

CATALYTIC PROCESSES AND SYSTEMS FOR BASE OIL PRODUCTION FROM HEAVY FEEDSTOCK

This application claims the benefit under 35 USC 119 of Provisional Application No.
5 61/359,717, filed June 29, 2010 and Non Provisional Application No. 13/159,665 filed on
June 14, 2011.

FIELD OF THE INVENTION

10 This invention relates to processes and systems for dewaxing hydrocarbon feedstocks.

BACKGROUND OF THE INVENTION

High quality lubricating oils are critical for the operation of modern machinery and
15 motor vehicles. However, current crude oil supplies are inadequate to meet present demands for
such lubricants. Therefore, it is necessary to upgrade crude oil fractions otherwise unsuitable
for lubricant manufacture. As an example, high-quality lubricating oils must often be produced
from waxy feeds. Numerous processes have been proposed for producing lubricating base oils
by upgrading ordinary and low quality feedstocks.

20 Hydrocarbon feedstocks may be catalytically dewaxed by hydrocracking or
hydroisomerization. Hydrocracking generally leads to a loss in yield due to the production of
lower molecular weight hydrocarbons, such as middle distillates and even lighter C₄ products,
whereas hydroisomerization generally provides higher yields by minimizing cracking.

U.S. Patent No. 7,384,538 discloses hydroisomerization of waxy feed for base oil
25 production in an isomerization zone comprising a catalyst bed having at least two
isomerization catalysts, wherein a first catalyst has a channel diameter of at least 6.2 Å, and a
second catalyst has a channel diameter not more than 5.8 Å. U.S. Patent Application
Publication No. 2008/0083657 discloses dewaxing a hydrocarbon feed with a metal-modified
small crystallite MTT framework molecular sieve. U.S. Patent Application Publication No.
30 2009/0166252 discloses lube basestock production using two isomerization catalysts, wherein
a first catalyst has a Constraint Index (CI) of not more than 2, and a second catalyst has a CI
greater than 2.

Apart from product yield, another important factor in the catalytic production of base
oil is the minimization of catalyst aging. In this regard, U.S. Patent No. 5,951,848 discloses

the use of a two catalyst system comprising a hydrotreating catalyst and a dewaxing catalyst. The aging of the dewaxing catalyst may be slowed by the presence of the hydrotreating catalyst layer.

U.S. Patent Nos. 6,468,417 and 6,468,418 disclose the production of lube oil having a reduced tendency to form a haze by a process including contacting a dewaxed lube stock or base oil feed with a solid sorbent to produce a dehazed base oil having a reduced cloud point relative to that of the dewaxed lube stock or base oil feed.

There is a continuing need for improved dewaxing processes and catalyst systems showing increased isomerization selectivity and conversion of waxy hydrocarbon feedstocks for the production of valuable Group II and Group III base oils.

SUMMARY OF THE INVENTION

This invention relates to processes for efficiently converting wax-containing hydrocarbon feedstocks into high-grade products, including lubricant base oils having a low pour point, a low cloud point, a low pour-cloud spread, and a high viscosity index (VI). Such processes employ a layered catalyst system comprising a plurality of hydroisomerization dewaxing catalysts. Hydroisomerization converts aliphatic, unbranched paraffinic hydrocarbons (n-paraffins) to isoparaffins and cyclic species, thereby decreasing the pour point and cloud point of the base oil product as compared with the feedstock. In an embodiment, a layered catalyst system of the present invention may further comprise a hydrotreating catalyst as a guard layer, whereby "aging" of the hydroisomerization catalysts is decelerated, and base oil product yield can be maintained for longer periods of time, as compared with conventional processes, at a temperature in the range from about 450°F to about 725°F (232°C to 385°C).

According to one aspect of the present invention there is provided a process for catalytically dewaxing a waxy hydrocarbon feedstock comprising contacting the hydrocarbon feedstock in a first hydroisomerization zone under first hydroisomerization dewaxing conditions with a first hydroisomerization catalyst to provide a first isomerization stream, and contacting at least a portion of the first isomerization stream in a second hydroisomerization zone under second hydroisomerization dewaxing conditions with a second hydroisomerization catalyst to provide a second isomerization stream. Each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may comprise a molecular sieve and a Group VIII metal. Each of the first hydroisomerization catalyst and the

second hydroisomerization catalyst may be selective for isomerization of n-paraffins in the feedstock. The first hydroisomerization zone and the second hydroisomerization zone may be disposed within the same reactor. Each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may be doped with a metal modifier selected from the group consisting of Mg, Ca, Sr, Ba, K, La, Pr, Nd, Cr, and combinations thereof.

In an embodiment the present invention provides a process for catalytically dewaxing a heavy hydrocarbon feedstock comprising contacting the hydrocarbon feedstock in a first hydroisomerization zone under first hydroisomerization dewaxing conditions with a first hydroisomerization catalyst to provide a first isomerization stream, contacting at least a portion of the first isomerization stream in a second hydroisomerization zone under second hydroisomerization dewaxing conditions with a second hydroisomerization catalyst to provide a second isomerization stream, and contacting the second isomerization stream with a hydrofinishing catalyst to provide a base oil product having a pour point of not more than about -12°C and a pour-cloud spread of not more than about 5°C. Each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may comprise a 1-D, 10-ring molecular sieve and a Group VIII metal. Each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may be doped with a metal modifier selected from the group consisting of Mg, Ca, Sr, Ba, K, La, Pr, Nd, Cr, and combinations thereof. The first and second hydroisomerization catalysts may be disposed in the same reactor.

In another embodiment, the present invention provides a layered catalyst system comprising a first hydroisomerization zone comprising a first hydroisomerization catalyst, and a second hydroisomerization zone comprising a second hydroisomerization catalyst. Each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may comprise a 1-D, 10-ring molecular sieve and a Group VIII metal. The first hydroisomerization catalyst has a first level of selectivity for the isomerization of n-paraffins, the second hydroisomerization catalyst has a second level of selectivity for the isomerization of n-paraffins, the layered catalyst system has a third level of selectivity for the isomerization of n-paraffins. The third level of selectivity may be higher than each of the first level of selectivity and the second level of selectivity.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically represents a system for hydrocarbon dewaxing processes, according to an embodiment of the present invention;

FIG. 2A-B each schematically represents a catalytic dewaxing system having a single dewaxing catalyst;

FIG. 2C schematically represents a layered catalytic dewaxing system, according to an embodiment of the present invention; and

- 5 FIG. 3 shows the yield of 800°F+ lube oil versus cloud point for individual dewaxing catalysts and a layered dewaxing catalyst system, according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

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The present invention provides a hydrocarbon dewaxing process which involves contacting a hydrocarbon feedstock with a layered catalyst system comprising a first hydroisomerization catalyst and a second hydroisomerization catalyst. In an embodiment, the present invention also provides a catalyst system for dewaxing a hydrocarbon feedstock, wherein the first hydroisomerization catalyst may be upstream from the second hydroisomerization catalyst.

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In an embodiment, the first hydroisomerization catalyst may be in a first hydroisomerization layer or zone of the catalyst system, and the second hydroisomerization catalyst may be in a second hydroisomerization layer or zone of the catalyst system. The first hydroisomerization catalyst and the second hydroisomerization catalyst may be in the same reactor. The first hydroisomerization catalyst and the second hydroisomerization catalyst may be disposed in separate beds in the same reactor. Alternatively, at least a portion of the first hydroisomerization catalyst may be in the same bed as at least a portion of the second hydroisomerization catalyst, and/or at least a portion of the second hydroisomerization catalyst may be in the same bed as at least a portion of the first hydroisomerization catalyst.

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Applicants have now demonstrated that layered catalyst systems of the present invention comprising first and second hydroisomerization catalysts with a combined volume, V , can provide superior results, e.g., overall greater isomerization selectivity as determined by increased yield and/or higher viscosity index (VI) of the base oil product, as compared with the same volume (V) of either the first hydroisomerization catalyst alone or the second hydroisomerization catalyst alone.

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In an embodiment, catalyst systems of the present invention may further comprise a hydrotreating catalyst. The hydrotreating catalyst may comprise, and may function as, a guard layer or guard bed. The hydrotreating catalyst of the guard layer may be disposed upstream

from the first hydroisomerization catalyst. The hydrotreating catalyst of the guard layer may serve to protect the first and second hydroisomerization catalysts from contaminants in the feedstock that could deactivate the hydroisomerization catalysts. Thus, the presence of the guard layer can substantially increase the longevity of the first and second hydroisomerization catalysts. In an embodiment, the guard layer may be disposed in the same reactor as the first and second hydroisomerization catalysts. Accordingly, processes of the present invention may be practiced in a single reactor.

In an embodiment, the reaction conditions for processes of the present invention may be determined, *inter alia*, by the temperature required for the first and second hydroisomerization catalysts to achieve a target pour point of a desired base oil product of the invention. Typically, the hydroisomerization catalysts may have an operating temperature in the range from about 390°F to about 800°F (199°C to 427°C), and usually from about 550°F to about 750°F (288°C to 399°C). In practice, the process temperature may depend on various other process parameters, such as the feed composition, the feed rate, the operating pressure, the formulation of the catalyst system, and the “age” of the hydroisomerization catalysts.

Definitions

The following terms used herein have the meanings as defined herein below, unless otherwise indicated.

The term “hydrotreating” refers to processes or steps performed in the presence of hydrogen for the hydrodesulfurization, hydrodenitrogenation, hydrodemetallation, and/or hydrodearomatization of components (e.g., impurities) of a hydrocarbon feedstock, and/or for the hydrogenation of unsaturated compounds in the feedstock. Depending on the type of hydrotreating and the reaction conditions, products of hydrotreating processes may have improved viscosities, viscosity indices, saturates content, low temperature properties, volatilities and depolarization, for example.

The terms “guard layer” and “guard bed” may be used herein synonymously and interchangeably to refer to a hydrotreating catalyst or hydrotreating catalyst layer. The guard layer may be a component of a catalyst system for hydrocarbon dewaxing, and may be disposed upstream from at least one hydroisomerization catalyst.

As used herein the term “molecular sieve” refers to a crystalline material containing pores, cavities, or interstitial spaces of a uniform size in which molecules small enough to pass through the pores, cavities, or interstitial spaces are adsorbed while larger molecules are

not. Examples of molecular sieves include zeolites and non-zeolite molecular sieves such as zeolite analogs including, but not limited to, SAPOs (silicoaluminophosphates), MeAPOs (metalloaluminophosphates), AlPO_4 , and ELAPOs (nonmetal substituted aluminophosphate families).

5 As used herein, the term “pour point” refers to the temperature at which an oil will begin to flow under controlled conditions. The pour point may be determined by, for example, ASTM D5950.

10 “Target pour point” means the desired or required pour point of a lubricant base oil product. The target pour point is generally less than about -10°C , and typically in the range from about -10°C to -50°C .

15 As used herein, “cloud point” refers to the temperature at which a lube oil sample begins to develop a haze as the oil is cooled under specified conditions. The cloud point of a lube base oil is complementary to its pour point. Cloud point may be determined by, for example, ASTM D5773.

 The “pour point/cloud point spread,” or “pour-cloud spread” of a base oil, refers to the spread or difference between the cloud point and the pour point, and is defined as the cloud point minus the pour point, as measured in $^\circ\text{C}$. Generally, it is desirable to minimize the spread between the pour and cloud points.

20 The Periodic Table of the Elements referred to in this disclosure is the CAS version published by the Chemical Abstract Service in the *Handbook of Chemistry and Physics*, 72nd edition (1991-1992).

 “Group VIII metal” refers to elemental metal(s) selected from Group VIII of the Periodic Table of the Elements and/or to metal compounds comprising such metal(s).

25 Unless otherwise specified, the “feed rate” of a hydrocarbon feedstock being fed to a catalytic reaction zone is expressed herein as the volume of feed per volume of catalyst per hour, which may be referred to as liquid hourly space velocity (LHSV) with units of reciprocal hours (h^{-1}).

30 The term “hydroisomerization” refers to a process in which n-paraffins (n-alkanes) are isomerized to their more branched counterparts in the presence of hydrogen over a hydroisomerization (dewaxing) catalyst.

 Unless otherwise specified, the recitation of a genus of elements, materials, or other components from which an individual component or mixture of components can be selected is intended to include all possible sub-generic combinations of the listed components and

mixtures thereof. Also, "include" and its variants are intended to be non-limiting, such that recitation of items in a list is not to the exclusion of other like items that may also be useful in the materials, compositions, and methods of this invention.

Properties for the materials described herein may be determined as follows:

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(a) $\text{SiO}_2/\text{Al}_2\text{O}_3$ Ratio (SAR): determined by ICP elemental analysis. A SAR of infinity (∞) represents the case where there is no aluminum in the zeolite, i.e., the mole ratio of silica to alumina is infinity. In that case, the molecular sieve is comprised essentially of all silica.

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(b) Surface area: determined by N_2 adsorption at its boiling temperature. BET surface area is calculated by the 5-point method at $P/P_0 = 0.050, 0.088, 0.125, 0.163$, and 0.200 . Samples are first pre-treated at 400°C for 6 hours in the presence of flowing, dry N_2 so as to eliminate any adsorbed volatiles like water or organics.

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(c) Micropore volume: determined by N_2 adsorption at its boiling temperature. Micropore volume is calculated by the t-plot method at $P/P_0 = 0.050, 0.088, 0.125, 0.163$, and 0.200 . Samples are first pre-treated at 400°C for 6 hours in the presence of flowing, dry N_2 so as to eliminate any adsorbed volatiles like water or organics.

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(d) Mesopore pore diameter: determined by N_2 adsorption at its boiling temperature. Mesopore pore diameter is calculated from N_2 isotherms by the BJH method described in E.P. Barrett, L.G. Joyner and P.P. Halenda, "The determination of pore volume and area distributions in porous substances. I. Computations from nitrogen isotherms" *J. Am. Chem. Soc.* 1951 73, 373-380. Samples are first pre-treated at 400°C for 6 hours in the presence of flowing, dry N_2 so as to eliminate any adsorbed volatiles like water or organics.

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(e) Total pore volume: determined by N_2 adsorption at its boiling temperature at $P/P_0 = 0.990$. Samples are first pre-treated at 400°C for 6 hours in the presence of flowing, dry N_2 so as to eliminate any adsorbed volatiles like water or organics.

Where permitted, all publications, patents and patent applications cited in this application are incorporated by reference herein in their entirety, to the extent such disclosure is not inconsistent with the present invention.

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Hydrotreating Catalysts

In an embodiment, catalyst systems of the present invention may include a hydrotreating catalyst, e.g., in the form of a guard layer. Hydrotreating catalysts of the present

invention may comprise a refractory inorganic oxide support and a Group VIII metal. The oxide support may also be referred to herein as a binder. The support of the hydrotreating catalyst may be prepared from or comprise alumina, silica, silica/alumina, titania, magnesia, zirconia, and the like, or combinations thereof. The catalyst support may comprise amorphous materials, crystalline materials, or combinations thereof. Examples of amorphous materials include, but are not limited to, amorphous alumina, amorphous silica, amorphous silica-alumina, and the like.

In an embodiment, the support may comprise amorphous alumina. When using a combination of silica and alumina, the distribution of silica and alumina in the support may be either homogeneous or heterogeneous. In some embodiments, the support may consist of an alumina gel in which is dispersed the silica, silica/alumina, or alumina base material. The support may also contain refractory materials other than alumina or silica, such as for example other inorganic oxides or clay particles, provided that such materials do not adversely affect the hydrogenation activity of the final catalyst or lead to deleterious cracking of the feedstock.

In a sub-embodiment, silica and/or alumina will generally comprise at least about 90 wt. % of the support of the hydrotreating catalyst, and in some embodiments the support may be at least substantially all silica or all alumina. Regardless of the type of support material in the hydrotreating catalyst, the hydrotreating catalyst used in processes and catalyst systems of the present invention will typically have low acidity. Where appropriate, the acidity of the support can be decreased by treatment with alkali and/or alkaline earth metal cations.

Various crystalline and non-crystalline catalyst support materials that may be used in practicing the present invention, as well as the quantification of their acidity levels and methods for neutralizing acid sites in the catalyst support, are described in co-pending, commonly assigned U.S. Patent Application Publication No. 2011/0079540, the disclosure of which is incorporated by reference herein in its entirety.

The Group VIII metal component(s) of the hydrotreating catalyst may comprise platinum, palladium, or combinations thereof. In an embodiment, the hydrotreating catalyst comprises platinum and palladium with a Pt:Pd ratio in the range from about 5:1 to about 1:5, typically from about 3:1 to about 1:3, and often from about 1:1 to about 1:2. The Group VIII metal content of the hydrotreating catalyst may generally be in the range from about 0.01 wt. % to about 5 wt. %, typically from about 0.2 wt. % to about 2 wt. %. In an embodiment, the hydrotreating catalyst may comprise platinum at a concentration in the range from about 0.1 to about 1.0 wt. %, and palladium at a concentration in the range from about 0.2 to about 1.5 wt. %. In a sub-embodiment, the hydrotreating catalyst may comprise about 0.3 wt. % platinum

and about 0.6 wt. % palladium. Hydrotreating catalysts of the present invention generally exhibit sulfur tolerance as well as high catalytic activity.

In an embodiment, the Group VIII metal of the hydrotreating catalyst may be dispersed on the inorganic oxide support. A number of methods are known in the art to deposit platinum and/or palladium metal, or compounds comprising platinum and/or palladium, onto the support; such methods include ion exchange, impregnation, and co-precipitation. In an embodiment, the impregnation of the support with platinum and/or palladium metal may be performed at a controlled pH value. The platinum and/or palladium is typically added to the impregnating solution as a metal salt, such as a halide salt, and/or an amine complex, and/or a salt of a mineral acid. Ammonium salts have been found to be particularly useful in preparing solutions for Group VIII metal impregnation. Other examples of metal salts that may be used include nitrates, carbonates, and bicarbonates, as well as carboxylic acid salts such as acetates, citrates, and formates.

Optionally, the impregnated support may be allowed to stand with the impregnating solution, e.g., for a period in the range from about 2 to about 24 hours. Following impregnation of the oxide support with the Group VIII metal, the impregnated support can be dried and/or calcined. After the hydrotreating catalyst has been dried and calcined, the prepared catalyst may be reduced with hydrogen, as is conventional in the art, and placed into service.

Hydroisomerization Catalysts

In an embodiment, processes of the present invention use a layered catalyst system comprising a first hydroisomerization catalyst and a second hydroisomerization catalyst, wherein the first hydroisomerization catalyst may be disposed upstream from the second hydroisomerization catalyst. In an embodiment, both of the first and second hydroisomerization catalysts may be selective for the isomerization of n-paraffins in the hydrocarbon feed. In an embodiment, the first and second hydroisomerization catalysts have different formulations. According to various embodiments of the present invention, the first and second hydroisomerization catalysts may have different levels of selectivity for the isomerization of n-paraffins in the hydrocarbon feed, or the first and second hydroisomerization catalysts may have at least substantially the same level of selectivity for the isomerization of n-paraffins.

Each of the first and second hydroisomerization catalysts may comprise a molecular sieve and a Group VIII metal. In an embodiment, the molecular sieve of each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may comprise a 1-D,

10-ring molecular sieve. The Group VIII metal of the first and second hydroisomerization catalysts may comprise platinum, palladium, or a combination thereof. In an embodiment, each of the first and second hydroisomerization catalysts may comprise from about 0.1 to about 1.5 wt. % of the Group VIII metal, typically from about 0.2 to about 1.0 wt. %, and usually from about 0.325 to about 1.0 wt. % of the Group VIII metal. In an embodiment, at least one of the first hydroisomerization catalyst and the second hydroisomerization catalyst may further comprise a metal modifier selected from the group consisting of Mg, Ca, Sr, Ba, K, La, Pr, Nd, Cr, and combinations thereof, substantially as described herein below.

Typically, each of the first and second hydroisomerization catalysts will still further comprise a support or binder. The support may comprise a refractory inorganic oxide. Suitable inorganic oxide supports for the hydroisomerization catalysts include silica, alumina, titania, magnesia, zirconia, silica-alumina, silica-magnesia, silica-titania, and the like, and combinations thereof. Each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may comprise from about 5 to about 95 wt. % or more of the molecular sieve component, typically from about 15 to about 85 wt. % of the molecular sieve, and usually from about 25 to about 75 wt. % of the molecular sieve. Generally, it is advantageous to minimize the molecular sieve component for economic reasons, provided that the catalyst retains the required activity and selectivity levels. Each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may comprise from about 0 to about 95 wt. % of the support material, and more typically from about 5 to about 90 wt. %.

In an exemplary catalyst system for dewaxing hydrocarbon feedstocks according to processes of the present invention, each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may comprise a 1-D, 10-ring molecular sieve and a Group VIII metal. The molecular sieve of at least one of the first hydroisomerization catalyst and the second hydroisomerization catalyst may comprise a medium pore zeolite, e.g., a zeolite having a pore aperture in the range from about 0.39 nm to about 0.7 nm. In an embodiment, each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may further comprise from about 0.325 wt. % to about 1 wt. % platinum.

Examples of molecular sieves that may be useful in formulating at least one of the first and second hydroisomerization catalysts include molecular sieves of the AEL framework type code, such as SAPO-11, SAPO-31, SM-3, SM-6; as well as zeolite type materials of the MTT or TON codes. Molecular sieves of the MTT code include ZSM-23, SSZ-32, EU-13, ISI-4, and KZ-1. Molecular sieves of the TON code that may be useful in practicing the

present invention include Theta-1, ISI-1, KZ-2, NU-10, and ZSM-22. The parameters of MTT and TON type molecular sieves are further described in the *Atlas of Zeolite Framework Types* which is published by the International Zeolite Association (IZA). In an embodiment, at least one of the first hydroisomerization catalyst and the second hydroisomerization catalyst contain zeolite SSZ-32. In a sub-embodiment, each of the first hydroisomerization catalyst and the second hydroisomerization catalyst contain SSZ-32. Processes of the present invention are not limited to any particular hydroisomerization catalyst formulations.

Metal Loading of Catalysts

In an embodiment, at least one of the first hydroisomerization catalyst and the second hydroisomerization catalyst may further comprise one or more metal modifier(s). In a sub-embodiment, both the first hydroisomerization catalyst and the second hydroisomerization catalyst may each comprise a metal modifier. Typically, the metal modifier(s) may be selected from the group consisting of Mg, Ca, Sr, Ba, K, La, Pr, Nd, Cr, and combinations thereof. In a sub-embodiment, the metal modifier may comprise Mg. As a non-limiting example, the first and second hydroisomerization catalysts may comprise a 1-D, 10-ring molecular sieve, such as SSZ-32; a Group VIII noble metal, such as platinum; and in some embodiments a metal modifier such as magnesium. In an embodiment, a metal-modified catalyst of the present invention may comprise from about 0.5 to about 3.5 wt. % of Mg or other metal modifier(s), typically from about 0.5 to about 2.5 wt. %, and usually from about 0.9 to about 2.5 wt. % of Mg or other metal modifier(s).

In formulating a catalyst or catalyst system for dewaxing processes of the present invention, a mixture of a molecular sieve and an oxide binder may be formed into a particle or extrudate having a wide range of physical shapes and dimensions. In an embodiment, the extrudate or particle may be dried and calcined prior to metal loading. Calcination may be performed at temperatures typically in the range from about 390°F to about 1100°F (199°C to 593°C) for periods of time ranging from about 0.5 to about 5 hours, or more. The calcined extrudate or formed particle may then be loaded with at least one metal modifier selected from the group consisting of Ca, Cr, Mg, La, Na, Pr, Sr, K, Nd, and combinations thereof. While not being bound by theory, such metals may effectively reduce the number of acid sites on the molecular sieve of the metal-modified hydroisomerization catalyst, thereby increasing the catalyst's selectivity for isomerization (versus cracking) of n-paraffins in the feed.

The loading of modifying metal(s) on the catalyst(s) may be accomplished by techniques known in the art, such as by impregnation or ion exchange. Ion exchange techniques typically involve contacting the extrudate or particle with a solution containing a salt of the desired metal cation(s). A variety of metal salts, such as halides, nitrates, and sulfates, may be used in this regard. Following contact with a salt solution of the desired metal cation(s), the extrudate or particle may be dried, e.g., at temperatures in the range from about 150°F to about 800°F (66°C to 427°C). The extrudate or particle may thereafter be further loaded with a Group VIII metal component of the catalyst.

In an embodiment, a molecular sieve or catalyst of the invention may be co-impregnated with a modifying metal and a Group VIII metal. After loading the Group VIII and modifying metals, the catalyst may be calcined in air or inert gas at temperatures in the range from about 500°F to about 900°F (260°C to 482°C). The preparation of molecular sieve catalysts comprising a metal modifier is disclosed in commonly assigned U.S. Patent No. 7,141,529 and in U.S. Patent Application Publication No. 2008/0083657, the disclosure of each of which is incorporated by reference herein in its entirety.

Dewaxing Catalyst Systems

According to an embodiment of the present invention, a dewaxing catalyst system **10** for the production of base oils from a hydrocarbon feedstock may be described with reference to FIG. 1, as follows. Catalyst system **10** may be a layered system comprising a plurality of hydroisomerization catalyst layers. In an embodiment, each of the layers of hydroisomerization catalyst may have a different formulation, activity, and/or n-paraffin isomerization selectivity. By “n-paraffin isomerization selectivity” is meant the propensity of a given catalyst to isomerize, as opposed to crack, n-paraffins in the feedstock.

Catalyst system **10** may include a hydrotreating zone or guard layer **12**, a first hydroisomerization zone **14**, and a second hydroisomerization zone **16**. Guard layer **12**, first hydroisomerization zone **14**, and second hydroisomerization zone **16** may contain, respectively, a hydrotreating catalyst **18**, a first hydroisomerization catalyst **20**, and a second hydroisomerization catalyst **22**. Guard layer **12** may be disposed upstream from first hydroisomerization catalyst **20**, and first hydroisomerization catalyst **20** may be disposed upstream from second hydroisomerization catalyst **22**. In an embodiment as shown in FIG. 1, guard layer **12**, first hydroisomerization zone **14**, and second hydroisomerization zone **16** may be housed within a single reactor **24**. Although the invention has been described with

reference to FIG. 1 as comprising two hydroisomerization zones and a guard layer, other numbers of zones and layers are also possible under the present invention.

A hydrocarbon feed **26** may be introduced into reactor **24** via a first conduit **28a**, while hydrogen gas may be introduced into reactor **24** via a second conduit **28b**. Within
5 reactor **24**, feed **26** may be contacted with hydrotreating catalyst **18** in the presence of hydrogen to provide a hydrotreated feedstock **30**. Hydrotreated feedstock **30** may be contacted with first hydroisomerization catalyst **20** under first hydroisomerization conditions in first hydroisomerization zone **14** to provide a first isomerization stream **32**. First
isomerization stream **32** may be contacted with second hydroisomerization catalyst **22** under
10 second hydroisomerization conditions in second hydroisomerization zone **16** to provide a second isomerization stream **34**.

Second isomerization stream **34** may be fed to a hydrofinishing unit (not shown) to provide a suitable quality and yield of the desired base oil product. The base oil product may have a pour point not higher than about -9°C, typically not higher than about -12°C, and
15 usually not higher than about -14°C. The base oil product may have a cloud point not higher than about -5°C, typically not higher than about -7°C, and usually not higher than about -12°C. The base oil product may have a pour-cloud spread of not more than about 7°C, typically not more than about 5°C, and usually not more than about 3°C. In an embodiment, the base oil product having the above properties may be obtained at a yield of at least about
20 89%.

In general, dewaxing catalysts having higher isomerization selectivity are favored for lube oil production, since catalysts with higher selectivity tend to provide higher base oil yields. However, a longstanding but heretofore unresolved problem in the art is the correlation between catalyst selectivity and cloud point of the oil product, namely a higher
25 cloud point of products obtained using catalysts of increased selectivity. This correlation between catalyst selectivity and cloud point is particularly pronounced for heavy feeds. The correlation between catalyst selectivity and cloud point can be seen, for example, in FIG. 3, which plots cloud point versus yield for i) a first dewaxing catalyst (A), ii) a second dewaxing catalyst (B), and iii) a layered catalyst system (A/B) comprising the first catalyst
30 upstream from the second catalyst. It can be seen from FIG. 3 that the first and second dewaxing catalysts gave similar yields at a given cloud point, indicating similar or substantially the same levels of isomerization selectivity for the first and second dewaxing catalysts. Therefore, it was unexpected that the layered catalyst system comprising a combination of the first and second dewaxing catalysts showed substantially higher

selectivity and about a 3% increase in yield at a given cloud point, as compared with either the first or second dewaxing catalyst alone.

In an embodiment, hydrotreating catalyst **18** may be a high activity catalyst capable of operating effectively at a relatively high hourly liquid space velocity (e.g., LHSV $>1\text{ h}^{-1}$) and at a temperature in the range from about 550°F to about 750°F (288°C to 399°C). The hydrotreating catalyst (guard layer) may occupy from about 3% to about 30% by volume of the total catalyst volume, i.e., the hydrotreating catalyst may comprise from about 3% to about 30% of the sum of the volume of the hydrotreating catalyst plus the volume of the first hydroisomerization catalyst plus the volume of the second hydroisomerization catalyst.

Typically, the hydrotreating catalyst may comprise from about 5% to about 20% of the total catalyst volume, and usually from about 5% to about 15% of the total catalyst volume.

In an embodiment, the ratio of the volume of the first hydroisomerization catalyst to the volume of the second hydroisomerization catalyst may be in the range from about 7:3 to about 3:7, typically from about 3:2 to about 2:3, and usually from about 5:4 to about 4:5. In a sub-embodiment, the ratio of the volume of the first hydroisomerization catalyst to the volume of the second hydroisomerization catalyst may be about 1:1.

Feed for Base Oil Production

The instant invention may be used to dewax a wide variety of hydrocarbon feedstocks, including whole crude petroleum, reduced crudes, vacuum tower residua, cycle oils, synthetic crudes, gas oils, vacuum gas oils, foots oils, Fischer-Tropsch derived waxes, and the like. In an embodiment, the hydrocarbon feedstocks can be described as waxy feeds having pour points generally above about 0°C, and having a tendency to solidify, precipitate, or otherwise form solid particulates upon cooling to about 0°C. Straight chain n-paraffins, either alone or with only slightly branched chain paraffins, having 16 or more carbon atoms may be referred to herein as waxes. The feedstock will usually be a C₁₀₊ feedstock generally boiling above about 350°F (177°C).

The present invention may also be suitable for processing waxy distillate stocks such as middle distillate stocks including gas oils, kerosenes, and jet fuels, lubricating oil stocks, heating oils, and other distillate fractions whose pour point and viscosity need to be maintained within certain specification limits.

Feedstocks for processes of the present invention may typically include olefin and naphthene components, as well as aromatic and heterocyclic compounds, in addition to higher

molecular weight n-paraffins and slightly branched paraffins. During processes of the present invention, the degree of cracking of n-paraffins and slightly branched paraffins in the feed is strictly limited so that the product yield loss is minimized, thereby preserving the economic value of the feedstock.

5 Typical feedstocks include hydrotreated or hydrocracked gas oils, hydrotreated lube oil raffinates, brightstocks, lubricating oil stocks, synthetic oils, foots oils, Fischer-Tropsch synthesis oils, high pour point polyolefins, normal alphaolefin waxes, slack waxes, deoiled waxes and microcrystalline waxes. Other hydrocarbon feedstocks suitable for use in processes of the present invention may be selected, for example, from gas oils and vacuum gas oils;
10 residuum fractions from an atmospheric pressure distillation process; solvent-deasphalted petroleum residua; shale oils, cycle oils; animal and vegetable derived fats, oils and waxes; petroleum and slack wax; and waxes produced in chemical plant processes.

 In an embodiment, the feedstock may comprise a heavy feed. Herein, the term "heavy feed" may be used to refer to a hydrocarbon feedstock wherein at least about 80% of the
15 components have a boiling point above about 900°F (482°C). Examples of heavy feeds suitable for practicing the present invention include heavy neutral (600N) and bright stock.

 In an embodiment, the hydrocarbon feedstocks of the present invention may generally have a pour point above 0°C, and in some embodiments above about 20°C. In contrast, the base oil products of processes of the present invention, resulting from hydroisomerization dewaxing
20 of the feedstock, generally have pour points below 0°C, typically below about -12°C, and often below about -14°C.

 In an embodiment, the feedstock employed in processes of the present invention can be a waxy feed which contains more than about 20% wax, more than about 50% wax, or even greater than about 70% wax. More typically, the feed will contain from about 5% to about 30%
25 wax. As used herein, the term "waxy hydrocarbon feedstocks" may include plant waxes and animal derived waxes in addition to petroleum derived waxes.

 According to one aspect of the present invention, a wide range of feeds may be used to produce lubricant base oils in high yield with good performance characteristics, including low pour point, low cloud point, low pour-cloud spread, and high viscosity index. The quality and
30 yield of the lube base oil product of the instant invention may depend on a number of factors, including the formulation of the hydroisomerization catalysts comprising the layered catalyst systems and the configuration of the catalyst layers of the catalyst systems.

 In an embodiment, the present invention may provide base oil production, e.g., from a heavy feed, using a layered catalyst system. The layered catalyst system may comprise first

and second hydroisomerization catalysts, wherein the first hydroisomerization is disposed upstream from the second hydroisomerization catalyst. The first hydroisomerization catalyst may have a first level of selectivity for the isomerization of n-paraffins, the second hydroisomerization catalyst may have a second level of selectivity for the isomerization of n-paraffins. In an embodiment, the first and second levels of selectivity may be the same or at least substantially the same. Applicants have now discovered that the layered catalyst system may have a third level of selectivity for the isomerization of n-paraffins, wherein the third level of selectivity is higher than each of the first level of selectivity and the second level of selectivity. Therefore, a layered catalyst system according to the present invention may provide superior results as compared with conventional dewaxing processes and catalysts. As an example, FIG. 3 shows that the first and second dewaxing catalysts alone gave similar yields at a given cloud point, indicating similar or substantially the same levels of isomerization selectivity for the first and second dewaxing catalysts. Therefore, it was unexpected that the layered catalyst system comprising a combination of the first and second dewaxing catalysts showed substantially higher selectivity and about a 3% increase in yield at a given pour point, as compared with either the first or second dewaxing catalysts alone.

Dewaxing Processes

According to one embodiment of the present invention a catalytic dewaxing process for the production of base oils from a heavy hydrocarbon feedstock may involve introducing the feed into a reactor containing a dewaxing catalyst system. Hydrogen gas may also be introduced into the reactor so that the process may be performed in the presence of hydrogen, e.g., as described herein below with reference to the process conditions.

Within the reactor, the feed may be contacted with a hydrotreating catalyst under hydrotreating conditions in a hydrotreating zone or guard layer to provide a hydrotreated feedstock. Contacting the feedstock with the hydrotreating catalyst in the guard layer may serve to effectively hydrogenate aromatics in the feedstock, and to remove N- and S-containing compounds from the feed, thereby protecting the first and second hydroisomerization catalysts of the catalyst system. By “effectively hydrogenate aromatics” is meant that the hydrotreating catalyst is able to decrease the aromatic content of the feedstock by at least about 20%. The hydrotreated feedstock may generally comprise C₁₀₊ n-paraffins and slightly branched isoparaffins, with a wax content of typically at least about 20%.

The hydrotreated feedstock may be contacted with the first hydroisomerization catalyst under first hydroisomerization dewaxing conditions in a first hydroisomerization zone to provide a first isomerization stream. Thereafter, the first isomerization stream may be contacted with the second hydroisomerization catalyst under second hydroisomerization dewaxing conditions in a second hydroisomerization zone to provide a second isomerization stream. The guard layer, the first hydroisomerization catalyst, and the second hydroisomerization catalyst may all be disposed within a single reactor. The hydrotreating and hydroisomerization conditions that may be used for catalytic dewaxing processes of the present invention are described herein below.

The second isomerization stream may be fed to a hydrofinishing unit to provide a suitable quality and yield of the desired base oil product. Such a hydrofinishing step, may remove traces of any aromatics, olefins, color bodies, and the like from the base oil product. The hydrofinishing unit may include a hydrofinishing catalyst comprising an alumina support and a noble metal, typically palladium, or platinum in combination with palladium. In an embodiment, the noble metal content of the hydrofinishing catalyst may typically be in the range from about 0.1 to about 1.0 wt. %, usually from about 0.1 to about 0.6 wt. %, and often from about 0.2 to about 0.5 wt. %.

Each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may comprise a 1-D, 10-ring molecular sieve and a Group VIII metal, e.g., substantially as described herein above under "Hydroisomerization Catalysts." Each of the first hydroisomerization catalyst and the second hydroisomerization catalyst may be selective for the isomerization of n-paraffins in the feedstock, such that feedstock components are preferentially isomerized rather than cracked.

FIG. 2A schematically represents a first catalytic dewaxing system **10A** disposed in a reactor **24**, wherein dewaxing system **10A** may consist essentially of a first hydroisomerization catalyst **120**. FIG. 2B schematically represents a second catalytic dewaxing system **10B** disposed in a reactor **24**, wherein dewaxing system **10B** may consist essentially of a second hydroisomerization catalyst **122**. First hydroisomerization catalyst **120** and second hydroisomerization catalyst **122** may have, respectively, first and second levels of selectivity for the isomerization of n-paraffins. In an embodiment, the first and second levels of selectivity may be similar or at least substantially the same. Systems **10A** and **10B** may provide a dewaxed product **A** and a dewaxed product **B**, respectively, by dewaxing a hydrocarbon feed in the presence of hydrogen, wherein the yield of products **A** and **B** may be

at least substantially the same. The hydrocarbon feed may be a heavy feed. Optionally, systems **10A** and **10B** may include a guard layer.

FIG. 2C schematically represents a layered dewaxing catalyst system **10C**, according to an embodiment of the present invention. Catalyst system **10C** may comprise first hydroisomerization catalyst **120** disposed upstream from second hydroisomerization catalyst **122**. In an embodiment, catalyst system **10C** has a third level of selectivity for the isomerization of n-paraffins, wherein the third level of selectivity is higher than each of the first level of selectivity of catalyst **120** and the second level of selectivity of catalyst **122**. As a result, system **10C** may provide a dewaxed product **C** at a significantly higher yield, for a given cloud point, as compared with the yield of either product **A** or product **B**. In an embodiment, layered dewaxing system **10C** may include a guard layer disposed upstream from first hydroisomerization catalyst **120** (see, for example, FIG. 1).

Thus, according to an embodiment of the present invention, applicants have found that the combination of first and second hydroisomerization catalysts **120** and **122** (see, e.g., FIG. 2C) can provide superior results, as compared with the same volume of either first hydroisomerization catalyst **120** alone or second hydroisomerization catalyst **122** alone. Such superior results may be manifest not only as increased product yield but also improved product qualities.

Reaction Conditions

The conditions under which processes of the present invention are carried out will generally include a temperature within a range from about 390°F to about 800°F (199°C to 427°C). In an embodiment, each of the first and second hydroisomerization dewaxing conditions includes a temperature in the range from about 550°F to about 700°F (288°C to 371°C). In a further embodiment, the temperature may be in the range from about 590°F to about 675°F (310°C to 357°C). The pressure may be in the range from about 15 to about 3000 psig (0.10 to 20.68 MPa), and typically in the range from about 100 to about 2500 psig (0.69 to 17.24 MPa).

Typically, the feed rate to the catalyst system/reactor during dewaxing processes of the present invention may be in the range from about 0.1 to about 20 h⁻¹ LHSV, and usually from about 0.1 to about 5 h⁻¹ LHSV. Generally, dewaxing processes of the present invention are performed in the presence of hydrogen. Typically, the hydrogen to hydrocarbon ratio may be

in a range from about 2000 to about 10,000 standard cubic feet H₂ per barrel hydrocarbon, and usually from about 2500 to about 5000 standard cubic feet H₂ per barrel hydrocarbon.

The above conditions may apply to the hydrotreating conditions of the hydrotreating zone as well as to the hydroisomerization conditions of the first and second

5 hydroisomerization zones (see, for example, FIG. 1). The reactor temperature and other process parameters may vary according to factors such as the nature of the hydrocarbon feedstock used and the desired characteristics (e.g., pour point, cloud point, VI) and yield of the base oil product.

The hydrotreating catalyst may be disposed upstream from the hydroisomerization
10 catalysts and in the same reactor as the hydroisomerization catalysts. In an embodiment, a temperature difference may exist between the first and second hydroisomerization zones. For example, the first hydroisomerization zone may be at a first temperature and the second hydroisomerization zone may be at a second temperature, wherein the second temperature may be from about 20°F to about 60°F higher than the first temperature, more typically from about
15 30°F to about 50°F higher, and usually from about 35°F to about 45°F higher than the first temperature.

The effluent or stream from a catalyst system of the present invention, e.g., the second hydroisomerization stream from the second hydroisomerization zone, may be further treated by hydrofinishing. Such hydrofinishing may be performed in the presence of a hydrogenation
20 catalyst, as is known in the art. The hydrogenation catalyst used for hydrofinishing may comprise, for example, platinum, palladium, or a combination thereof on an alumina support. The hydrofinishing may be performed at a temperature in the range from about 400°F to about 650°F (204°C to 343°C), and a pressure in the range from about 400 psig to about 4000 psig (2.76 to 27.58 MPa). Hydrofinishing for the production of lubricating oils is described, for
25 example, in U.S. Patent No. 3,852,207, the disclosure of which is incorporated by reference herein.

Base Oil Product

30 In an embodiment, processes of the invention provide a high value, high quality lubricant oil in good yield from a low value waxy hydrocarbon feedstock. The lubricant oils of the present invention will typically have a pour point less than about -9°C, usually less than about -12°C, and often less than about -14°C, e.g., as measured by ASTM D97. In an embodiment, the lubricant oil product may have a pour point in the range from about -10°C to

about -30°C. The products of the present invention will generally have viscosities in the range of 3 to 30 cSt at 100°C, and a VI in the range from about 95 to about 170 as measured by ASTM D445.

As noted herein above, the dewaxed second hydroisomerization stream (FIG. 1) may be further hydrotreated, for example, over one or more hydrofinishing catalysts to obtain a final lubricant oil product having the desired characteristics. As an example, at least a portion of the second hydroisomerization stream may be hydrofinished to remove any colored materials and/or to hydrogenate any aromatic species in order to meet the desired lubricant oil specifications and/or to improve the stability of the base oil product.

The following Examples illustrate but do not limit the present invention.

EXAMPLES

Example 1

Preparation of Dewaxing Catalysts

Hydroisomerization catalyst A was prepared as follows. Zeolite SSZ-32 was composited with alumina to provide a mixture containing 75 wt. % zeolite, and the mixture was extruded, dried, and calcined. The dried and calcined extrudate was impregnated with a solution containing both platinum and magnesium, and the co-impregnated catalyst was then dried and calcined. The overall platinum loading was 1 wt. %, and the magnesium loading was 0.9 wt. %.

Hydroisomerization catalyst B was prepared generally as described for catalyst A, except the mixture contained 65 wt. % zeolite. The dried and calcined extrudate was co-impregnated with platinum and magnesium to give a platinum loading of 0.325 wt. % and a magnesium loading of 0.9 wt. %.

A layered hydroisomerization dewaxing catalyst system A/B was prepared by combining a layer of catalyst A with an equal volume of a layer of catalyst B, such that catalyst A was the upper layer, i.e., catalyst A was disposed upstream from catalyst B.

Catalysts A alone, catalyst B alone, as well as catalyst system A/B were each used for dewaxing a heavy hydrocarbon feed, as described in Example 2.

Example 2

Comparative Catalytic Dewaxing of Heavy Feed

The layered catalyst system A/B was compared with an equal volume of catalyst A alone and catalyst B alone in dewaxing a waxy heavy hydrocrackate (600N) feed using a down-flow reactor under isothermal conditions. A previous generation dewaxing catalyst C (SSZ-32 loaded with 0.325 wt. % Pt and prepared without a modifier metal, e.g., Mg) was also tested (as base case) using the same feed and process conditions. The reactors for catalysts A and C contained 100% catalyst A and 100% catalyst C, respectively; the reactor for catalyst B contained 91 vol. % of catalyst B downstream from 9 vol. % guard layer; and the reactor for catalyst system A/B contained 45 vol. % of catalyst B downstream from 46 vol. % of catalyst A and 9 vol. % guard layer. The guard layer in each case comprised alumina loaded with 0.3 wt. % Pt and 0.6 wt. % Pd.

FIG. 3 shows the yield of 800°F+ lube oil versus the cloud point obtained using the layered catalyst system A/B (catalyst A + catalyst B) and catalysts A, B, and C alone. The yield/cloud point data was generated by changing the operating temperature of the dewaxing catalyst; for example, a lower cloud point is generally achieved by increasing the catalyst temperature. It can be seen from Fig. 3 that the layered catalyst system A/B, unexpectedly gave an approximately 3% increase in yield as compared with the same volume of either catalyst A alone or catalyst B alone. This result was particularly unexpected in light of the substantially similar selectivities shown by catalysts A and B alone (see, e.g., FIG. 3).

Thus, according to one aspect of the present invention, a less expensive catalyst (e.g., having a lower concentration of molecular sieve and/or a lower concentration of Group VIII noble metal) may be combined with a more expensive catalyst to form a catalyst system that provides better performance at a lower cost, as compared with the same amount of the more expensive catalyst alone.

Numerous variations of the present invention may be possible in light of the teachings and examples herein. It is therefore understood that within the scope of the following claims, the invention may be practiced otherwise than as specifically described or exemplified herein.

CLAIMS:

1. A process for catalytically dewaxing a waxy hydrocarbon feedstock, comprising:
 - a) contacting the hydrocarbon feedstock in a first hydroisomerization zone under first hydroisomerization dewaxing conditions with a first hydroisomerization catalyst to provide a first isomerization stream; and
 - b) contacting at least a portion of the first isomerization stream in a second hydroisomerization zone under second hydroisomerization dewaxing conditions with a second hydroisomerization catalyst to provide a second isomerization stream;wherein each of the first hydroisomerization catalyst and the second hydroisomerization catalyst comprises a molecular sieve and a Group VIII metal, each of the first hydroisomerization catalyst and the second hydroisomerization catalyst is selective for isomerization of n-paraffins in the feedstock;wherein the first hydroisomerization zone and the second hydroisomerization zone are disposed within the same reactor; andwherein each of the first hydroisomerization catalyst and the second hydroisomerization catalyst is doped with a metal modifier selected from the group consisting of Mg, Ca, Sr, Ba, K, La, Pr, Nd, Cr, and combinations thereof.
2. The process according to claim 1, wherein the molecular sieve of each of the first hydroisomerization catalyst and the second hydroisomerization catalyst comprises a 1-D, 10-ring molecular sieve, and wherein the first hydroisomerization catalyst has a higher concentration of the molecular sieve than the second hydroisomerization catalyst.
3. The process according to claim 2, wherein the first hydroisomerization catalyst has a higher concentration of the Group VIII metal than the second hydroisomerization catalyst, and wherein the Group VIII metal of each of the first hydroisomerization catalyst and the second hydroisomerization catalyst comprises Pt.
4. The process according to claim 1, wherein the molecular sieve of each of the first hydroisomerization catalyst and the second hydroisomerization catalyst comprises zeolite SSZ-32.

5. The process according to claim 1, wherein the first and second hydroisomerization catalysts comprise a layered catalyst system, the first hydroisomerization catalyst is disposed upstream from the second hydroisomerization catalyst, the first hydroisomerization catalyst has a first level of selectivity for the isomerization of n-paraffins, the second
- 5 hydroisomerization catalyst has a second level of selectivity for the isomerization of n-paraffins, the layered catalyst system has a third level of selectivity for the isomerization of n-paraffins, and wherein the third level of selectivity is higher than each of the first level of selectivity and the second level of selectivity.
- 10 6. The process according to claim 5, wherein the first level of selectivity is at least substantially the same as the second level of selectivity.
7. The process according to claim 1, wherein the metal modifier comprises Mg at a concentration in the range from about 0.5 to about 2.5 wt. %.
- 15 8. The process according to claim 1, further comprising:
c) prior to step a), contacting the hydrocarbon feedstock in a hydrotreating zone under hydrotreating conditions with a hydrotreating catalyst, wherein the hydrotreating zone comprises a guard layer, the hydrotreating catalyst comprises a refractory inorganic oxide in combination with Pt, Pd, or a combination thereof; and wherein the guard layer, the first
- 20 hydroisomerization zone, and the second hydroisomerization zone are disposed within a single reactor.
9. The process according to claim 8, wherein the hydrotreating catalyst occupies a
- 25 volume in the range from about 3% to about 30% of the total volume of the hydrotreating catalyst, the first hydroisomerization catalyst, and the second hydroisomerization catalyst.
10. The process according to claim 1, wherein the ratio of the volume of the first hydroisomerization catalyst to the volume of the second hydroisomerization catalyst is in the
- 30 range from about 3:2 to about 2:3.
11. The process according to claim 1, wherein each of the first and second hydroisomerization dewaxing conditions includes a temperature in the range from about 550°F to about 700°F (288°C to 371°C).

12. The process according to claim 1, further comprising:

d) contacting the second isomerization stream with a hydrofinishing catalyst to provide a base oil product having a pour point of not more than about -12°C, and a pour-cloud spread of not more than about 5°C.

13. The process according to claim 12, wherein the base oil product is obtained at a yield of at least about 87%.

14. The process according to claim 13, wherein at least about 80% of the feedstock components have a boiling point above about 900°F (482°C).

15. A process for catalytically dewaxing a heavy hydrocarbon feedstock, comprising:

a) contacting the hydrocarbon feedstock in a first hydroisomerization zone under first hydroisomerization dewaxing conditions with a first hydroisomerization catalyst to provide a first isomerization stream;

b) contacting at least a portion of the first isomerization stream in a second hydroisomerization zone under second hydroisomerization dewaxing conditions with a second hydroisomerization catalyst to provide a second isomerization stream, wherein each of the first hydroisomerization catalyst and the second hydroisomerization catalyst comprises a 1-D, 10-ring molecular sieve and a Group VIII metal, each of the first hydroisomerization catalyst and the second hydroisomerization catalyst is doped with a metal modifier selected from the group consisting of Mg, Ca, Sr, Ba, K, La, Pr, Nd, Cr, and combinations thereof; and wherein the first and second hydroisomerization catalysts are disposed in the same reactor; and

c) contacting the second isomerization stream with a hydrofinishing catalyst to provide a base oil product having a pour point of not more than about -12°C and a pour-cloud spread of not more than about 5°C.

16. The process according to claim 15, wherein the molecular sieve of each of the first and second hydroisomerization catalysts comprises zeolite SSZ-32, the Group VIII metal of each of the first and second hydroisomerization catalysts comprises Pt, the first hydroisomerization catalyst has a higher concentration of SSZ-32 than the second

hydroisomerization catalyst, and wherein the first hydroisomerization catalyst has a higher Pt concentration than the second hydroisomerization catalyst.

17. The process according to claim 15, wherein the first and second hydroisomerization catalysts comprise a layered catalyst system, the first hydroisomerization catalyst has a first level of selectivity for the isomerization of n-paraffins, the second hydroisomerization catalyst has a second level of selectivity for the isomerization of n-paraffins, the layered catalyst system has a third level of selectivity for the isomerization of n-paraffins, and wherein the third level of selectivity is higher than each of the first level of selectivity and the second level of selectivity.

18. A layered catalyst system, comprising:
a first hydroisomerization zone comprising a first hydroisomerization catalyst; and
a second hydroisomerization zone comprising a second hydroisomerization catalyst,
wherein each of the first hydroisomerization catalyst and the second hydroisomerization catalyst comprises a 1-D, 10-ring molecular sieve and a Group VIII metal, wherein the first hydroisomerization catalyst has a first level of selectivity for the isomerization of n-paraffins, the second hydroisomerization catalyst has a second level of selectivity for the isomerization of n-paraffins, the layered catalyst system has a third level of selectivity for the isomerization of n-paraffins, and wherein the third level of selectivity is higher than each of the first level of selectivity and the second level of selectivity.

19. The layered catalyst system according to claim 18, wherein:
the first hydroisomerization catalyst has a higher concentration of the molecular sieve than the second hydroisomerization catalyst,
the first hydroisomerization catalyst has a higher concentration of the Group VIII metal than the second hydroisomerization catalyst,
each of the first hydroisomerization catalyst and the second hydroisomerization catalyst further comprises a metal modifier selected from the group consisting of Mg, Ca, Sr, Ba, K, La, Pr, Nd, Cr, and combinations thereof, and wherein
the first hydroisomerization catalyst and the second hydroisomerization catalyst are disposed within a single reactor.

20. The layered catalyst system according to claim 18, wherein:

the molecular sieve of each of the first hydroisomerization catalyst and the second hydroisomerization catalyst comprises zeolite SSZ-32,

the Group VIII metal of each of the first hydroisomerization catalyst and the second hydroisomerization catalyst comprises Pt, and wherein

5 the ratio of the volume of the first hydroisomerization catalyst to the volume of the second hydroisomerization catalyst is in the range from about 3:2 to about 2:3.