

**BASE OIL PRODUCTION USING UNCONVERTED OIL****CROSS REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims the benefit of priority to U.S. Provisional Appl. Ser. Nos. 63/138,940, filed on January 19, 2021 and 63/138,779, filed on January 18, 2021, the disclosures of which are herein incorporated in their entirety.

**TECHNICAL FIELD**

[0002] The present disclosure concerns methods and systems for producing base oil products, methods of modifying base oil product manufacturing processes and systems, base oil products, lubricants, and associated uses.

**BACKGROUND**

[0003] Base oils find application as base stocks for the manufacture of lubricants. The American Petroleum Institute (API) categorises base oils into five Grades I-V. API Grades I-III concern base oils refined from crude petroleum and are distinguished by sulfur content, saturate level and viscosity index (VI), while Grades IV and V relate to synthetic base oils or base oils obtained from other sources (e.g. silicone). While Grade I and Grade II base oils require a VI between 80 and 120, a base oil refined from petroleum must achieve a VI greater than 120 to qualify as a Grade III base oil.

[0004] Grade I to III base oils are produced by refining crude petroleum. Grade I base oils are the least refined type and can be produced by solvent-refining or hydrotreating crude oil distillates. Grade II base oils are typically produced by hydrocracking distillates and are therefore more refined than Grade I base oils. Grade III base oils, which are the most refined, have typically undergone substantial hydrocracking, hydroisomerization and/or hydrotreating processes. Dewaxing, either by physical or chemical processes, is typically necessary to reduce the wax content for all of Grades I-III.

[0005] Due to the high values of VI required, high-quality feedstocks (such as straight-run vacuum gas oils obtained from light or medium crudes) are typically used in the production of Group III base oils. The production of Group III base oils from lower-quality, heavier feedstocks (including, for example, upgraded bottoms fractions (such as heavy coker gas oils) or obtained from heavier crudes) is desirable. However, it can be difficult to achieve the necessary VI for qualification as a Grade III base oil when starting with such lower-quality, heavier feedstocks. In general, improved methods and systems for increasing the VI of base oils produced from any type of feedstock would be desirable.

**SUMMARY**

[0006] According to a first aspect, there is provided a method of producing a base oil product. The method comprises: hydroprocessing unconverted oil from a hydrocracker to produce upgraded unconverted oil; and dewaxing the upgraded unconverted oil to produce the base oil product.

[0007] It will be appreciated that hydrocracking generally involves contacting a hydrocarbonaceous feedstock with a hydrocracking catalyst in the presence of hydrogen, resulting in cracking and hydrogenation of longer hydrocarbon molecules and the production of smaller hydrocarbon molecules. Hydrocracking of hydrocarbonaceous feedstocks such as gas oils (e.g. vacuum gas oils (VGOs), atmospheric gas oils, coker gas oils such as heavy coker gas oils (HCGOs), visbreaker gas oils), demetallized oils, vacuum residua, atmospheric residua, deasphalted oils, Fischer-Tropsch streams and/or FCC streams, typically produces a hydrocracked effluent including, for example, impurity products (e.g. hydrogen sulfide (H<sub>2</sub>S) and ammonia (NH<sub>3</sub>)), light ends (such as refinery gas, propane, butane and naphtha), middle distillate products (e.g. jet, kerosene and diesel) and unconverted oil (UCO). Unconverted oil is therefore the portion of the hydrocracker effluent remaining when impurity products, light ends and middle distillates have been removed. Unconverted oil typically has a boiling point range from about 662 °F to about 1112 °F (i.e., from about 350 °C to about 600 °C). Unconverted oil can be separated from other components of hydrocracker effluent by fractional distillation.

[0008] The method comprises hydroprocessing unconverted oil from a hydrocracker to produce upgraded unconverted oil. An input to the method may therefore be unconverted oil from a hydrocracker. That is to say, the method of the first aspect may comprise: providing or obtaining unconverted oil from a hydrocracker; and hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil. The method may therefore be carried out independently of the hydrocracking, for example, in a location which is different (e.g. in a different plant) from where the hydrocracker is situated.

[0009] Alternatively, the method of the first aspect may include a hydrocracking step. For example, the method may comprise, prior to hydroprocessing the unconverted oil from the hydrocracker: hydrocracking a hydrocarbonaceous feedstock in the hydrocracker to produce a hydrocracked effluent comprising the unconverted oil; and separating the unconverted oil from the hydrocracked effluent (for example, by fractional distillation). Hydrocracking and hydroprocessing may therefore take place in the same location (e.g. in the same plant). The hydrocarbonaceous feedstock may have a boiling point in the range from about 572 °F to about 1112 °F (i.e., about 300 °C to about 600 °C). The hydrocarbonaceous feedstock may comprise gas oils (e.g. vacuum gas oils (VGOs), atmospheric gas oils, coker gas oils such as heavy coker gas oils (HCGOs), visbreaker gas oils), demetallized oils, vacuum residua, atmospheric residua, deasphalted oils, Fischer-Tropsch streams and/or FCC streams. In some examples, the hydrocarbonaceous feedstock comprises a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO).

[0010] Hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil may comprise increasing the viscosity index (VI) of the unconverted oil. It will be appreciated that the viscosity index of a fluid is a measure of the tendency of the fluid's viscosity to

change as a function of temperature. The viscosity index of a fluid can be measured by the method set out in standard ASTM D-2270, which is hereby incorporated by reference in its entirety. According to ASTM D-2270, the viscosity index is calculated based on the kinematic viscosity of the fluid as measured at 40 °C (i.e., 104 °F) and at 100 °C (i.e., 212 °F). The viscosity index obtained by this method is a unitless value. A higher viscosity index indicates a smaller decrease in kinematic viscosity with increasing temperature. Accordingly, hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil typically reduces the tendency for the kinematic viscosity of the upgraded oil to decrease as a function of increasing temperature. The inventors have found that, by increasing the VI of the unconverted oil prior to dewaxing, the method enables base oil products meeting the requirements for classification as Grade II or Grade III base oils to be produced from lower-quality, heavier feedstocks such as upgraded bottoms fractions (e.g. HCGOs) or obtained from heavier crudes.

[0011] Hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil may comprise contacting the unconverted oil with a hydroprocessing catalyst in the presence of hydrogen under hydroprocessing conditions. The hydroprocessing catalyst and/or the hydroprocessing conditions may be selected such that VI-increasing molecular transformations predominate in the hydroprocessing. It will be appreciated that VI-increasing molecular transformations are molecular transformations which tend to increase the viscosity index of the unconverted oil. Examples of VI-increasing molecular transformations include hydroisomerization and hydrogenation. Hydroisomerization transformations may increase hydrocarbon branching, for example converting normal paraffins (i.e., normal alkanes) into iso-paraffins (i.e., branched alkanes). Additionally, or alternatively, hydroisomerization transformations may include ring-opening molecular transformations, for example converting naphthenes (i.e., cycloalkanes) into paraffins (i.e., linear alkanes). Hydrogenation transformations may include saturating aromatic and/or olefinic (i.e., alkene) hydrocarbons.

[0012] The hydroprocessing catalyst typically comprises: (a) one or more metals selected from Groups VI and VIII to X of the Periodic Table of Elements and/or one or more compounds (for example, one or more oxides or sulfides) thereof; and (b) a catalyst support (for example, a porous refractory support, such as an alumina, a silica, an amorphous silica-alumina material, or a combination thereof). The hydroprocessing catalyst may optionally further comprise: (c) one or more molecular sieves (for example, one or more zeolites).

[0013] For the avoidance of doubt, Group VI of the Periodic Table of Elements comprises chromium (Cr), molybdenum (Mo), tungsten (W) and seaborgium (Sg). Group VII of the Periodic Table of Elements comprises manganese (Mn), technetium (Tc), rhenium (Re) and bohrium (Bh). Group VIII of the Periodic Table of Elements comprises iron (Fe), ruthenium (Ru), osmium (Os) and hassium (Hs). Group IX of the Periodic Table of Elements comprises cobalt (Co), rhodium (Rh), iridium (Ir) and meitnerium (Mt).

Group X of the Periodic Table of Elements comprises nickel (Ni), palladium (Pd), platinum (Pt) and darmstadtium (Ds).

[0014] The hydroprocessing catalyst may be provided in the form of catalyst extrudates and/or formed particles. The catalyst extrudates and/or formed particles may have diameters from about 0.5 mm to about 5 mm, for example, from about 1 mm to about 3 mm, or from about 1 mm to about 2 mm. The catalyst extrudates and/or formed particles may have length/diameter ratios of from about 1 to about 5, for example, from about 1 to about 4, or from about 2 to about 5, or from about 2 to about 4, or from about 2 to about 3. The catalyst extrudates and/or formed particles may be combined with interstitial packing material, for example, glass beads.

[0015] The hydroprocessing catalyst may be a hydrotreating catalyst, a hydrocracking catalyst and/or a hydroisomerizing catalyst.

[0016] For example, the hydroprocessing catalyst may be a hydrotreating catalyst comprising: (a) one or more metals selected from Groups VI and VIII to X and/or one or more compounds (for example, one or more oxides or sulfides) thereof; and (b) a catalyst support (for example, a porous refractory support, such as an alumina, a silica, an amorphous silica-alumina material, or a combination thereof). Examples of hydrotreating catalysts include alumina supported cobalt-molybdenum, nickel sulphide, nickel-tungsten, cobalt-tungsten and nickel-molybdenum. The hydrotreating catalyst may be presulfided.

[0017] Alternatively, the hydroprocessing catalyst may be a hydrocracking catalyst comprising: (a) one or more metals selected from Groups VI and VIII to X and/or one or more compounds (for example, one or more oxides or sulfides) thereof; (b) a catalyst support (for example, a porous refractory support, such as an alumina, a silica, an amorphous silica-alumina material, or a combination thereof); and (c) one or more molecular sieves (for example, one or more zeolites). The hydrocracking catalyst is typically a bifunctional catalyst. The one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof may be selected from the group consisting of iron, chromium, molybdenum, tungsten, cobalt, nickel, platinum and palladium, and sulphides or oxides thereof. The one or more molecular sieves may be one or more zeolites selected from Y-type (e.g. SY, USY and VUSY), REX, REY, beta and/or ZSM-5 zeolites. The hydrocracking catalyst may comprise one or more promoters, for example, selected from phosphorous, boron, fluorine, silicon, aluminium, zinc, manganese, and mixtures thereof. A balance between the hydrocracking catalyst's cracking function and hydrogenation function can be adjusted to optimize activity and selectivity.

[0018] Further alternatively, the hydroprocessing catalyst may be a hydroisomerization catalyst comprising: (a) one or more metals selected from Groups VI and VIII to X and/or one or more compounds (for example, one or more oxides or sulfides) thereof; (b) a catalyst support (for example, a porous refractory support, such as an alumina, a silica, an amorphous silica-alumina material, or a

combination thereof); and (c) one or more molecular sieves (for example, one or more zeolites). The hydroisomerization catalyst is typically a bifunctional catalyst. The one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof may be selected from the group consisting of iron, chromium, molybdenum, tungsten, cobalt, nickel, platinum and palladium, and sulphides or oxides thereof. The one or more molecular sieves may be one or more zeolites selected from MFI, MEL, TON, MTT, \*MRE, FER, AEL, EUO-type, SSZ-32, small crystal SSZ-32, ZSM-23, ZSM-48, MCM-22, ZSM-5, ZSM-12, ZSM-22, ZSM-35 and MCM-68-type zeolites, and/or zeolites having \*MRE and/or MTT framework topologies. The hydroisomerization catalyst may comprise one or more promoters, for example, selected from magnesium, calcium, strontium, barium, potassium, lanthanum, praseodymium, neodymium, chromium, and mixtures thereof.

[0019] Hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil may comprise contacting the unconverted oil with two or more (i.e., different) hydroprocessing catalysts in the presence of hydrogen under hydroprocessing conditions. The two or more hydroprocessing catalysts may be of the same general type (for example, two or more hydrotreating catalysts, two or more hydrocracking catalysts, or two or more hydroisomerization catalysts). Alternatively, the two or more hydroprocessing catalysts may be of different general types (for example, combining (i) one or more hydrotreating catalysts and one or more hydrocracking catalysts, (ii) one or more hydrocracking catalysts and one or more hydroisomerization catalysts, (iii) one or more hydroisomerization catalysts and one or more hydrotreating catalysts, or (iv) one or more hydrotreating catalysts, one or more hydrocracking catalysts and one or more hydroisomerization catalysts).

[0020] As discussed hereinabove, the hydroprocessing catalyst(s) may be selected such that VI-increasing molecular transformations (such as hydroisomerization and hydrogenation) predominate in the hydroprocessing. For example, the method may comprise selecting one or more hydrotreating and/or hydroisomerization catalysts such that hydrogenation and/or hydroisomerization molecular transformations predominate over hydrocracking. Additionally, or alternatively, the method may comprise selecting one or more mild hydrocracking catalysts. It will be appreciated that a mild hydrocracking catalyst is a hydrocracking catalyst which contains less active molecular sieves (e.g. zeolites) and/or lower amounts (e.g. zero amount) of molecular sieves (e.g. zeolites) in comparison to hydrocracking catalysts traditionally used in a hydrocracker. Accordingly, a hydrocarbonaceous feedstock exposed to a mild hydrocracking catalyst typically undergoes less hydrocracking (and typically more hydroisomerization) than when exposed to a stronger hydrocracking catalyst under the same reaction conditions.

[0021] In some examples, the hydroprocessing catalyst comprises: (a) sulphides of one or more metals selected from Groups VI and VIII to X; (b) a catalyst support comprising alumina and/or

amorphous silica-alumina material; and (c) one or more zeolites. For example, the hydroprocessing catalyst may comprise: (a) sulphides of one or more metals selected from Groups VI and VIII to X; (b) a catalyst support comprising alumina and/or amorphous silica-alumina material; and (c) one or more Y-type zeolites. In some examples, the hydroprocessing catalyst is a mild hydrocracking catalyst which comprises: (a) sulphides of one or more metals selected from Groups VI and VIII to X; (b) a catalyst support comprising alumina and/or amorphous silica-alumina material; and (c) one or more low-activity Y-type zeolites.

[0022] The hydroprocessing conditions may comprise a reaction temperature no less than about 400 °F, for example, no less than about 450 °F, no less than about 500 °F, no less than about 550 °F, no less than about 600 °F, no less than about 650 °F, no less than about 700 °F, or no less than about 750 °F, or no less than about 800 °F. The hydroprocessing conditions may comprise a reaction temperature no greater than about 950 °F, for example, no greater than about 900 °F, or no greater than about 850 °F, or no greater than about 800 °F, or no greater than about 750 °F, or no greater than about 700 °F. The hydroprocessing conditions may comprise a reaction temperature from about 400 °F to about 950 °F, for example, from about 400 °F to about 900 °F, or from about 400 °F to about 850 °F, or from about 400 °F to about 800 °F, or from about 400 °F to about 750 °F, or from about 400 °F to about 700 °F, or from about 450 °F to about 950 °F, or from about 450 °F to about 900 °F, or from about 450 °F to about 850 °F, or from about 450 °F to about 800 °F, or from about 450 °F to about 750 °F, or from about 450 °F to about 700 °F, or from about 500 °F to about 950 °F, or from about 500 °F to about 900 °F, or from about 500 °F to about 850 °F, or from about 500 °F to about 800 °F, or from about 500 °F to about 750 °F, or from about 500 °F to about 700 °F, or from about 550 °F to about 950 °F, or from about 550 °F to about 900 °F, or from about 550 °F to about 850 °F, or from about 550 °F to about 800 °F, or from about 550 °F to about 750 °F, or from about 550 °F to about 700 °F, or from about 600 °F to about 950 °F, or from about 600 °F to about 900 °F, or from about 600 °F to about 850 °F, or from about 600 °F to about 800 °F, or from about 600 °F to about 750 °F, or from about 600 °F to about 700 °F, or from about 650 °F to about 950 °F, or from about 650 °F to about 900 °F, or from about 650 °F to about 850 °F, or from about 650 °F to about 800 °F, or from about 650 °F to about 750 °F, or from about 650 °F to about 700 °F, or from about 700 °F to about 950 °F, or from about 700 °F to about 900 °F, or from about 700 °F to about 850 °F, or from about 700 °F to about 800 °F, or from about 700 °F to about 750 °F, or from about 750 °F to about 950 °F, or from about 750 °F to about 900 °F, or from about 750 °F to about 850 °F, or from about 750 °F to about 800 °F, or from about 750 °F to about 850 °F, or from about 800 °F to about 950 °F, or from about 800 °F to about 900 °F, or from about 800 °F to about 850 °F.

[0023] The hydroprocessing conditions may comprise a reaction gauge pressure no less than about 500 psi, for example, no less than about 750 psi, or no less than about 1000 psi, or no less than about 1200 psi, or no less than about 1500 psi, or no less than about 2000 psi. The hydroprocessing conditions

may comprise a reaction gauge pressure no greater than about 5000 psi, for example, no greater than about 4000 psi, or no greater than about 3000 psi, or no greater than about 2500 psi, or no greater than about 2000 psi. The hydroprocessing conditions may comprise a reaction gauge pressure from about 500 psi to about 5000 psi, for example, from about 500 psi to about 4000 psi, or from about 500 psi to about 3000 psi, or from about 500 psi to about 2500 psi, or from about 500 psi to about 2000 psi, or from about 750 psi to about 5000 psi, or from about 750 psi to about 4000 psi, or from about 750 psi to about 3000 psi, or from about 750 psi to about 2500 psi, or from about 750 psi to about 2000 psi, or from about 1000 psi to about 5000 psi, or from about 1000 psi to about 4000 psi, or from about 1000 psi to about 3000 psi, or from about 1000 psi to about 2500 psi, or from about 1000 psi to about 2000 psi, or from about 1200 psi to about 5000 psi, or from about 1200 psi to about 4000 psi, or from about 1200 psi to about 3000 psi, or from about 1200 psi to about 2500 psi, or from about 1200 psi to about 2000 psi, or from about 1500 psi to about 5000 psi, or from about 1500 psi to about 4000 psi, or from about 1500 psi to about 3000 psi, or from about 1500 psi to about 2500 psi, or from about 1500 psi to about 2000 psi, or from about 2000 psi to about 5000 psi, or from about 2000 psi to about 4000 psi, or from about 2000 psi to about 3000 psi, or from about 2000 psi to about 2500 psi.

[0024] The hydroprocessing conditions may comprise a liquid hourly space velocity (LHSV) no less than about  $0.1 \text{ hr}^{-1}$ , for example, no less than about  $0.2 \text{ hr}^{-1}$ , or no less about  $0.5 \text{ hr}^{-1}$ , or no less than about  $1 \text{ hr}^{-1}$ . The hydroprocessing conditions may comprise an LHSV no greater than about  $15 \text{ hr}^{-1}$ , for example, no greater than about  $10 \text{ hr}^{-1}$ , or no greater than about  $5 \text{ hr}^{-1}$ , or no greater than about  $2.5 \text{ hr}^{-1}$ . The hydroprocessing conditions may comprise an LHSV from about  $0.1 \text{ hr}^{-1}$  to about  $15 \text{ hr}^{-1}$ , for example from about  $0.1 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ , or from about  $0.1 \text{ hr}^{-1}$  to about  $5 \text{ hr}^{-1}$ , or from about  $0.1 \text{ hr}^{-1}$  to about  $2.5 \text{ hr}^{-1}$ , or from about  $0.2 \text{ hr}^{-1}$  to about  $15 \text{ hr}^{-1}$ , or from about  $0.2 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ , or from about  $0.2 \text{ hr}^{-1}$  to about  $5 \text{ hr}^{-1}$ , or from about  $0.2 \text{ hr}^{-1}$  to about  $2.5 \text{ hr}^{-1}$ , or from about  $0.5 \text{ hr}^{-1}$  to about  $15 \text{ hr}^{-1}$ , or from about  $0.5 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ , or from about  $0.5 \text{ hr}^{-1}$  to about  $5 \text{ hr}^{-1}$ , or from about  $0.5 \text{ hr}^{-1}$  to about  $2.5 \text{ hr}^{-1}$ , or from about  $1 \text{ hr}^{-1}$  to about  $15 \text{ hr}^{-1}$ , or from about  $1 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ , or from about  $1 \text{ hr}^{-1}$  to about  $5 \text{ hr}^{-1}$ , or from about  $1 \text{ hr}^{-1}$  to about  $2.5 \text{ hr}^{-1}$ .

[0025] The hydroprocessing conditions may comprise a hydrogen consumption no less than about 100 scf per barrel of liquid hydrocarbon feed, for example, no less than about 200 scf per barrel of liquid hydrocarbon feed, or no less than about 300 scf per barrel of liquid hydrocarbon feed, or no less than about 400 scf per barrel of liquid hydrocarbon feed, or no less than about 500 scf per barrel of liquid hydrocarbon feed. The hydroprocessing conditions may comprise a hydrogen consumption no greater than about 2500 scf per barrel of liquid hydrocarbon feed, for example, no greater than about 2000 scf per barrel of liquid hydrocarbon feed, or no greater than about 1500 scf per barrel of liquid hydrocarbon feed, or no greater than about 1000 scf per barrel of liquid hydrocarbon feed. The hydroprocessing conditions may comprise a hydrogen consumption from about 100 scf to about 2500 scf per barrel of

liquid hydrocarbon feed, for example, from about 100 scf to about 2000 scf per barrel of liquid hydrocarbon feed, or from about 100 scf to about 1500 scf per barrel of liquid hydrocarbon feed, or from about 100 scf to about 1000 scf per barrel of liquid hydrocarbon feed, or from about 200 scf to about 2500 scf per barrel of liquid hydrocarbon feed, or from about 200 scf to about 2000 scf per barrel of liquid hydrocarbon feed, or from about 200 scf to about 1500 scf per barrel of liquid hydrocarbon feed, or from about 200 scf to about 1000 scf per barrel of liquid hydrocarbon feed, or from about 300 scf to about 2500 scf per barrel of liquid hydrocarbon feed, or from about 300 scf to about 2000 scf per barrel of liquid hydrocarbon feed, or from about 300 scf to about 1500 scf per barrel of liquid hydrocarbon feed, or from about 300 scf to about 1000 scf per barrel of liquid hydrocarbon feed, or from about 400 scf to about 2500 scf per barrel of liquid hydrocarbon feed, or from about 400 scf to about 2000 scf per barrel of liquid hydrocarbon feed, or from about 400 scf to about 1500 scf per barrel of liquid hydrocarbon feed, or from about 400 scf to about 1000 scf per barrel of liquid hydrocarbon feed, or from about 500 scf to about 2500 scf per barrel of liquid hydrocarbon feed, or from about 500 scf to about 2000 scf per barrel of liquid hydrocarbon feed, or from about 500 scf to about 1500 scf per barrel of liquid hydrocarbon feed, or from about 500 scf to about 1000 scf per barrel of liquid hydrocarbon feed.

[0026] Accordingly, the hydroprocessing conditions may comprise: (a) a reaction temperature from about 400 °F to about 950 °F, for example, from about 400 °F to about 900 °F, or from about 400 °F to about 850 °F, or from about 400 °F to about 800 °F, or from about 400 °F to about 750 °F, or from about 400 °F to about 700 °F, or from about 450 °F to about 950 °F, or from about 450 °F to about 900 °F, or from about 450 °F to about 850 °F, or from about 450 °F to about 800 °F, or from about 450 °F to about 750 °F, or from about 450 °F to about 700 °F, or from about 500 °F to about 950 °F, or from about 500 °F to about 900 °F, or from about 500 °F to about 850 °F, or from about 500 °F to about 800 °F, or from about 500 °F to about 750 °F, or from about 500 °F to about 700 °F, or from about 550 °F to about 950 °F, or from about 550 °F to about 900 °F, or from about 550 °F to about 850 °F, or from about 550 °F to about 800 °F, or from about 550 °F to about 750 °F, or from about 550 °F to about 700 °F, or from about 600 °F to about 950 °F, or from about 600 °F to about 900 °F, or from about 600 °F to about 850 °F, or from about 600 °F to about 800 °F, or from about 600 °F to about 750 °F, or from about 600 °F to about 700 °F, or from about 650 °F to about 950 °F, or from about 650 °F to about 900 °F, or from about 650 °F to about 850 °F, or from about 650 °F to about 800 °F, or from about 650 °F to about 750 °F, or from about 650 °F to about 700 °F, or from about 700 °F to about 950 °F, or from about 700 °F to about 900 °F, or from about 700 °F to about 850 °F, or from about 700 °F to about 800 °F, or from about 700 °F to about 750 °F, or from about 750 °F to about 950 °F, or from about 750 °F to about 900 °F, or from about 750 °F to about 850 °F, or from about 750 °F to about 800 °F, or from about 800 °F to about 950 °F, or from about 800 °F to about 900 °F, or from about 800 °F to about 850 °F; (b) a

reaction gauge pressure from about 500 psi to about 5000 psi, for example, from about 500 psi to about 4000 psi, or from about 500 psi to about 3000 psi, or from about 500 psi to about 2500 psi, or from about 500 psi to about 2000 psi, or from about 750 psi to about 5000 psi, or from about 750 psi to about 4000 psi, or from about 750 psi to about 3000 psi, or from about 750 psi to about 2500 psi, or from about 750 psi to about 2000 psi, or from about 1000 psi to about 5000 psi, or from about 1000 psi to about 4000 psi, or from about 1000 psi to about 3000 psi, or from about 1000 psi to about 2500 psi, or from about 1000 psi to about 2000 psi, or from about 1200 psi to about 5000 psi, or from about 1200 psi to about 4000 psi, or from about 1200 psi to about 3000 psi, or from about 1200 psi to about 2500 psi, or from about 1200 psi to about 2000 psi, or from about 1500 psi to about 5000 psi, or from about 1500 psi to about 4000 psi, or from about 1500 psi to about 3000 psi, or from about 1500 psi to about 2500 psi, or from about 1500 psi to about 2000 psi, or from about 2000 psi to about 5000 psi, or from about 2000 psi to about 4000 psi, or from about 2000 psi to about 3000 psi, or from about 2000 psi to about 2500 psi; (c) an LHSV from about  $0.1 \text{ hr}^{-1}$  to about  $15 \text{ hr}^{-1}$ , for example from about  $0.1 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ , or from about  $0.1 \text{ hr}^{-1}$  to about  $5 \text{ hr}^{-1}$ , or from about  $0.1 \text{ hr}^{-1}$  to about  $2.5 \text{ hr}^{-1}$ , or from about  $0.2 \text{ hr}^{-1}$  to about  $15 \text{ hr}^{-1}$ , or from about  $0.2 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ , or from about  $0.2 \text{ hr}^{-1}$  to about  $5 \text{ hr}^{-1}$ , or from about  $0.2 \text{ hr}^{-1}$  to about  $2.5 \text{ hr}^{-1}$ , or from about  $0.5 \text{ hr}^{-1}$  to about  $15 \text{ hr}^{-1}$ , or from about  $0.5 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ , or from about  $0.5 \text{ hr}^{-1}$  to about  $5 \text{ hr}^{-1}$ , or from about  $0.5 \text{ hr}^{-1}$  to about  $2.5 \text{ hr}^{-1}$ , or from about  $1 \text{ hr}^{-1}$  to about  $15 \text{ hr}^{-1}$ , or from about  $1 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ , or from about  $1 \text{ hr}^{-1}$  to about  $5 \text{ hr}^{-1}$ , or from about  $1 \text{ hr}^{-1}$  to about  $2.5 \text{ hr}^{-1}$ ; and/or (d) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed, for example, from about 100 scf to about 2000 scf per barrel of liquid hydrocarbon feed, or from about 100 scf to about 1500 scf per barrel of liquid hydrocarbon feed, or from about 100 scf to about 1000 scf per barrel of liquid hydrocarbon feed, or from about 200 scf to about 2500 scf per barrel of liquid hydrocarbon feed, or from about 200 scf to about 2000 scf per barrel of liquid hydrocarbon feed, or from about 200 scf to about 1500 scf per barrel of liquid hydrocarbon feed, or from about 200 scf to about 1000 scf per barrel of liquid hydrocarbon feed, or from about 300 scf to about 2500 scf per barrel of liquid hydrocarbon feed, or from about 300 scf to about 2000 scf per barrel of liquid hydrocarbon feed, or from about 300 scf to about 1500 scf per barrel of liquid hydrocarbon feed, or from about 300 scf to about 1000 scf per barrel of liquid hydrocarbon feed, or from about 400 scf to about 2500 scf per barrel of liquid hydrocarbon feed, or from about 400 scf to about 2000 scf per barrel of liquid hydrocarbon feed, or from about 400 scf to about 1500 scf per barrel of liquid hydrocarbon feed, or from about 400 scf to about 1000 scf per barrel of liquid hydrocarbon feed, or from about 500 scf to about 2500 scf per barrel of liquid hydrocarbon feed, or from about 500 scf to about 2000 scf per barrel of liquid hydrocarbon feed, or from about 500 scf to about 1500 scf per barrel of liquid hydrocarbon feed, or from about 500 scf to about 1000 scf per barrel of liquid hydrocarbon feed.

[0027] In some examples, the hydroprocessing conditions comprise: (a) a reaction temperature from about 400 °F to about 950 °F, for example, from about 650 °F to about 850 °F; (b) a reaction gauge pressure from about 500 psi to about 5000 psi, for example, from about 1500 psi to about 2500 psi, or from about 1200 psi to about 2500 psi; (c) an LHSV from about 0.1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example, from about 0.2 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>, or from about 0.2 hr<sup>-1</sup> to about 2.5 hr<sup>-1</sup>, or from about 0.1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and/or (d) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed, for example, from about 200 scf to about 2500 scf per barrel of liquid hydrocarbon feed, or from about 100 scf to about 1500 scf per barrel of liquid hydrocarbon feed.

[0028] As discussed hereinabove, the hydroprocessing conditions may be selected such that VI-increasing molecular transformations (such as hydroisomerization and hydrogenation) predominate in the hydroprocessing. The hydroprocessing conditions may therefore be selected dependent on the selected hydroprocessing catalyst(s).

[0029] For example, it may be that the method comprises contacting the unconverted oil with one or more hydrotreating catalysts in the presence of hydrogen under hydrotreating conditions comprising: (a) a reaction temperature from about 400 °F to about 950 °F, for example, from about 650 °F to about 850 °F; (b) a reaction gauge pressure from about 500 psi to about 5000 psi, for example, from about 1200 psi to about 2500 psi; (c) an LHSV from about 0.1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example, from about 0.2 hr<sup>-1</sup> to about 2.5 hr<sup>-1</sup>; and/or (d) a hydrogen consumption from about 200 scf to about 2500 scf per barrel of liquid hydrocarbon feed. Alternatively, it may be that the method comprises contacting the unconverted oil with one or more hydrocracking catalysts in the presence of hydrogen under hydrocracking conditions comprising: (a) a reaction temperature from about 400 °F to about 950 °F, for example, from about 650 °F to about 850 °F; (b) a reaction gauge pressure from about 500 psi to about 5000 psi, for example, from about 1500 psi to about 2500 psi; (c) an LHSV from about 0.5 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example, from about 1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and/or (d) a hydrogen consumption from about 100 scf to about 1500 scf per barrel of liquid hydrocarbon feed. Further alternatively, it may be that the method comprises contacting the unconverted oil with one or more hydroisomerization catalysts in the presence of hydrogen under hydroisomerization conditions comprising: (a) a reaction temperature from about 400 °F to about 950 °F, for example, from about 650 °F to about 850 °F; (b) a reaction gauge pressure from about 500 psi to about 5000 psi, for example, from about 1500 psi to about 2500 psi; (c) an LHSV from about 0.5 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example, from about 1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and/or (d) a hydrogen consumption from about 100 scf to about 1500 scf per barrel of liquid hydrocarbon feed.

[0030] It will be appreciated that the catalytic activity of the hydroprocessing catalyst may be affected by the hydroprocessing conditions. For example, the selectivity of the hydroprocessing catalyst may depend on the hydroprocessing conditions. Accordingly, in some examples, the method comprises contacting the unconverted oil with a hydrocracking catalyst in the presence of hydrogen under

hydroprocessing conditions which cause VI-increasing molecular transformations (e.g. hydrogenation and/or hydroisomerization transformations) to predominate (e.g. over hydrocracking transformations). For example, the method may comprise contacting the unconverted oil with a hydrocracking catalyst in the presence of hydrogen under mild hydrocracking conditions (for example, at relatively low temperatures) such that hydroisomerization reactions predominate over hydrocracking reactions.

[0031] Accordingly, hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil may comprise hydrotreating, hydroisomerizing and/or hydrocracking the unconverted oil from the hydrocracker. However, hydrotreating and/or hydroisomerization reactions typically outweigh hydrocracking reactions in the hydroprocessing. For example, it may be that hydroprocessing the unconverted oil from the hydrocracker comprises hydrocracking the unconverted oil from the hydrocracker, but the level of hydrocracking conversion (for example, the apparent conversion, which is the mass of resultant hydrocracking products (i.e. light ends and middle distillates) expressed as a proportion (e.g. as a percentage) of the mass of unconverted oil hydroprocessed) during hydrocracking the unconverted oil from the hydrocracker is less than the level of hydrocracking conversion (for example, the apparent conversion) during hydrocracking the hydrocarbonaceous feedstock in the hydrocracker. In some examples, hydrocracking the unconverted oil from the hydrocracker takes place at a hydrocracking conversion (i.e. apparent conversion) of from about 5 % to about 30 % (for example, from about 5 % to about 20 %, or from about 10 % to about 30 %, or from about 10 % to about 20 %), while hydrocracking the hydrocarbonaceous feedstock in the hydrocracker takes place at a hydrocracking conversion (i.e. apparent conversion) of from about 30 % to about 70 % (for example, from about 40 % to about 70 %, or from about 50 % to about 70 %, or from about 30 % to about 60 %, or from about 40 % to about 60 %, or from about 50 % to about 60 %, or from about 30 % to about 50 %, or from about 40 % to about 50 %).

[0032] The method may comprise hydroprocessing the unconverted oil under clean conditions. For example, prior to hydroprocessing the unconverted oil, it may be that the sulfur, nitrogen and/or metal content of the unconverted oil is low. In some examples, the unconverted oil, prior to hydroprocessing, is substantially sulfur-, nitrogen- and/or metal-free. For example, prior to hydroprocessing the unconverted oil from the hydrocracker, the unconverted oil may comprise: (a) no greater than about 100 ppm, for example, no greater than about 75 ppm, or no greater than about 50 ppm, of sulfur; (b) no greater than about 20 ppm, for example, no greater than about 15 ppm, or no greater than about 10 ppm, of nitrogen; and/or (c) no greater than about 1 ppm, for example, no greater than about 0.5 ppm, of nickel, vanadium and/or copper.

[0033] Additionally or alternatively, prior to hydroprocessing the unconverted oil from the hydrocracker, the unconverted oil may have: (a) an API gravity of from about 25 to about 45, for example, from about 30 to about 45, or from about 25 to about 40, or from about 30 to about 40, or

from about 25 to about 35, or from about 30 to about 35; (b) a true boiling point (TBP) 95% point (i.e. the temperature at which 95 % of the unconverted oil is vaporized) from about 800 °F to about 1100 °F, for example from about 900 °F to about 1100 °F, or from about 800 °F to about 1000 °F, or from about 900 °F to about 1000 °F; and/or (c) a viscosity index (VI), measured according to ASTM D-2270, of from about 100 to about 150, for example, from about 110 to about 150, or from about 120 to about 150, or from about 100 to about 140, or from about 110 to about 140, or from about 120 to about 140, or from about 100 to about 130, or from about 110 to about 130, or from about 120 to about 130, or from about 100 to about 120, or from about 110 to about 120, at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (i.e. 212 °F).

[0034] Hydroprocessing the unconverted oil to produce the base oil product may comprise increasing the VI of the unconverted oil by no less than about 5, for example, no less than about 10, or no less than about 15. Hydroprocessing the unconverted oil to produce the base oil product may comprise increasing the VI of the unconverted oil by no greater than about 30, for example, no greater than about 25, or no greater than about 20. Hydroprocessing the unconverted oil to produce the base oil product may comprise increasing the VI of the unconverted oil by about 5 to by about 30, for example, by about 10 to by about 30, or by about 15 to by about 30, or by about 5 to by about 25, or by about 10 to by about 25, or by about 15 to by about 25, or by about 5 to by about 20, or by about 10 to by about 20, or by about 15 to by about 20.

[0035] It will be appreciated that dewaxing the upgraded unconverted oil reduces the wax content of the upgraded unconverted oil. Dewaxing the upgraded unconverted oil may comprise removing wax from the upgraded unconverted oil by one or more physical processes, for example, by cooling the upgraded unconverted oil to solidify wax components and filtering to remove the solidified wax components. For example, dewaxing the upgraded unconverted oil may comprise solvent dewaxing the upgraded unconverted oil, wherein solvent dewaxing comprises: diluting the upgraded unconverted oil with solvent; cooling the diluted upgraded unconverted oil to solidify wax components; filtering to separate the solidified wax components and the filtrate; and recovering the solvent from the solidified wax components and/or the filtrate. Additionally, or alternatively, dewaxing the upgraded unconverted oil may comprise reducing the wax content of the upgraded unconverted oil by one or more chemical processes, for example, by catalytically cracking and/or isomerizing wax molecules. For example, dewaxing the upgraded unconverted oil may comprise catalytically dewaxing the upgraded unconverted oil by hydrocracking wax components and/or iso-dewaxing the upgraded unconverted oil by hydroisomerizing wax components. Hydrocracking and/or hydroisomerizing wax components may make use of hydrocracking and/or hydroisomerizing catalysts such as iso-dewaxing catalysts.

[0036] The base oil product produced by the method may have a VI, measured according to ASTM D-2270, of no less than about 120, for example, no less than about 130, or no less than about 140, at a

kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (i.e., 212 °F). The base oil product produced by the method may have a VI, measured according to ASTM D-2270, of no greater than about 200, for example, no greater than about 175, or no greater than about 150, at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (i.e., 212 °F). The base oil product produced by the method may have a VI, measured according to ASTM D-2270, of from about 120 to about 200, for example, from about 120 to about 175, or from about 120 to about 150, or from about 130 to about 200, or from about 130 to about 175, or from about 130 to about 150, or from about 140 to about 200, or from about 140 to about 175, or from about 140 to about 150, measured according to ASTM D-2270.

[0037] The base oil product produced by the method may be a Group III base oil product as defined by the American Petroleum Institute (API).

[0038] The base oil product may be a base oil for use in the manufacture of lubricating oils, motor oils and/or metal processing fluids (e.g. cutting fluids). The base oil product may be a blend of two or more (i.e. different) base oils.

[0039] The method may be carried out in a base oil production plant. Hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil may take place in an unconverted oil upgrade reactor, for example according to the third aspect described hereinbelow.

[0040] The method may include, as necessary, any other steps known in the art for producing base oil products, including filtering, distillation, stripping and/or hydrofinishing steps.

[0041] In a second aspect, there is provided a method of modifying an existing base oil product manufacturing process to increase a viscosity index (VI) of the base oil produced. The existing base oil product manufacturing process comprises: hydrocracking a hydrocarbonaceous feedstock in a hydrocracker to produce a hydrocracked effluent comprising unconverted oil; separating the unconverted oil from the hydrocracked effluent; and dewaxing the unconverted oil separated from the hydrocracked effluent to produce the base oil product. The method of modifying the existing base oil product manufacturing process comprises: hydroprocessing the unconverted oil separated from the hydrocracked effluent prior to dewaxing the unconverted oil to produce the base oil product.

[0042] The hydrocarbonaceous feedstock may be any hydrocarbonaceous feedstock as described hereinabove in relation to the first aspect.

[0043] The steps of the method (including the hydrocracking, separating, hydroprocessing and dewaxing steps) may have, *mutatis mutandis*, any of the features (including input feeds, outputs, molecular transformations, catalysts and reaction conditions) of the corresponding steps of the method according to the first aspect.

[0044] In a third aspect, there is provided a system for producing a base oil product. The system comprises: a hydrocracker for hydrocracking a hydrocarbonaceous feedstock to produce a hydrocracked

effluent comprising unconverted oil; and an unconverted oil upgrade reactor for hydroprocessing unconverted oil, separated from the hydrocracked effluent, to produce upgraded unconverted oil.

[0045] The unconverted oil upgrade reactor may be configured to hydroprocess the unconverted oil, separated from the hydrocracked effluent, by the method according to the first aspect described hereinabove. Accordingly, the input feeds to, the outputs from, and the catalysts and reaction conditions within, the unconverted oil upgrade reactor may be as described hereinabove in relation to the first aspect.

[0046] The unconverted oil upgrade reactor may have a hydroprocessing zone comprising one or more beds containing one or more hydroprocessing catalysts as described hereinabove in relation to the first aspect. The one or more beds may be fixed beds, slurry bed and/or fluidized (e.g. ebullated) beds. In examples in which the one or more beds contain more than one (i.e. different) hydroprocessing catalysts, the said more than one hydroprocessing catalysts may be layered. The one or more beds may further contain interstitial packing material, for example, glass beads. The hydroprocessing zone may be maintained at hydroprocessing conditions as described hereinabove in relation to the first aspect.

[0047] The system may further comprise: a dewaxing unit for dewaxing unconverted oil, produced by the unconverted oil upgrade reactor, to produce the base oil product. The dewaxing unit may be configured to dewax the unconverted oil by any of the dewaxing methods (e.g. solvent dewaxing, catalytic dewaxing and/or iso-dewaxing) described in relation to the first aspect.

[0048] The system may be a base oil production plant.

[0049] In a fourth aspect, there is provided a method of modifying an existing system for producing a base oil product to increase a viscosity index (VI) of the base oil product. The existing system for producing the base oil product comprises: a hydrocracker for hydrocracking a hydrocarbonaceous feedstock to produce a hydrocracked effluent comprising unconverted oil; and a dewaxing unit for dewaxing unconverted oil, separated from the hydrocracked effluent, to produce the base oil product. The method of modifying the existing system comprises installing in the existing system an unconverted oil upgrade reactor for hydroprocessing the unconverted oil, separated from the hydrocracked effluent, prior to dewaxing the unconverted oil to produce the base oil product.

[0050] The hydrocarbonaceous feedstock may be any hydrocarbonaceous feedstock as described hereinabove in relation to the first aspect.

[0051] The unconverted oil upgrade reactor may have, *mutatis mutandis*, any of the features (including input feeds, outputs, structure, function, molecular transformations, catalysts and reaction conditions) of the unconverted oil upgrade reactor as described hereinabove in relation to the third aspect. Moreover, modifying the existing system by installing in the existing system the unconverted oil upgrade reactor may result in a system having any of the features of the system as described in relation to the third aspect.

[0052] In a fifth aspect, there is provided an unconverted oil upgrade reactor for hydroprocessing unconverted oil, separated from the hydrocracked effluent of a hydrocracker, prior to dewaxing the unconverted oil to produce a base oil product. The unconverted oil upgrade reactor may have, *mutatis mutandis*, any of the features (including input feeds, outputs, structure, function, molecular transformations, catalysts and reaction conditions) of the unconverted oil upgrade reactor as described hereinabove in relation to the third aspect.

[0053] In a sixth aspect, there is provided a base oil product produced (a) by the method according to the first aspect, (b) by the method as modified by the method of the second aspect, (c) using the system according to the third aspect, or (d) using the system as modified by the method according to the fourth aspect. The base oil product may be a Group II base oil product or a Group III base oil product, preferably a Group III base oil product.

[0054] The base oil product may be a base oil for use in the manufacture of lubricating oils, motor oils and/or metal processing fluids (e.g., cutting fluids). The base oil product may be a blend of two or more (i.e., different) base oils.

[0055] In a seventh aspect, there is provided a lubricant comprising the base oil product according to the sixth aspect. The lubricant may comprise two or more (i.e. different) base oil products (e.g. base oils). The lubricant may further comprise one or more additives, such as anti-wear additives, corrosion inhibitors, detergents, dispersants, friction modifiers, pour-point depressants and/or viscosity index improvers. The lubricant may be a lubricating oil (such as a motor oil), a metal processing fluid (such as a cutting fluid) or a lubricating grease (such as a soap emulsified with the base oil product).

[0056] In an eighth aspect, there is provided a use of an upgraded unconverted oil in the manufacture of a base oil product to increase the viscosity index (VI) of the manufactured base oil product.

[0057] The upgraded unconverted oil may be produced by upgrading (e.g. hydroprocessing) unconverted oil obtained from a hydrocracker by the method according to the first aspect or using the system according to the third aspect. For example, the upgraded unconverted oil may be obtained by hydroprocessing unconverted oil obtained from hydrocracking a hydrocarbonaceous feedstock having a boiling point in the range from about 572 °F to about 1112 °F (i.e., about 300 °C to about 600 °C) and/or comprising a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO). The manufacture of the base oil product may comprise dewaxing the upgraded unconverted oil in a dewaxing unit.

[0058] In a ninth aspect, there is provided a use of a dewaxed, upgraded unconverted oil as a base oil product in a lubricant to increase the viscosity index (VI) of the lubricant.

[0059] The dewaxed, upgraded unconverted oil may be obtained by: upgrading (e.g. hydroprocessing) unconverted oil obtained from a hydrocracker by the method according to the first aspect or using the system according to the third aspect or the unconverted oil upgrade reactor of the

fifth aspect; and dewaxing the upgraded unconverted oil. For example, the dewaxed, upgraded unconverted oil may be obtained by: (a) hydroprocessing unconverted oil obtained from hydrocracking a hydrocarbonaceous feedstock having a boiling point in the range from about 572 °F to about 1112 °F (i.e., about 300 °C to about 600 °C) and/or comprising a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO); and (b) dewaxing the hydroprocessed unconverted oil.

[0060] The skilled person will appreciate that, except where mutually exclusive, a feature described in relation to any one of the above aspects may be applied *mutatis mutandis* to any other aspect.

Furthermore, except where mutually exclusive, any feature described herein may be applied to any aspect and/or combined with any other feature described herein.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0061] Embodiments will now be described by way of example only, with reference to the Figures, in which:

[0062] **FIG. 1** is a schematic process flow diagram illustrating a process for manufacturing a base oil;

[0063] **FIG. 2** is a plot of viscosity index (VI) as a function of percentage hydrocracking conversion (X) for unconverted oil obtained directly from hydrocracking (a) a straight-run vacuum gas oil and (b) a blend of a straight-run vacuum gas oil and heavy coker gas oil;

[0064] **FIG. 3** is a plot of VI as a function of viscosity at 100 °C for unconverted oil obtained directly from hydrocracking (a) a straight-run vacuum gas oil and (b) a blend of a straight-run vacuum gas oil and heavy coker gas oil;

[0065] **FIG. 4** is a plot of VI as a function of X for dewaxed oil obtained by dewaxing unconverted oil obtained directly from hydrocracking (a) a straight-run vacuum gas oil and (b) a blend of a straight-run vacuum gas oil and heavy coker gas oil;

[0066] **FIG. 5** is a plot of VI as a function of viscosity at 100 °C for dewaxed oil obtained by dewaxing unconverted oil obtained directly from hydrocracking (a) a straight-run vacuum gas oil and (b) a blend of a straight-run vacuum gas oil and heavy coker gas oil;

[0067] **FIG. 6** is a plot of VI as a function of viscosity at 100 °C for unconverted oil obtained directly from hydrocracking (a) a straight-run vacuum gas oil and (b) a blend of a straight-run vacuum gas oil and heavy coker gas oil, each at three different percentage hydrocracking conversions (X);

[0068] **FIG. 7** is a plot of VI as a function of viscosity at 100 °C for dewaxed oil obtained by dewaxing unconverted oil obtained directly from hydrocracking (a) a straight-run vacuum gas oil and (b) a blend of a straight-run vacuum gas oil and heavy coker gas oil, each at three different values of X;

[0069] **FIG. 8** is a plot of VI as a function of viscosity at 100 °C for dewaxed oil obtained by dewaxing (a) unconverted oil obtained directly from hydrocracking a blend of a straight-run vacuum gas oil and heavy coker gas oil at 63.5 % hydrocracking conversion, (b) unconverted oil obtained directly from

hydrocracking a blend of a straight-run vacuum gas oil and heavy coker gas oil at 74 % hydrocracking conversion, and (c) upgraded unconverted oil obtained by upgrading unconverted oil, obtained directly from hydrocracking a blend of a straight-run vacuum gas oil and heavy coker gas oil at 63.5 % hydrocracking conversion, to a total percentage hydrocracking conversion of 74%; and

[0070] **FIG. 9** is a plot of VI as a function of viscosity at 100 °C for dewaxed oil obtained by dewaxing (a) unconverted oil obtained directly from hydrocracking straight-run vacuum gas oil at 77 % hydrocracking conversion and (b) upgraded unconverted oil obtained by upgrading unconverted oil, obtained directly from hydrocracking a blend of a straight-run vacuum gas oil and heavy coker gas oil at 63.5 % hydrocracking conversion, to a total percentage hydrocracking conversion of 74%.

#### DETAILED DESCRIPTION

[0071] For the purposes of this specification and appended claims, unless otherwise indicated, all numbers expressing quantities, percentages or proportions, and other numerical values used in the specification and claims, are to be understood as being modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the following specification and attached claims are approximations that can vary depending upon the desired properties sought to be obtained. It is noted that, as used in this specification and the appended claims, the singular forms “a,” “an,” and “the,” include plural references unless expressly and unequivocally limited to one referent. As used herein, the term “include” and its grammatical 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 can be substituted or added to the listed items. As used herein, the term “comprising” means including elements or steps that are identified following that term, but any such elements or steps are not exhaustive, and an embodiment can include other elements or steps.

[0072] 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. In addition, all number ranges presented herein are inclusive of their upper and lower limit values.

[0073] If a standard test is mentioned herein, unless otherwise stated, the version of the test to be referred to is the most recent at the time of filing this patent application.

[0074] The patentable scope is defined by the claims, and can include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims. To an extent not inconsistent herewith, all citations referred to herein are hereby incorporated by reference.

**Process flow**

[0075] FIG. 1 illustrates an example process flow for manufacturing a base oil for use in the manufacture of lubricants. An initial hydrocarbonaceous feedstock 1 is fed into a hydrocracker 2 in which the hydrocarbonaceous feedstock 1 undergoes hydrocracking, thereby producing unconverted oil 3 and other products (not shown in FIG. 1). Unconverted oil 3 is fed from the hydrocracker 2 into a dewaxing block 10, which includes an upgrade reactor 4, a dewaxing reactor 6 and a hydrofinishing reactor 8. The unconverted oil is fed inside the dewaxing block 10 first into the upgrade reactor 4 in which the unconverted oil 3 is upgraded to increase the viscosity index (VI) of the unconverted oil 3, thereby producing an upgraded unconverted oil 5. Upgraded unconverted oil 5 is fed from the upgrade reactor 4 into the dewaxing reactor 6 in which the upgraded unconverted oil 5 is dewaxed to produce a dewaxed oil (DWO) 7. Dewaxed oil 7 is fed from the upgrade reactor 6 into the hydrofinishing reactor 8 in which the dewaxed oil 7 is hydrofinished to produce a base oil 9 suitable for use as a base stock in the manufacture of lubricants.

[0076] The example process flow illustrated in FIG. 1 is suitable for processing many different types of hydrocarbonaceous feedstocks (including, for example, gas oils (e.g., vacuum gas oils (VGOs), atmospheric gas oils, coker gas oils such as heavy coker gas oils (HCGOs), visbreaker gas oils), demetallized oils, vacuum residua, atmospheric residua, deasphalted oils, Fischer-Tropsch streams and/or FCC streams) as known in the art. In some examples, typical input feeds include hydrocarbons having boiling points in the range from about 572 °F to about 1112 °F (i.e., about 300 °C to about 600 °C) and therefore can include gas oils (e.g., VGOs) obtained directly (i.e., "straight-run") from the fractional distillation of crude petroleum, as well as gas oils (e.g., coker gas oil) obtained from bottoms fractions upgrading processes (e.g. coking of vacuum resid). The process flow illustrated in FIG. 1 is particularly suited to the manufacture of base oils from hydrocarbonaceous feeds typically considered lower quality or generally more difficult to process, such as heavy coker gas oils (e.g., HCGOs) or gas oils (e.g., VGOs) obtained from medium or heavy crudes (i.e. crude oil products having relatively low API gravity, e.g., less than about 31.1°, or less than about 22.3°).

[0077] The VI of the hydrocarbonaceous feedstock 1 depends on its composition and origin. Typical gas oil feeds may have VI values from about 60 to about 100. The VI values of straight-run gas oils are generally higher than those of gas oils obtained by upgrading bottoms fractions. For example, straight-run VGOs typically have VI values from about 70 to about 100, whereas coker gas oils typically have VI values below about 60.

[0078] The hydrocracker 2 may take any form known in the art for hydrocracking hydrocarbonaceous feeds such as VGOs and/or coker gas oils (e.g., HCGOs). The hydrocracker 2 typically includes one or more beds (e.g., fixed beds, slurry beds, fluidized (e.g., ebullated) beds) containing one or more hydrocracking catalysts.

[0079] Hydrocracking catalysts are well-known in the art and may contain one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof, a hydrocracking catalyst support (e.g., an amorphous silica-alumina material), and, optionally, one or more molecular sieves (e.g., zeolites). Hydrocracking catalysts are typically bi-functional: hydrogenation/dehydrogenation reactions are facilitated by the metals present, whereas cracking reactions are facilitated by solid acids (e.g. the zeolites and/or amorphous silica-alumina material). Typical metals used include iron, chromium, molybdenum, tungsten, cobalt or nickel, or sulphides or oxides thereof, and/or platinum or palladium. Typical zeolites used include Y-type (e.g., SY, USY and VUSY), REX, REY, beta and ZSM-5. Hydrocracking catalysts may also include one or more promoters, such as phosphorous, boron, fluorine, silicon, aluminium, zinc, manganese, or mixtures thereof.

[0080] During hydrocracking, the hydrocarbonaceous feed is passed through the one or more beds of the hydrocracker 2, bringing the hydrocarbonaceous feed into contact with the hydrocracking catalyst and hydrogen. The hydrocracking process is typically carried out at temperatures from about 400 °F to about 950 °F (i.e., about 204 °C to about 510 °C) and at gauge pressures from about 500 psi to about 5000 psi (i.e. about 3447 kPa to about 34474 kPa), with a liquid hourly space velocity (LHSV) from about 0.1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup> and a hydrogen consumption from about 500 scf to about 2500 scf per barrel of liquid hydrocarbon feed (i.e., from about 89 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed).

[0081] Hydrocracking results in cleaving of carbon-carbon bonds in longer hydrocarbon chains, thereby forming carbocations which undergo isomerization and dehydrogenation to form olefinic intermediate products. Olefins are then hydrogenated to form lower boiling point middle distillate products such as light and heavy naphthas, jet, kerosene and diesel. In this way, heavier hydrocarbons are converted into lighter hydrocarbons, while aromatics and naphthenes are converted into non-cyclic paraffins.

[0082] Hydrotreating may also take place in the hydrocracker 2. Hydrotreating is a process by which impurities such as nitrogen, sulphur, oxygen and metals are removed from the hydrocarbonaceous feed. The hydrocracker 2 may therefore also include one or more beds (e.g., fixed beds, slurry beds or fluidized (e.g., ebullated) beds) containing one or more hydrotreating catalysts. Hydrotreating catalysts are well-known in the art and may contain one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof, and a hydrotreating catalyst support such as a porous refractory support (e.g. alumina). Examples of hydrotreating catalysts are alumina supported cobalt-molybdenum, nickel sulphide, nickel-tungsten, cobalt-tungsten and nickel-molybdenum. Hydrotreating catalysts are typically presulfided.

[0083] In some examples, the hydrocracker 2 includes two or more different catalysts. For example, the hydrocracker 2 may include both hydrocracking catalysts and hydrotreating catalysts. Different catalysts may be layered within the hydrocracker 2, for example within the same bed.

[0084] The output from the hydrocracker 2 typically includes impurity products (e.g., H<sub>2</sub>S and NH<sub>3</sub>), light ends (such as refinery gas, propane, butane and naphtha), middle distillate products (e.g., jet, kerosene and diesel) and unconverted oil (UCO). The UCO is therefore the portion of the effluent from the hydrocracker 2 remaining when the impurities, light ends and middle distillates have been removed, and typically has a boiling point range between about 662 °F and about 1112 °F (i.e., between about 350 °C and about 600 °C). UCO can be separated from the other components of the effluent by fractional distillation.

[0085] The VI of UCO exiting the hydrocracker 2 depends on the nature of the input hydrocarbonaceous feed 1, the catalyst(s) used in the hydrocracker 2, the reaction conditions inside the hydrocracker 2 and, therefore, the level of hydrocracking conversion. However, UCO exiting the hydrocracker 2 typically has a VI from about 110 to about 160. The VI of UCO produced by hydrocracking straight-run gas oils is generally higher than that of UCO produced by hydrocracking gas oils obtained by upgrading bottoms fractions. For example, hydrocracking straight-run VGOs at apparent conversion levels (i.e. the mass of light ends and middle distillates produced by the hydrocracker, expressed as a proportion of the total mass of input hydrocarbonaceous feedstock to the hydrocracker) from about 50 % to about 80 % typically produces UCOs having VIs from about 120 to about 160, whereas hydrocracking a blend of straight-run VGO with HCGO (e.g. containing about 85 vol.% straight-run VGO and about 15 vol.% HCGO) at conversion levels from about 50 % to about 80 % typically produces UCOs having VIs from about 100 to about 140.

[0086] The upgrade reactor 4 receives UCO 3 from the hydrocracker 2. The upgrade reactor 4 includes one or more beds (e.g., fixed beds, slurry beds, fluidized (e.g. ebullated) beds) containing one or more hydroprocessing catalysts for hydroprocessing the UCO. During upgrading, low-VI components of the UCO are typically converted into higher-VI components. Accordingly, the upgrade reactor 4 is generally configured such that hydroprocessing the UCO results in an increase in the VI of UCO. That is to say, the one or more hydroprocessing catalysts and/or the reaction conditions within the upgrade reactor 4 are selected such that VI-increasing molecular transformations predominate. VI-increasing molecular transformations typically include hydrotreating, hydrogenation and/or isomerization (e.g. hydroisomerization) transformations. For example, during upgrading of the UCO, aromatic and olefinic hydrocarbons may be saturated and cyclic hydrocarbons (such as naphthenes) may undergo ring-opening transformations, thereby increasing the paraffin content of the UCO. The one or more hydroprocessing catalysts and/or the reaction conditions can therefore be selected such that hydrotreating, hydrogenation and/or isomerization (e.g., hydroisomerization) transformations predominate (for example, over hydrocracking transformations).

[0087] The one or more hydroprocessing catalysts may be hydrotreating catalysts, hydroisomerization catalysts and/or hydrocracking catalysts. Hydrotreating and hydrocracking catalysts

are described hereinabove. Hydroisomerization catalysts are well-known in the art and may contain one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof, a hydroisomerization catalyst support (e.g., an amorphous silica-alumina material), and, optionally, one or more molecular sieves (e.g., zeolites). Hydroisomerization catalysts are typically bi-functional: hydrogenation/dehydrogenation reactions are facilitated by the metals present, whereas isomerization reactions are facilitated by solid acids (e.g., the zeolites and/or amorphous silica-alumina material). Typical metals used include iron, chromium, molybdenum, tungsten, cobalt or nickel, or sulphides or oxides thereof, and/or platinum or palladium. Typical molecular sieves used include MFI, MEL, TON, MTT, \*MRE, FER, AEL and EUO-type, SSZ-32, small crystal SSZ-32, ZSM-23, ZSM-48, MCM-22, ZSM-5, ZSM-12, ZSM-22, ZSM-35 and MCM-68-type, as well as molecular sieves having \*MRE and/or MTT framework topologies. Hydroisomerization catalysts may also include one or more promoters, such as magnesium, calcium, strontium, barium, potassium, lanthanum, praseodymium, neodymium, chromium, or mixtures thereof.

[0088] For example, in some implementations, the upgrade reactor 4 includes a hydrotreating catalyst as described hereinabove. In other examples, the upgrade reactor 4 includes a hydrocracking catalyst as described hereinabove. In further examples, the upgrade reactor 4 includes a hydroisomerization catalyst as described hereinabove. In yet further examples, the upgrade reactor 4 contains both hydrotreating and hydrocracking catalysts, both hydrocracking and hydroisomerization catalysts, or both hydrotreating and hydroisomerization catalysts. In some examples, the upgrade reactors includes a hydrotreating catalyst, a hydrocracking catalyst and a hydroisomerization catalyst.

[0089] As discussed hereinabove, the one or more hydroprocessing catalysts and/or the reaction conditions within the upgrade reactor 4 are selected such that VI-increasing molecular transformations (such as hydroisomerization transformations) predominate.

[0090] In some implementations, the one or more hydroprocessing catalysts are selected such that VI-increasing molecular transformations (such as hydroisomerization transformations) predominate. For example, one or more hydrotreating and/or hydroisomerization catalysts may be selected such that VI-increasing molecular transformations (such as hydroisomerization transformations) predominate over hydrocracking transformations. Additionally or alternatively, one or more mild hydrocracking catalysts may be selected, wherein mild hydrocracking catalysts are understood as being hydrocracking catalysts containing less active molecular sieves (e.g., zeolites) and/or lower amounts of molecular sieves (e.g. zeolites) in comparison to hydrocracking catalysts traditionally used in a hydrocracker. In some examples, mild hydrocracking catalysts contain substantially no molecular sieve material (e.g., zeolite).

[0091] In other implementations, the reaction conditions within the upgrade reactor 4 are selected such that VI-increasing molecular transformations (such as hydroisomerization transformations)

predominate. For example, one or more hydrocracking catalysts may be selected, while reaction conditions are selected such that only low levels of hydrocracking take place. For example, the one or more hydrocracking catalysts may be operated at low temperatures (relative to the temperatures traditionally used in a hydrocracker) such that hydroisomerization predominates over hydrocracking.

[0092] In yet further implementations, both the one or more hydroprocessing catalysts and the reaction conditions are selected such that VI-increasing molecular transformations (such as hydroisomerization transformations) predominate.

[0093] During upgrading, the UCO 3 is passed through the one or more beds in the upgrade reactor, bringing the oil into contact with the one or more hydroprocessing catalysts and hydrogen. The upgrade process is typically carried out at temperatures from about 400 °F to about 800 °F (i.e., about 204 °C to about 427 °C) and at gauge pressures from about 500 psi to about 5000 psi, with a liquid hourly space velocity from about 1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup> and a hydrogen consumption from about 100 scf to about 1500 scf per barrel of liquid hydrocarbon feed. As hydroisomerization reactions predominate in the upgrade reactor 4, and any hydrocracking which takes place is typically selective and mild, the upgrade process may be carried out at higher liquid hourly space velocities and with reduced hydrogen consumption (in comparison the operation of the hydrocracker 2).

[0094] The upgrade reactor 4 also generally operates under clean conditions. This means that the UCO 3 received by the upgrade reactor 4 typically contains only low levels of nitrogen or sulfur. In particular, the majority of the nitrogen and sulfur originally present in the hydrocarbonaceous feedstock is removed in the form of ammonia and hydrogen sulphide when the effluent from the hydrocracker 2 is fractionated before the UCO 3 reaches the upgrade reactor 4. For example, the UCO 3 received by the upgrade reactor 4 may contain less than about 20 ppm nitrogen and less than about 100 ppm sulfur. In addition, the upgrade reactor 4 may share a dewaxing block hydrogen supply with the dewaxer 6 and the hydrofinisher 8. The dewaxing block hydrogen supply typically provides higher purity hydrogen than the hydrogen supply system of the hydrocracking block, since lower levels of contaminants are generated during upgrading, dewaxing and hydrofinishing and because hydrogen is recirculated within the dewaxing block 10.

[0095] Because the upgrade reactor 4 operates under clean conditions, and therefore the hydroprocessing catalysts used in the upgrade reactor 4 are exposed to lower levels of contaminants (such as nitrogen) known to inhibit hydrocracking, the reaction conditions in the upgrade reactor 4 are typically selected so as to be less severe (for example, the reaction temperatures and pressures may be lower) than in the hydrocracker 2 so that excessive hydrocracking does not take place in the upgrade reactor 4 and, again, so that VI-increasing molecular transformations predominate.

[0096] The upgraded UCO 5 produced by the upgrade reactor 4 therefore generally exhibits a higher VI in comparison to the UCO prior to upgrade. For example, upgrading the UCO may increase the value of the VI by about 5 to by about 30.

[0097] The dewaxing reactor 6 receives upgraded UCO 5 from the upgrade reactor 4 and produces dewaxed oil (DWO) 7. The dewaxing reactor 6 may take any form known in the art for dewaxing oils. For example, the dewaxing reactor 6 may be configured for dewaxing oils by solvent dewaxing, catalytic dewaxing and/or isodewaxing processes as are well-known in the art.

[0098] Solvent dewaxing is a physical wax removing process in which the UCO is diluted with a solvent, chilled to solidify wax components, and filtered to remove the solidified wax. Solvent is then recovered from the wax and filtrate for recycling. Catalytic dewaxing is a chemical wax removing process in which hydrocracking catalysts and conditions are used to crack and isomerise waxy normal paraffins in the UCO to produce shorter-chain isoparaffins. Isodewaxing is a chemical wax removing process in which catalysts and conditions are selected such that isomerisation reactions predominate over cracking, thereby enabling waxy normal paraffins to be converted to isoparaffins and cyclic species while preserving paraffinicity. Isodewaxing may be preferred over alternative solvent dewaxing or catalytic dewaxing techniques as it typically leads to higher dewaxed oil yields and higher viscosity indices.

[0099] Dewaxing is carried out to reduce the pour point and cloud point of the oil. The dewaxing process also tends to increase the viscosity and reduce the VI of the oil. For example, dewaxing UCO can increase the viscosity by about 1 % to about 10 % and reduce the viscosity index by about 5 % to about 25 %.

[00100] The hydrofinishing reactor 8 receives dewaxed oil 7 from the dewaxing reactor 6 and produces base oil 9. The hydrofinishing reactor 8 may take any form known in the art for hydrofinishing base oils. Hydrofinishing, as is well-known in the art, involves improving the colour, as well as oxidative and thermal stability, of dewaxed oils by carrying out hydrotreating at relatively low temperatures and pressures to remove aromatics and heterocyclic compounds and/or exposing the oil to materials such as clay or bauxite. The hydrofinishing reactor 8 therefore typically makes use of a hydrotreating catalyst as described hereinabove.

[00101] In the example process flow illustrated in FIG. 1, the upgrade reactor 4, dewaxing reactor 6 and hydrofinishing reactor 8 all form part of the same dewaxing block 10. This means that the upgrade, dewaxing and hydrofinishing processes all take place under clean conditions discussed hereinabove.

[00102] The following examples serve to illustrate, but not limit, the invention.

#### ***Examples***

[00103] Base oils were produced starting from two different hydrocarbonaceous feeds A and B. Feed A was a straight-run Middle Eastern VGO. Feed B was a blend consisting of 85 vol.% of the

straight-run Middle Eastern VGO of feed A and 15 vol.% of HCGO. Details of feeds A and B are provided in Table 1.

Table 1

| Feed                             | A      | B                      |
|----------------------------------|--------|------------------------|
| Feed description                 | SR VGO | Blend of SR VGO + HCGO |
| API Gravity at 60/60             | 21.8   | 21                     |
| Sulfur content, wt. %            | 2.215  | 2.083                  |
| Nitrogen content, ppm            | 998    | 20830                  |
| Microcarbon residue (MCR), wt. % | 0.28   | 0.48                   |
| Hydrogen content, wt. %          | 12.28  | 12.01                  |
| Cloud point, °C                  | >46    | >35                    |
| Pour point, °C                   | 40     | 34                     |
| Viscosity Index, VI              | 85     | 78                     |
| Viscosity at 70°C, Vis70, cSt    | 18.27  | 19.32                  |
| Viscosity at 100°C, Vis100, cSt  | 7.82   | 8.094                  |
| 22x22 MS type, vol. %            |        |                        |
| Total Aromatics                  | 34     | 38                     |
| Mono-Aromatics                   | 7.3    | 10.6                   |
| Naphthenes                       | 31.5   | 31.6                   |
| Paraffins                        | 16.4   | 15.1                   |
| Sulfur compounds                 | 18.1   | 15.3                   |
| Aromatic rings by HPLC-RI, wt. % |        |                        |
| 1 ring                           | 20.9   | 26.5                   |
| 2 rings                          | 11.8   | 10                     |
| 3 rings                          | 3.0    | 2.8                    |
| 4+ rings                         | 9.6    | 9.9                    |
| Total                            | 45.3   | 49.2                   |
| Simdist, T (°F) at wt. %         |        |                        |
| 0.5                              | 626    | 588                    |
| 5                                | 687    | 682                    |
| 10                               | 721    | 716                    |
| 30                               | 789    | 787                    |
| 50                               | 840    | 839                    |
| 70                               | 895    | 893                    |
| 90                               | 974    | 969                    |
| 95                               | 1012   | 1003                   |
| 99                               | 1082   | 1066                   |

[00104] Both feeds A and B were separately cracked in a hydrocracker operated in a Single Stage Once-Through mode using a layered catalyst system including a hydrotreating catalyst and a hydrocracking catalyst. The hydrotreating catalyst consisted of sulfided NiMo on an alumina support. The hydrocracking catalyst consisted of sulfided base metals, a Y-type zeolite and an alumina support. The two catalysts were layered from top to bottom within the reactor in the volume percentages

“hydrotreating catalyst : hydrocracking catalyst : hydrotreating catalyst” = 45:50:5. The catalyst extrudates had a diameter of about 1.5 mm and were shortened to a length/diameter ratio of 2 to 3 before use. Glass beads of 60/80 mesh size were used as interstitial packing in the catalyst layers in the reactor.

[00105] The catalyst system was sulfided per standard procedure prior to introducing feed A or B. The process conditions during hydrocracking were as follows: the LHSV was 0.8 h<sup>-1</sup>; the hydrogen/oil ratio was 5000 scf/bbl; and the total gauge pressure was 2300 psi. Unconverted hydrogen was recycled to the reactor inlet. Three liquid product streams were separated and collected in a separation section: naphtha, diesel and UCO.

[00106] The reactor temperature was adjusted during hydrocracking so that three different conversion levels in the mid 50s, mid 60s and mid 70s were achieved for both of feeds A and B. Generally, the catalyst system responded with about 1 % conversion change per 1 °F of temperature change. Processing of the blend feed B required temperatures about 10 °F higher in order to achieve similar conversion levels compared to feed A. Feed A was hydroprocessed at temperatures in the range from 748 °F to 768 °F, and feed B was hydroprocessed at temperatures in the range from 758 °F to 775 °F. UCO product samples from all six yield periods were prepared and analyzed, and three cuts of equal volumes were also separated from each yield period.

[00107] Table 2 presents four 12-hour yield periods with different conversion levels obtained with feed A.

Table 2

| FEED                            | A     |        | A     |        | A     |        | A     |        |
|---------------------------------|-------|--------|-------|--------|-------|--------|-------|--------|
| 12-HOUR PERIOD                  | 1     |        | 2     |        | 3     |        | 4     |        |
| LHSV, h <sup>-1</sup>           | 0.8   |        | 0.8   |        | 0.8   |        | 0.8   |        |
| PRESSURE (PSIG)                 | 2300  |        | 2300  |        | 2300  |        | 2300  |        |
| H <sub>2</sub> AVG PRESS (PSIA) | 2037  |        | 2013  |        | 2011  |        | 1987  |        |
| NO LOSS PROD. YIELDS            | Wt. % | Vol. % | Wt. % | Vol. % | Wt. % | Vol. % | Wt. % | Vol. % |
| C1                              | 0.16  |        | 0.21  |        | 0.2   |        | 0.25  |        |
| C2                              | 0.2   |        | 0.25  |        | 0.23  |        | 0.31  |        |
| C3                              | 0.53  |        | 0.69  |        | 0.67  |        | 0.94  |        |
| IC4                             | 0.68  | 1.11   | 0.92  | 1.5    | 0.96  | 1.58   | 1.36  | 2.23   |
| NC4                             | 0.64  | 1      | 0.63  | 0.99   | 0.79  | 1.24   | 1.15  | 1.82   |
| C5-167 °F                       | 2.48  | 3.47   | 3.5   | 4.92   | 3.61  | 5.07   | 5.29  | 7.43   |
| 167-311 °F                      | 11.63 | 14.18  | 14.68 | 18.08  | 14.5  | 17.83  | 18.72 | 23.06  |
| 311-482 °F                      | 16.75 | 19.11  | 21.2  | 24.49  | 20.89 | 24.11  | 25.2  | 29.26  |
| 482-710 °F                      | 23.67 | 25.84  | 25.03 | 27.55  | 24.78 | 27.26  | 23.91 | 26.48  |
| 710 °F- EP                      | 42.97 | 46.04  | 32.89 | 35.52  | 33.37 | 36.04  | 23.1  | 25.21  |
| TOTAL C4-                       | 2.2   |        | 2.68  |        | 2.85  |        | 4.01  |        |
| TOTAL C5+                       | 97.5  | 108.64 | 97.31 | 110.55 | 97.16 | 110.31 | 96.22 | 111.43 |

|                                    |       |       |       |       |
|------------------------------------|-------|-------|-------|-------|
| H <sub>2</sub> consumption (SCF/B) | 1324  | 1488  | 1496  | 1642  |
| Apparent Conversion 710°F-, wt.%   | 57.0  | 67.1  | 66.6  | 76.9  |
| UCO properties                     |       |       |       |       |
| Viscosity Index, VI                | 133   | 137   | 137   | 145   |
| Viscosity at 70 °C, Vis70, cSt     | 10.66 | 9.999 | 10.02 | 8.766 |
| Viscosity at 100 °C, Vis100, cSt   | 5.415 | 5.162 | 5.173 | 4.683 |
| Pour point, °C                     | 42    | 41    | 42    | 41    |
| DWO in UCO, wt%                    | 77%   | 74%   | 80%   | 78%   |
| DWO properties                     |       |       |       |       |
| VI                                 | 115   | 121   | 125   | 128   |
| Viscosity at 40 °C, Vis40, cSt     | 32.33 | 28.48 | 28.32 |       |
| Viscosity at 100 °C, Vis100, cSt   | 5.663 | 5.309 | 5.349 | 4.731 |

[00108] Table 3 presents four 12-hour yield periods with different conversion levels obtained with feed B.

Table 3

| FEED                               | B     |        | B     |        | B     |        | B     |        |
|------------------------------------|-------|--------|-------|--------|-------|--------|-------|--------|
| 12-HOUR PERIOD                     | 1     |        | 2     |        | 3     |        | 4     |        |
| LHSV, h <sup>-1</sup>              | 0.8   |        | 0.8   |        | 0.8   |        | 0.8   |        |
| PRESSURE (PSIG)                    | 2300  |        | 2300  |        | 2300  |        | 2300  |        |
| H <sub>2</sub> AVG PRESS (PSIA)    | 2017  |        | 1986  |        | 1987  |        | 1960  |        |
| Product yields                     | Wt. % | Vol. % | Wt. % | Vol. % | Wt. % | Vol. % | Wt. % | Vol. % |
| C1                                 | 0.19  |        | 0.25  |        | 0.24  |        | 0.31  |        |
| C2                                 | 0.24  |        | 0.3   |        | 0.3   |        | 0.38  |        |
| C3                                 | 0.49  |        | 0.69  |        | 0.66  |        | 0.91  |        |
| IC4                                | 0.39  | 0.65   | 0.71  | 1.16   | 0.66  | 1.09   | 1.02  | 1.69   |
| NC4                                | 0.52  | 0.82   | 0.75  | 1.19   | 0.74  | 1.17   | 1     | 1.59   |
| C5-167 °F                          | 1.96  | 2.77   | 2.98  | 4.19   | 2.86  | 4.03   | 4.35  | 6.13   |
| 167-311 °F                         | 8.69  | 10.59  | 12.71 | 15.61  | 11.84 | 14.52  | 16.5  | 20.32  |
| 311-482 °F                         | 14.13 | 15.98  | 19.82 | 22.74  | 18.52 | 21.19  | 23.77 | 27.47  |
| 482-710 °F                         | 25.07 | 27.2   | 25.7  | 28.14  | 25.5  | 27.86  | 25.34 | 27.9   |
| 710 °F - EP                        | 48.06 | 51.35  | 36.19 | 39.1   | 38.69 | 41.62  | 26.73 | 29.04  |
| TOTAL C4-                          | 1.84  |        | 2.71  |        | 2.6   |        | 3.62  |        |
| TOTAL C5+                          | 97.92 | 107.88 | 97.41 | 109.78 | 97.41 | 109.2  | 96.69 | 110.87 |
| H <sub>2</sub> consumption (SCF/B) | 1318  |        | 1537  |        | 1480  |        | 1660  |        |
| Apparent Conversion 710°F-, wt%    | 51.9  |        | 63.8  |        | 61.3  |        | 73.3  |        |

|                     |       |       |       |       |
|---------------------|-------|-------|-------|-------|
| UCO properties      | 0     | 0     | 0     | 0     |
| Viscosity Index, VI | 126   | 134   | 132   | 137   |
| Vis70, cSt          | 11.24 | 10.24 | 10.56 | 9.367 |
| Vis100, cSt         | 5.603 | 5.246 | 5.364 | 4.895 |
| Pour point, °C      | 42    | 42    | 42    | 38    |
| DWO in UCO, wt%     | 81%   | 78%   | 74%   | 81%   |
| DWO properties      |       |       |       |       |
| VI                  |       | 121   | 116   | 124   |
| Vis40, cSt          |       | 29.43 | 31.44 | 25.53 |
| Vis100, cSt         |       | 5.42  | 5.577 | 5.008 |

[00109] Table 4 presents two extended yield periods with conversion levels in the 60s and 70s obtained with the blend feed B.

Table 4

| FEED                               |       | B      |       | B      |
|------------------------------------|-------|--------|-------|--------|
| RUN                                |       | 5      |       | 6      |
| REACTOR 1 TEMP (°F)                |       | 763    |       | 775    |
| LHSV, h <sup>-1</sup>              |       | 0.8    |       | 0.8    |
| PRESSURE (PSIG)                    |       | 2300   |       | 2300   |
| H <sub>2</sub> AVG PRESS (PSIA)    |       | 1988   |       | 1962   |
| PROD. YIELDS                       |       |        |       |        |
| C1                                 | 0.25  |        | 0.31  |        |
| C2                                 | 0.3   |        | 0.38  |        |
| C3                                 | 0.69  |        | 0.93  |        |
| IC4                                | 0.7   | 1.16   | 1.04  | 1.71   |
| NC4                                | 0.76  | 1.21   | 1.01  | 1.6    |
| C5-167 °F                          | 3.04  | 4.28   | 4.39  | 6.18   |
| 167-311 °F                         | 12.62 | 15.5   | 16.79 | 20.69  |
| 311-482 °F                         | 19.7  | 22.59  | 23.59 | 27.28  |
| 482-710 °F                         | 25.58 | 27.98  | 26    | 28.64  |
| 710 °F - EP                        | 36.47 | 39.36  | 25.88 | 28.11  |
| TOTAL C4-                          | 2.7   |        | 3.67  |        |
| TOTAL C5+                          | 97.41 | 109.71 | 96.66 | 110.91 |
| H <sub>2</sub> consumption (SCF/B) | 1535  |        | 1672  |        |
| Apparent Conversion 710°F-, wt%    | 63.5  |        | 74.1  |        |

[00110] Table 5 presents the properties of the UCO product samples from the six extended yield periods (both of feeds A and B at three conversion levels, X, each).

Table 5

| Feed | X, % | API  | S, ppm | N, ppm | H, wt% | VI  | Vis70, cSt | Vis100, cSt |
|------|------|------|--------|--------|--------|-----|------------|-------------|
| A    | 55   | 33.5 | 20     | 1.4    | 13.98  | 131 | 10.69      | 5.414       |
| A    | 66   | 34.7 | 9      | <0.3   | 14.13  | 137 | 10.01      | 5.163       |

|   |      |      |    |      |       |     |       |       |
|---|------|------|----|------|-------|-----|-------|-------|
| A | 76   | 36.3 | <5 | <0.3 | 14.32 | 141 | 8.905 | 4.719 |
| B | 50   | 32.2 | 31 | 5.4  | 13.87 | 126 | 11.27 | 5.617 |
| B | 63.5 | 33.8 | 14 | 1.6  | 13.97 | 134 | 10.34 | 5.283 |
| B | 74.1 | 34.9 | 9  | 1.0  | 14.03 | 138 | 9.325 | 4.883 |

[00111] FIG. 2 shows a plot of VI as a function of percentage hydrocracking conversion, X, for UCO obtained directly from hydrocracking feed A (indicated using filled circles) and feed B (indicated using filled squares). Although the VI increases continuously as a function of the conversion level for both feeds, the VI of the UCO obtained from the blend feed B is consistently lower than that of the UCO obtained from feed A for the same conversion level.

[00112] FIG. 3 shows a plot of VI as a function of viscosity at 100 °C (i.e., 212 °F) for UCO obtained directly from hydrocracking feed A (indicated using filled circles) and feed B (indicated using filled squares). The VI decreases continuously as a function of the viscosity for the UCO obtained from both feeds A and B. The VI of UCO obtained from the blend feed B is lower than that of UCO obtained from straight-run feed A at lower viscosities.

[00113] Samples of the six UCOs presented in Table 5 were dewaxed, by cooling the samples to 5 °F (i.e., -15 °C) and filtering out solidified wax, to produce six dewaxed oil (DWO) samples. Properties of the six dewaxed oil samples are set out in Table 6.

Table 6

| Feed | X, % | Sample, g | Oil, g | Wax, g | Dewaxed Oil |     |            |             |
|------|------|-----------|--------|--------|-------------|-----|------------|-------------|
|      |      |           |        |        | DWO, wt%    | VI  | Vis40, cSt | Vis100, cSt |
| A    | 55   | 86.2      | 63.91  | 21.88  | 74.5%       | 115 | 32.36      | 5.671       |
| A    | 66   | 88.64     | 67.85  | 20.36  | 76.9%       | 122 | 28.46      | 5.32        |
| A    | 76   | 88.07     | 62.04  | 25.57  | 70.8%       | 126 | 23.33      | 4.764       |
| B    | 50   | 89.7      | 68.6   | 20.65  | 76.9%       | 108 | 35.78      | 5.922       |
| B    | 63.5 | 85.08     | 67.25  | 17.39  | 79.5%       | 118 | 30.16      | 5.466       |
| B    | 74.1 | 89.91     | 63.45  | 25.93  | 71.0%       | 123 | 25.52      | 4.984       |

[00114] This data is also plotted in FIGs. 4 and 5. In particular, FIG. 4 shows a plot of VI as a function of percentage hydrocracking conversion for dewaxed oil obtained by dewaxing UCO obtained directly from hydrocracking of feed A (filled circles) and feed B (filled squares). FIG. 5 shows a plot of VI as a function of viscosity at 100 °C (i.e., 212 °F) for dewaxed oil obtained by dewaxing UCO obtained directly from hydrocracking feed A (filled circles) and feed B (filled squares).

[00115] As can be seen in Table 6 and FIGs. 4 and 5, UCO made from both feeds A and B is suitable for making API Group II base oils, which require VI values from 80 to 120. It is also possible to make API Group III base oils, which require VI values greater than 120, from UCO obtained from straight-run feed A. However, it is more difficult to produce API Group III base oils from UCO obtained directly from

hydrocracking blend feed B, particularly when targeting a viscosity of 4 cSt at 100 °C (i.e., 212 °F). In particular, when processing feed B, a conversion level of about 70 % or above was needed in order to achieve a dewaxed oil VI greater than 120; however, the viscosity at 100 °C (i.e., 212 °F) for such a dewaxed oil will be close to 5 cSt.

[00116] The six UCO samples identified in Table 6 were cut by distillation into three parts of equal volume having different viscosities. The properties of the three cuts, with Cut 1 being the lightest and Cut 3 the heaviest, are set out in Tables 7 and 8.

Table 7

| Feed | X, % | API   |       |       | VI    |       |       |
|------|------|-------|-------|-------|-------|-------|-------|
|      |      | Cut 1 | Cut 2 | Cut 3 | Cut 1 | Cut 2 | Cut 3 |
| A    | 55   | 34    | 34    | 32.6  | 116   | 127   | 133   |
| A    | 66   | 35.2  | 35.2  | 33.8  | 121   | 132   | 140   |
| A    | 76   | 37    | 36.9  | 35.1  | 128   | 136   | 145   |
| B    | 50   | 32.2  | 32.7  | 31.8  | 110   | 123   | 132   |
| B    | 63.5 | 34.1  | 34.4  | 33    | 117   | 128   | 136   |
| B    | 74.1 | 35.3  | 35.7  | 34    | 120   | 132   | 140   |

Table 8

| Feed | X, % | Vis70, cSt |       |       | Vis100, cSt |       |       |
|------|------|------------|-------|-------|-------------|-------|-------|
|      |      | Cut 1      | Cut 2 | Cut 3 | Cut 1       | Cut 2 | Cut 3 |
| A    | 55   | 7.158      | 9.411 | 17.36 | 3.847       | 4.86  | 8.155 |
| A    | 66   | 6.878      | 8.73  | 15.82 | 3.745       | 4.599 | 7.619 |
| A    | 76   | 6.234      | 7.711 | 13.91 | 3.483       | 4.175 | 6.881 |
| B    | 50   | 7.546      | 9.844 | 18.11 | 3.987       | 5.01  | 8.441 |
| B    | 63.5 | 6.991      | 9.021 | 16.76 | 3.78        | 4.702 | 7.963 |
| B    | 74.1 | 6.457      | 8.208 | 15.25 | 3.556       | 4.375 | 7.397 |

[00117] FIG. 6 shows a plot of VI as a function of viscosity at 100 °C (i.e., 212 °F) for the different Cuts 1, 2 and 3 obtained from feeds A and B at three different percentage hydrocracking conversions, X. The VI increases as a function of the viscosity for both feeds A and B processed under all conditions.

[00118] The distillation cuts of the UCO samples were again dewaxed by cooling to 5 °F (i.e., -15 °C) and filtering out the solidified wax. Properties of the resultant dewaxed oils are set out in Table 9.

Table 9

| Feed | X, % | VI    |       |       | Vis100, cSt |       |       |
|------|------|-------|-------|-------|-------------|-------|-------|
|      |      | Cut 1 | Cut 2 | Cut 3 | Cut 1       | Cut 2 | Cut 3 |
| A    | 55   | 104   | 114   | 113   | 4.006       | 5.146 | 8.980 |
| A    | 66   | 110   | 119   | 120   | 3.865       | 4.794 | 8.193 |
| A    | 76   | 116   | 124   | 126   | 3.549       | 4.290 | 7.233 |

|   |      |     |     |     |       |       |       |
|---|------|-----|-----|-----|-------|-------|-------|
| B | 50   | 96  | 108 | 107 | 4.173 | 5.346 | 9.387 |
| B | 63.5 | 106 | 116 | 120 | 3.910 | 4.933 | 8.832 |
| B | 74.1 | 110 | 120 | 122 | 3.651 | 4.541 | 7.924 |

[00119] FIG. 7 shows a plot of VI as a function of viscosity at 100 °C (i.e., 212 °F) for the different cuts of dewaxed oil given in Table 9. As seen in Table 9 and FIG. 7, the lighter fraction of the UCO made from feed A at high hydrocracking conversion levels has properties suitable for use in the manufacture of API Group III base oils (i.e., a VI greater than 120 at a viscosity of about 4 cSt at 100 °C). In contrast, even high hydrocracking conversion levels cannot produce a UCO suited for the manufacture of Group III base oils when starting with the feed blend B.

[00120] Samples of the three distillation cuts of the UCO obtained from hydrocracking feed B at 63.5 % conversion were then subjected to upgrading in an upgrade reactor. In the upgrade reactor, the samples were contacted with hydrogen in the presence of a mild hydrocracking catalyst consisting of sulfided base metals, a small amount of a low activity Y-zeolite, amorphous silica-alumina and alumina. The catalyst extrudates had a diameter of about 1.5 mm and were shortened to a length/diameter ratio of about 2 to 3 before use. Glass beads of 60/80 mesh size were used as interstitial packing in the catalyst layers in the reactor. The upgrade process was carried out at temperatures between 680 °F and 710 °F (i.e., between 360 °C and 377 °C) and at a gauge pressure of 2300 psi, with a liquid hourly space velocity between 2.5 hr<sup>-1</sup> and 5 hr<sup>-1</sup> at a hydrogen to oil ratio of 4000 scf/bbl. The hydrogen consumption was, depending on conditions, between 20 and 600 scf per barrel of liquid hydrocarbon feed. The conversion levels achieved in the upgrade reactor were in the range 20% to 50 %. When combining the initial conversion level of feed B in the hydrocracker with the additional conversion of the UCO in the upgrade reactor, the overall conversion levels relative to the original feed B were between 72 and 81 %. Upgraded oil samples obtained from the upgrade process were again dewaxed by cooling to 5 °F (i.e., -15 °C) and filtering out the solidified wax.

[00121] FIG. 8 shows a plot of the VI as a function of viscosity at 100 °C (i.e., 212 °F) for the dewaxed, upgraded UCO obtained from the three distillation cuts, as compared to the non-upgraded dewaxed oil obtained from hydrocracking feed B at 63.5 and 74 % conversion levels. As can be seen from FIG. 8, the upgrade process significantly increases the VI of the dewaxed oil at all viscosities, whether compared to the dewaxed oil obtained from feed B hydrocracked to the same initial level (63.5 %) or to the dewaxed oil obtained from feed B hydrocracked to the same final level (74 %). The VI of the dewaxed, upgraded oil is, in particular, greater than 120 at a viscosity of 4 cSt at 100 °C, and is therefore suitable for producing API Grade III base oils.

[00122] FIG. 9 shows a plot comparing the VI as a function of viscosity at 100 °C (i.e., 212 °F) for the dewaxed, upgraded UCO shown in FIG. 8 with dewaxed oil obtained by hydrocracking straight-run

feed A. From FIG. 9, it can be seen that the upgrade process enables the same, or better, properties to be obtained from blend feed B as compared to feed A processed without upgrade.

[00123] For the avoidance of doubt, the present application is directed to the subject-matter described in the following numbered paragraphs:

1. Method of producing a base oil product, the method comprising:  
hydroprocessing unconverted oil from a hydrocracker to produce upgraded unconverted oil; and  
dewaxing the upgraded unconverted oil to produce the base oil product.
2. The method according to claim 1, further comprising, prior to hydroprocessing the unconverted oil from the hydrocracker:  
hydrocracking a hydrocarbonaceous feedstock in the hydrocracker to produce a hydrocracked effluent comprising the unconverted oil; and  
separating the unconverted oil from the hydrocracked effluent.
3. The method according to claim 2, wherein the hydrocarbonaceous feedstock has a boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprises a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO).
4. The method according to any preceding claim, wherein hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil comprises increasing the viscosity index (VI) of the unconverted oil.
5. The method according to any preceding claim, wherein hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil comprises contacting the unconverted oil with a hydroprocessing catalyst in the presence of hydrogen under hydroprocessing conditions.
6. The method according to claim 5, wherein the hydroprocessing catalyst and/or the hydroprocessing conditions are selected such that VI-increasing molecular transformations predominate in the hydroprocessing.
7. The method according to claim 5 or claim 6, wherein the hydroprocessing catalyst comprises:  
(a) one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof; and  
(b) a catalyst support, for example a porous refractory support, for example an alumina, a silica, an amorphous silica-alumina material, or a combination thereof; and, optionally,  
(c) one or more molecular sieves, for example zeolites.
8. The method according to any of claims 5 to 7, wherein the hydroprocessing conditions comprise:

(a) a reaction temperature from about 400 °F to about 950 °F (from about 204 °C to about 510 °C), for example from about 650 °F to about 850 °F (from about 343 °C to about 454 °C);

(b) a reaction gauge pressure from about 500 psi to about 5000 psi (from about 3447 kPa to about 34474 kPa), for example, from about 1500 psi to about 2500 psi (from about 10342 kPa to about 17237 kPa), or from about 1200 psi to about 2500 psi from about 8274 kPa to about 17237 kPa);

(c) an LHSV from about 0.1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example from about 0.2 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>, or from about 0.2 hr<sup>-1</sup> to about 2.5 hr<sup>-1</sup>, or from about 0.1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and/or

(d) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed (from about 17.8 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), for example from about 200 scf to about 2500 scf per barrel (from about 35.6 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), or from about 100 scf to about 1500 scf per barrel (from about 17.8 to about 267 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed).

9. The method according to any preceding claim, wherein hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil comprises hydrotreating, hydroisomerizing and/or hydrocracking the unconverted oil from the hydrocracker.

10. The method according to claim 9, where dependent on claim 2, wherein hydroprocessing the unconverted oil from the hydrocracker comprises hydrocracking the unconverted oil from the hydrocracker and wherein the level of hydrocracking conversion during hydrocracking the unconverted oil from the hydrocracker is less than the level of hydrocracking conversion during hydrocracking the hydrocarbonaceous feedstock in the hydrocracker.

11. The method according to claim 10, wherein hydrocracking the unconverted oil from the hydrocracker takes place at a hydrocracking conversion of from about 5 % to about 30 %, and wherein hydrocracking the hydrocarbonaceous feedstock in the hydrocracker takes place at a hydrocracking conversion of from about 30 % to about 70 %.

12. The method according to any preceding claim, wherein, prior to hydroprocessing the unconverted oil from the hydrocracker, the unconverted oil comprises:

(a) no greater than about 100 ppm of sulfur;

(b) no greater than about 20 ppm of nitrogen; and/or

(c) no greater than about 1 ppm of nickel, vanadium and/or copper.

13. The method according to any preceding claim, wherein, prior to hydroprocessing the unconverted oil from the hydrocracker, the unconverted oil has:

(a) an API gravity of from about 25 to about 45;

(b) a TBP 95% point from about 800 °F to about 1100 °F (from about 427 °C to about 593 °C); and/or

(c) a viscosity index (VI), measured according to ASTM D-2270, of from about 100 to about 150 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

14. The method according to any preceding claim, wherein hydroprocessing the unconverted oil to produce the base oil product comprises increasing the viscosity index (VI) of the unconverted oil by about 5 to by about 30.

15. The method according to any preceding claim, wherein the base oil product has a viscosity index (VI), measured according to ASTM D-2270, of no less than 120 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

16. The method according to any preceding claim, wherein the base oil product is a Group III base oil product.

17. The method according to any preceding claim, wherein hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil takes place in an unconverted oil upgrade reactor.

18. Method of modifying an existing base oil product manufacturing process to increase a viscosity index (VI) of the base oil produced, the existing base oil product manufacturing process comprising:  
hydrocracking a hydrocarbonaceous feedstock in a hydrocracker to produce a hydrocracked effluent comprising unconverted oil;  
separating the unconverted oil from the hydrocracked effluent; and  
dewaxing the unconverted oil separated from the hydrocracked effluent to produce the base oil product;  
wherein the method of modifying the existing base oil product manufacturing process comprises:  
hydroprocessing the unconverted oil separated from the hydrocracked effluent prior to dewaxing the unconverted oil to produce the base oil product.

19. The method according to claim 18, wherein the hydrocarbonaceous feedstock has a boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprises a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO).

20. The method according to claim 18 or claim 19, wherein hydroprocessing the unconverted oil comprises increasing the viscosity index (VI) of the unconverted oil.

21. The method according to any of claims 18 to 20, wherein hydroprocessing the unconverted oil comprises contacting the unconverted oil with a hydroprocessing catalyst in the presence of hydrogen under hydroprocessing conditions.

22. The method according to claim 21, wherein the hydroprocessing catalyst and/or the hydroprocessing conditions are selected such that VI-increasing molecular transformations predominate in the hydroprocessing.
23. The method according to claim 21 or claim 22, wherein the hydroprocessing catalyst comprises:
- (a) one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof; and
  - (b) a catalyst support, for example a porous refractory support, for example an alumina, a silica, an amorphous silica-alumina material, or a combination thereof; and, optionally,
  - (c) one or more molecular sieves, for example zeolites.
24. The method according to any of claims 21 to 23, wherein the hydroprocessing conditions comprise:
- (a) a reaction temperature from about 400 °F to about 950 °F (from about 204 °C to about 510 °C), for example from about 650 °F to about 850 °F (from about 343 °C to about 454 °C);
  - (b) a reaction gauge pressure from about 500 psi to about 5000 psi (from about 3447 kPa to about 34474 kPa), for example, from about 1500 psi to about 2500 psi (from about 10342 kPa to about 17237 kPa), or from about 1200 psi to about 2500 psi from about 8274 kPa to about 17237 kPa);
  - (c) an LHSV from about 0.1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example from about 0.2 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>, or from about 0.2 hr<sup>-1</sup> to about 2.5 hr<sup>-1</sup>, or from about 0.1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and/or
  - (d) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed (from about 17.8 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), for example from about 200 scf to about 2500 scf per barrel (from about 35.6 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), or from about 100 scf to about 1500 scf per barrel (from about 17.8 to about 267 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed).
25. The method according to any of claims 18 to 24, wherein hydroprocessing the unconverted oil comprises hydrotreating, hydroisomerizing and/or hydrocracking the unconverted oil.
26. The method according to claim 25, wherein hydroprocessing the unconverted oil comprises hydrocracking the unconverted oil and wherein the level of hydrocracking conversion during hydrocracking the unconverted oil is less than the level of hydrocracking conversion during hydrocracking the hydrocarbonaceous feedstock in the hydrocracker.
27. The method according to claim 26, wherein hydrocracking the unconverted takes place at a hydrocracking conversion of from about 5 % to about 30 %, and wherein hydrocracking the hydrocarbonaceous feedstock in the hydrocracker takes place at a hydrocracking conversion of from about 30 % to about 70 %.
28. The method according to any of claims 18 to 27, wherein, prior to hydroprocessing the unconverted oil, the unconverted oil comprises:

- (a) no greater than about 100 ppm of sulfur;
- (b) no greater than about 20 ppm of nitrogen; and/or
- (c) no greater than about 1 ppm of nickel, vanadium and/or copper.

29. The method according to any of claims 18 to 28, wherein, prior to hydroprocessing the unconverted oil, the unconverted oil has:

- (a) an API gravity of from about 25 to about 45;
- (b) a TBP 95% point from about 800 °F to about 1100 °F (from about 427 °C to about 593 °C); and/or
- (c) a viscosity index (VI), measured according to ASTM D-2270, of from about 100 to about 150 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

30. The method according to any of claims 18 to 29, wherein hydroprocessing the unconverted oil comprises increasing the viscosity index (VI) of the unconverted oil by about 5 to by about 30.

31. The method according to any of claims 18 to 30, wherein the base oil product has a viscosity index (VI), measured according to ASTM D-2270, of no less than 120 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

32. The method according to any of claims 18 to 31, wherein the base oil product is a Group III base oil product.

33. The method according to any of claims 18 to 32, wherein hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil takes place in an unconverted oil upgrade reactor.

34. System for producing a base oil product, the system comprising:

- a hydrocracker for hydrocracking a hydrocarbonaceous feedstock to produce a hydrocracked effluent comprising unconverted oil; and
- an unconverted oil upgrade reactor for hydroprocessing unconverted oil, separated from the hydrocracked effluent, to produce upgraded unconverted oil.

35. The system according to claim 34, further comprising:

- a dewaxing unit for dewaxing unconverted oil, produced by the unconverted oil upgrade reactor, to produce the base oil product.

36. The system according to claim 34 or claim 35, wherein the hydrocarbonaceous feedstock has a boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprises a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO).

37. The system according to any of claims 34 to 36, wherein the unconverted oil upgrade reactor is configured to increase the viscosity index (VI) of the unconverted oil.

38. The system according to any of claims 34 to 37, wherein the unconverted oil upgrade reactor has a hydroprocessing zone comprising one or more beds containing a hydroprocessing catalyst, the hydroprocessing zone being maintained at hydroprocessing conditions.

39. The system according to claim 38, wherein the hydroprocessing catalyst and/or the hydroprocessing conditions are selected such that VI-increasing molecular transformations predominate in the hydroprocessing.

40. The system according to claim 38 or claim 39, wherein the hydroprocessing catalyst comprises:

- (a) one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof; and
- (b) a catalyst support, for example a porous refractory support, for example an alumina, a silica, an amorphous silica-alumina material, or a combination thereof; and, optionally,
- (c) one or more molecular sieves, for example zeolites.

41. The system according to any of claims 38 to 40, wherein the hydroprocessing conditions comprise:

- (a) a reaction temperature from about 400 °F to about 950 °F (from about 204 °C to about 510 °C), for example from about 650 °F to about 850 °F (from about 343 °C to about 454 °C);
- (b) a reaction gauge pressure from about 500 psi to about 5000 psi (from about 3447 kPa to about 34474 kPa), for example, from about 1500 psi to about 2500 psi (from about 10342 kPa to about 17237 kPa), or from about 1200 psi to about 2500 psi from about 8274 kPa to about 17237 kPa);
- (c) an LHSV from about 0.1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example from about 0.2 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>, or from about 0.2 hr<sup>-1</sup> to about 2.5 hr<sup>-1</sup>, or from about 0.1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and/or
- (d) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed (from about 17.8 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), for example from about 200 scf to about 2500 scf per barrel (from about 35.6 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), or from about 100 scf to about 1500 scf per barrel (from about 17.8 to about 267 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed).

42. The system according to any of claims 38 to 41, wherein hydroprocessing the unconverted oil comprises hydrotreating, hydroisomerizing and/or hydrocracking the unconverted oil.

43. The system according to claim 42, wherein hydroprocessing the unconverted oil comprises hydrocracking the unconverted oil and wherein the hydroprocessing zone and the hydrocracker are configured such that the level of hydrocracking conversion during hydrocracking the unconverted oil in the hydroprocessing zone is less than the level of hydrocracking conversion during hydrocracking the hydrocarbonaceous feedstock in the hydrocracker.

44. The system according to claim 43, wherein the hydroprocessing zone and the hydrocracker are configured such that hydrocracking the unconverted oil takes place at a hydrocracking conversion of

from about 5 % to about 30 % and such that hydrocracking the hydrocarbonaceous feedstock in the hydrocracker takes place at a hydrocracking conversion of from about 30 % to about 70 %.

45. The system according to any of claims 34 to 44 configured to feed to the unconverted oil upgrade reactor unconverted oil from the hydrocracker comprising:

- (a) no greater than about 100 ppm of sulfur;
- (b) no greater than about 20 ppm of nitrogen; and/or
- (c) no greater than about 1 ppm of nickel, vanadium and/or copper.

46. The system according to any of claims 34 to 45 configured to feed to the unconverted oil upgrade reactor unconverted oil from the hydrocracker having:

- (a) an API gravity of from about 25 to about 45;
- (b) a TBP 95% point from about 800 °F to about 1100 °F (from about 427 °C to about 593 °C); and/or
- (c) a viscosity index (VI), measured according to ASTM D-2270, of from about 100 to about 150 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

47. The system according to any of claims 34 to 46, wherein the unconverted oil upgrade reactor is configured to increase the viscosity index (VI) of the unconverted oil by about 5 to by about 30.

48. The system according to any of claims 34 to 47 configured to produce a base oil product having a viscosity index (VI), measured according to ASTM D-2270, of no less than 120 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

49. The system according to any of claims 34 to 48 configured to produce a Group III base oil product.

50. The system according to any of claims 34 to 49, wherein the system is a base oil production plant.

51. Method of modifying an existing system for producing a base oil product to increase a viscosity index (VI) of the base oil product, the existing system for producing the base oil product comprising:

a hydrocracker for hydrocracking a hydrocarbonaceous feedstock to produce a hydrocracked effluent comprising unconverted oil; and

a dewaxing unit for dewaxing unconverted oil, separated from the hydrocracked effluent, to produce the base oil product;

wherein the method of modifying the existing system comprises:

installing in the existing system an unconverted oil upgrade reactor for hydroprocessing the unconverted oil, separated from the hydrocracked effluent, prior to dewaxing the unconverted oil to produce the base oil product.

52. The method according to claim 51, wherein the hydrocarbonaceous feedstock has a boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprises a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO).
53. The method according to claim 51 or claim 52, wherein the unconverted oil upgrade reactor is configured to increase the viscosity index (VI) of the unconverted oil.
54. The method according to any of claims 51 to 53, wherein the unconverted oil upgrade reactor has a hydroprocessing zone comprising one or more beds containing a hydroprocessing catalyst, the hydroprocessing zone being maintained at hydroprocessing conditions.
55. The method according to claim 54, wherein the hydroprocessing catalyst and/or the hydroprocessing conditions are selected such that VI-increasing molecular transformations predominate in the hydroprocessing.
56. The method according to claim 54 or claim 55, wherein the hydroprocessing catalyst comprises:
- (a) one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof; and
  - (b) a catalyst support, for example a porous refractory support, for example an alumina, a silica, an amorphous silica-alumina material, or a combination thereof; and, optionally,
  - (c) one or more molecular sieves, for example zeolites.
57. The method according to any of claims 54 to 56, wherein the hydroprocessing conditions comprise:
- (a) a reaction temperature from about 400 °F to about 950 °F (from about 204 °C to about 510 °C), for example from about 650 °F to about 850 °F (from about 343 °C to about 454 °C);
  - (b) a reaction gauge pressure from about 500 psi to about 5000 psi (from about 3447 kPa to about 34474 kPa), for example, from about 1500 psi to about 2500 psi (from about 10342 kPa to about 17237 kPa), or from about 1200 psi to about 2500 psi from about 8274 kPa to about 17237 kPa);
  - (c) an LHSV from about 0.1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example from about 0.2 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>, or from about 0.2 hr<sup>-1</sup> to about 2.5 hr<sup>-1</sup>, or from about 0.1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and/or
  - (d) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed (from about 17.8 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), for example from about 200 scf to about 2500 scf per barrel (from about 35.6 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), or from about 100 scf to about 1500 scf per barrel (from about 17.8 to about 267 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed).
58. The method according to any of claims 51 to 57, wherein hydroprocessing the unconverted oil comprises hydrotreating, hydroisomerizing and/or hydrocracking the unconverted oil.
59. The method according to claim 58, wherein hydroprocessing the unconverted oil comprises hydrocracking the unconverted oil and wherein the hydroprocessing zone and the hydrocracker are

configured such that the level of hydrocracking conversion during hydrocracking the unconverted oil in the hydroprocessing zone is less than the level of hydrocracking conversion during hydrocracking the hydrocarbonaceous feedstock in the hydrocracker.

60. The method according to claim 59, wherein the hydroprocessing zone and the hydrocracker are configured such that hydrocracking the unconverted oil takes place at a hydrocracking conversion of from about 5 % to about 30 % and such that hydrocracking the hydrocarbonaceous feedstock in the hydrocracker takes place at a hydrocracking conversion of from about 30 % to about 70 %.

61. The method according to any of claims 51 to 60, wherein the method comprises configuring the existing system to feed to the unconverted oil upgrade reactor unconverted oil from the hydrocracker comprising:

- (a) no greater than about 100 ppm of sulfur;
- (b) no greater than about 20 ppm of nitrogen; and/or
- (c) no greater than about 1 ppm of nickel, vanadium and/or copper.

62. The method according to any of claims 51 to 61, wherein the method comprises configuring the existing system to feed to the unconverted oil upgrade reactor unconverted oil from the hydrocracker comprising:

- (a) an API gravity of from about 25 to about 45;
- (b) a TBP 95% point from about 800 °F to about 1100 °F (from about 427 °C to about 593 °C); and/or
- (c) a viscosity index (VI), measured according to ASTM D-2270, of from about 100 to about 150 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

63. The method according to any of claims 51 to 62, wherein the unconverted oil upgrade reactor is configured to increase the viscosity index (VI) of the unconverted oil by about 5 to by about 30.

64. The method according to any of claims 51 to 63, wherein, after modifying the existing system, the base oil product produced has a viscosity index (VI), measured according to ASTM D-2270, of no less than 120 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

65. The method according to any of claims 51 to 64, wherein, after modifying the existing system, the base oil product produced is a Group III base oil product.

66. The method according to any of claims 51 to 65, wherein the existing system is a base oil production plant.

67. An unconverted oil upgrade reactor for hydroprocessing unconverted oil, separated from the hydrocracked effluent of a hydrocracker, prior to dewaxing the unconverted oil to produce a base oil product, the unconverted oil upgrade reactor:

- (a) having a hydroprocessing zone comprising one or more beds containing a hydroprocessing catalyst, the hydroprocessing zone being maintained at hydroprocessing conditions; and
- (b) being configured to increase the viscosity index (VI) of the unconverted oil.

68. The unconverted oil upgrade reactor according to claim 67, wherein:

- (a) the hydroprocessing catalyst comprises:
  - (i) one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof; and
  - (ii) a catalyst support, for example a porous refractory support, for example an alumina, a silica, an amorphous silica-alumina material, or a combination thereof; and, optionally,
  - (iii) one or more molecular sieves, for example zeolites; and/or
- (b) the hydroprocessing conditions comprise:
  - (i) a reaction temperature from about 400 °F to about 950 °F (from about 204 °C to about 510 °C), for example from about 650 °F to about 850 °F (from about 343 °C to about 454 °C);
  - (ii) a reaction gauge pressure from about 500 psi to about 5000 psi (from about 3447 kPa to about 34474 kPa), for example, from about 1500 psi to about 2500 psi (from about 10342 kPa to about 17237 kPa), or from about 1200 psi to about 2500 psi from about 8274 kPa to about 17237 kPa);
  - (iii) an LHSV from about 0.1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example from about 0.2 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>, or from about 0.2 hr<sup>-1</sup> to about 2.5 hr<sup>-1</sup>, or from about 0.1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and/or
  - (iv) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed (from about 17.8 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), for example from about 200 scf to about 2500 scf per barrel (from about 35.6 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), or from about 100 scf to about 1500 scf per barrel (from about 17.8 to about 267 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed).

69. Base oil product produced (a) by the method according to any of claims 1 to 17, (b) using the system according to any of claims 34 to 50, or (c) using the system modified by the method according to any of claims 51 to 66.

70. Lubricant comprising the base oil product of claim 69.

71. Use of an upgraded unconverted oil in the manufacture of a base oil product to increase the viscosity index (VI) of the manufactured base oil product.

72. The use according to claim 71, wherein the manufacture of the base oil product comprises dewaxing the upgraded unconverted oil in a dewaxing unit.

73. The use according to claim 71 or claim 72, wherein the upgraded unconverted oil is obtained by hydroprocessing unconverted oil obtained from hydrocracking a hydrocarbonaceous feedstock having a

boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprising a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO).

74. Use of a dewaxed, upgraded unconverted oil as a base oil product in a lubricant to increase the viscosity index (VI) of the lubricant.

75. The use according to claim 74, wherein the dewaxed, upgraded unconverted oil is obtained by (a) hydroprocessing unconverted oil obtained from hydrocracking a hydrocarbonaceous feedstock having a boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprising a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO) and (b) dewaxing the hydroprocessed unconverted oil.

[00124] It will be understood that the invention is not limited to the embodiments described above and various modifications and improvements can be made without departing from the concepts described herein. Except where mutually exclusive, any of the features may be employed separately or in combination with any other features and the disclosure extends to and includes all combinations and sub-combinations of one or more features described herein.

**WHAT IS CLAIMED IS:**

1. Method of producing a base oil product, the method comprising:  
hydroprocessing unconverted oil from a hydrocracker in a separate unconverted oil upgrade reactor to produce upgraded unconverted oil; and  
dewaxing the upgraded unconverted oil to produce the base oil product.
2. The method according to claim 1, further comprising, prior to hydroprocessing the unconverted oil from the hydrocracker:  
hydrocracking a hydrocarbonaceous feedstock in the hydrocracker to produce a hydrocracked effluent comprising the unconverted oil; and  
separating the unconverted oil from the hydrocracked effluent.
3. The method according to claim 2, wherein the hydrocarbonaceous feedstock has a boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprises a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO).
4. The method according to any preceding claim, wherein hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil comprises increasing the viscosity index (VI) of the unconverted oil.
5. The method according to any preceding claim, wherein hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil comprises contacting the unconverted oil with a hydroprocessing catalyst in the presence of hydrogen under hydroprocessing conditions.
6. The method according to claim 5, wherein the hydroprocessing catalyst and/or the hydroprocessing conditions are selected such that VI-increasing molecular transformations predominate in the hydroprocessing.
7. The method according to claim 5 or claim 6, wherein the hydroprocessing catalyst comprises:
  - (a) one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof; and
  - (b) a catalyst support, for example a porous refractory support, for example an alumina, a silica, an amorphous silica-alumina material, or a combination thereof; and, optionally,
  - (c) one or more molecular sieves, for example zeolites.

8. The method according to any of claims 5 to 7, wherein the hydroprocessing conditions comprise:
- (a) a reaction temperature from about 400 °F to about 950 °F (from about 204 °C to about 510 °C), for example from about 650 °F to about 850 °F (from about 343 °C to about 454 °C);
  - (b) a reaction gauge pressure from about 500 psi to about 5000 psi (from about 3447 kPa to about 34474 kPa), for example, from about 1500 psi to about 2500 psi (from about 10342 kPa to about 17237 kPa), or from about 1200 psi to about 2500 psi from about 8274 kPa to about 17237 kPa);
  - (c) an LHSV from about 0.1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example from about 0.2 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>, or from about 0.2 hr<sup>-1</sup> to about 2.5 hr<sup>-1</sup>, or from about 0.1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and/or
  - (d) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed (from about 17.8 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), for example from about 200 scf to about 2500 scf per barrel (from about 35.6 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), or from about 100 scf to about 1500 scf per barrel (from about 17.8 to about 267 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed).
9. The method according to any preceding claim, wherein hydroprocessing the unconverted oil from the hydrocracker to produce upgraded unconverted oil comprises hydrotreating, hydroisomerizing and/or hydrocracking the unconverted oil from the hydrocracker.
10. The method according to claim 9, where dependent on claim 2, wherein hydroprocessing the unconverted oil from the hydrocracker comprises hydrocracking the unconverted oil from the hydrocracker and wherein the level of hydrocracking conversion during hydrocracking the unconverted oil from the hydrocracker is less than the level of hydrocracking conversion during hydrocracking the hydrocarbonaceous feedstock in the hydrocracker.
11. The method according to claim 10, wherein hydrocracking the unconverted oil from the hydrocracker takes place at a hydrocracking conversion of from about 5 % to about 30 %, and wherein hydrocracking the hydrocarbonaceous feedstock in the hydrocracker takes place at a hydrocracking conversion of from about 30 % to about 70 %.
12. The method according to any preceding claim, wherein, prior to hydroprocessing the unconverted oil from the hydrocracker, the unconverted oil comprises:
- (a) no greater than about 100 ppm of sulfur;
  - (b) no greater than about 20 ppm of nitrogen; and/or
  - (c) no greater than about 1 ppm of nickel, vanadium and/or copper.
13. The method according to any preceding claim, wherein, prior to hydroprocessing the unconverted oil from the hydrocracker, the unconverted oil has:

- (a) an API gravity of from about 25 to about 45;
  - (b) a TBP 95% point from about 800 °F to about 1100 °F (from about 427 °C to about 593 °C); and/or
  - (c) a viscosity index (VI), measured according to ASTM D-2270, of from about 100 to about 150 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).
14. The method according to any preceding claim, wherein hydroprocessing the unconverted oil to produce the base oil product comprises increasing the viscosity index (VI) of the unconverted oil by about 5 to by about 30.
15. The method according to any preceding claim, wherein the base oil product has a viscosity index (VI), measured according to ASTM D-2270, of no less than 120 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).
16. The method according to any preceding claim, wherein the base oil product is a Group III base oil product.
17. Method of modifying an existing base oil product manufacturing process to increase a viscosity index (VI) of the base oil produced, the existing base oil product manufacturing process comprising:
- hydrocracking a hydrocarbonaceous feedstock in a hydrocracker to produce a hydrocracked effluent comprising unconverted oil;
  - separating the unconverted oil from the hydrocracked effluent; and
  - dewaxing the unconverted oil separated from the hydrocracked effluent to produce the base oil product;
- wherein the method of modifying the existing base oil product manufacturing process comprises:
- hydroprocessing the unconverted oil separated from the hydrocracked effluent in a separate unconverted oil upgrade reactor prior to dewaxing the unconverted oil to produce the base oil product.
18. The method according to claim 17, wherein the hydrocarbonaceous feedstock has a boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprises a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO).
19. The method according to claim 17 or claim 18, wherein hydroprocessing the unconverted oil comprises increasing the viscosity index (VI) of the unconverted oil.
20. The method according to any of claims 17 to 19, wherein hydroprocessing the unconverted oil comprises contacting the unconverted oil with a hydroprocessing catalyst in the presence of hydrogen under hydroprocessing conditions.

21. The method according to claim 20, wherein the hydroprocessing catalyst and/or the hydroprocessing conditions are selected such that VI-increasing molecular transformations predominate in the hydroprocessing.
22. The method according to claim 20 or claim 21, wherein the hydroprocessing catalyst comprises:
- (a) one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof; and
  - (b) a catalyst support, for example a porous refractory support, for example an alumina, a silica, an amorphous silica-alumina material, or a combination thereof; and, optionally,
  - (c) one or more molecular sieves, for example zeolites.
23. The method according to any of claims 20 to 22, wherein the hydroprocessing conditions comprise:
- (a) a reaction temperature from about 400 °F to about 950 °F (from about 204 °C to about 510 °C), for example from about 650 °F to about 850 °F (from about 343 °C to about 454 °C);
  - (b) a reaction gauge pressure from about 500 psi to about 5000 psi (from about 3447 kPa to about 34474 kPa), for example, from about 1500 psi to about 2500 psi (from about 10342 kPa to about 17237 kPa), or from about 1200 psi to about 2500 psi from about 8274 kPa to about 17237 kPa);
  - (c) an LHSV from about 0.1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example from about 0.2 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>, or from about 0.2 hr<sup>-1</sup> to about 2.5 hr<sup>-1</sup>, or from about 0.1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and/or
  - (d) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed (from about 17.8 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), for example from about 200 scf to about 2500 scf per barrel (from about 35.6 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), or from about 100 scf to about 1500 scf per barrel (from about 17.8 to about 267 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed).
24. The method according to any of claims 17 to 23, wherein hydroprocessing the unconverted oil comprises hydrotreating, hydroisomerizing and/or hydrocracking the unconverted oil.
25. The method according to claim 24, wherein hydroprocessing the unconverted oil comprises hydrocracking the unconverted oil and wherein the level of hydrocracking conversion during hydrocracking the unconverted oil is less than the level of hydrocracking conversion during hydrocracking the hydrocarbonaceous feedstock in the hydrocracker.
26. The method according to claim 25, wherein hydrocracking the unconverted takes place at a hydrocracking conversion of from about 5 % to about 30 %, and wherein hydrocracking the hydrocarbonaceous feedstock in the hydrocracker takes place at a hydrocracking conversion of from about 30 % to about 70 %.

27. The method according to any of claims 17 to 26, wherein, prior to hydroprocessing the unconverted oil, the unconverted oil comprises:

- (a) no greater than about 100 ppm of sulfur;
- (b) no greater than about 20 ppm of nitrogen; and/or
- (c) no greater than about 1 ppm of nickel, vanadium and/or copper.

28. The method according to any of claims 17 to 27, wherein, prior to hydroprocessing the unconverted oil, the unconverted oil has:

- (a) an API gravity of from about 25 to about 45;
- (b) a TBP 95% point from about 800 °F to about 1100 °F (from about 427 °C to about 593 °C); and/or
- (c) a viscosity index (VI), measured according to ASTM D-2270, of from about 100 to about 150 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

29. The method according to any of claims 17 to 28, wherein hydroprocessing the unconverted oil comprises increasing the viscosity index (VI) of the unconverted oil by about 5 to by about 30.

30. The method according to any of claims 17 to 29, wherein the base oil product has a viscosity index (VI), measured according to ASTM D-2270, of no less than 120 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

31. The method according to any of claims 17 to 30, wherein the base oil product is a Group III base oil product.

32. System for producing a base oil product, the system comprising:

- a hydrocracker for hydrocracking a hydrocarbonaceous feedstock to produce a hydrocracked effluent comprising unconverted oil; and
- a separate unconverted oil upgrade reactor for hydroprocessing unconverted oil, separated from the hydrocracked effluent, to produce upgraded unconverted oil.

33. The system according to claim 32, further comprising:

- a dewaxing unit for dewaxing unconverted oil, produced by the unconverted oil upgrade reactor, to produce the base oil product.

34. The system according to claim 32 or claim 33, wherein the hydrocarbonaceous feedstock has a boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprises a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO).

35. The system according to any of claims 32 to 34, wherein the unconverted oil upgrade reactor is configured to increase the viscosity index (VI) of the unconverted oil.
36. The system according to any of claims 32 to 35, wherein the unconverted oil upgrade reactor has a hydroprocessing zone comprising one or more beds containing a hydroprocessing catalyst, the hydroprocessing zone being maintained at hydroprocessing conditions.
37. The system according to claim 36, wherein the hydroprocessing catalyst and/or the hydroprocessing conditions are selected such that VI-increasing molecular transformations predominate in the hydroprocessing.
38. The system according to claim 36 or claim 37, wherein the hydroprocessing catalyst comprises:
- (a) one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof; and
  - (b) a catalyst support, for example a porous refractory support, for example an alumina, a silica, an amorphous silica-alumina material, or a combination thereof; and, optionally,
  - (c) one or more molecular sieves, for example zeolites.
39. The system according to any of claims 36 to 38, wherein the hydroprocessing conditions comprise:
- (a) a reaction temperature from about 400 °F to about 950 °F (from about 204 °C to about 510 °C), for example from about 650 °F to about 850 °F (from about 343 °C to about 454 °C);
  - (b) a reaction gauge pressure from about 500 psi to about 5000 psi (from about 3447 kPa to about 34474 kPa), for example, from about 1500 psi to about 2500 psi (from about 10342 kPa to about 17237 kPa), or from about 1200 psi to about 2500 psi from about 8274 kPa to about 17237 kPa);
  - (c) an LHSV from about 0.1 hr<sup>-1</sup> to about 15 hr<sup>-1</sup>, for example from about 0.2 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>, or from about 0.2 hr<sup>-1</sup> to about 2.5 hr<sup>-1</sup>, or from about 0.1 hr<sup>-1</sup> to about 10 hr<sup>-1</sup>; and/or
  - (d) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed (from about 17.8 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), for example from about 200 scf to about 2500 scf per barrel (from about 35.6 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), or from about 100 scf to about 1500 scf per barrel (from about 17.8 to about 267 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed).
40. The system according to any of claims 36 to 39, wherein hydroprocessing the unconverted oil comprises hydrotreating, hydroisomerizing and/or hydrocracking the unconverted oil.
41. The system according to claim 40, wherein hydroprocessing the unconverted oil comprises hydrocracking the unconverted oil and wherein the hydroprocessing zone and the hydrocracker are

configured such that the level of hydrocracking conversion during hydrocracking the unconverted oil in the hydroprocessing zone is less than the level of hydrocracking conversion during hydrocracking the hydrocarbonaceous feedstock in the hydrocracker.

42. The system according to claim 41, wherein the hydroprocessing zone and the hydrocracker are configured such that hydrocracking the unconverted oil takes place at a hydrocracking conversion of from about 5 % to about 30 % and such that hydrocracking the hydrocarbonaceous feedstock in the hydrocracker takes place at a hydrocracking conversion of from about 30 % to about 70 %.

43. The system according to any of claims 32 to 42 configured to feed to the unconverted oil upgrade reactor unconverted oil from the hydrocracker comprising:

- (a) no greater than about 100 ppm of sulfur;
- (b) no greater than about 20 ppm of nitrogen; and/or
- (c) no greater than about 1 ppm of nickel, vanadium and/or copper.

44. The system according to any of claims 32 to 43 configured to feed to the unconverted oil upgrade reactor unconverted oil from the hydrocracker having:

- (a) an API gravity of from about 25 to about 45;
- (b) a TBP 95% point from about 800 °F to about 1100 °F (from about 427 °C to about 593 °C); and/or
- (c) a viscosity index (VI), measured according to ASTM D-2270, of from about 100 to about 150 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

45. The system according to any of claims 32 to 44, wherein the unconverted oil upgrade reactor is configured to increase the viscosity index (VI) of the unconverted oil by about 5 to by about 30.

46. The system according to any of claims 32 to 45 configured to produce a base oil product having a viscosity index (VI), measured according to ASTM D-2270, of no less than 120 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).

47. The system according to any of claims 32 to 46 configured to produce a Group III base oil product.

48. The system according to any of claims 32 to 47, wherein the system is a base oil production plant.

49. Method of modifying an existing system for producing a base oil product to increase a viscosity index (VI) of the base oil product, the existing system for producing the base oil product comprising:

- a hydrocracker for hydrocracking a hydrocarbonaceous feedstock to produce a hydrocracked effluent comprising unconverted oil; and

a dewaxing unit for dewaxing unconverted oil, separated from the hydrocracked effluent, to produce the base oil product;

wherein the method of modifying the existing system comprises:

installing in the existing system a separate unconverted oil upgrade reactor for hydroprocessing the unconverted oil, separated from the hydrocracked effluent, prior to dewaxing the unconverted oil to produce the base oil product.

50. The method according to claim 49, wherein the hydrocarbonaceous feedstock has a boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprises a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO).

51. The method according to claim 49 or claim 50, wherein the unconverted oil upgrade reactor is configured to increase the viscosity index (VI) of the unconverted oil.

52. The method according to any of claims 49 to 51, wherein the unconverted oil upgrade reactor has a hydroprocessing zone comprising one or more beds containing a hydroprocessing catalyst, the hydroprocessing zone being maintained at hydroprocessing conditions.

53. The method according to claim 52, wherein the hydroprocessing catalyst and/or the hydroprocessing conditions are selected such that VI-increasing molecular transformations predominate in the hydroprocessing.

54. The method according to claim 52 or claim 53, wherein the hydroprocessing catalyst comprises:

(a) one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof; and

(b) a catalyst support, for example a porous refractory support, for example an alumina, a silica, an amorphous silica-alumina material, or a combination thereof; and, optionally,

(c) one or more molecular sieves, for example zeolites.

55. The method according to any of claims 52 to 54, wherein the hydroprocessing conditions comprise:

(a) a reaction temperature from about 400 °F to about 950 °F (from about 204 °C to about 510 °C), for example from about 650 °F to about 850 °F (from about 343 °C to about 454 °C);

(b) a reaction gauge pressure from about 500 psi to about 5000 psi (from about 3447 kPa to about 34474 kPa), for example, from about 1500 psi to about 2500 psi (from about 10342 kPa to about 17237 kPa), or from about 1200 psi to about 2500 psi from about 8274 kPa to about 17237 kPa);

(c) an LHSV from about  $0.1 \text{ hr}^{-1}$  to about  $15 \text{ hr}^{-1}$ , for example from about  $0.2 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ , or from about  $0.2 \text{ hr}^{-1}$  to about  $2.5 \text{ hr}^{-1}$ , or from about  $0.1 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ ; and/or

(d) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed (from about  $17.8$  to about  $445 \text{ m}^3 \text{ H}_2/\text{m}^3$  feed), for example from about 200 scf to about 2500 scf per barrel (from about  $35.6$  to about  $445 \text{ m}^3 \text{ H}_2/\text{m}^3$  feed), or from about 100 scf to about 1500 scf per barrel (from about  $17.8$  to about  $267 \text{ m}^3 \text{ H}_2/\text{m}^3$  feed).

56. The method according to any of claims 49 to 55, wherein hydroprocessing the unconverted oil comprises hydrotreating, hydroisomerizing and/or hydrocracking the unconverted oil.

57. The method according to claim 56, wherein hydroprocessing the unconverted oil comprises hydrocracking the unconverted oil and wherein the hydroprocessing zone and the hydrocracker are configured such that the level of hydrocracking conversion during hydrocracking the unconverted oil in the hydroprocessing zone is less than the level of hydrocracking conversion during hydrocracking the hydrocarbonaceous feedstock in the hydrocracker.

58. The method according to claim 57, wherein the hydroprocessing zone and the hydrocracker are configured such that hydrocracking the unconverted oil takes place at a hydrocracking conversion of from about 5 % to about 30 % and such that hydrocracking the hydrocarbonaceous feedstock in the hydrocracker takes place at a hydrocracking conversion of from about 30 % to about 70 %.

59. The method according to any of claims 49 to 58, wherein the method comprises configuring the existing system to feed to the unconverted oil upgrade reactor unconverted oil from the hydrocracker comprising:

- (a) no greater than about 100 ppm of sulfur;
- (b) no greater than about 20 ppm of nitrogen; and/or
- (c) no greater than about 1 ppm of nickel, vanadium and/or copper.

60. The method according to any of claims 49 to 59, wherein the method comprises configuring the existing system to feed to the unconverted oil upgrade reactor unconverted oil from the hydrocracker comprising:

- (a) an API gravity of from about 25 to about 45;
- (b) a TBP 95% point from about  $800^\circ\text{F}$  to about  $1100^\circ\text{F}$  (from about  $427^\circ\text{C}$  to about  $593^\circ\text{C}$ ); and/or
- (c) a viscosity index (VI), measured according to ASTM D-2270, of from about 100 to about 150 at a kinematic viscosity of  $4 \text{ cSt}$  ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at  $100^\circ\text{C}$  ( $212^\circ\text{F}$ ).

61. The method according to any of claims 49 to 60, wherein the unconverted oil upgrade reactor is configured to increase the viscosity index (VI) of the unconverted oil by about 5 to by about 30.
62. The method according to any of claims 49 to 61, wherein, after modifying the existing system, the base oil product produced has a viscosity index (VI), measured according to ASTM D-2270, of no less than 120 at a kinematic viscosity of 4 cSt ( $4 \text{ mm}^2 \text{ s}^{-1}$ ) at 100 °C (212 °F).
63. The method according to any of claims 49 to 62, wherein, after modifying the existing system, the base oil product produced is a Group III base oil product.
64. The method according to any of claims 49 to 63, wherein the existing system is a base oil production plant.
65. An unconverted oil upgrade reactor for hydroprocessing unconverted oil, separated from the hydrocracked effluent of a hydrocracker, prior to dewaxing the unconverted oil to produce a base oil product, the unconverted oil upgrade reactor:
- (a) having a hydroprocessing zone comprising one or more beds containing a hydroprocessing catalyst, the hydroprocessing zone being maintained at hydroprocessing conditions; and
  - (b) being configured to increase the viscosity index (VI) of the unconverted oil.
66. The unconverted oil upgrade reactor according to claim 65, wherein:
- (a) the hydroprocessing catalyst comprises:
    - (i) one or more metals selected from Groups VI and VIII to X and/or one or more compounds thereof; and
    - (ii) a catalyst support, for example a porous refractory support, for example an alumina, a silica, an amorphous silica-alumina material, or a combination thereof; and, optionally,
    - (iii) one or more molecular sieves, for example zeolites; and/or
  - (b) the hydroprocessing conditions comprise:
    - (i) a reaction temperature from about 400 °F to about 950 °F (from about 204 °C to about 510 °C), for example from about 650 °F to about 850 °F (from about 343 °C to about 454 °C);
    - (ii) a reaction gauge pressure from about 500 psi to about 5000 psi (from about 3447 kPa to about 34474 kPa), for example, from about 1500 psi to about 2500 psi (from about 10342 kPa to about 17237 kPa), or from about 1200 psi to about 2500 psi from about 8274 kPa to about 17237 kPa);
    - (iii) an LHSV from about  $0.1 \text{ hr}^{-1}$  to about  $15 \text{ hr}^{-1}$ , for example from about  $0.2 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ , or from about  $0.2 \text{ hr}^{-1}$  to about  $2.5 \text{ hr}^{-1}$ , or from about  $0.1 \text{ hr}^{-1}$  to about  $10 \text{ hr}^{-1}$ ; and/or

(iv) a hydrogen consumption from about 100 scf to about 2500 scf per barrel of liquid hydrocarbon feed (from about 17.8 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), for example from about 200 scf to about 2500 scf per barrel (from about 35.6 to about 445 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed), or from about 100 scf to about 1500 scf per barrel (from about 17.8 to about 267 m<sup>3</sup> H<sub>2</sub>/m<sup>3</sup> feed).

67. Base oil product produced (a) by the method according to any of claims 1 to 16, (b) using the system according to any of claims 32 to 48, or (c) using the system modified by the method according to any of claims 49 to 64.

68. Lubricant comprising the base oil product of claim 67.

69. Use of an upgraded unconverted oil in the manufacture of a base oil product to increase the viscosity index (VI) of the manufactured base oil product.

70. The use according to claim 69, wherein the manufacture of the base oil product comprises dewaxing the upgraded unconverted oil in a dewaxing unit.

71. The use according to claim 69 or claim 70, wherein the upgraded unconverted oil is obtained by hydroprocessing unconverted oil obtained from hydrocracking a hydrocarbonaceous feedstock having a boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprising a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO).

72. Use of a dewaxed, upgraded unconverted oil as a base oil product in a lubricant to increase the viscosity index (VI) of the lubricant.

73. The use according to claim 72, wherein the dewaxed, upgraded unconverted oil is obtained by (a) hydroprocessing unconverted oil obtained from hydrocracking a hydrocarbonaceous feedstock having a boiling point in the range from about 572 °F to about 1112 °F (about 300 °C to about 600 °C) and/or comprising a gas oil such as vacuum gas oil (VGO) or heavy coker gas oil (HCGO) and (b) dewaxing the hydroprocessed unconverted oil.