		6434		5954	
R1 Temperature (°F)	730		717		709		733		723	
R2 Temperature (°F)	750		737		729		753		743	
LHSV (hr ⁻¹)	0.5		0.5		0.5		0.5		0.5	
Total Pressure (psig)	1845		1827		1835		1847		1841	
Gas Rate (SCFB)	4407		4405		4408		4404		4402	
No Loss Yields (wt.%):										
C1	0.3		0.2		0.2		0.2		0.2	
C2	0.3		0.2		0.2		0.3		0.2	
C3	0.5		0.4		0.3		0.4		0.4	
i-C4	0.2		0.1		0.1		0.2		0.1	
n-C4	0.5		0.4		0.3		0.5		0.4	
C5-180°F	2.1		1.5		1.1		2.2		1.4	
180-250°F	1.9		1.0		0.7		1.6		1.0	
250-550°F	19.6		13.7		10.4		18.1		13.7	
550-737°F	23.5		22.2		20.9					
550-746°F							23.0		22.5	
737°F+	49.1		58.3		63.6					
746°F+							51.8		58.4	
C5+	96.3		96.6		96.7		96.8		97.0	
Synthetic Conversion										
737°F- (wt.%)	55.9		45.9		40.0					
Synthetic Conversion										
746°F- (wt.%)							52.8		45.6	
Mass Closure (wt.%)	99.4		99.6		99.2		99.1		98.8	
V3O Results:										
Viscosity Index, VI (D2270)										
Viscosity, 40°C, (cSt)										
Viscosity, 100°C, (cSt)										
V3B Results:										
Viscosity Index, VI										
Viscosity, 100°C, (cSt)										
Viscosity, 70°C (cSt)										
STO API										
Average CAT (°F)	740		727		719		743		733	
Waxy Product Yield:	W220	W600	W220	W600	W220	W600	W220	W600	W220	W600
Rate, 40 KBPD feed basis (KBPD)	18.6	8.45	4.7	18.92	14.92	15.52	16.71	8.07	14.83	12.49
Kinematic Viscosity, KV100 (cSt)	6.064	11.799	6.396	11.801	6.397	11.802	6.209	11.799	6.247	11.801
Viscosity Index, VI (D2270)	114	122	86	102	92	103	112	120	104	112
Noack Volatility, (wt.%)	11.5	0.9	14.1	3	13	1.8	11.5	1.2	12.4	1.6
Yield on feed basis (vol.%)	46.5	21.1	11.8	47.3	37.3	38.8	41.8	20.2	37.1	31.2

Table 7c - Yield Comparison for HHVGO/VGO Blend Feeds at 109 VI W220

Feed	VGO	9% HHVGO2/VGO	9% HHVGO4/VGO
Sample ID	2358	3574	3915
W220 Viscosity Index, VI	109	109	109
W220 yield (vol.%)	40.3	40.9	40.0
W600 yield (vol.%)	25.8	25.4	24.3
Total waxy yield (vol. %)	66.1	66.3	64.3
Average CAT (°F)	738	725	739

[00104] The foregoing description of one or more embodiments of the invention is primarily for illustrative purposes, it being recognized that variations might be used which would still incorporate the essence of the invention. Reference should be made to the following claims in determining the scope of the invention.

[00105] For the purposes of U.S. patent practice, and in other patent offices where permitted, all patents and publications cited in the foregoing description of the invention are incorporated herein by reference to the extent that any information contained therein is consistent with and/or supplements the foregoing disclosure.